A Multi-Objective Strategy for the Pareto-optimal Domino-tiling of Orthogonal Polygon Phased Arrays

P. Rocca, N. Anselmi, A. Polo, and A. Massa

Contents

1 Introduction

This work presents an innovative tiling optimization strategy for arbitrary orthogonal-polygon shaped apertures. An exhaustive search approach, together with a multi-objective strategy, has been used in order to obtain optimal tiling configurations, jointly optimizing two different pattern features of interest. A simple example validating the proposed method has been finally reported.

2 Numerical Results

2.1 Orthogonal Polygon #2

Array Analysis Parameters:

- Total Number of Elements: $P = 50$
- Spacing: $d = \lambda/2$
- Total Number of Configurations: $\Gamma = 176220$
- Number of Inner Lattice Points: $N_{inn} = 34$

2.1.1 ETM-MOP vs OTM-MOP - Gaussian Reference Excitations, SLL = -20 [dB] - SLL vs {HPBW}

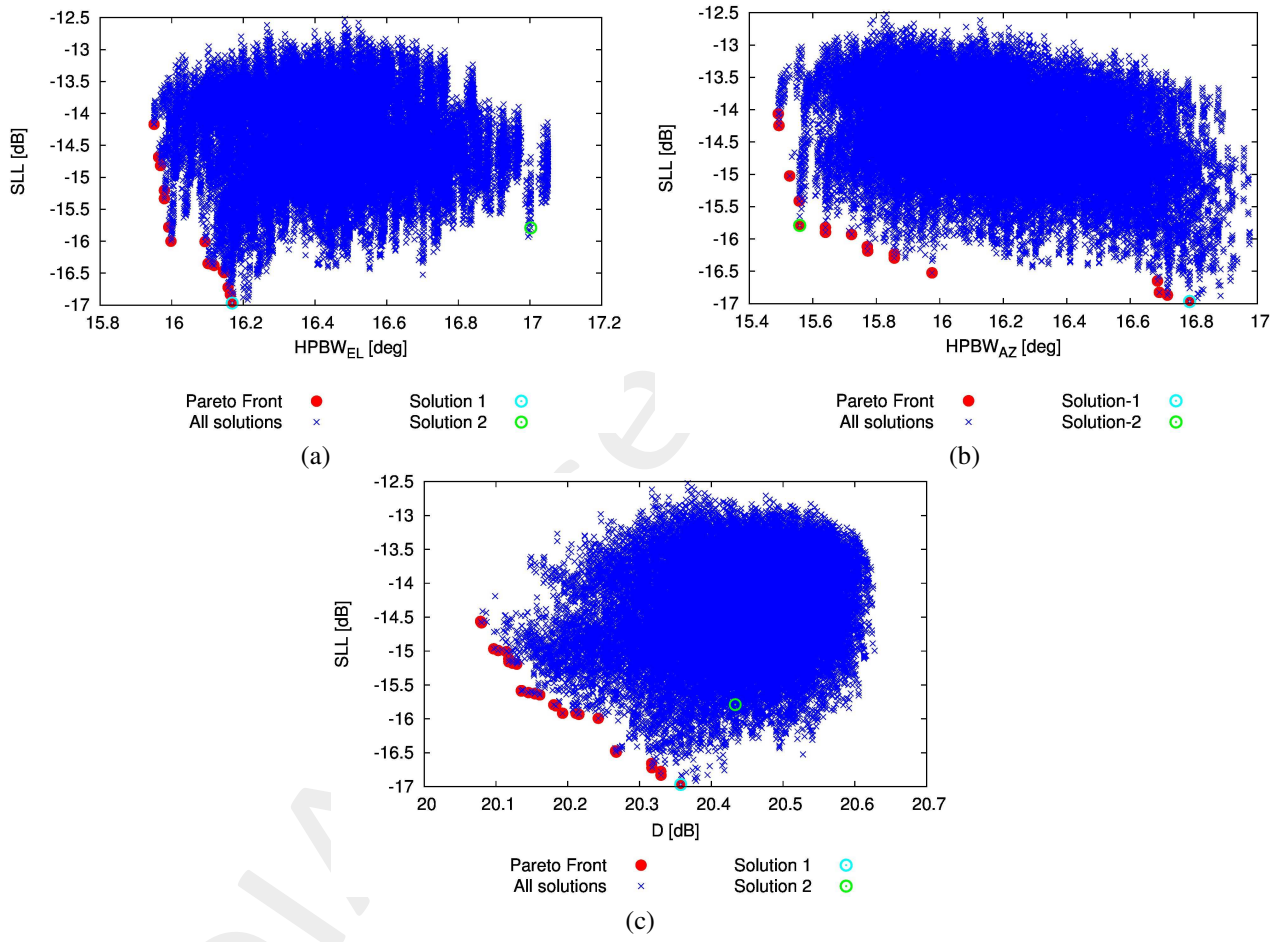

Figure 1: Pareto front of the ETM soutions considering: $OBJ^{(1)} = SLL, OBJ^{(2)} = HPBW_{AZ}$ (a), $OBJ^{(1)} = SLL$, $OBJ^{(3)} = HPBW_{EL}$(b), $OBJ^{(1)} = SLL, OBJ^{(4)} = D$ (c).

