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***Abstract*-All electrical properties of an antenna are determined by its current distribution. It is possible to numerically solve a current distribution producing optimal performance in some sense. However, this ideal current distribution is nearly impossible to realize in practice. We propose the discretized antenna concept, which makes it possible to realize nearly optimal current distributions in practice. The method does not necessitate manual error and trial type iteration and it can be solved with many design goals. In this paper, we describe the design steps.**

I. Introduction

Antenna is typically a piece of shaped metal converting an oscillating current at its feed point into radiating waves. The art of antenna design is to find a good shape for the metal piece with the help of electromagnetic simulation software. However, this conventional manual error and trial method is very laborious and does not generally converge to the optimal antenna shape.

Fundamentally, all electrical properties of the antenna are determined by the current distribution the antenna excites. The theoretical and numerical electromagnetics research community has derived fundamental performance limitations for the antennas, such as the famous Chu's limit defining the lower bound for the quality factor of an electrically small antenna [1]. Furthermore, the community has established relatively straightforward ways to solve the ultimately best current or field distributions of an antenna, which would, in certain conditions, result into best possible radiation properties (see e.g., [2]–[5]). However, although the optimal current distribution can be found numerically, it is generally very challenging or even impossible to excite in practice. Addition of any exciting element would affect the dynamics and the previously solved optimal current distribution would become less than optimal.

To summarize, practical antenna designers do not have efficient tools to obtain the best antenna shape, and numerical electromagnetics community have tools to solve the optimal current distribution, but lack means to realize that in practice. This paper presents a discretized antenna concept, which bridges the gap between the two communities. The discretized antenna concept makes it possible to realize nearly optimal current distribution for a given design goal in practice, using a computationally efficient procedure not relying on manual iteration. The method is based on use of multiple discrete current, or equivalently radiating elements in a collaborative manner. The method can be used to design fixed antenna elements, but it could also enable re-configurable antennas provided that the multi-element structure is excited with a multi-channel transceiver with adjustable feed signals.

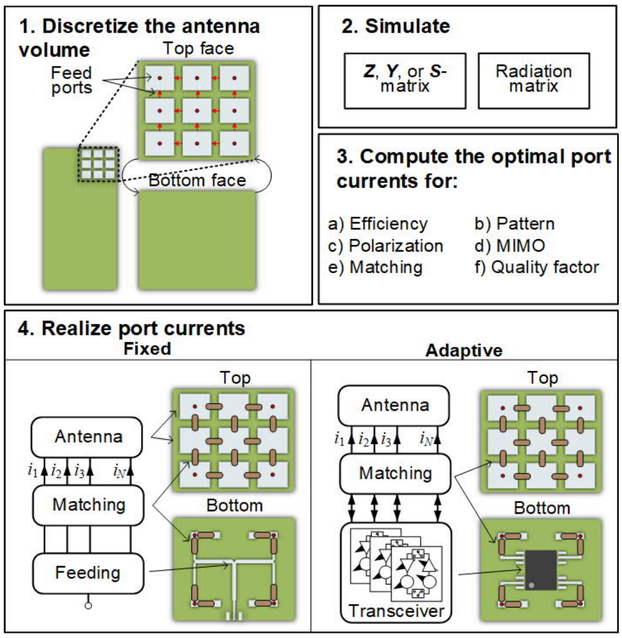

Figure 1. Design procedure based on discretized antenna concept consists of four steps: 1) Filling the available antenna area with discretized radiators connected with feed ports, 2) simulating the structure electromagnetically and solving the impedance and radiation matrices, 3) solving the optimal port currents for the given design goal, and 4) realizing the port currents using either a fixed feed and matching network or with an adaptive setup based on a multi-channel transceiver.

II. Discretized Antenna Concept

We next describe the procedure to design antennas based on the discretized radiators. Fig. 1 illustrates the design procedure, which consists of four steps.

Step 1: Discretizing the antenna volume

We are given certain volume or area, where we realize the antenna. As an example, certain area on top side of a printed-circuit board is reserved for the antenna. As the first step, we fill the area with discretized radiating elements. The discretized elements could be for instance patches that are small compared to the wavelength. We further connect the discretized elements together using feed ports (shown in red in Fig. 1) in electromagnetic simulations. Feed ports makes it possible to relate port currents to antenna properties. The smaller the discretized elements, the better will be the electrical performance. However, small discretization also leads to increased structural complexity.

Step 2: Electromagnetic simulations

We next simulate the structure electromagnetically. The simulation is only done once, and the simulation generates two matrices fully characterizing the structure: impedance matrix (or equivalently admittance or S-parameter matrix) and radiation matrix. The impedance matrix relates currents and voltages in different ports, whereas the radiation matrix relates port currents to radiated fields. Once both matrices are known, the originally complex electromagnetic design problem transforms into a significantly less complex circuit design problem.

Step 3: Solving the optimal port currents

We next choose the design goal for the antenna. Possible design goals include matching efficiency [6], [7], radiation efficiency [8], total efficiency [9], radiation pattern properties, polarization properties and quality factor. The chosen design goal is next expressed mathematically in the form of generalized Rayleigh quotient so that the port current vector is the variable. The optimal port currents are next obtained by solving the eigenvalues and corresponding eigenvectors of the matrix. The eigenvectors set the solution space, and the eigenvalues define the smallest and largest values for the optimized variable. Note that we can also realize MIMO antennas in the shared volume, as the current eigenvectors are orthogonal. Several MIMO antennas designed with the multi-feed approach have been recently presented [9]-[11].

As an example, the radiation efficiency of an antenna can be expressed as [8]

$$\eta_{rad} = 2\frac{\boldsymbol{I}^H\mathbf{R}_{rad}\boldsymbol{I}}{\boldsymbol{I}^H(\mathbf{Z}^H+\mathbf{Z})\boldsymbol{I}}, \tag{1}$$

where $\boldsymbol{I}$ is the vector containing the port currents, $\mathbf{R}_{rad}$ is the radiation matrix, and $\mathbf{Z}$ is the impedance matrix.

Step 4: Realizing port currents

As the last step, the optimal currents are realized in the structure. The currents can be realized either using a fixed feed network, or the current distribution can be made reconfigurable by feeding the multi-port structure with a multi-channel transceiver. In the case of fixed feed network, we first calculate the active port impedances, that is, what are the port voltages at the chosen port currents. If the port impedances differ from our reference impedance, we design matching networks for each port. We next design a power splitting and phase delaying network, so that power fed to its input generates the desired currents at different ports. The feed network can be realized for instance on the PCB on the other side than the antenna.

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