Matching and Directivity of a Layer Stacked Array for VHF Radar Applications

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Early-warning radars operating in the very high frequency (VHF) band have been widely employed for long range detection of its targets. High directivity is realized by utilizing a large two-dimensional (2D) antenna array (largest dimension $\geq 10\lambda$), and further increase in directivity is possible to obtain through the use of directive elements (using directors and reflectors) or by stacking several layers of the 2D-array. The latter would imply increasing the number of feeds from N_xN_y to $N_xN_yN_z$, assuming N_z layers of the 2D-array.

We investigate the impact that adding additional layers of the 2D-array may have on both maximum directivity (D_0) and overall matching of the system. An appropriate measure for a multiport system is the Total Active Reflection Coefficient (TARC) (M. Mantegi and Y. Rahmat-Samii, IEEE Trans. Antennas Propag., 53, 466-474, 2005): $\sqrt{(\sum_n |b_n|^2)/(\sum_n |a_n|^2)}$. Here, b_n and a_n represent the backward- and forward-propagating wave in port n respectively. These are related through the scattering matrix, i.e., $\boldsymbol{b} = \mathbf{S}\boldsymbol{a}$. Evidently, the TARC represents the overall matching under a single frequency excitation. Matching and directivity are addressed jointly using a convex optimization problem formulation with the input waves $\boldsymbol{a}$ as degrees of freedom:

$$\begin{aligned} \text{min.} \quad & \alpha||\mathbf{S}\boldsymbol{a}||_2^2 + (1-\alpha)||\sqrt{\mathbf{I}-\mathbf{S}^{\mathrm{H}}\mathbf{S}}\boldsymbol{a}||_2^2 \\ \text{s. t.} \quad & F(\theta_0,\phi_0) = 1, \quad \max_{(\theta_{\mathrm{e}},\phi)\notin\Omega_0} |F(\theta_{\mathrm{e}},\phi)| \leq F_0. \end{aligned} \tag{1}$$

$F(\theta_{\mathrm{e}},\phi)$ is the far field amplitude in the direction $(\theta_{\mathrm{e}},\phi)$, F_0 is a specified side lobe level, and Ω_0 is the main lobe solid angle. By fixing the radiation intensity in a chosen direction (θ_0,ϕ_0), D_0 is optimized by minimizing the term $||\sqrt{\mathbf{I}-\mathbf{S}^{\mathrm{H}}\mathbf{S}}\boldsymbol{a}||_2^2$ (total radiated power of a lossless antenna). The parameter α controls the trade-off between the optimization objectives. The routine is run on a 20 × 10 × 5 bowtie array, simulated using a hybrid Method of Moments code capable of treating very large antenna arrays (J. Helander and D. Tayli, "Synthesis of Large Endfire Antenna Arrays using Convex Optimization", IEEE Trans. Antennas Propag., accepted, 2017). Initial results (Fig. 1) indicate that both D_0 and the TARC are compromised when a conventional feeding approach (uniform amplitude and progressive phase shift) is employed on the layered array. Both quantities can be improved by finding optimum feeding coefficients using (1). A continuing study addresses the same problem, but using a matching network approach between the layers in order to suppress the mutual impedance that presumably is a source to the worsened matching.

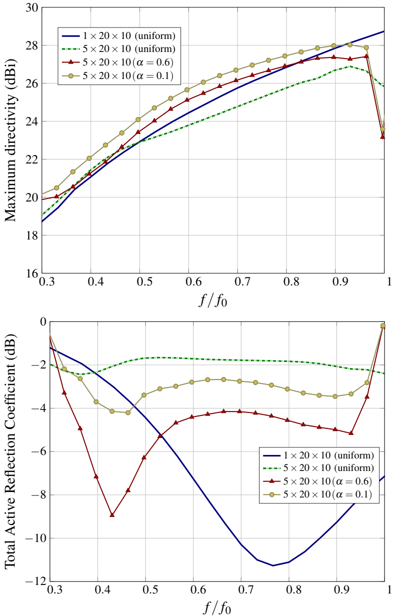

Figure 1: D_0 and TARC.