	SLL [dB]	D [dBi]	$HPBW_{az}$ [deg]	$HPBW_{el}$ [deg]	$\Psi\,(T)$
$Reference$	-20.5	21.14	13.49	19.61	–
$Solution-1$	-17.82	21.15	13.41	19.05	–

Table I: Pattern descriptors and fitness values for the presented solutions.

RESULTS - Pareto Fronts (MOP)

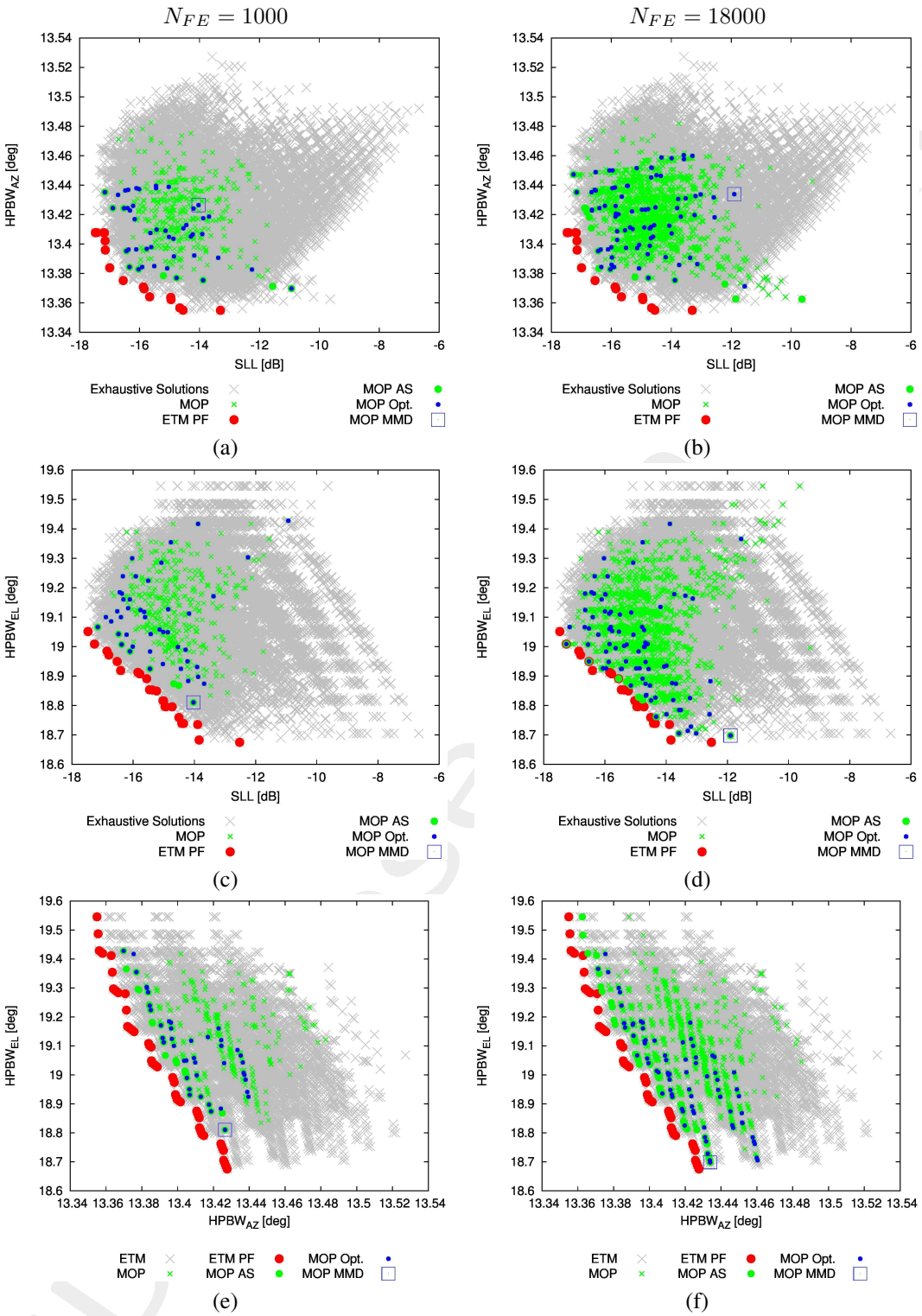

Figure 2: Exhaustive Pareto front as compared to the MOP Approximation Set considering: $OBJ^{(1)} = SLL$ vs $OBJ^{(2)} = HPBW_{AZ}$ (a)(b), $OBJ^{(1)} = SLL$ vs $OBJ^{(3)} = HPBW_{EL}$(c)(d), $OBJ^{(2)} = HPBW_{AZ}$ vs $OBJ^{(3)} = HPBW_{EL}$(e)(f), for $N_{FE} = 1000$ and $N_{FE} = 18000$ fitness evaluations.

