On the Multiscale Design of Task-Oriented Reflectarrays

G. Oliveri, A. Gelmini, A. Polo, N. Anselmi, and A. Massa

Contents

1 Phoenix Patch Reflectarray: 30x30 SLL=-25dB

1.1 Optimization target

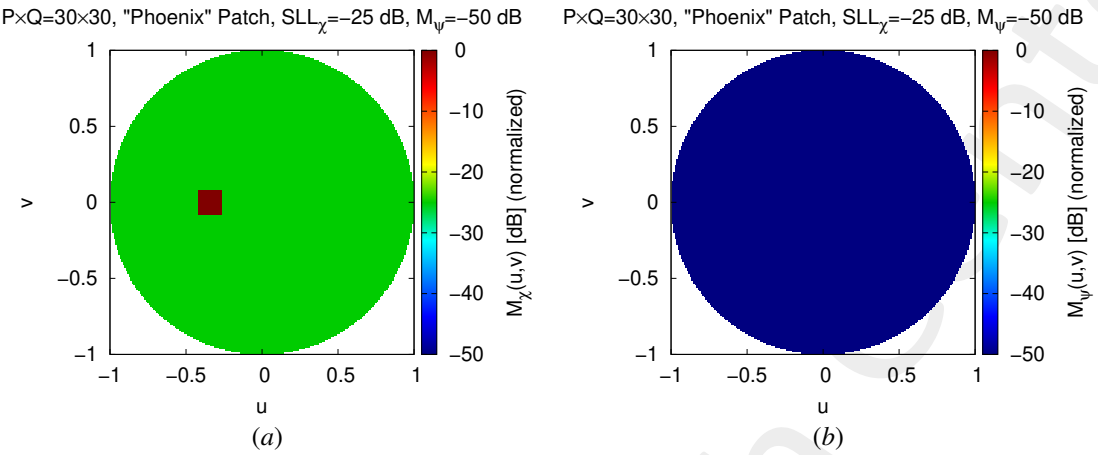

Figure 1: Phoenix Patch Reflectarray 30 × 30 SLL=-25 dB - Optimization target: SLL on the wanted polarization(a), mask on the unwanted polarization (b).

1.2 Optimization results

1.2.1 Cost Function

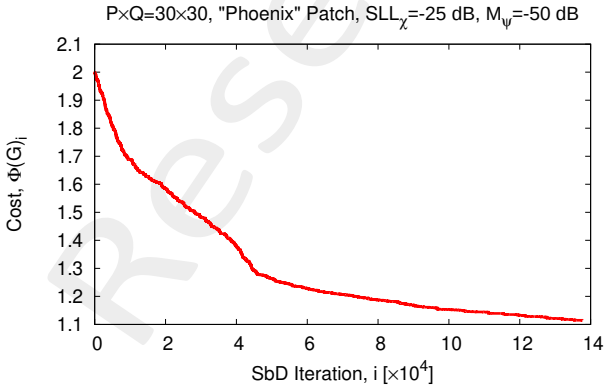

Figure 2: Phoenix Patch Reflectarray 30 × 30 SLL=-25 dB - Optimization: Cost function behavior.

1.2.2 Geometrical Design

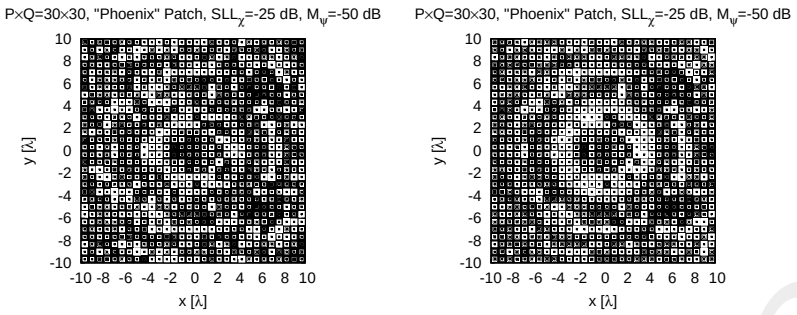

Figure 3: Phoenix Patch Reflectarray 30×30 SLL=-25 dB - Optimization: Starting reflectarray configuration(a) and optimized reflectarray configuration (b).

1.2.3 Reflection Coefficient

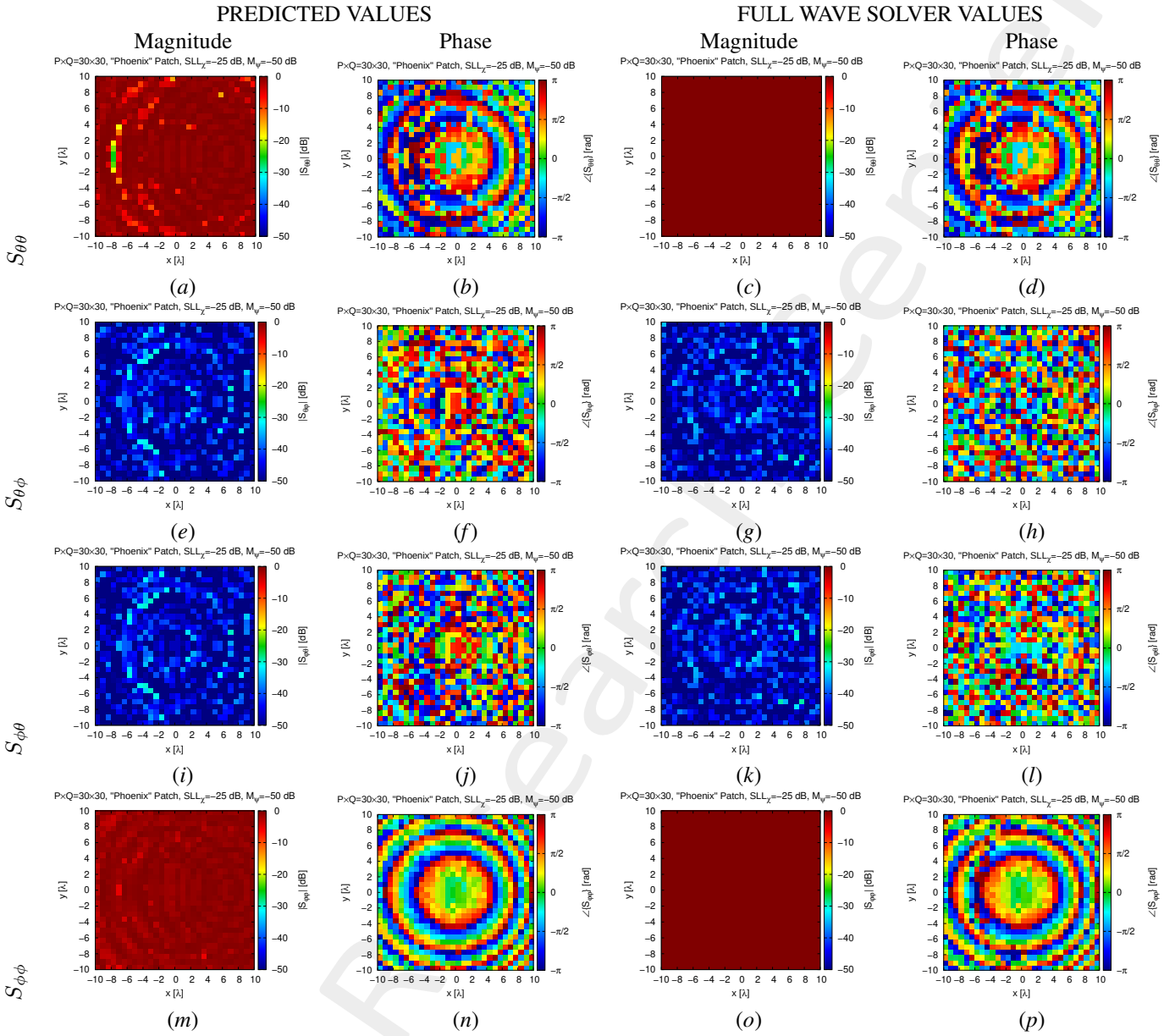

Figure 4: Phoenix Patch Reflectarray 30 × 30 SLL=-25 dB - Optimization - Reflection Coefficients: predicted(a)(b)(e)(f)(i)(j)(m)(n) vs. full-wave simulation (c)(d)(g)(h)(k)(l)(o)(p) of the magnitude(a)(c)(e)(g)(i)(k)(m)(o) and phase (b)(d)(f)(h)(j)(l)(n)(p) of $S_{\theta\theta}$(a)(b)(c)(d), $S_{\theta\phi}$(e)(f)(g)(h), $S_{\phi\theta}$(i)(j)(k)(l) and $S_{\phi\phi}$(m)(n)(o)(p).

