An Analytic Synthesis Method for Two-Element Biomimetic Antenna Arrays

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A biomimetic antenna array (BMAA) is a multiple-element electrically-small antenna array that uses a passive external coupling network to produce a considerably higher output phase sensitivity compared to a regular antenna array of the same size. This offers a promising solution for direction finding applications that require precise angular resolving capabilities from small apertures. In the previously published works on BMAAs, the external coupling networks were designed by using a numerical optimization procedure to find acceptably sub-optimal solutions for the reactive elements constituting the coupling networks. In this paper, we present a method for analytically synthesizing a unique set of reactive element values for a given coupling network topology using its scattering matrix (S-matrix) and demonstrate this synthesis procedure on different network topologies for a two-element BMAA.

The proposed synthesis approach for the four-port coupling network of a two-element BMAA consists of two stages: (1) deriving an S-matrix for the coupling network and (2) calculating reactive element values of the network based on the S-matrix. First, we formulated the S-matrix of the network with the assumptions that it is lossless, symmetric, reciprocal, and designed to match the impedances of the antenna array at the operating frequency in both common and differential modes to 50 **Ω**. An additional condition of the output-voltage phasors in the common and differential modes being orthogonal at boresight was used to maximize the phase enhancement factor of the BMAA. Under these conditions, the values of S_{11} and S_{12} can be uniquely determined. This leaves us with eight unknowns, consisting of the real and imaginary parts of the remaining four S-parameters, and only seven equations. Thus, we have one degree of freedom to introduce another constrain for calculating the whole S-matrix of the coupling network, which will be used in the next stage for deriving element values of the coupling network. Additionally, we examined all the possibilities for a lossless, symmetric, and reciprocal four-port coupling network consisting of six reactive elements and found that there are thirteen unique topologies in total that can satisfy all the constraints for the S-matrix. For each of these thirteen possible topologies, the six reactance's values can be uniquely determined to produce the exact common- and differential-mode transmission matrices that are transformed from the previously derived S-matrix.

We applied the presented synthesis procedure to design external coupling networks for a BMAA that consists of two 12.5 cm long monopole antennas separated by 5 cm. We extracted the two-port impedance matrix of the antenna array from simulations in CST Microwave Studio to use for calculating the S-matrix of the external coupling network at the operating frequency of 600 MHz. We used two different conditions that result in two S-matrices. The first S-matrix was calculated by adding the condition of the phase of S_{21} in the common mode being equal to 90° and the second one was determined by minimizing the value of the derivation of the output reactance in the differential mode with respect to frequency at 600 MHz. The effects of these two S-matrices and different network topologies on the bandwidths of differential-mode impedance matching were investigated in the simulations conducted in Agilent ADS. Simulation results show that, across different topologies, the largest and smallest bandwidths are 7.4 and 3.3 MHz for the first S-matrix, and 7.5 and 6.6 MHz for the second S-matrix, respectively. The impedance-matching bandwidths in the differential mode for the second S-matrix are typically larger and less sensitive to choices of network topology compared to those for the first S-matrix. Moreover, certain topologies consistently yield larger bandwidths than others for both S-matrices and the influence of different S-matrices on the bandwidths for these high-performance topologies is insignificant. We plan to fabricate four coupling networks using two different topologies and the two S-matrices to demonstrate our proposed synthesis approach and verify the simulation results. More details on the synthesis process, simulation and experimental results will be shown and discussed in the symposium.