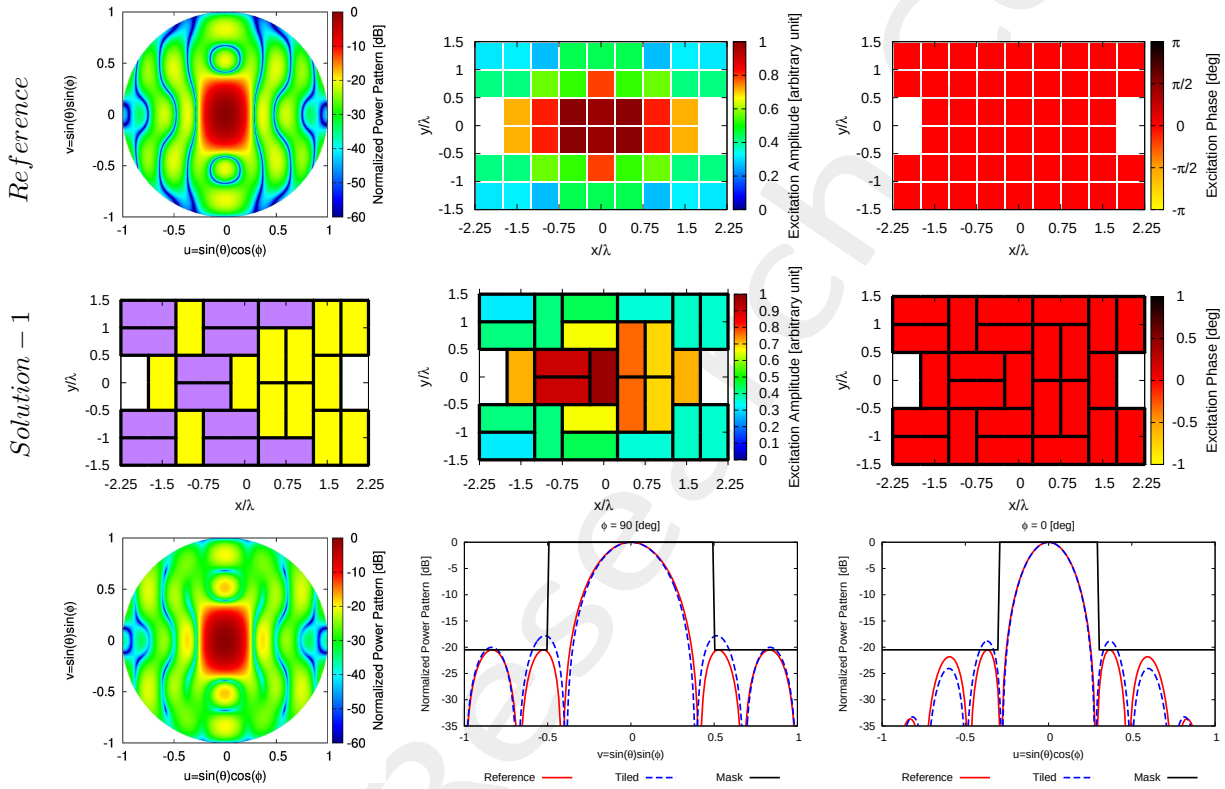

Figure 3: Tiling Configurations/Excitations.

OUTCOME:

- Solution-56770.

2.1.2 ETM-MOP - CP Reference Excitations, Symmetric Mask, SLL = -20 [dB] - Mask Matching vs {SLL, D, HPBW}

Reference Fully-Populated Array:

- Number of Samples along u: 512
- Number of Samples along v: 512
- Steering θ Direction: $\theta_s = 0$
- Steering ϕ Direction: $\phi_s = 0$
- Tapering: CP - Asymmetric Mask:
- Main Lobe Window Width along u: $MW_u = 0.3$ [u]
- Main Lobe Window Width along v: $MW_v = 0.5$ [v]
- Side Lobe levels: $SLL = -20.5$

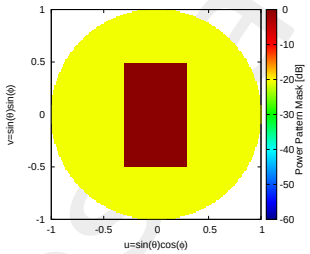

Figure 4: The power pattern mask used for the reference tapering optimization with CP.

Cost Function:

- $OBJ^{(1)} = SLL$
- $OBJ^{(2)} = HPBW_{AZ}$
- $OBJ^{(3)} = HPBW_{EL}$
- $OBJ^{(4)} = D$
- $OBJ^{(5)} = \int_{-1}^{1}\int_{-1}^{1} \left[M\left(u,v\right) - P\left(u,v;\underline{C}\right)\right] \mathcal{H}\left[P\left(u,v;\underline{C}\right) - M\left(u,v\right)\right] dudv$