1.2.4 Superficial Currents

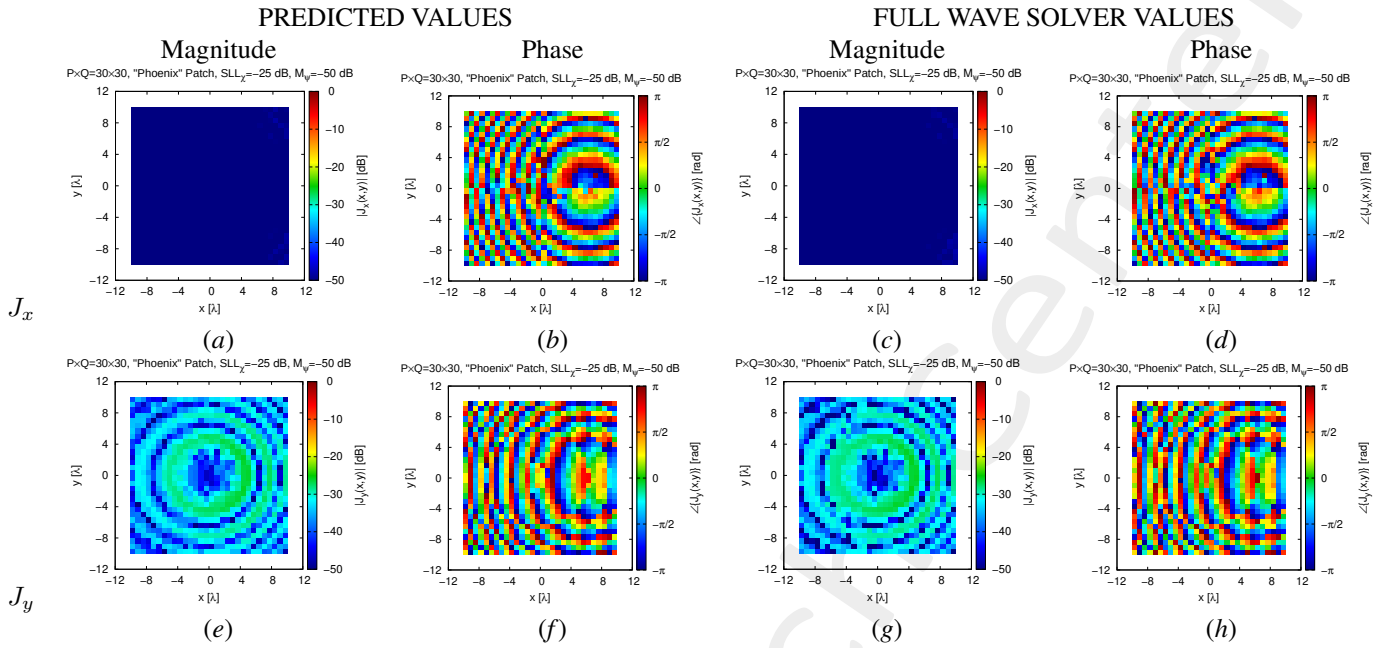

Figure 5: Phoenix Patch Reflectarray 30 × 30 SLL=-25 dB - Optimization - Superficial Currents: predicted(a)(b)(e)(f) vs. full-wave simulation (c)(d)(g)(h)of the magnitude(a)(c)(e)(g) and phase (b)(d)(f)(h) of J_x(a)(b)(c)(d) and J_y(e)(f)(g)(h).

1.2.5 Fields

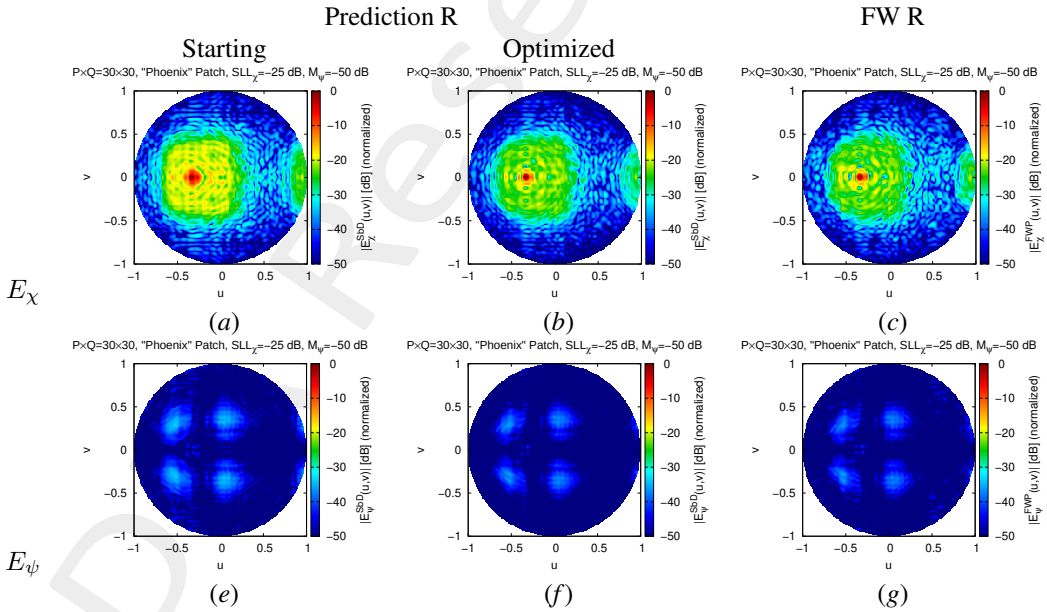

Figure 6: Phoenix Patch Reflectarray 30 × 30 SLL=-25 dB - Optimization - Radiated Fields: predicted(a)(b)(e)(f) vs. full-wave simulation of R (c)(g) vs. full-wave simulation of the entire structure (d)(h) of the magnitude of E_χ(a)(b)(c)(d) and E_ψ(e)(f)(g)(h).

1.2.6 Fields Cut

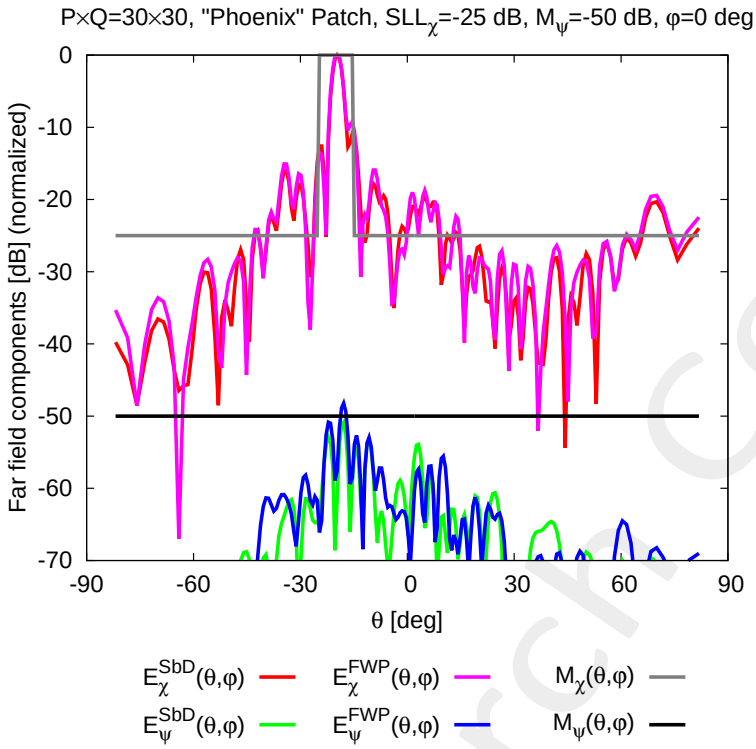

Figure 7: Phoenix Patch Reflectarray 30×30 SLL=-25 dB - Optimization - Radiated Field Cut with the comparison.

2 Phoenix Patch Reflectarray: 35x35 SLL=-25dB

2.1 Optimization target

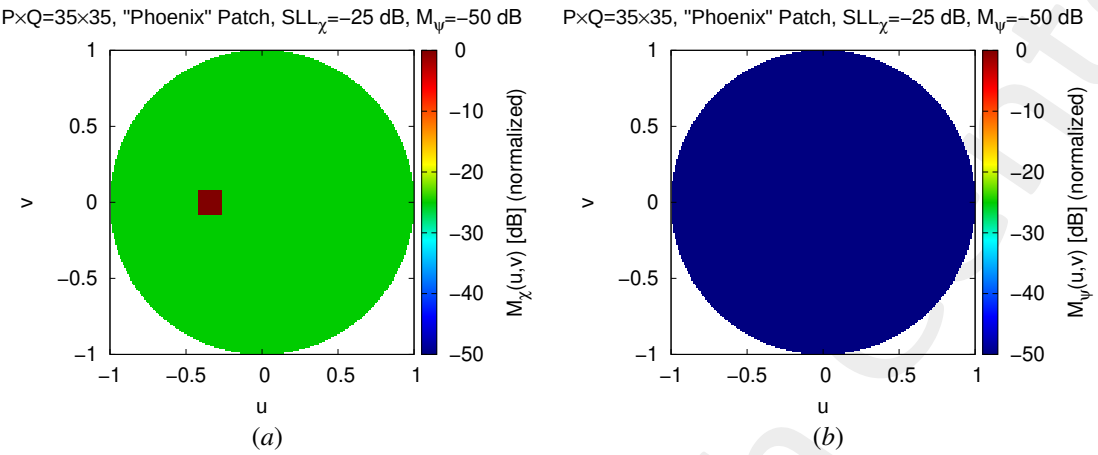

Figure 8: Phoenix Patch Reflectarray 35×35 SLL=-25 dB - Optimization target: SLL on the wanted polarization(a), mask on the unwanted polarization (b).

2.2 Optimization results

2.2.1 Cost Function

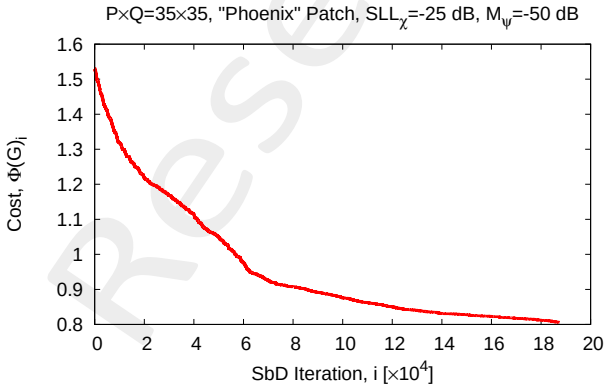

Figure 9: Phoenix Patch Reflectarray 35×35 SLL=-25 dB - Optimization: Cost function behavior.

