Shaped-Beam Reflectarray with a 15% Bandwidth Optimized Using Support Vector Regression

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***Abstract*—Support Vector Regression (SVR) is employed in a wideband, copolar reflectarray optimization to achieve a 15% bandwidth. The reflectarray is square and 1 meter wide. A European coverage with a minimum gain requirement of 28 dBi has been chosen. After the optimization, the minimum copolar gain in the coverage zone is improved more than 10 dB at the upper frequency while maintaining an accurate and computationally efficient design procedure.**

***Index Terms*—Machine learning, support vector regression (SVR), wideband reflectarray antenna, shaped-beam**

I. INTRODUCTION

Reflectarrays exhibit an inherit narrow bandwidth due to the narrowband resonant elements and the differential spatial delay [1]. The first issue may be overcome by employing wideband elements, such as stacked patches of variable size, parallel dipoles or sub-wavelength elements [2]. The second issue affects most notably very large flat reflectarrays and may be overcome by optimizing the unit cell at different frequencies [1], increasing the F/D ratio or using conformal reflectarrays [3].

We present a wideband design technique applied to reflectarray antennas based on a machine learning technique, namely support vector regression (SVR) [4], to notably accelerate the process without a significant loss precision. The surrogate model is compared with in-house method of moments based on local periodicity (MoM-LP) simulations showing a high degree of agreement. A wideband reflectarray design is carried out using the SVR models and the generalized intersection approach (gIA) [5]. The optimized layout almost fulfils specifications in a 15% bandwidth.

II. SURROGATE MODEL OF THE UNIT CELL

Surrogate models for reflectarray unit cells try to predict the matrix of reflection coefficients that relate the tangential incident field coming from the feed and the tangential reflected field:

$$\boldsymbol{R}(f) = \begin{pmatrix} \rho_{xx}(f) & \rho_{xy}(f) \\ \rho_{yx}(f) & \rho_{yy}(f) \end{pmatrix}. \tag{1}$$

This coefficients characterize the behaviour of the unit cell in a periodic environment and also vary with frequency. The direct coefficients ρ_{xx} and ρ_{yy} define the shape and losses of the copolar pattern through their phases and magnitudes, respectively. Thus, for a copolar-only optimization, the cross-coefficients can be assumed to be zero ($\rho_{xy} = \rho_{yx} = 0$).

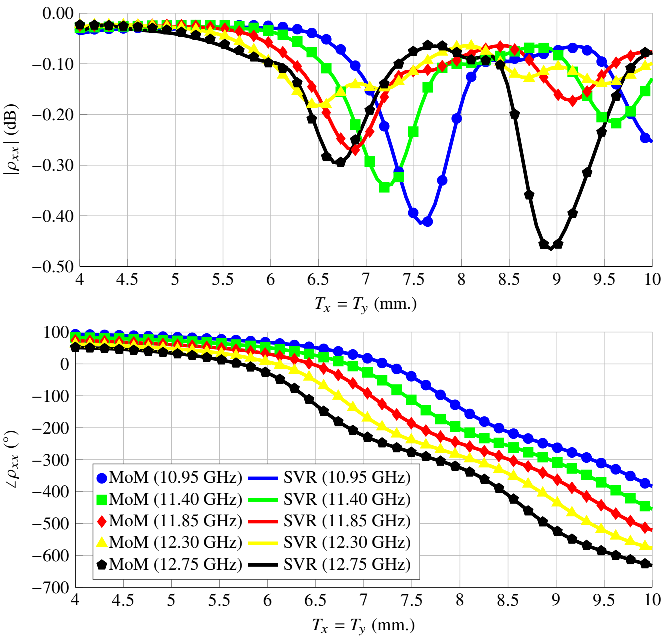

Figure 1. For ρ_{xx} with an oblique angle of incidence (30°, 50°), comparison at five different frequencies between MoM-LP and the SVR surrogate model for phases (top) and magnitudes (bottom).

The same unit cell described in [4] is used here. It is comprised of two sets of four parallel dipoles dipoles, with each set controlling the phase-shift for a linear polarization. Thus, the reflectarray will work in dual-linear polarization. To that end, two variables, T_x and T_y are defined to control the length of each set of dipoles, as explained in [4]. Then, the SVR provides a surrogate model for the real and imaginary parts of the reflection coefficients as:

$$\tilde{\rho}_{R,I}(\vec{x}) = \sum_{k=1}^{N_s} \left[\left(\alpha_k^- - \alpha_k^+ \right) K(\vec{x}_k, \vec{x}) \right] + b, \tag{2}$$

where $\vec{x} = [T_x, T_y]$; $\vec{x}_k$ is the k-th support vector; N_s is the number of support vectors; α_k^- and α_k^+ are the optimital Langrange multipliers; b is the offset and K the Gaussian kernel.