RESULTS

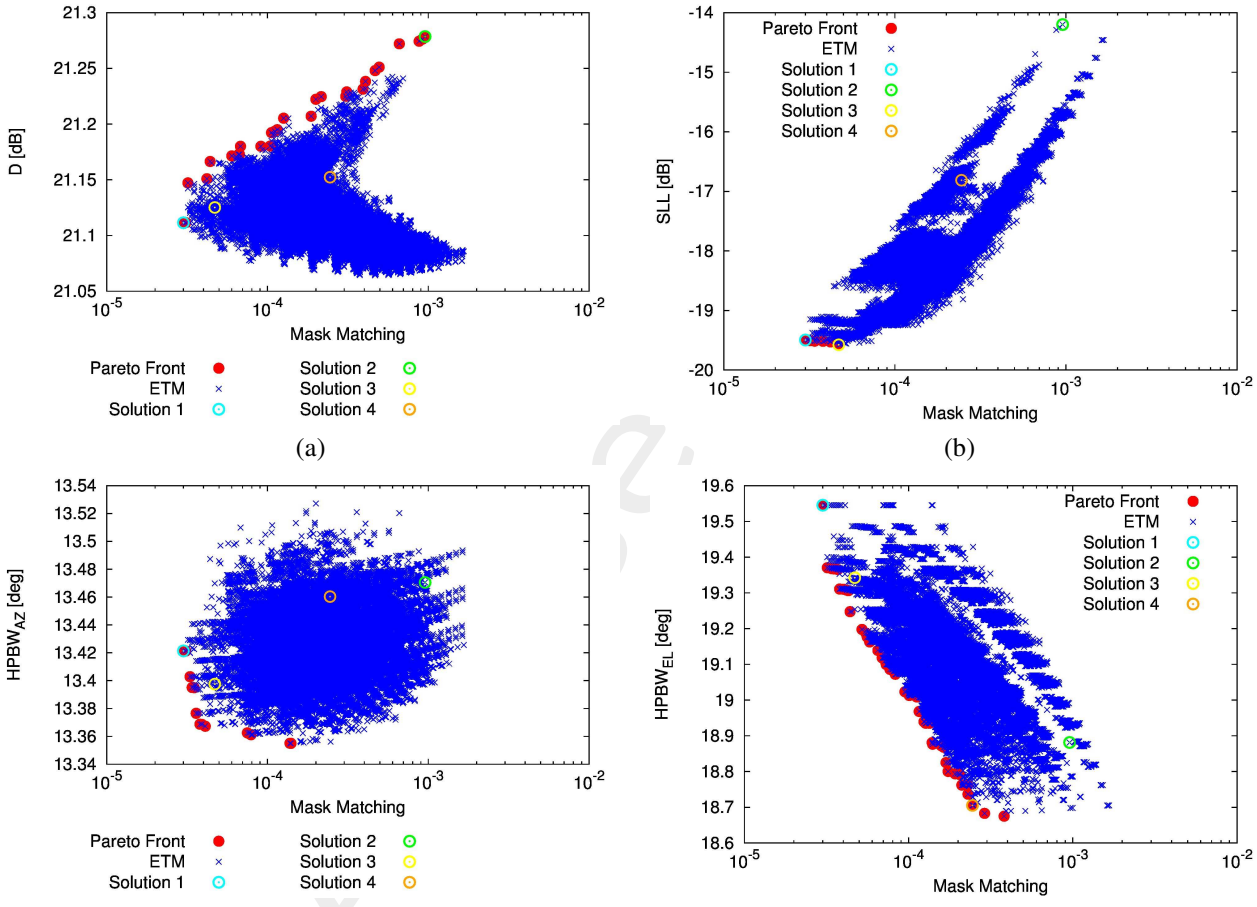

Figure 5: Pareto front of the ETM soutions.

	$Solution\,ID$	SLL [dB]	D [dBi]	$HPBW_{az}$ [deg]	$HPBW_{el}$ [deg]	$Mask\,Matching$
$Reference$	–	-20.49	21.14	13.249	19.61	0.00
$Solution-1$	4418	-19.50	21.11	13.42	19.55	3.00×10^{-5}
$Solution-2$	701	-14.20	21.28	13.47	18.88	9.56×10^{-4}
$Solution-3$	123663	-19.58	21.13	13.40	19.34	4.70×10^{-5}
$Solution-4$	77716	-16.81	21.15	13.46	18.71	2.45×10^{-4}

Table II: Pattern descriptors and fitness values for the presented solutions.