2.2.2 Geometrical Design

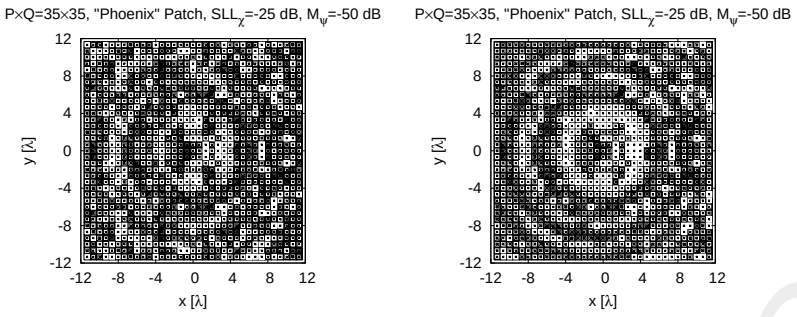

Figure 10: Phoenix Patch Reflectarray 35×35 SLL=-25 dB - Optimization: Starting reflectarray configuration(a) and optimized reflectarray configuration (b).

2.2.3 Reflection Coefficient

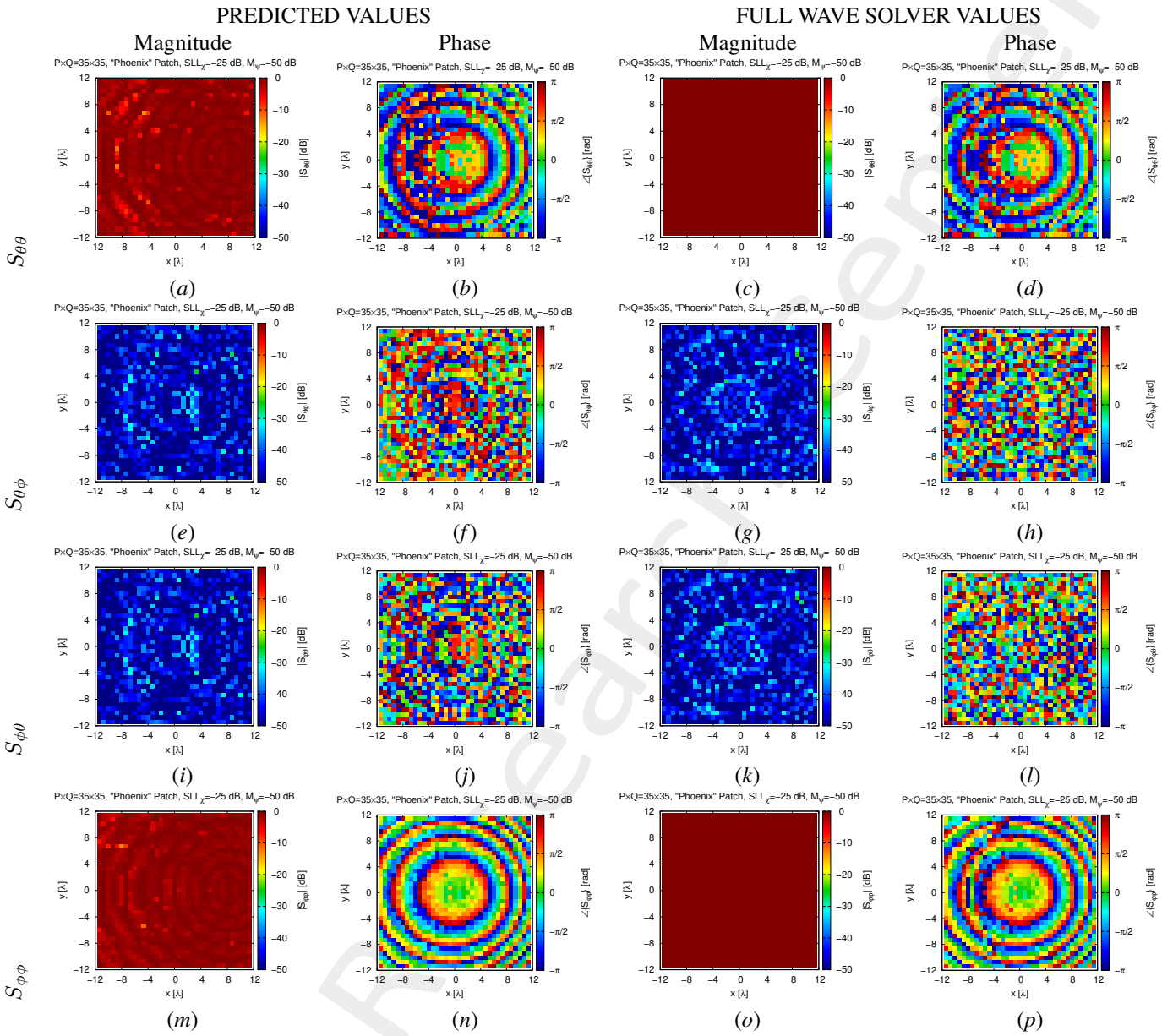

Figure 11: Phoenix Patch Reflectarray 35 × 35 SLL=-25 dB - Optimization - Reflection Coefficients: predicted(a)(b)(e)(f)(i)(j)(m)(n) vs. full-wave simulation (c)(d)(g)(h)(k)(l)(o)(p) of the magnitude(a)(c)(e)(g)(i)(k)(m)(o) and phase (b)(d)(f)(h)(j)(l)(n)(p) of $S_{\theta\theta}$(a)(b)(c)(d), $S_{\theta\phi}$(e)(f)(g)(h), $S_{\phi\theta}$(i)(j)(k)(l) and $S_{\phi\phi}$(m)(n)(o)(p).

2.2.4 Superficial Currents

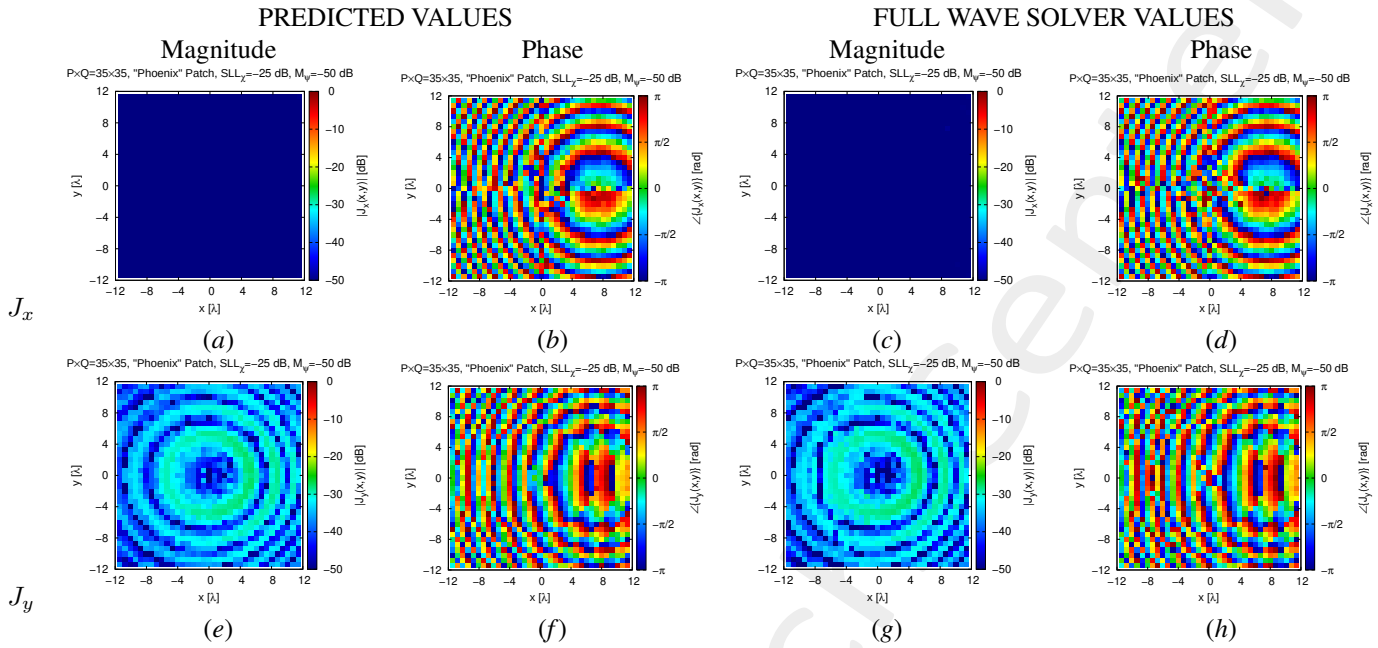

Figure 12: Phoenix Patch Reflectarray 35×35 SLL=-25 dB - Optimization - Superficial Currents: predicted(a)(b)(e)(f) vs. full-wave simulation (c)(d)(g)(h)of the magnitude(a)(c)(e)(g) and phase (b)(d)(f)(h) of J_x(a)(b)(c)(d) and J_y(e)(f)(g)(h).

2.2.5 Fields

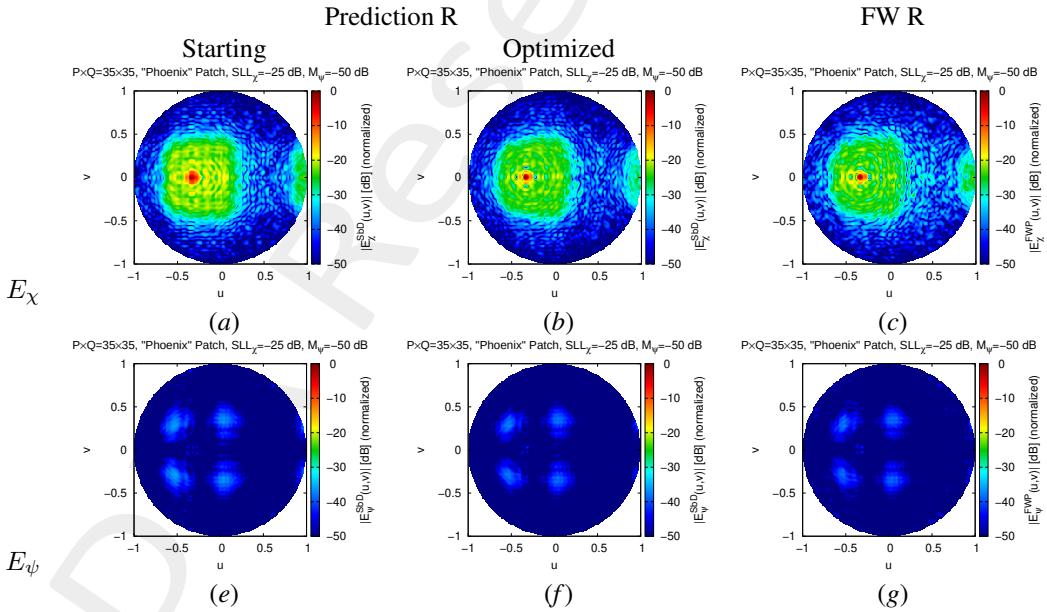

Figure 13: Phoenix Patch Reflectarray 35×35 SLL=-25 dB - Optimization - Radiated Fields: predicted(a)(b)(e)(f) vs. full-wave simulation of R (c)(g) vs. full-wave simulation of the entire structure (d)(h) of the magnitude of E_χ(a)(b)(c)(d) and E_ψ(e)(f)(g)(h).

