On the Design of Reflectarrays through the Inverse Source Framework

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Contents

Part I

Numerical Analysis

1 Phase Range [-135:135] - Test Case 1 - 55x55 - Linear Polarization

This section is aimed at showing the result of setting the wanted phase range to $[-135, 135]$ using a PSO with different parameters.

1.1 Parameters

- Reflectarray Geometry:
  - number of elements along x: $M = 55$;
  - number of elements along y: $N = 55$;
  - element spacing along x: $\Delta x = 0.373333$ $[\lambda]$;
  - element spacing along y: $\Delta y = 0.373333$ $[\lambda]$;
  - non radiating dimension: 2337;
  - truncation order: $H = 688$;
- PSO Parameters
  - max iteration number: $I = \{2 \times 10^4, 10^5\}$;
  - number of NR-Basis: $K = \{100, 200, 400, 800, 2000\}$;
  - swarm size:
    - for $K = \{100, 200\}$: $P = \{10, 20, 40\}$;
    - for $K = \{400\}$: $P = \{10, 20, 40, 100, 200\}$;
    - for $K = \{800, 2000\}$: $P = \{\frac{K}{8}, \frac{K}{4}, \frac{K}{2}\}$;
  - inertial weight: 0.4;
  - inertial: 2 -> consider constant inertial velocity;
  - alpha: 0.4,
  - beta: 0.4;
  - c1: 2.0;
  - c2: 2.0;
  - random seed: {1, 2}.
- Optimization Parameters
  - $\phi_q^{MAX}(x, y) = 135$ $[deg]$;
  - $\phi_q^{MIN}(x, y) = -135$ $[deg]$;
  - $\min\{\Re\{\underline{\alpha}\}\} = -1.0$;

- $\max\{\Re\{\underline{\alpha}\}\} = 1.0$;
- $\min\{\Im\{\underline{\alpha}\}\} = -1.0$;
- $\max\{\Im\{\underline{\alpha}\}\} = 1.0$.

Initialialization We use a population with:

- an agent with the $\underline{\alpha} = \underline{0}$,
- all the other agents with random initialized $\underline{\alpha}$.

1.2 K=100, P=10, I=100000

In the Fig. 1 is depicted the behaviour of the Cost Function varying the random seed. The best value of cost function is achieved by Seed=1 and is $\Phi = 5.462 \times 10^{-1}$.

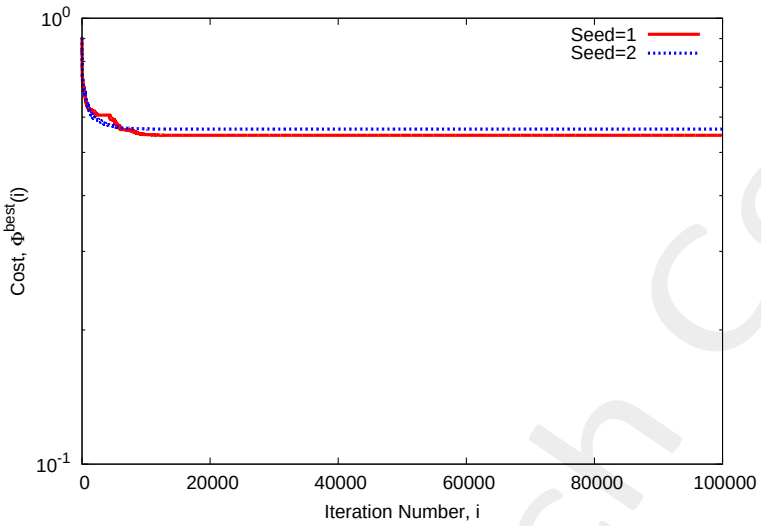


Figure 1: Cost Function behaviour at different random seed.

At this value of cost function the achieved performance on the Phase are showed in Fig. 2 and are numerically showed in table I.