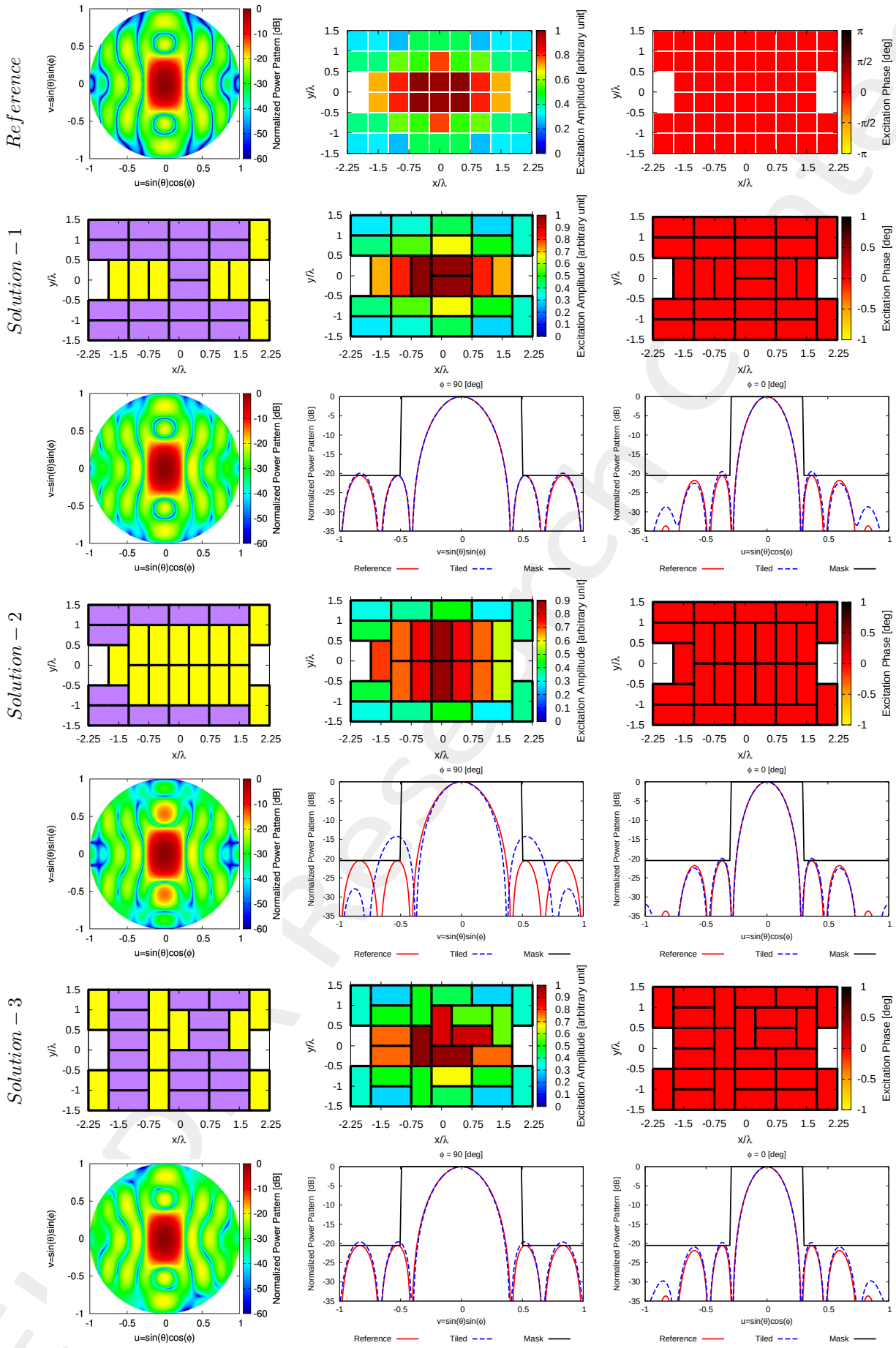

Figure 6: Power Patterns.

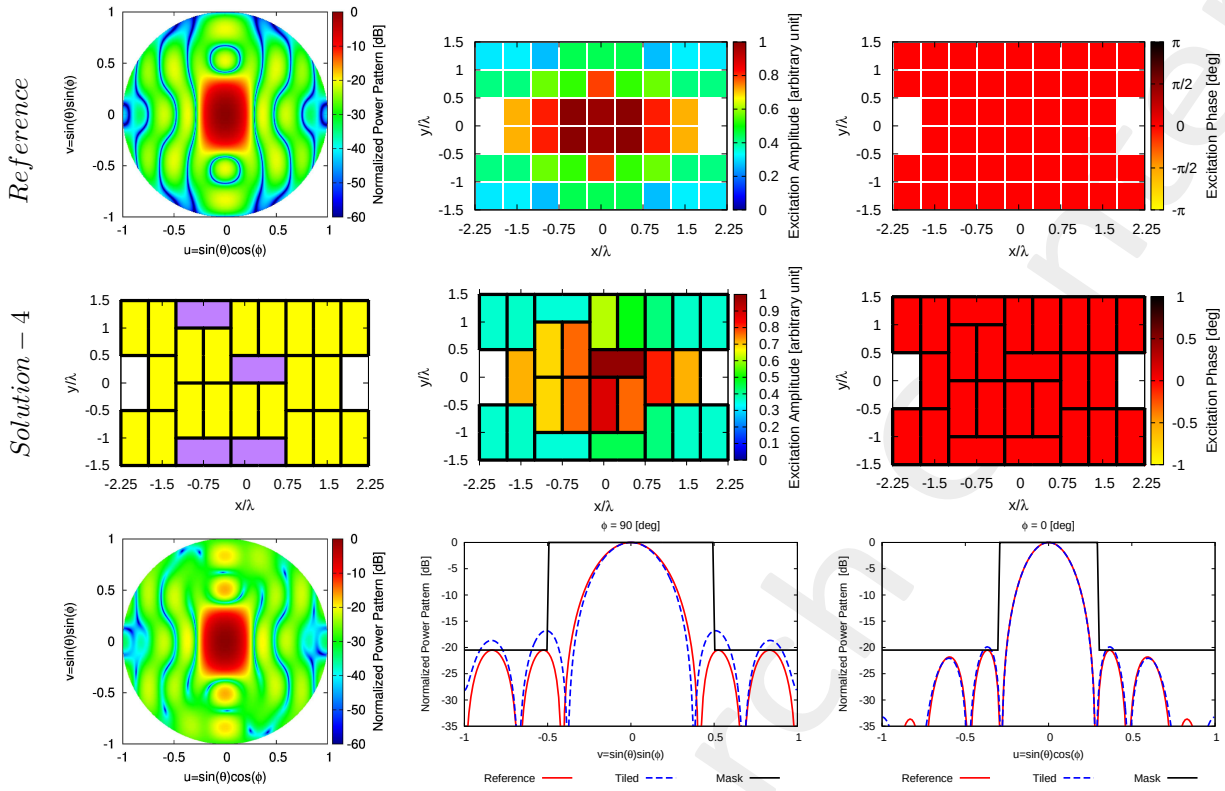

Figure 7: Power Patterns.