2.2.6 Fields Cut

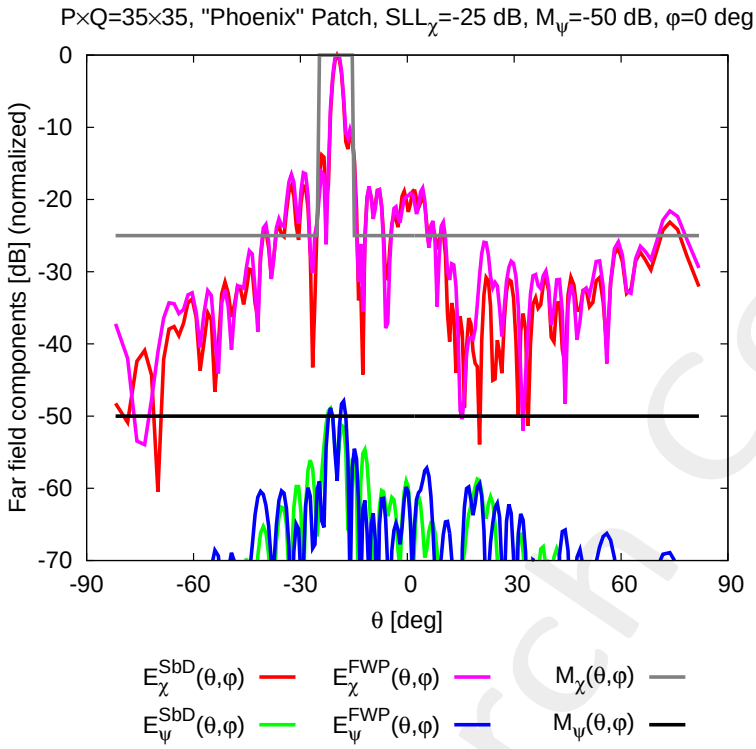

Figure 14: Phoenix Patch Reflectarray 35×35 SLL=-25 dB - Optimization - Radiated Field Cut with the comparison.

3 Double Layer Square Patch Reflectarray: 29x29

3.1 Unit cell geometry

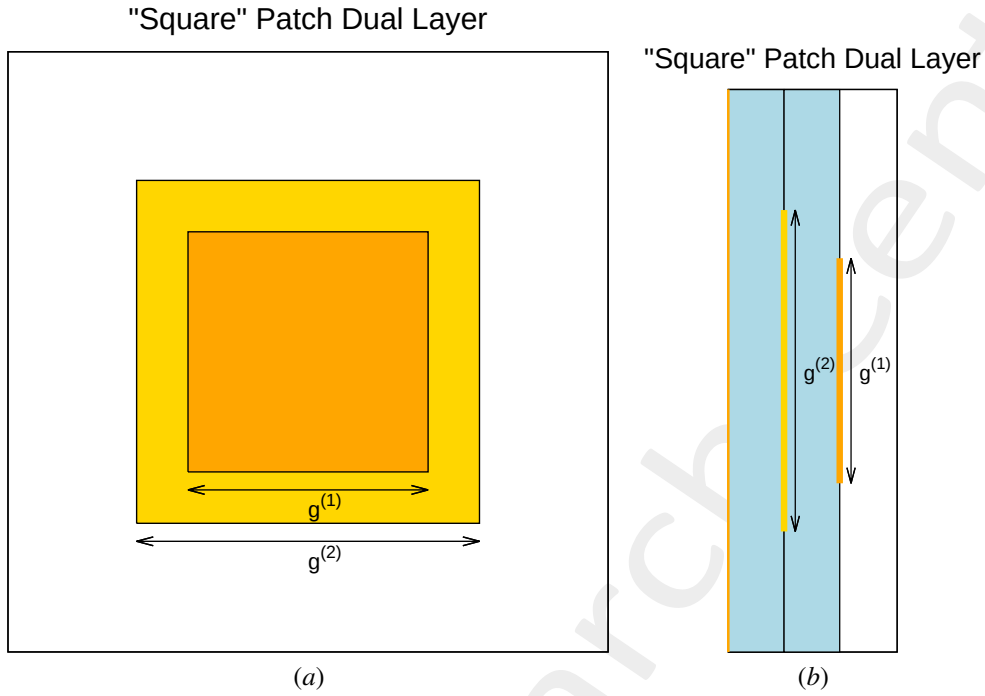

Figure 15: Square Patch Dual Layer unit cell, front (a) and side (b) view.

3.2 Optimization target

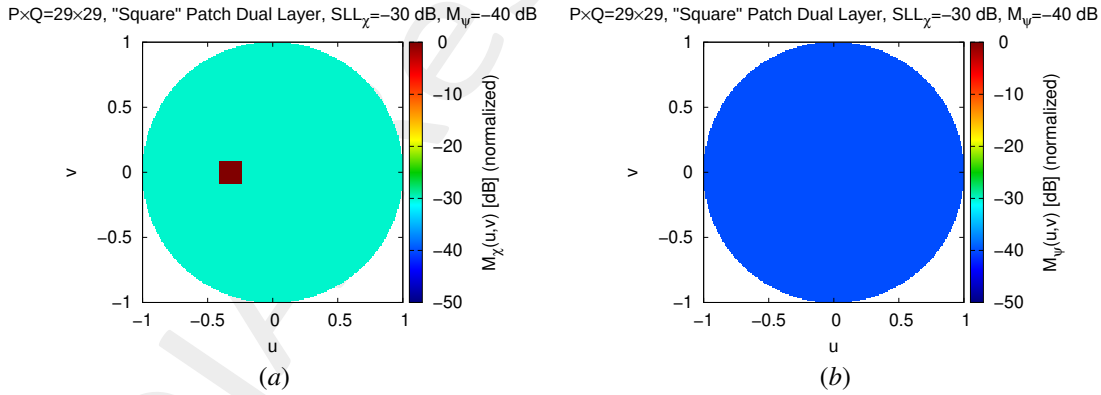

Figure 16: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = \alpha_\Gamma = 1.0$ - Optimization target: SLL on the wanted polarization(a), mask on the unwanted polarization (b).

3.3 Optimization results

3.3.1 Cost Function

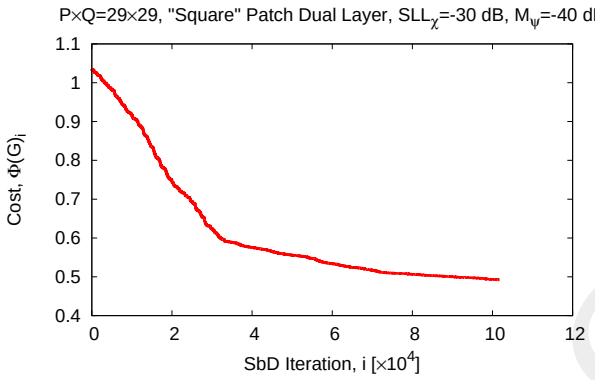

Figure 17: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = \alpha_\Gamma = 1.0$- Optimization: Cost function behavior.

3.3.2 Geometrical Design

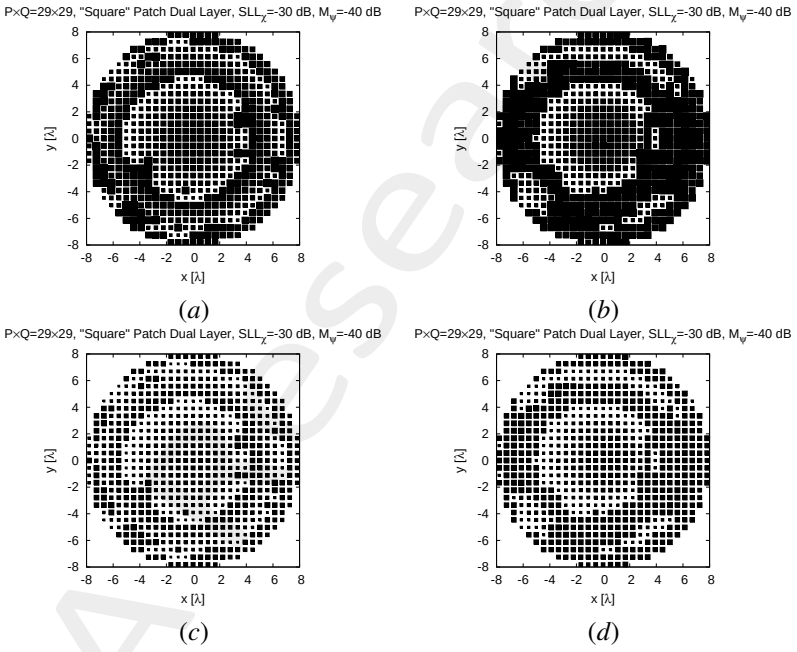

Figure 18: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = \alpha_\Gamma = 1.0$- Optimization: Starting reflectarray configuration(a)(c), optimized reflectarray configuration (b)(d) for layer one (a)(b) and layer two (c)(d).

