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Optimal design of a large dual-polarization microstrip reflectarray with China-coverage patterns for satellite communications

Key words: Reflectarray; Dual-polarization; Shaped beam; Phase-only synthesis

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Motivation

- Thanks to the advantages such as flat structure, low cost, easy deployment, and flexible shaped patterns, the reflectarray antenna is the best choice to replace the shaped reflector antenna in the future.
- Due to the complexly shaped areas and high gain requirement, the reflectarray should be large enough. There are two serious problems. One is that the spatial phase delay differences (PDPs) in the operating band rapidly increase. The other is that optimization of the huge number of reflectarray elements for China-coverage patterns is a tremendous challenge.

Method

- By optimizing the dimensions of each element, the spatial PDPs in the operating band can be compensated for.
- The intersection approach is used to determine the phase distributions of the reflective surface, with which the China coverage shaped patterns are realized by the reflectarray.
- To ensure convergence of the intersection approach, a new simple method for producing the initial solution is proposed.
- To reduce the spatial PDPs in the operating band, a new optimization model for each element is established, and the regular polyhedron method is used to solve the model.

Major results

- For the general case, if parameters a_1, a_2, a_3, b_1, b_2, and b_3 are adjusted freely in the reasonable ranges, the spatial PDP of the microstrip reflectarray will be compensated for to a large extent.

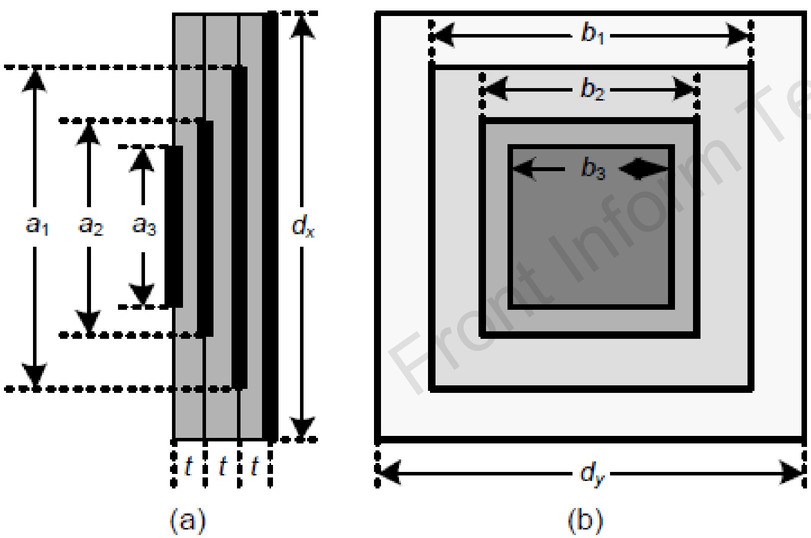


Fig. 1 Geometry of the reflectarray element: (a) side view; (b) top view

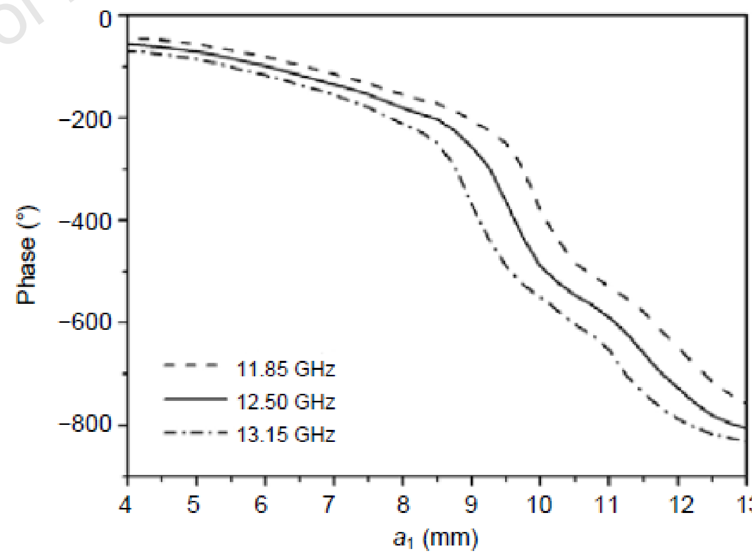


Fig. 2 Reflective phase shifts of the element versus parameter a_1 at three frequencies

Major results

- By properly moving the feed toward the reflectarray, a suitable out-of-phase distribution of the reflectarray is obtained, which is chosen as the initial phase distribution.