2.2 Orthogonal Polygon #3

2.2.1 OTM-MOP - CP Reference Excitations, Symmetric Mask, SLL = -30 [dB] - SLL vs {HPBW}

Array Analysis Parameters:

- Total Number of Elements: $P = 264$
- Spacing: $d = \lambda/2$
- Number of Samples along u: 512
- Number of Samples along v: 512
- Steering θ Direction: $\theta_s = 0$
- Steering ϕ Direction: $\phi_s = 0$
- Tapering: CP - Symmetric Mask:
- Main Lobe Window Width along u: $MW_u = 0.16$ [u]
- Main Lobe Window Width along v: $MW_v = 0.22$ [v]
- Side Lobe levels: $SLL = -30.0$

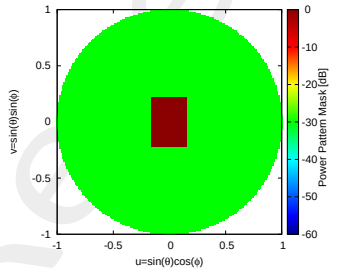

Figure 8: The power pattern mask used for the reference tapering optimization with CP.

Tiling Parameters:

- Tile: Domino
- Number of Elements in each Tile: $N_T = 2$
- Total Number of Configurations: $\Gamma > 2.4 \times 10^{28}$
- Number of Inner Lattice Points: $N_{inn} = 227$

Cost Function:

- $OBJ^{(1)} = arg\{SLL[P(u,v)]\}$
- $OBJ^{(2)} = HPBW_{AZ}$

- $OBJ^{(3)} = HPBW_{EL}$

RESULTS - Pareto Fronts (MOP)

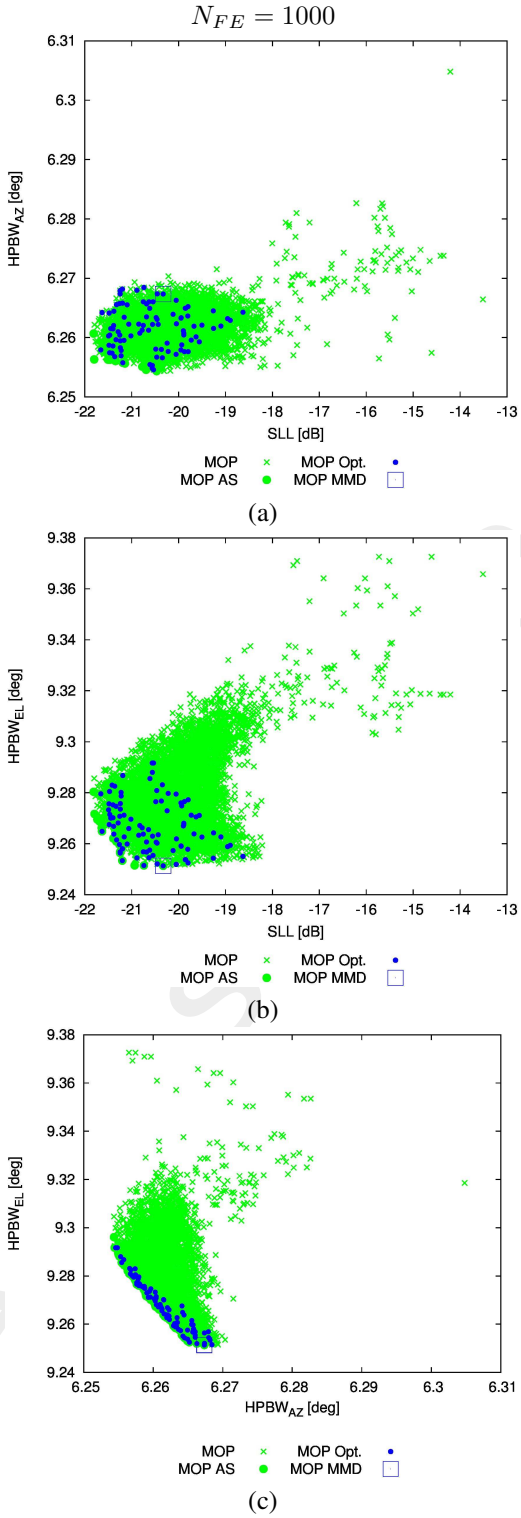

Figure 9: Exhaustive Pareto front as compared to the MOP Approximation Set considering: $OBJ^{(1)} = SLL$ vs $OBJ^{(2)} = HPBW_{AZ}$ (a), $OBJ^{(1)} = SLL$ vs $OBJ^{(3)} = HPBW_{EL}$(b), $OBJ^{(2)} = HPBW_{AZ}$ vs $OBJ^{(3)} = HPBW_{EL}$(c), for $N_{FE} = 1000$ fitness evaluations.