3.3.3 Reflection Coefficient

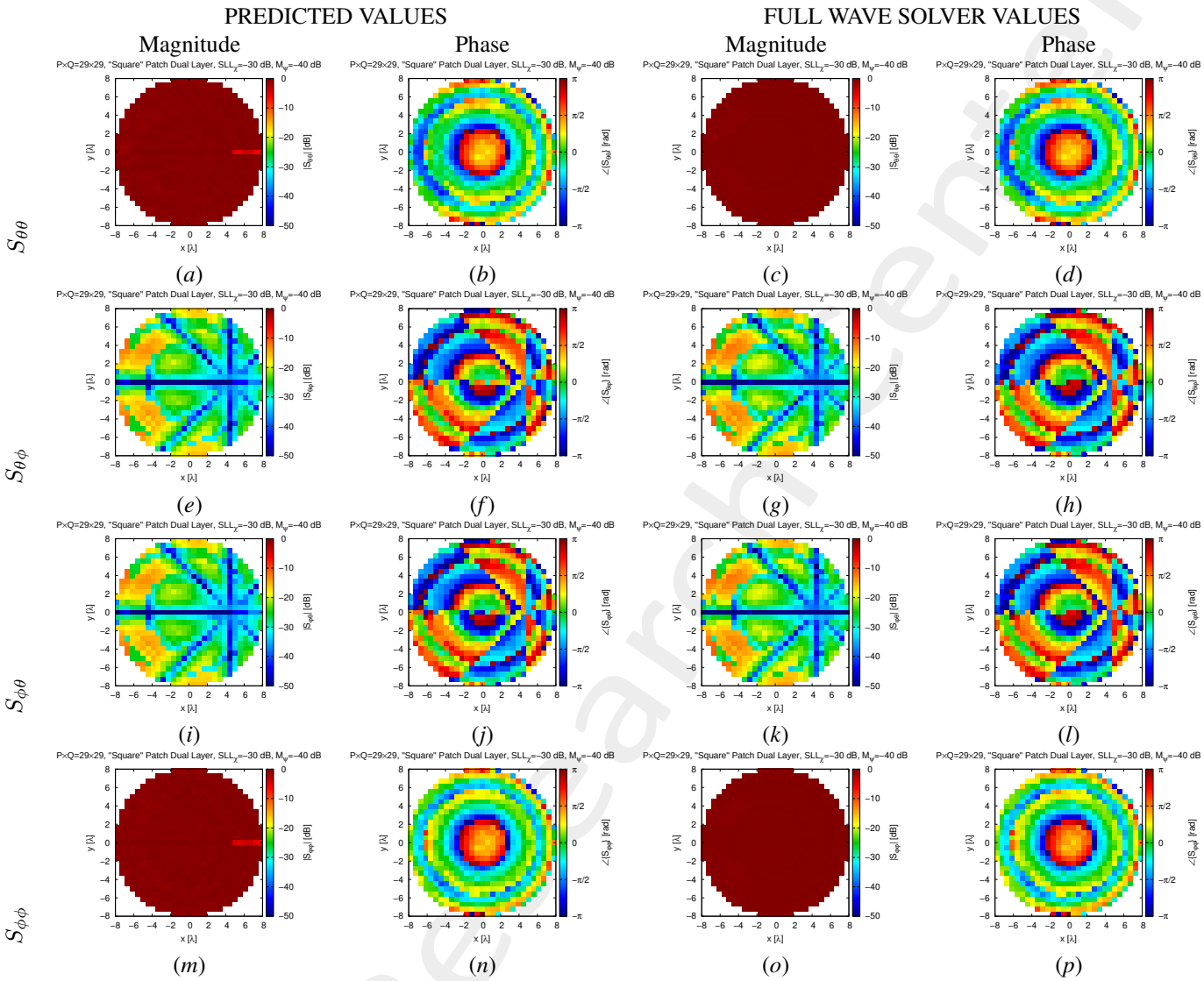

Figure 19: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = \alpha_\Gamma = 1.0$ - Optimization - Reflection Coefficients: predicted(a)(b)(e)(f)(i)(j)(m)(n) vs. full-wave simulation (c)(d)(g)(h)(k)(l)(o)(p) of the magnitude(a)(c)(e)(g)(i)(k)(m)(o) and phase (b)(d)(f)(h)(j)(l)(n)(p) of $S_{\theta\theta}$(a)(b)(c)(d), $S_{\theta\phi}$(e)(f)(g)(h), $S_{\phi\theta}$(i)(j)(k)(l) and $S_{\phi\phi}$(m)(n)(o)(p).

3.3.4 Superficial Currents

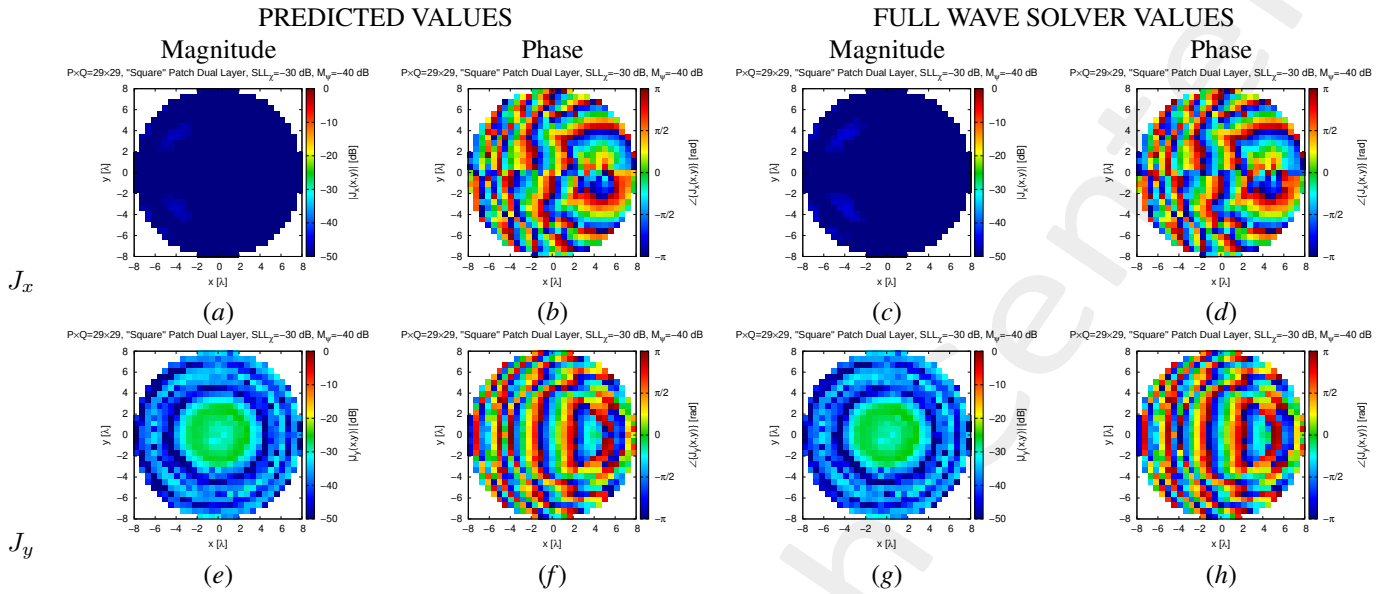

Figure 20: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = \alpha_\Gamma = 1.0$ - Optimization - Superficial Currents: predicted(a)(b)(e)(f) vs. full-wave simulation (c)(d)(g)(h)of the magnitude(a)(c)(e)(g) and phase (b)(d)(f)(h) of J_x(a)(b)(c)(d) and J_y(e)(f)(g)(h).

3.3.5 Fields

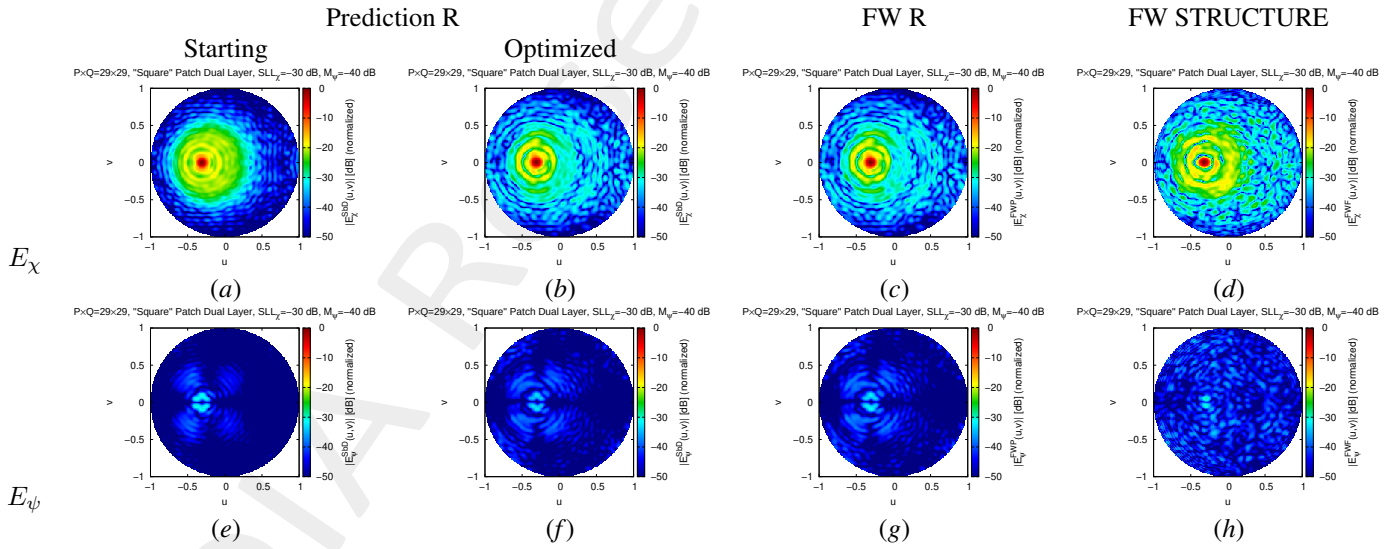

Figure 21: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = \alpha_\Gamma = 1.0$ - Optimization - Radiated Fields: predicted(a)(b)(e)(f) vs. full-wave simulation of R (c)(g) vs. full-wave simulation of the entire structure (d)(h) of the magnitude of E_χ(a)(b)(c)(d) and E_ψ(e)(f)(g)(h).