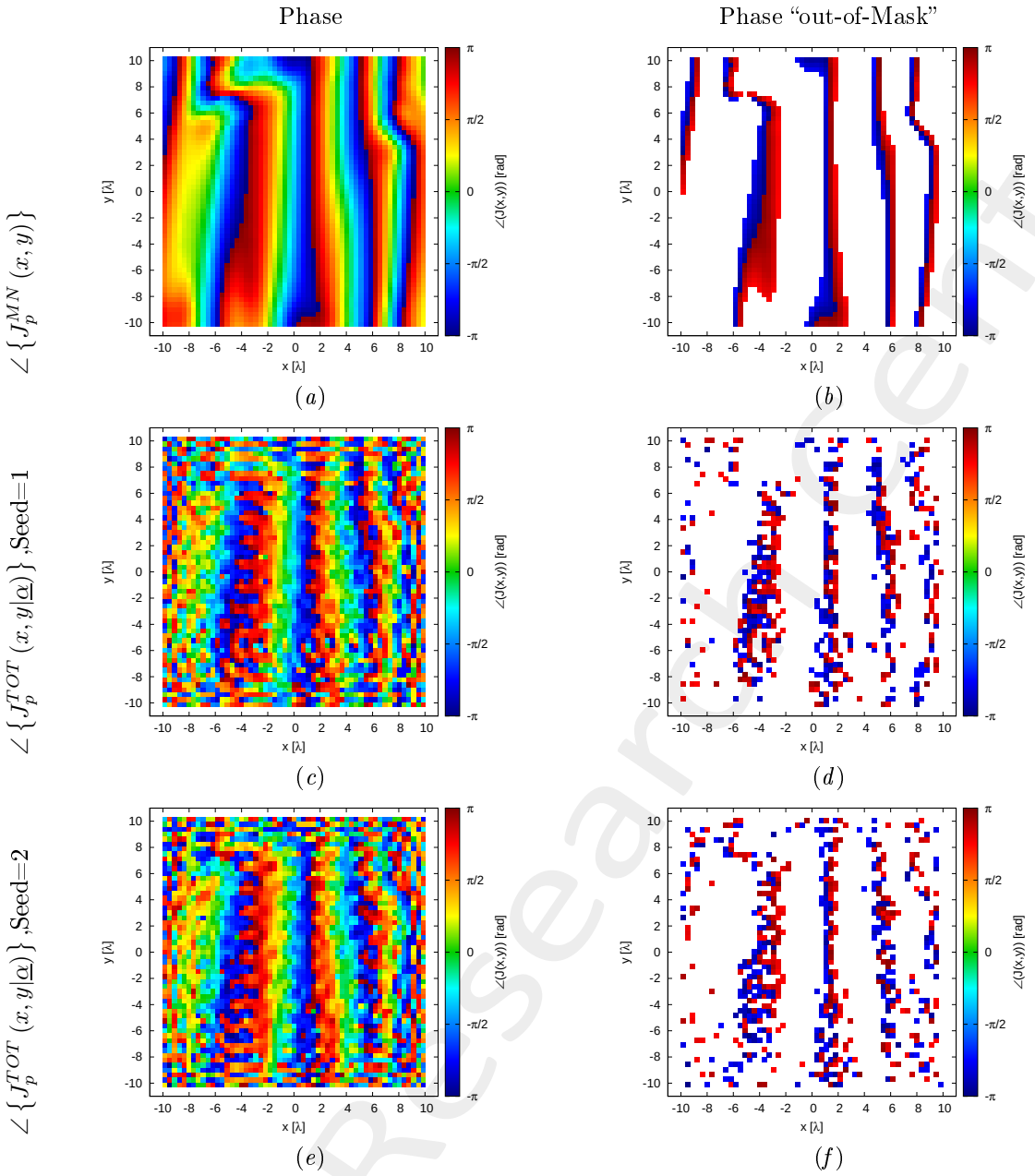


Figure 2: Phase $(a)(c)(e)$ and value of the phase out of the minimization range $(b)(d)(f)$ of the Minimum-Norm current $(\angle\{J_p^{MN}(x,y)\})(a)(b)$, of the total current for the random seed $= 1(c)(d)$ and for the random seed $= 2(e)(f)$.