	SLL [dB]	D [dBi]	$HPBW_{az}$ [deg]	$HPBW_{el}$ [deg]	$\Psi\,(T)$
$Reference$	-29.68	27.97	6.32	9.36	–
$Solution - 9667$	-26.62	27.99	6.30	9.25	–

Table III: Pattern descriptors and fitness values for the presented solutions.

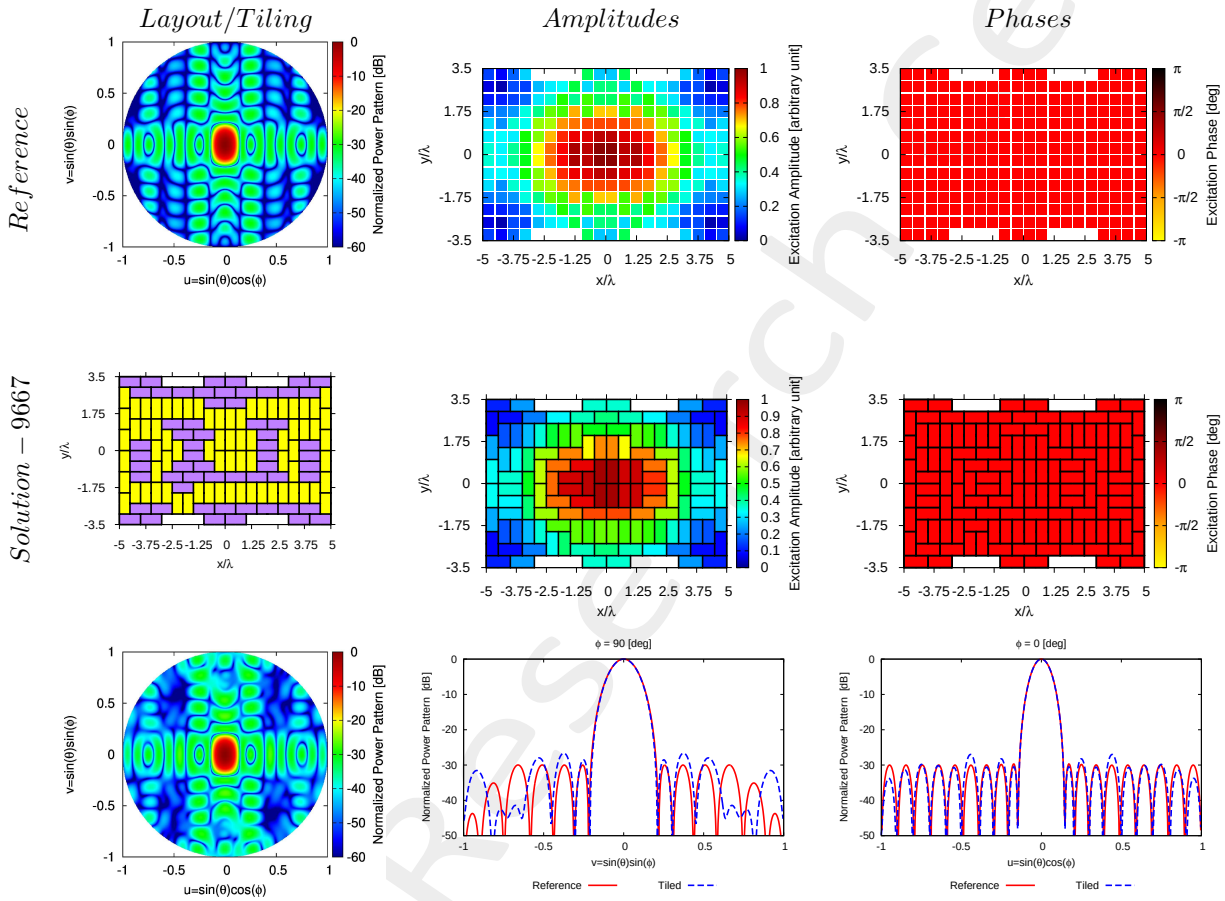

Figure 10: Tiling Configurations/Excitations.

OUTCOME:

- Solution-9667.

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

References

[1] M. Salucci, G. Gottardi, N. Anselmi, and G. Oliveri, "Planar thinned array design by hybrid analytical-stochastic optimization," IET Microwaves, Antennas & Propagation, vol. 11, no. 13, pp. 1841-1845, Oct. 2017

[2] P. Rocca, N. Anselmi, A. Polo, and A. Massa, "Pareto-optimal domino-tiling of orthogonal polygon phased arrays," IEEE Trans. Antennas Propag., vol. 70, no. 5, pp. 3329-3342, May 2022.

[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] M. Salucci, G. Oliveri, M. A. Hannan, and A. Massa, âSystem-by-design paradigm-based synthesis of complex systems: The case of spline-contoured 3D radomes,â IEEE Antennas and Propagation Magazine â Special Issue on âArtificial Intelligence in Electromagnetics,â, vol. 64, no. 1, pp. 72-83, Feb. 2022.

[13] 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.

[14] 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.

[15] 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.

[16] 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

[17] 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.

[18] 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.

[19] 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.

[20] L. Poli, D. Masotti, M. A. Hannan, A. Costanzo, and P. Rocca, "Codesign of switching sequence and diode parameters for multiple pattern optimization in time-modulated arrays," IEEE Antennas Wireless Propag. Lett. â Special Issue on âSpace-Time Modulated Antennas and Materialsâ, vol. 19, no. 11, pp. 1852-1856, Nov. 2020.