3.3.6 Fields Cut

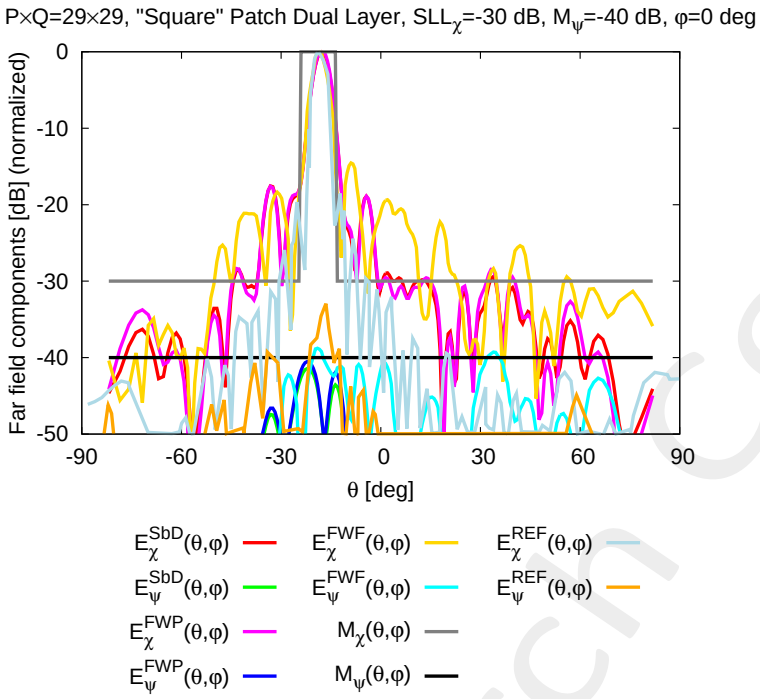

Figure 22: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = \alpha_\Gamma = 1.0$ - Optimization - Radiated Field Cut with the comparison.

4 Double Layer Square Patch Reflectarray: 29x29, Similarity Weight=10

4.1 Optimization target

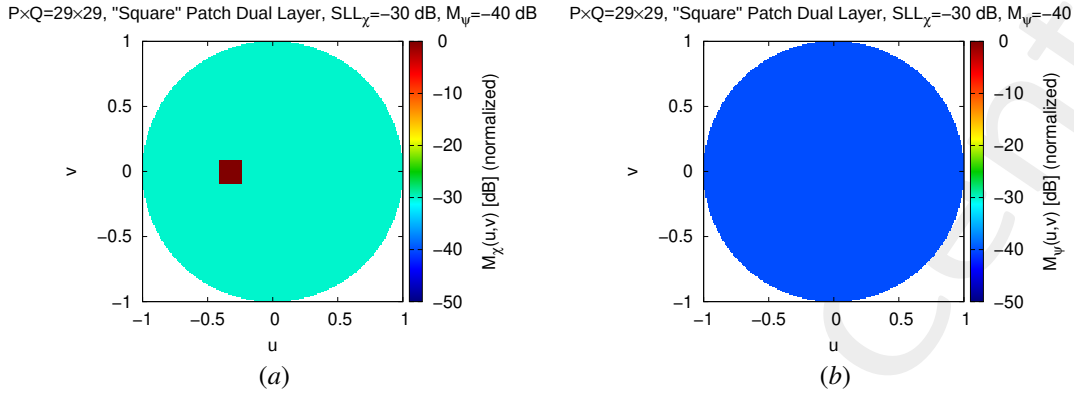

Figure 23: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = 1.0$, $\alpha_\Gamma = 10.0$ - Optimization target: SLL on the wanted polarization(a), mask on the unwanted polarization (b).

4.2 Optimization results

4.2.1 Cost Function

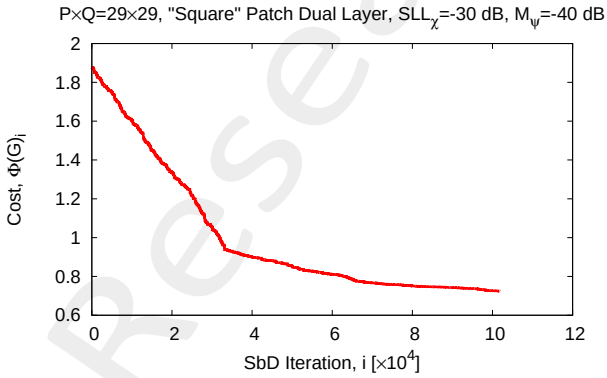

Figure 24: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = 1.0$, $\alpha_\Gamma = 10.0$- Optimization: Cost function behavior.

4.2.2 Geometrical Design

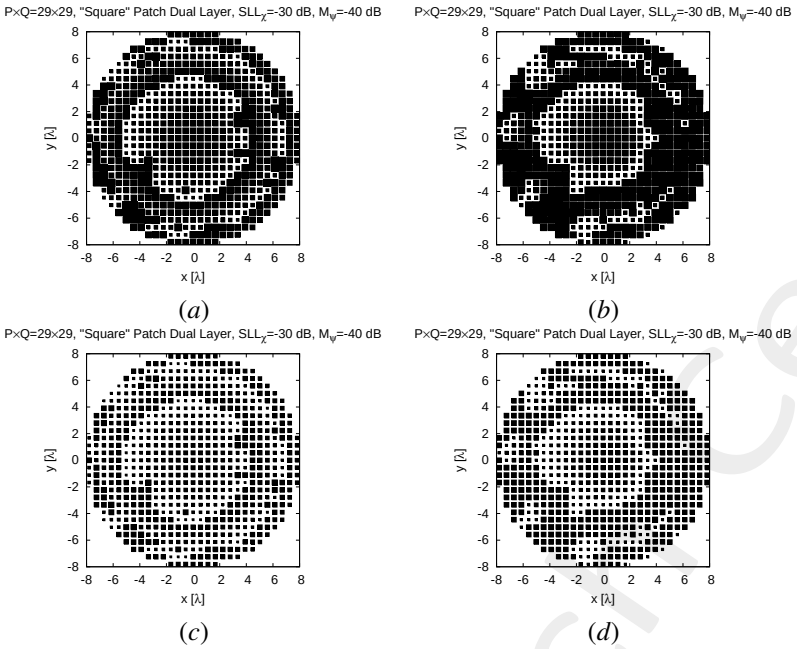

Figure 25: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = 1.0$, $\alpha_\Gamma = 10.0$- Optimization: Starting reflectarray configuration(a)(c), optimized reflectarray configuration (b)(d) for layer one (a)(b) and layer two (c)(d).