Case	Φ	Number of value $> \phi_p^{MAX}(x,y)$	Number of value $< \phi_p^{MIN}(x,y)$	Phase Range		Time $[s]$
				Min $[deg]$	Max $[deg]$	
MN	1.0	451	358	-179.87	179.63	
Seed=1	5.462×10^{-1}	287	300	-179.39	179.64	3.49×10^3
Seed=2	5.639×10^{-1}	301	306	-179.76	179.84	3.26×10^3

Table I: Cost Function value and statistics about the result.

The verification of the radiated field is showed in Fig. 3 and numerically in table II.

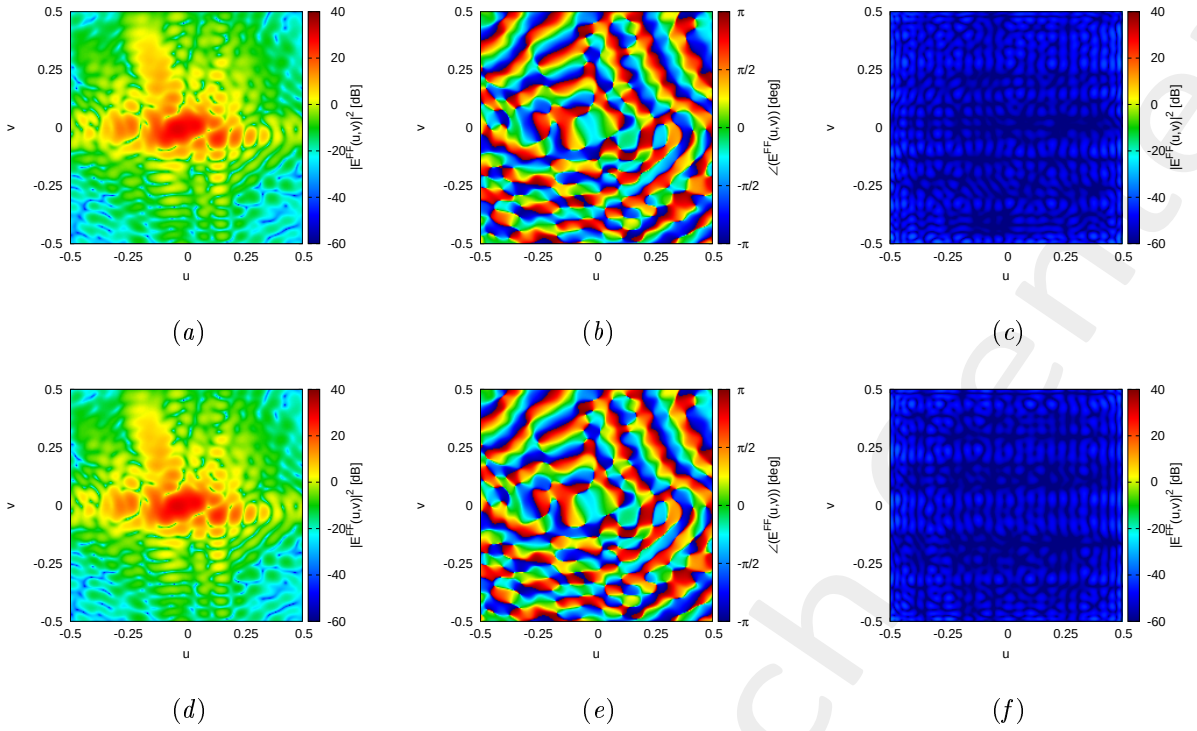


Figure 3: Magnitude $(a)(d)$, Phase $(b)(e)$ and Magnitude of the difference with respect to the original field $(c)(f)$ of the seed=1 $(a)(b)(c)$ and seed=2 $(d)(e)(f)$.