[21] P. Rocca, F. Yang, L. Poli, and S. Yang, "Time-modulated array antennas - Theory, techniques, and applications" Journal of Electromagnetic Waves and Applications, vol. 33, no. 12, pp. 1503-1531, Jun. 2019.

[22] L. Poli, P. Rocca, G. Oliveri, M. Chuan, C. Mazzucco, S. Verzura, R. Lombardi, and A. Massa, "Advanced pulse sequence design in time-modulated arrays for cognitive radio," IEEE Antennas Wireless Propagat. Lett., vol. 17, no. 5, pp. 898-902, May 2018.

[23] P. Rocca, G. Oliveri, R. J. Mailloux, and A. Massa, "Unconventional phased array architectures and design Methodologies - A review," Proceedings of the IEEE - Special Issue on 'Phased Array Technologies', Invited Paper, vol. 104, no. 3, pp. 544-560, March 2016.

[24] L. Poli, P. Rocca, G. Oliveri, and A. Massa, "Failure correction in time-modulated linear arrays," IET Radar, Sonar & Navigation, vol. 8, no. 3, pp. 195-201, 2014.

[25] L. Poli, T. Moriyama, and P. Rocca, "Pulse splitting for harmonic beamforming in time-modulated linear arrays," International Journal of Antennas and Propagation, vol. 2014, pp. 1-9, 2014.

[26] P. Rocca, Q. Zhu, E.T. Bekele, S. Yang, A. Massa, "4D arrays as enabling technology for cognitive radio systems" IEEE Trans. Antennas Propag., vol. 62, no. 3. pp. 1102-1116, Mar. 2014.

[27] E. T. Bekele, L. Poli, M. D'Urso, P. Rocca, and A. Massa, "Pulse-shaping strategy for time modulated arrays - Analysis and design," IEEE Trans. Antennas Propag., vol. 61, no. 7, pp. 3525-3537, July 2013.

[28] P. Rocca, M. D'Urso, and L. Poli, An iterative approach for the synthesis of optimized sparse time-modulated linear arrays," Progress In Electromagnetics Research B, vol. 55, pp. 365-382, 2013.

[29] 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.

[30] P. Rocca, L. Poli, and A. Massa, "Instantaneous directivity optimization in time-modulated array receivers," IET Microwaves, Antennas & Propagation, vol. 6, no. 14, pp. 1590-1597, Nov. 2012.

[31] P. Rocca, L. Poli, L. Manica, and A. Massa, "Synthesis of monopulse time-modulated planar arrays with controlled sideband radiation," IET Radar, Sonar & Navigation, vol. 6, no. 6, pp. 432-442, 2012.

[32] L. Poli, P. Rocca, and A. Massa, "Sideband radiation reduction exploiting pattern multiplication in directive time-modulated linear arrays," IET Microwaves, Antennas & Propagation, vol. 6, no. 2, pp. 214-222, 2012.

[33] P. Rocca, L. Poli, A. Polo, and A. Massa, "Optimal excitation matching strategy for sub-arrayed phased linear arrays generating arbitrary shaped beams," IEEE Trans. Antennas Propag., vol. 68, no. 6, pp. 4638-4647, Jun. 2020.

[34] G. Oliveri, G. Gottardi and A. Massa, "A new meta-paradigm for the synthesis of antenna arrays for future wireless communications," IEEE Trans. Antennas Propag., vol. 67, no. 6, pp. 3774-3788, Jun. 2019.

[35] P. Rocca, M. H. Hannan, L. Poli, N. Anselmi, and A. Massa, "Optimal phase-matching strategy for beam scanning of sub-arrayed phased arrays," IEEE Trans. Antennas and Propag., vol. 67, no. 2, pp. 951-959, Feb. 2019.

[36] 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.

[37] L. Poli, G. Oliveri, P. Rocca, M. Salucci, and A. Massa, "Long-Distance WPT Unconventional Arrays Synthesis" Journal of Electromagnetic Waves and Applications, vol. 31, no. 14, pp. 1399-1420, Jul. 2017.

[38] G. Gottardi, L. Poli, P. Rocca, A. Montanari, A. Aprile, and A. Massa, "Optimal Monopulse Beamforming for Side-Looking Airborne Radars," IEEE Antennas Wireless Propag. Lett., vol. 16, pp. 1221-1224, 2017.

[39] G. Oliveri, M. Salucci, and A. Massa, "Synthesis of modular contiguously clustered linear arrays through a sparseness-regularized solver," IEEE Trans. Antennas Propag., vol. 64, no. 10, pp. 4277-4287, Oct. 2016.

[40] P. Rocca, G. Oliveri, R. J. Mailloux, and A. Massa, "Unconventional phased array architectures and design Methodologies - A review" Proceedings of the IEEE = Special Issue on 'Phased Array Technologies', Invited Paper, vol. 104, no. 3, pp. 544-560, March 2016.

[41] P. Rocca, M. D'Urso, and L. Poli,"Advanced strategy for large antenna array design with subarray-only amplitude and phase contr," IEEE Antennas and Wireless Propag. Lett., vol. 13, pp. 91-94, 2014.