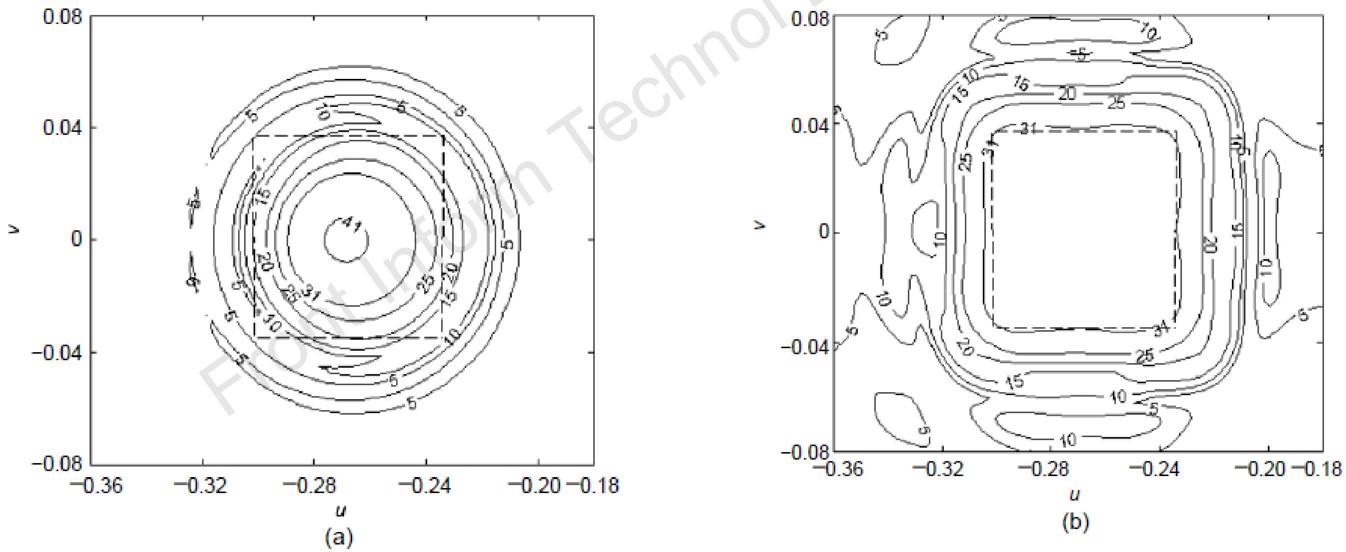


Fig. 6 Contour patterns of the reflectarray: (a) out-of- focus beam; (b) optimized beam

Major results

- Following geometric relationship should be satisfied to minimize the maximum PDP, which governs the coordinate relations that correspond to the optimal feed position.