4.2.3 Reflection Coefficient

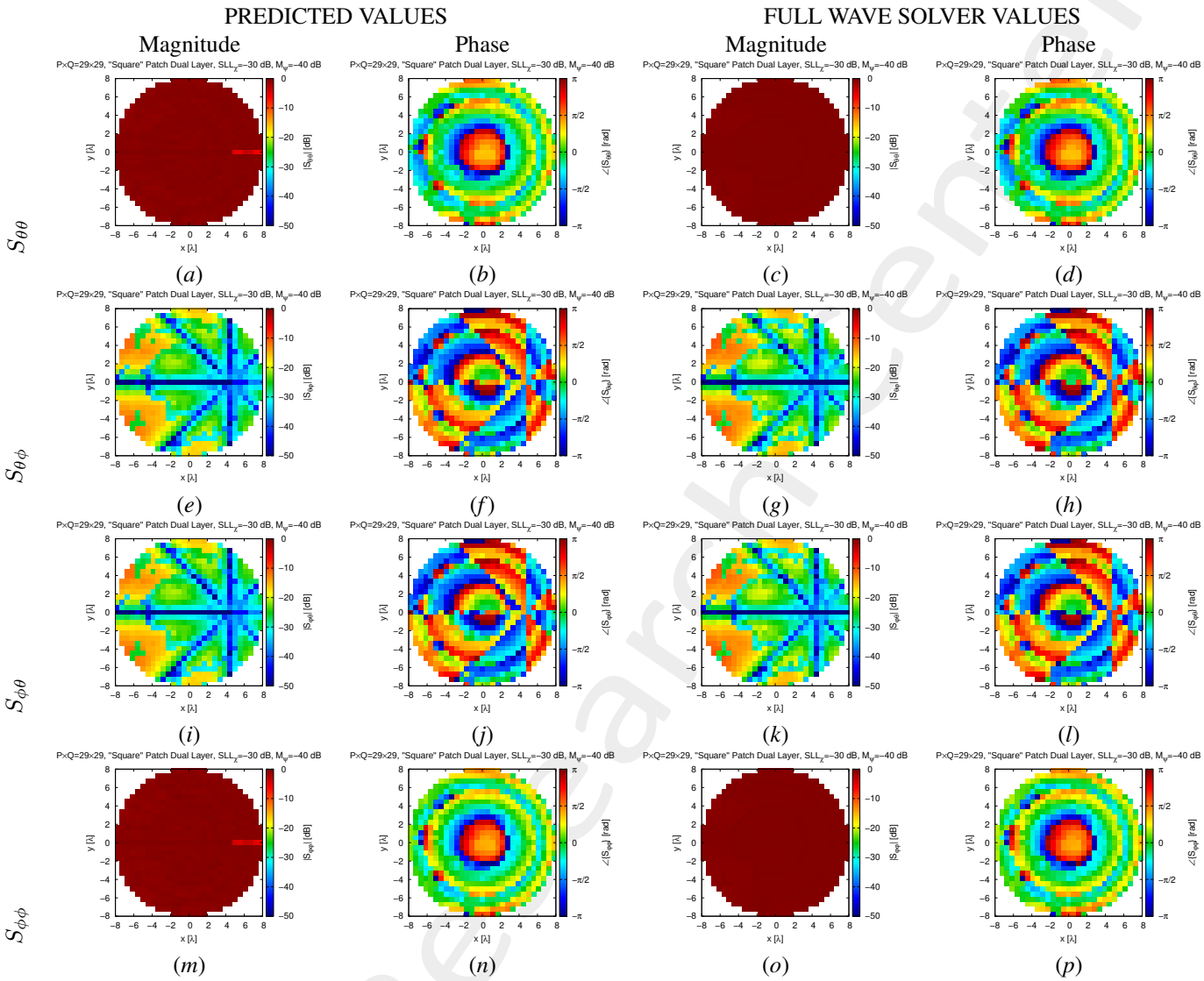

Figure 26: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = 1.0$, $\alpha_\Gamma = 10.0$ - Optimization - Reflection Coefficients: predicted(a)(b)(e)(f)(i)(j)(m)(n) vs. full-wave simulation (c)(d)(g)(h)(k)(l)(o)(p) of the magnitude(a)(c)(e)(g)(i)(k)(m)(o) and phase (b)(d)(f)(h)(j)(l)(n)(p) of $S_{\theta\theta}$(a)(b)(c)(d), $S_{\theta\phi}$(e)(f)(g)(h), $S_{\phi\theta}$(i)(j)(k)(l) and $S_{\phi\phi}$(m)(n)(o)(p).

4.2.4 Superficial Currents

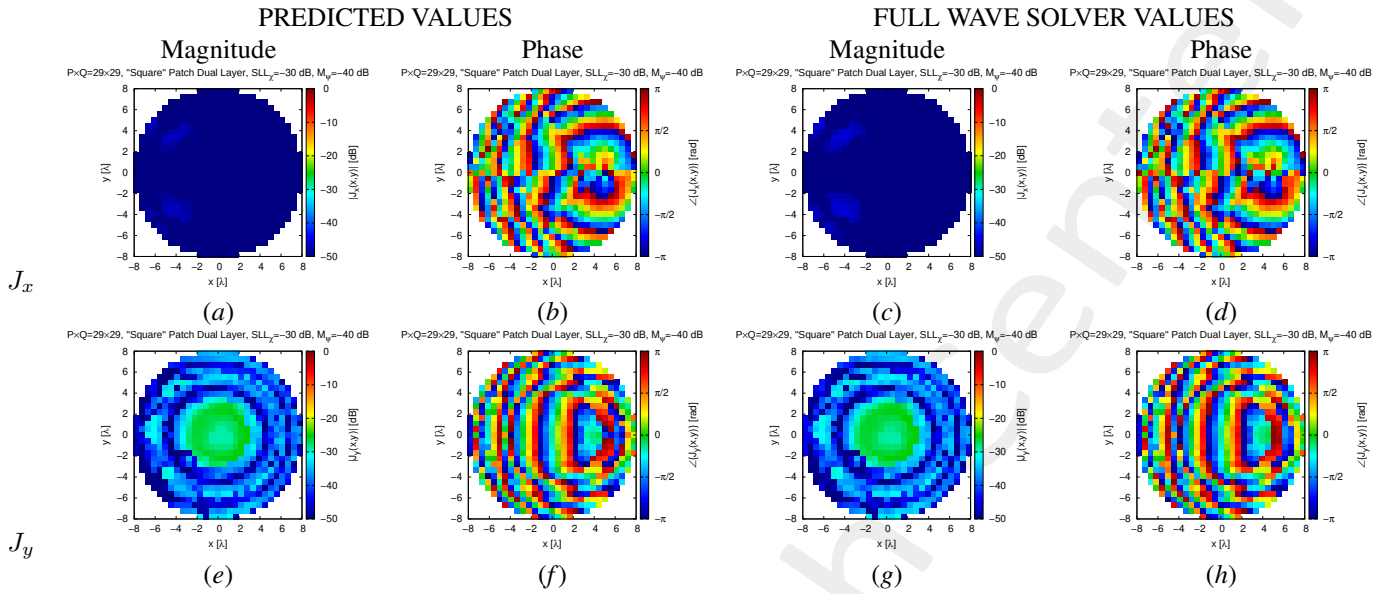

Figure 27: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = 1.0$, $\alpha_\Gamma = 10.0$ - Optimization - Superficial Currents: predicted(a)(b)(e)(f) vs. full-wave simulation (c)(d)(g)(h)of the magnitude(a)(c)(e)(g) and phase (b)(d)(f)(h) of J_x(a)(b)(c)(d) and J_y(e)(f)(g)(h).

4.2.5 Fields

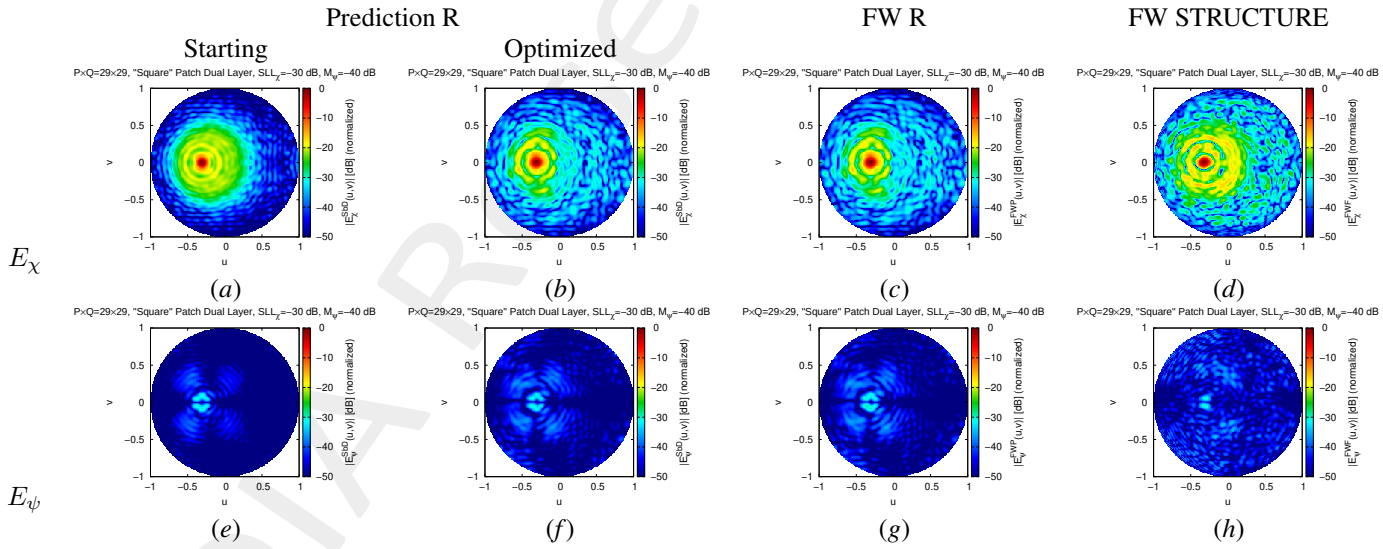

Figure 28: Double Layer Square Patch Reflectarray $29 \times 29 \alpha_\beta = 1.0$, $\alpha_\Gamma = 10.0$ - Optimization - Radiated Fields: predicted(a)(b)(e)(f) vs. full-wave simulation of R (c)(g) vs. full-wave simulation of the entire structure (d)(h) of the magnitude of E_χ(a)(b)(c)(d) and E_ψ(e)(f)(g)(h).

4.2.6 Fields Cut

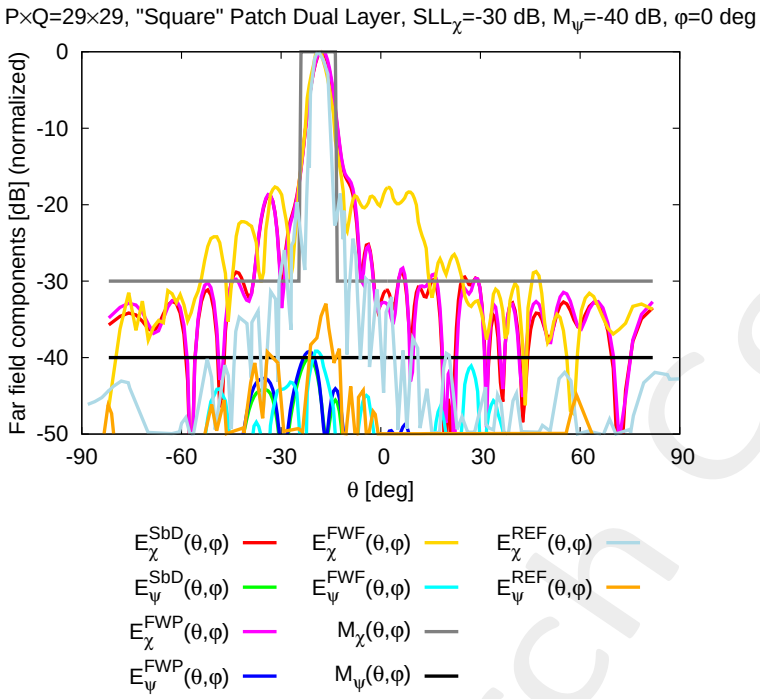

Figure 29: Double Layer Square Patch Reflectarray 29×29 $\alpha_\beta = 1.0$, $\alpha_\Gamma = 10.0$ - Optimization - Radiated Field Cut with the comparison .

More information on the topics of this document can be found in the following list of references.