Seed	ξ
1	2.12×10^{-3}
2	1.97×10^{-3}

Table II: Integral error of the difference between the original field and the one radiated by the total current.

1.3 K=100, P=20, I=100000

In the Fig. 4 is depicted the behaviour of the Cost Function varying the random seed. The best value of cost function is achieved by Seed=2 and is $\Phi = 4.553 \times 10^{-1}$.

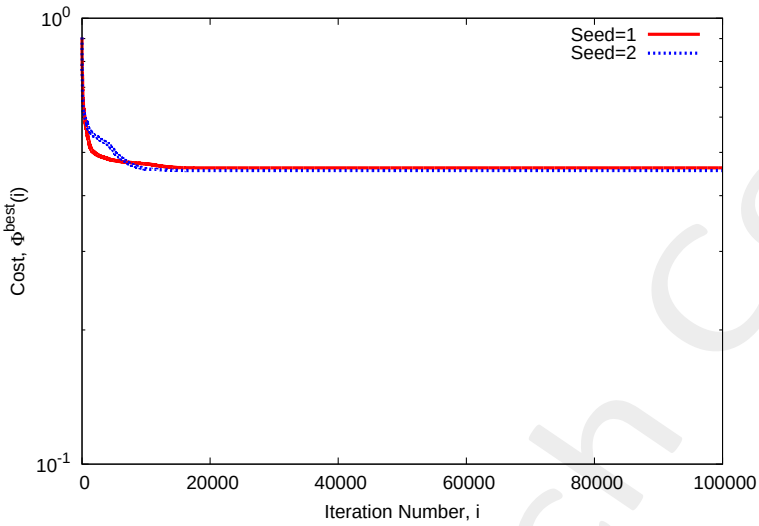


Figure 4: Cost Function behaviour at different random seed.

At this value of cost function the achieved performance on the Phase are showed in Fig. 5 and are numerically showed in table III.