$$z_{\mathrm{f}}^2 = x_{\mathrm{f}}^2 \cot^2\theta - 0.25D^2\cos^2\theta$$

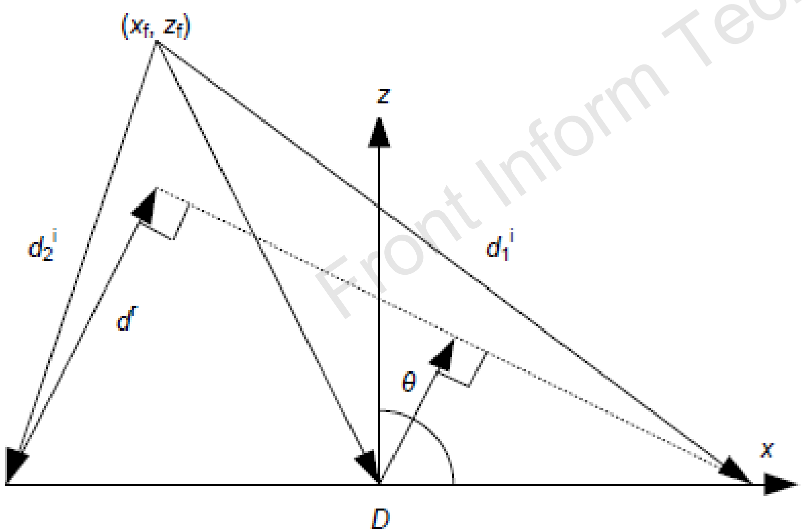


Fig. 10 Diagram of the offset-fed configuration

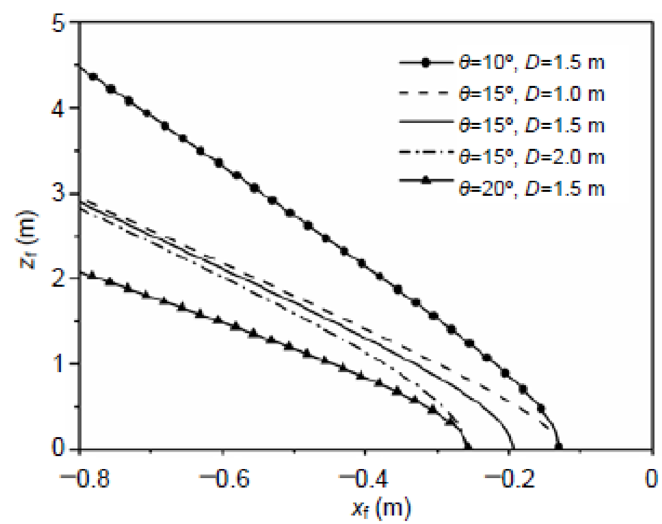


Fig. 11 Curves of the optimal feed positions with different aperture sizes and beam scanning angles

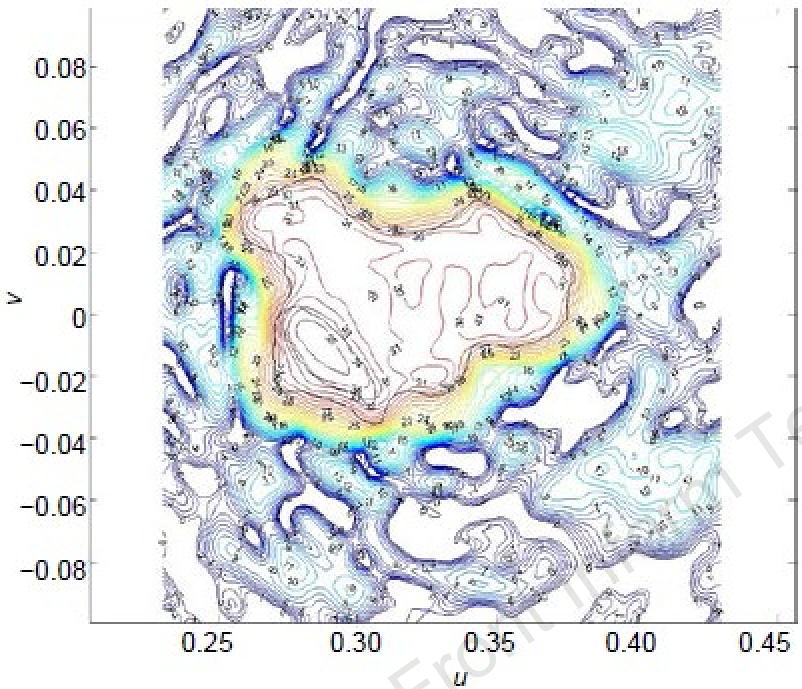
Major results

- To improve the shaped design results, six parameters of each element in two orthogonal directions are optimized simultaneously by solving the following problem using the regular polyhedron method:

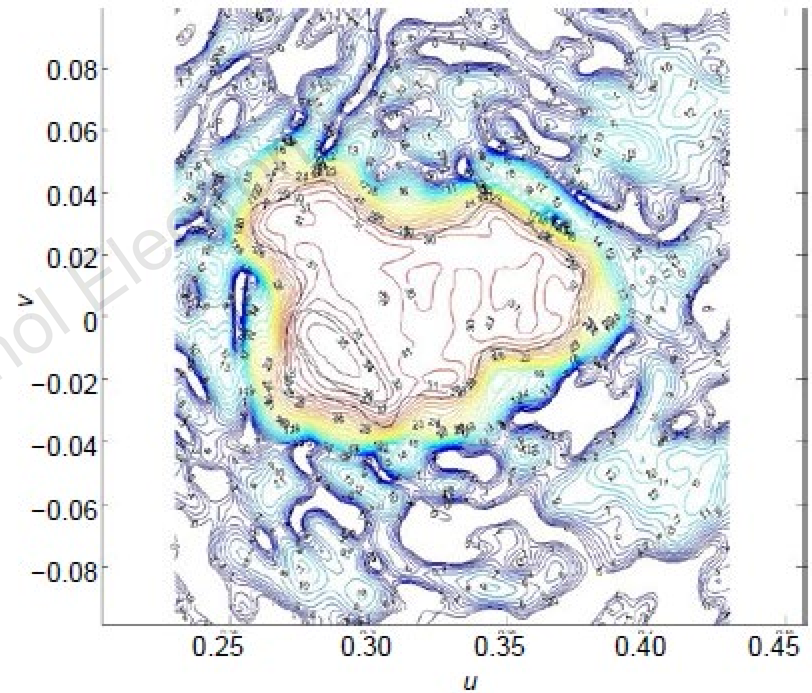
$$\begin{aligned} &\text{minimize} \quad e(\boldsymbol{v}^{(m,n)}) \\ &\text{subject to} \quad a_i^L \le a_i \le a_i^U,\ b_i^L \le b_i \le b_i^U,\ i = 1,2,3 \\ &\qquad\qquad \boldsymbol{v}^{(m,n)} = (a_1, a_2, a_3, b_1, b_2, b_3)^{\mathrm{T}} \end{aligned}$$

$$e(\boldsymbol{v}^{(m,n)}) = \sum_{i=1}^{N_{\mathrm{f}}} \Big[\left| \varphi_{\mathrm{a}}^{x}(f_i, \boldsymbol{v}^{(m,n)}) - \varphi_{\mathrm{r}}^{x}(f_i) \right| + \left| \varphi_{\mathrm{a}}^{y}(f_i, \boldsymbol{v}^{(m,n)}) - \varphi_{\mathrm{r}}^{y}(f_i) \right| \Big].$$

Major results



12.50 GHz



14.25 GHz

Radiation patterns at the central and extreme frequencies for the large reflectarray optimized in two operating bands

Conclusions

- The three-layer rectangular patch element is addressed, which is suitable for the large dual polarization reflectarray.
- The intersection approach based on the alternating projection is used to solve the phase-only synthesis problem, and a new method for producing a suitable initial solution is proposed to avoid undesired local minima.
- To find simultaneously optimal dimensions of each element such that its real reflective phases approach the desired phase shifts at some sample frequencies as close as possible, a new optimization model is established, which is solved by the regular polyhedron method.

Conclusions

- Simulation results show that patterns of the reflectarray meet the China-coverage requirements in two operating bands, and that the proposed optimization method for designing large reflectarrays with complexly shaped patterns is reliable and efficient.