References

[1] P. Rocca, M. Benedetti, M. Donelli, D. Franceschini, and A. Massa, "Evolutionary optimization as applied to inverse problems," *Inverse Problems - 25 th Year Special Issue of Inverse Problems, Invited Topical Review*, vol. 25, pp. 1-41, Dec. 2009.

[2] P. Rocca, G. Oliveri, and A. Massa, "Differential Evolution as applied to electromagnetics," *IEEE Antennas Propag. Mag.*, vol. 53, no. 1, pp. 38-49, Feb. 2011.

[3] P. Rocca, N. Anselmi, A. Polo, and A. Massa, "An irregular two-sizes square tiling method for the design of isophoric phased arrays," *IEEE Trans. Antennas Propag.*, vol. 68, no. 6, pp. 4437-4449, Jun. 2020.

[4] P. Rocca, N. Anselmi, A. Polo, and A. Massa, "Modular design of hexagonal phased arrays through diamond tiles," *IEEE Trans. Antennas Propag.*, vol.68, no. 5, pp. 3598-3612, May 2020.

[5] N. Anselmi, L. Poli, P. Rocca, and A. Massa, "Design of simplified array layouts for preliminary experimental testing and validation of large AESAs," *IEEE Trans. Antennas Propag.*, vol. 66, no. 12, pp. 6906-6920, Dec. 2018.

[6] N. Anselmi, P. Rocca, M. Salucci, and A. Massa, "Contiguous phase-clustering in multibeam-on-receive scanning arrays." *IEEE Trans. Antennas Propag.*, vol. 66, no. 11, pp. 5879-5891, Nov. 2018.

[7] G. Oliveri, G. Gottardi, F. Robol, A. Polo, L. Poli, M. Salucci, M. Chuan, C. Massagrande, P. Vinetti, M. Mattivi, R. Lombardi, and A. Massa, "Co-design of unconventional array architectures and antenna elements for 5G base station," *IEEE Trans. Antennas Propag.*, vol. 65, no. 12, pp. 6752-6767, Dec. 2017.

[8] N. Anselmi, P. Rocca, M. Salucci, and A. Massa, "Irregular phased array tiling by means of analytic schemata-driven optimization," *IEEE Trans. Antennas Propag.*, vol. 65, no. 9, pp. 4495-4510, September 2017.

[9] N. Anselmi, P. Rocca, M. Salucci, and A. Massa, "Optimization of excitation tolerances for robust beamforming in linear arrays," *IET Microwaves, Antennas & Propagation*, vol. 10, no. 2, pp. 208-214, 2016.

[10] P. Rocca, R. J. Mailloux, and G. Toso, "GA-Based optimization of irregular sub-array layouts for wideband phased arrays desig," *IEEE Antennas and Wireless Propag. Lett.*, vol. 14, pp. 131-134, 2015.

[11] P. Rocca, M. Donelli, G. Oliveri, F. Viani, and A. Massa, "Reconfigurable sum-difference pattern by means of parasitic elements for forward-looking monopulse radar," *IET Radar, Sonar & Navigation*, vol 7, no. 7, pp. 747-754, 2013.

[12] P. Rocca, L. Manica, and A. Massa, "Ant colony based hybrid approach for optimal compromise sum-difference patterns synthesis," *Microwave Opt. Technol. Lett.*, vol. 52, no. 1, pp. 128-132, Jan. 2010.

[13] P. Rocca, L. Manica, and A. Massa, "An improved excitation matching method based on an ant colony optimization for suboptimal-free clustering in sum-difference compromise synthesis," *IEEE Trans. Antennas Propag.*, vol. 57, no. 8, pp. 2297-2306, Aug. 2009.

[14] P. Rocca, L. Manica, and A. Massa, "Hybrid approach for sub-arrayed monopulse antenna synthesis," *Electronics Letters*, vol. 44, no. 2, pp. 75-76, Jan. 2008.

[15] P. Rocca, L. Manica, F. Stringari, and A. Massa, "Ant colony optimization for tree-searching based synthesis of monopulse array antenna," *Electronics Letters*, vol. 44, no. 13, pp. 783-785, Jun. 19, 2008.

[16] G. Oliveri, A. Gelmini, A. Polo, N. Anselmi, and A. Massa, "System-by-design multi-scale synthesis of task-oriented reflectarrays," *IEEE Trans. Antennas Propag.*, vol. 68, no. 4, pp. 2867-2882, Apr. 2020.

[17] M. Salucci, F. Robol, N. Anselmi, M. A. Hannan, P. Rocca, G. Oliveri, M. Donelli, and A. Massa, "S-Band spline-shaped aperture-stacked patch antenna for air traffic control applications," *IEEE Tran. Antennas Propag.*, vol. 66, no. 8, pp. 4292-4297, Aug. 2018.

[18] M. Salucci, L. Poli, A. F. Morabito, and P. Rocca, "Adaptive nulling through subarray switching in planar antenna arrays," *Journal of Electromagnetic Waves and Applications*, vol. 30, no. 3, pp. 404-414, February 2016

[19] T. Moriyama, L. Poli, and P. Rocca, "Adaptive nulling in thinned planar arrays through genetic algorithms," *IEICE Electronics Express*, vol. 11, no. 21, pp. 1-9, Sep. 2014.

[20] L. Poli, P. Rocca, M. Salucci, and A. Massa, "Reconfigurable thinning for the adaptive control of linear arrays," *IEEE Trans. Antennas Propag.*, vol. 61, no. 10, pp. 5068-5077, Oct. 2013.

[21] P. Rocca, L. Poli, G. Oliveri, and A. Massa, "Adaptive nulling in time-varying scenarios through time-modulated linear arrays," *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 101-104, 2012.

[22] M. Benedetti, G. Oliveri, P. Rocca, and A. Massa, "A fully-adaptive smart antenna prototype: ideal model and experimental validation in complex interference scenarios," *Progress in Electromagnetic Research*, PIER 96, pp. 173-191, 2009.

[23] M. Benedetti, R. Azaro, and A. Massa, "Memory enhanced PSO-based optimization approach for smart antennas control in complex interference scenarios," *IEEE Trans. Antennas Propag.*, vol. 56, no. 7, pp. 1939-1947, Jul. 2008.

[24] M. Benedetti, R. Azaro, and A. Massa, "Experimental validation of a fully-adaptive smart antenna prototype," *Electronics Letters*, vol. 44, no. 11, pp. 661-662, May 2008.

[25] R. Azaro, L. Ioriatti, M. Martinelli, M. Benedetti, and A. Massa, "An experimental realization of a fully-adaptive smart antenna," *Microwave Opt. Technol. Lett.*, vol. 50, no. 6, pp. 1715-1716, Jun. 2008.

[26] M. Donelli, R. Azaro, L. Fimognari, and A. Massa, "A planar electronically reconfigurable Wi-Fi band antenna based on a parasitic microstrip structure," *IEEE Antennas Wireless Propag. Lett.*, vol. 6, pp. 623-626, 2007.

[27] M. Benedetti, R. Azaro, D. Franceschini, and A. Massa, "PSO-based real-time control of planar uniform circular arrays," *IEEE Antennas Wireless Propag. Lett.*, vol. 5, pp. 545-548, 2006.

[28] G. Oliveri, P. Rocca, M. Salucci, and A. Massa, "Holographic smart EM skins for advanced beam power shaping in next generation wireless environments," *IEEE J. Multiscale Multiphysics Comput. Tech.*, vol. 6, pp. 171-182, Oct. 2021.

[29] M. Salucci, L. Tenuti, G. Gottardi, A. Hannan, and A. Massa, "System-by-design method for efficient linear array miniaturisation through low-complexity isotropic lenses," *Electronic Letters*, vol. 55, no. 8, pp. 433-434, May 2019.

[30] M. Salucci, N. Anselmi, S. Goudos, and A. Massa, "Fast design of multiband fractal antennas through a system-by-design approach for NB-IoT applications," *EURASIP J. Wirel. Commun. Netw.*, vol. 2019, no. 1, pp. 68-83, Mar. 2019.

[31] M. Salucci, G. Oliveri, N. Anselmi, and A. Massa, "Material-by-design synthesis of conformal miniaturized linear phased arrays," *IEEE Access*, vol. 6, pp. 26367-26382, 2018.

[32] M. Salucci, G. Oliveri, N. Anselmi, G. Gottardi, and A. Massa, "Performance enhancement of linear active electronically-scanned arrays by means of MbD-synthesized metalenses," *Journal of Electromagnetic Waves and Applications*, vol. 32, no. 8, pp. 927-955, 2018.

[33] G. Oliveri, M. Salucci, N. Anselmi and A. Massa, "Multiscale System-by-Design synthesis of printed WAIMs for waveguide array enhancement," *IEEE J. Multiscale Multiphysics Computat. Techn.*, vol. 2, pp. 84-96, 2017.

[34] A. Massa and G. Oliveri, "Metamaterial-by-Design: Theory, methods, and applications to communications and sensing - Editorial," *EPJ Applied Metamaterials*, vol. 3, no. E1, pp. 1-3, 2016.

[35] G. Oliveri, F. Viani, N. Anselmi, and A. Massa, "Synthesis of multi-layer WAIM coatings for planar phased arrays within the system-by-design framework," *IEEE Trans. Antennas Propag.*, vol. 63, no. 6, pp. 2482-2496, June 2015.

[36] G. Oliveri, L. Tenuti, E. Bekele, M. Carlin, and A. Massa, "An SbD-QCTO approach to the synthesis of isotropic metamaterial lenses," *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 1783-1786, 2014.

[37] A. Massa, G. Oliveri, P. Rocca, and F. Viani, "System-by-Design: a new paradigm for handling design complexity," *8th European Conference on Antennas Propag. (EuCAP 2014)*, The Hague, The Netherlands, pp. 1180-1183, Apr. 6-11, 2014.

[38] P. Rocca, G. Oliveri, R. J. Mailloux, and A. Massa, "Unconventional phased array architectures and design Methodologies - A review," *Proceedings of the IEEE*, vol. 104, no. 3, pp. 544-560, March 2016.