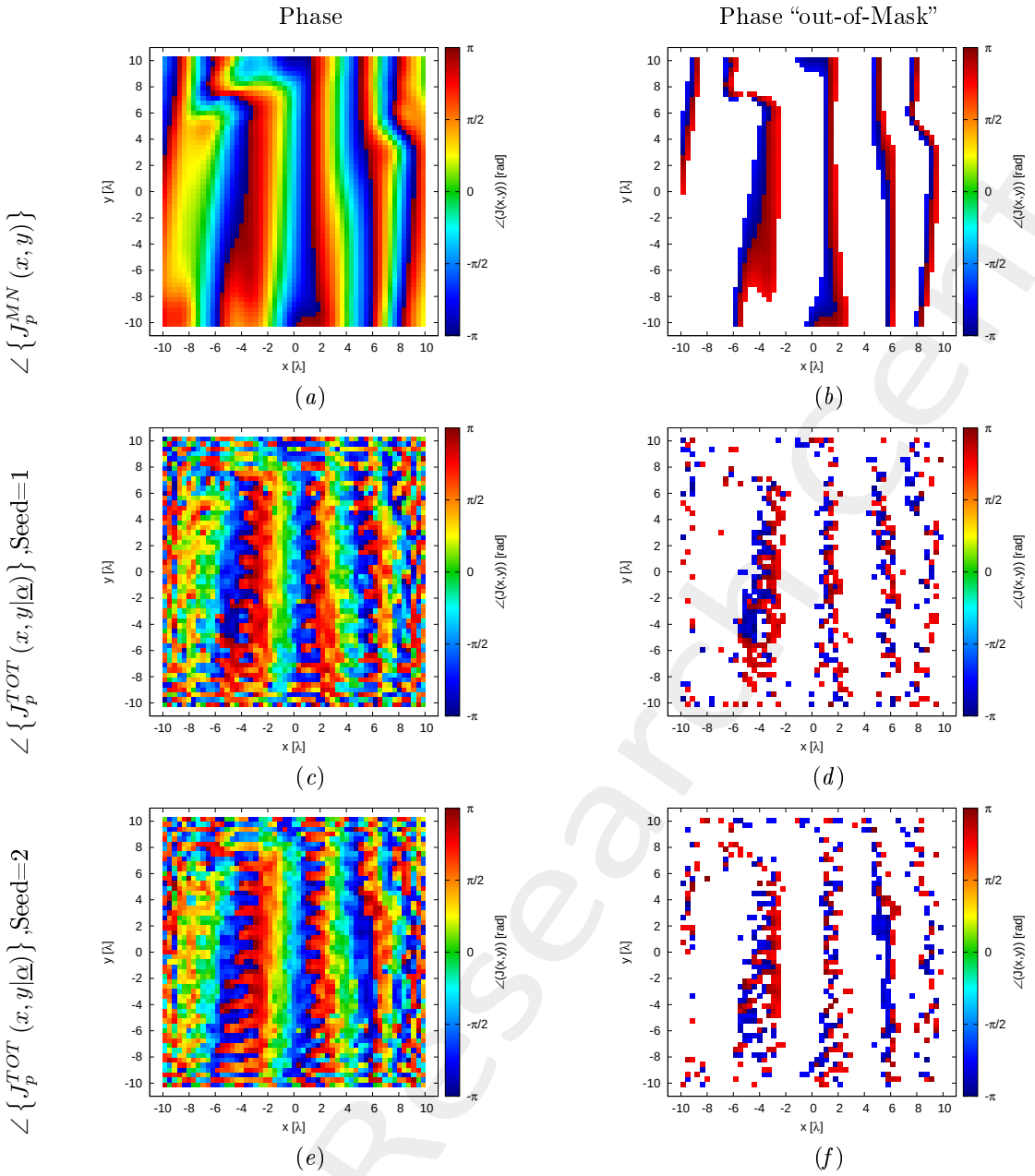


Figure 5: Phase $(a)(c)(e)$ and value of the phase out of the minimization range $(b)(d)(f)$ of the Minimum-Norm current $(\angle\{J_p^{MN}(x,y)\})(a)(b)$, of the total current for the random seed $= 1(c)(d)$ and for the random seed $= 2(e)(f)$.

Case	Φ	Number of value $> \phi_p^{MAX}(x,y)$	Number of value $< \phi_p^{MIN}(x,y)$	Phase Range		Time $[s]$
				Min $[deg]$	Max $[deg]$	
MN	1.0	451	358	-179.87	179.63	
Seed=1	4.617×10^{-1}	294	256	-179.70	179.94	6.07×10^3
Seed=2	4.553×10^{-1}	274	274	-179.27	179.97	6.30×10^3

Table III: Cost Function value and statistics about the result.

The verification of the radiated field is showed in Fig. 6 and numerically in table IV.