A set of 52 angles of incidence is considered, and one SVR model per angle of incidence is trained using 2500 samples in a random grid and cross-validation (70% of samples for the training set, 15% for validation and 15% for test). Figure 1

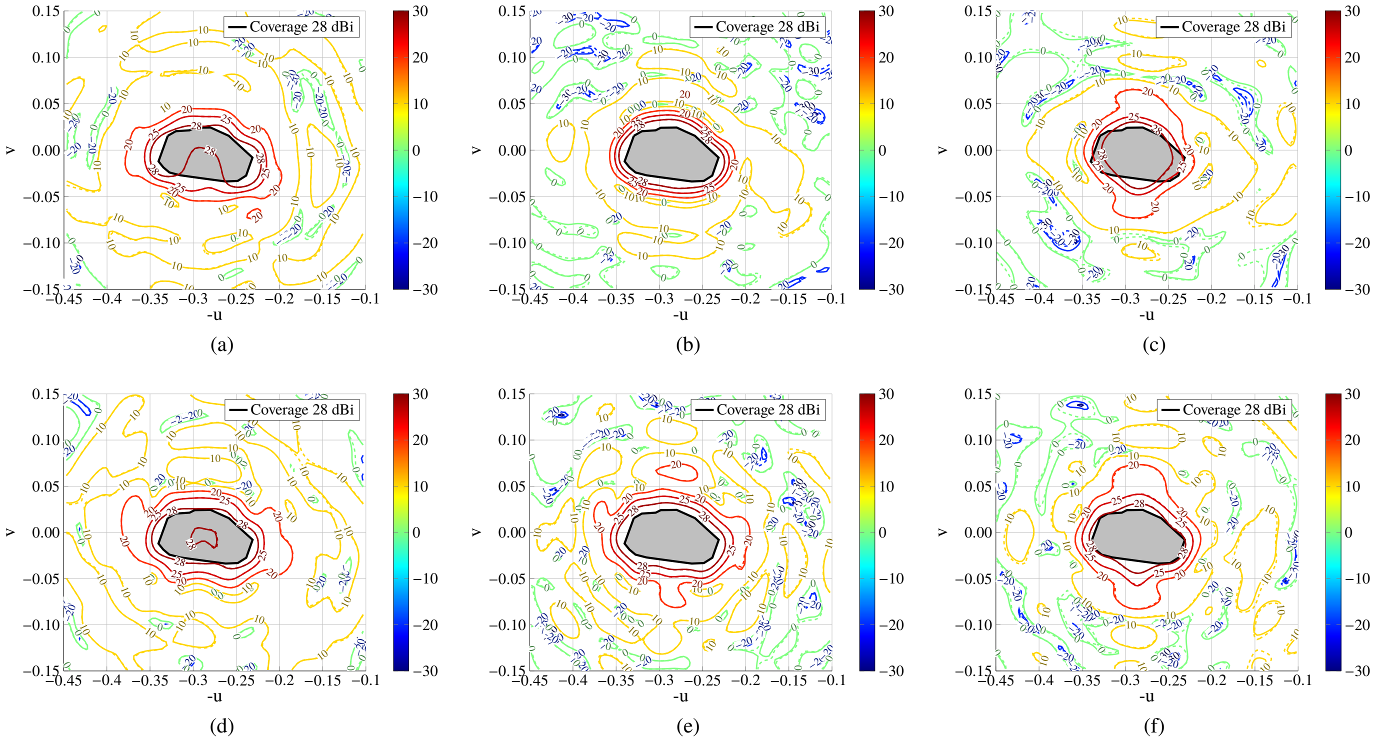

Figure 2. Initial (top) and optimized (bottom) radiation patterns for Y polarization (all of them in dBi) at (a), (d) 10.95 GHz; (b), (e) 11.85 GHz; and (c), (f) 12.75 GHz simulated with MoM-LP (solid lines) and SVR (dashed lines). (u,v) coordinates are in the reflectarray coordinate system [1].

shows the phase and magnitude of ρ_{xx} at oblique incidence. The mean absolute deviation for the phase is 2.25°, and for the magnitude is -56.8 dB.

III. Results for Wideband Performance

The gIA [5] was used to perform a copolar-only wideband design of a 1-meter reflectarray antenna with European coverage. The minimum copolar gain specification is set to 28 dBi. In addition, the SVR model is employed in the optimization to accelerate computations. Figure 2 shows the radiation pattern for Y polarization at central (11.85 GHz) and extreme (10.95 GHz and 12.75 GHz) frequencies, corresponding to a 15% bandwidth. Both MoM-LP and SVR-based simulations are superimposed, showing the high accuracy of the surrogate models. Although at 10.95 GHz it does not achieve a minimum copolar gain of 28 dBi, it fulfils specifications in 90.3% of the coverage surface. Nevertheless, the reflectarray fulfils the 28 dBi in a more restricted bandwidth in the range 11.05 GHz–12.50 GHz in dual-linear polarization, which corresponds to a 12.2% bandwidth. This was achieved using only one degree of freedom per element and polarization.

Finally, using SVR for the wideband design, a speed-up factor of 21 with regard to employing MoM-LP has been achieved, reducing the total time from 102 h using MoM-LP to only 4.8 h with SVR.

IV. Conclusion

A wideband, shaped-beam reflectarray with European coverage has been designed using surrogate models based on support vector regression. The results demonstrate the usefulness of surrogate models based on SVR for the efficient in-band design of reflectarray antennas.

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