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FIELD INTENSITY FOCUSING AND SHAPING IN COMPLEX 3D SCENARIOS: A UNITARY PERSPECTIVE FOR ACTUAL OPTIMALITY

Giada Maria Battaglia

DIIES, Università Mediterranea di Reggio Calabria
Loc. Feo di Vito, I-89124 Reggio Calabria, Italy

I. INTRODUCTION

Generating a field with a given intensity behavior into the region of interest is a fundamental problem of wave physics. From the applicative point of view, the paradigm of arbitrarily shaping in complex 3D scenarios the field intensity is relevant in instances spanning from near field focusing for RFID, [1], through-the-wall imaging [2] to several biomedical applications including lithotripsy [3], microwave hyperthermia (MWH) [4] and many others. Many efforts have been also devoted to the 'near field focusing' problems, including [5-6].

In case of scalar fields, the problem of maximizing the field intensity in a given point or direction (and subject to arbitrary upper bounds elsewhere) by means of the excitations of given sources has been solved by Italian researchers since the nineties [7]. Notably, which is often overlooked in the literature, the approach therein is able to deal in a globally optimal fashion with both cases of near field target points as well as with the case of near field constraints. In fact, it is shown that the problem can be conveniently formulated as a Convex Programming problem, with the inherent advantages. Later, the approach has been successfully generalized and applied to 3D complex scenarios and hyperthermia problems for the case where one component of the field is dominant. As a matter of fact, 'FOCO' (Focusing by Constrained Optimization FOCO) is now under test in Clinical environments [8-9].

On the other hand, no simple and effective procedure guaranteeing the global optimality of the solution seem to exist (with the same constraints outside the target region) in the related problems of maximizing the field intensity in a given point or shaping the field intensity in a given target region. These problems are of interest not only in hyperthermia treatment planning, but in areas as different as near field focusing, remote activation of drugs, wireless power transfer, and many others. Notably, the general problem we are posing also includes as a special case the optimal shaping of array fields, which is a canonical problem still looking for a globally optimal solution (but for the simple case of linear arrays and related).

By taking advantage from 'FOCO', we delineate in the following a possible solution strategy for both problems identifying their causes of non-convexity (and hence difficulties) and proposing an effective way out.

II. FROM (3D) FIELD FOCUSING TO (3D) FIELD SHAPING, AND TO (3D) INTENSITY FOCUSING

The field radiated from a generic set of N radiators can be written as:

$$F(\underline{r}) = \sum_{n=1}^{N} I_n \Psi_n(\underline{r}) \qquad (1)$$

wherein $\underline{r}$ denotes the coordinate spanning the observation space, $\Psi_n(\underline{r})$ represents the (scalar or vector) total field induced by the unitary excited *n-th* antenna in the region of interest Ω when all the other antennas are off, and I_n (n=1,….,N) a set of complex excitation coefficients.

The problem we are dealing with is that of the determining the optimal excitations able to grant the desired shape in the 'target' region Λ while enforcing arbitrary upper-bound constraints in the 'sidelobes' region, i.e., $\Omega\backslash\Lambda$.

When considering the Field intensity problem, it can be easily argued that the problem can be conveniently formulated as an optimization over the possible polarizations of the field at the target point. In fact, for any given polarization the problem turns back to the basic 'FOCO' formulation. As a consequence, the overall problem can be formulated as a nested optimization wherein one looks externally (by means of a global optimization procedure) to the most convenient polarization, while the internal optimization looks for the optimal excitations corresponding to the polarization at hand.

A similar approach is possible for the 'optimal shaping' problem. By considering by the sake of simplicity a scalar field (see below for extensions), one can fruitfully consider a set of 'control points' within the target region and fix the relationships amongst the corresponding amplitudes therein. For example, one can pursue an equal amplitude in all control points (which would be the case with 'flat top' patterns). Then, the problem of raising as much as possible this 'flat top zone' while fulfilling given upper bounds elsewhere can be formulated as the search for the optimal values of phase shifts amongst the fields in the control points. By so doing, one can have the same kind of 'nested' optimization procedure as before. In fact, for any set of phase shifts the problem becomes essentially identical to FOCO (just more convex constraints are required), so that one just needs (but for some subtleties) to optimize the phase shifts.

Of course, a proper mixing of the two approaches as above also can allow the optimal shaping of the intensity of vector fields.

It has to be noted that the common strategy in all three cases is that of identifying the causes of non-convexity of the problem and formulate its solution in such a way that the (required) global optimization procedures only have to deal with the corresponding unknowns. In such a way, global Optimization procedure deal with a minimal number of unknowns, with the inherent benefits. Further details, as well as different applicative examples, will be given at the Conference.

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