Perfect Absorption by an Array of Lossy Dipoles Located Close to a Ground Plane

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Abstract—This paper presents a thin absorbing structure comprising an array of finitely conductive terminal-loaded dipoles spaced about half a wavelength apart and located above a ground plane. We show that if the antennas are terminated with proper load impedance, instead of a conjugate-matched one, a perfect absorption can be attained even when the array lies close to the ground plane. We also identify a threshold height below which the absorption efficiency rapidly drops and perfect absorption cannot be realized. The idea is illustrated via a concrete example of array of dipoles printed with conductive ink technology on a Kapton HN flexible film backed by a rigid Rogers 4350B substrate. The array is designed for perfect absorption at 3.45 GHz when it is located one-tenth of a wavelength above the ground plane. Good agreement between simulation and measurement results is demonstrated.

Index Terms—Absorption efficiency, antenna arrays, dipole, electromagnetic wave absorption, silver ink.

I. INTRODUCTION

The study of structures that efficiently absorb the electromagnetic power is important in many application areas ranging from radar cross-section minimization [1] to detection by thermal bolometers [2]. The ability to attain perfect absorption by an infinite array of perfectly conducting terminal-loaded dipoles above a ground plane was proven theoretically in [3], using a Floquet modal analysis. The perfect absorption can be achieved for any height of the array above the ground and for any periodicity up to a size of one wavelength. The thin profile of structure and the tunability allowed by changing the load make this kind of design a good candidate for the realization of absorbers. Moreover, the distance permitted between the elements, which is larger than that typically used in metamaterial absorbers [4]–[8], yields a structure with a less dense distribution of inclusions.

However, in practice, especially in low-cost antenna production [9], the dipoles are not perfectly conducting, and the question whether perfect absorption can be attained in the presence of the losses has not been addressed to the best of author’s knowledge.

This paper extends our recent analysis of maximum absorption by a finite length terminal-loaded stand-alone dipole made of lossy material [10] to the case of an array of lossy dipoles above ground plane. In [10], it is shown that the optimal load that maximizes the total power absorbed (both by the load and the material of which the antenna is made) is different from the conjugate-matched load, which is required to maximize the load power alone. Likewise here, we show that the optimal load that maximizes the absorption efficiency of the infinite lossy array is different from the complex conjugate of the dipole’s active impedance [11], [12] required to maximize the array load power. The maximum absorption efficiency can reach 100%, but, contrary to infinite array of lossless dipoles [3], not for all heights of the array above the ground. Specifically, below some threshold height, which depends on the periodicity, geometry, and finite conductivity of dipoles, the absorption efficiency drops rapidly. However, this threshold height can still be sufficiently small to allow designs of low-profile perfect absorbers.

To experimentally validate the analysis, an array of dipoles made of silver-based conductive ink was designed, fabricated, and characterized. The dipoles were printed on a flexible Kapton HN material backed by a rigid Rogers 4350B substrate. The printed array was then placed above an aluminum ground plane using plastic spacers and screws. The array was designed for perfect absorption at 3.45 GHz when it is located at one-tenth of a wavelength above the ground. Despite the high structural losses due to finite conductivity of ink and closeness of array to the ground, perfect absorption was indeed achieved with good agreement between simulated and measured results.

The remainder of this paper is organized as follows. A theoretical analysis of absorption by an infinite array of lossy dipoles above ground plane is presented in Section II. Details about the fabricated array are given in Section III. The absorption measurement results are outlined in Section IV, followed by a conclusion in Section V.

II. ANALYSIS OF ABSORPTION BY LOSSY DIPOLE ARRAY

The concepts of optimal matching and threshold height for perfect absorption will now be discussed and illustrated via a concrete example of array of lossy dipoles. To simplify the implementation, we strived to have an array for which the optimal load impedance would be purely resistive, thereby avoiding the need to add reactive loading across the dipole terminals. Taking a clue from [10], the active impedance of such an array will require a small imaginary part, and, toward this end, we composed an array of half-wavelength dipoles, which are known to have a relatively small input reactance when radiating in free space. Finally, to render the optimal load reactance exactly zero, as desired, we tuned the array periodicity and proximity to the ground plane.