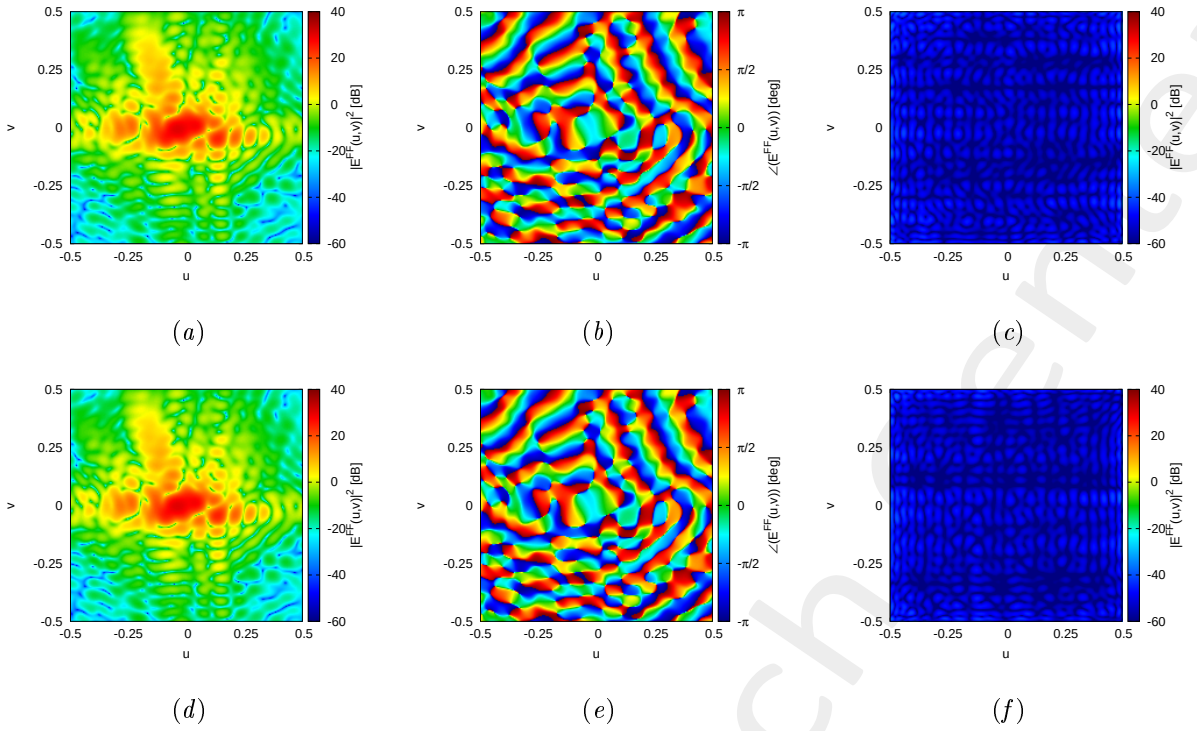


Figure 6: Magnitude $(a)(d)$, Phase $(b)(e)$ and Magnitude of the difference with respect to the original field $(c)(f)$ of the seed=1 $(a)(b)(c)$ and seed=2 $(d)(e)(f)$.

Seed	ξ
1	1.92×10^{-3}
2	1.78×10^{-3}

Table IV: Integral error of the difference between the original field and the one radiated by the total current.

1.4 K=100, P=20, I=300000

In the Fig. 7 is depicted the behaviour of the Cost Function varying the random seed. The best value of cost function is achieved by Seed=1 and is $\Phi = 4.253 \times 10^{-1}$.

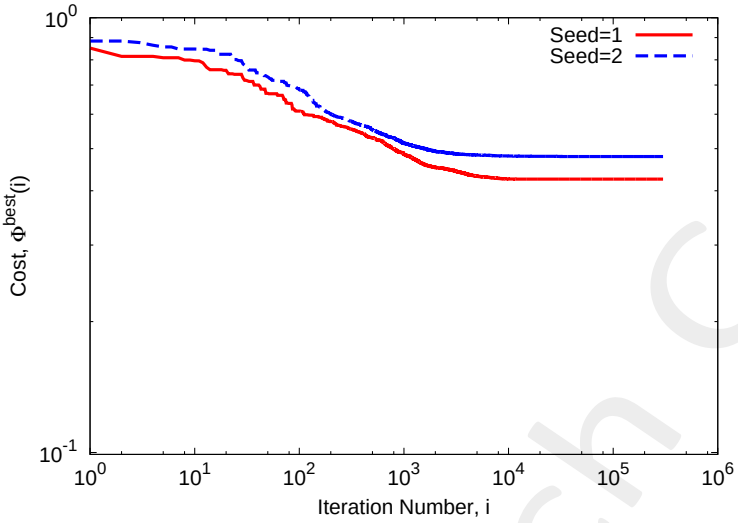


Figure 7: Cost Function behaviour at different random seed.

At this value of cost function the achieved performance on the Phase are showed in Fig. 8 and are numerically showed in table V.

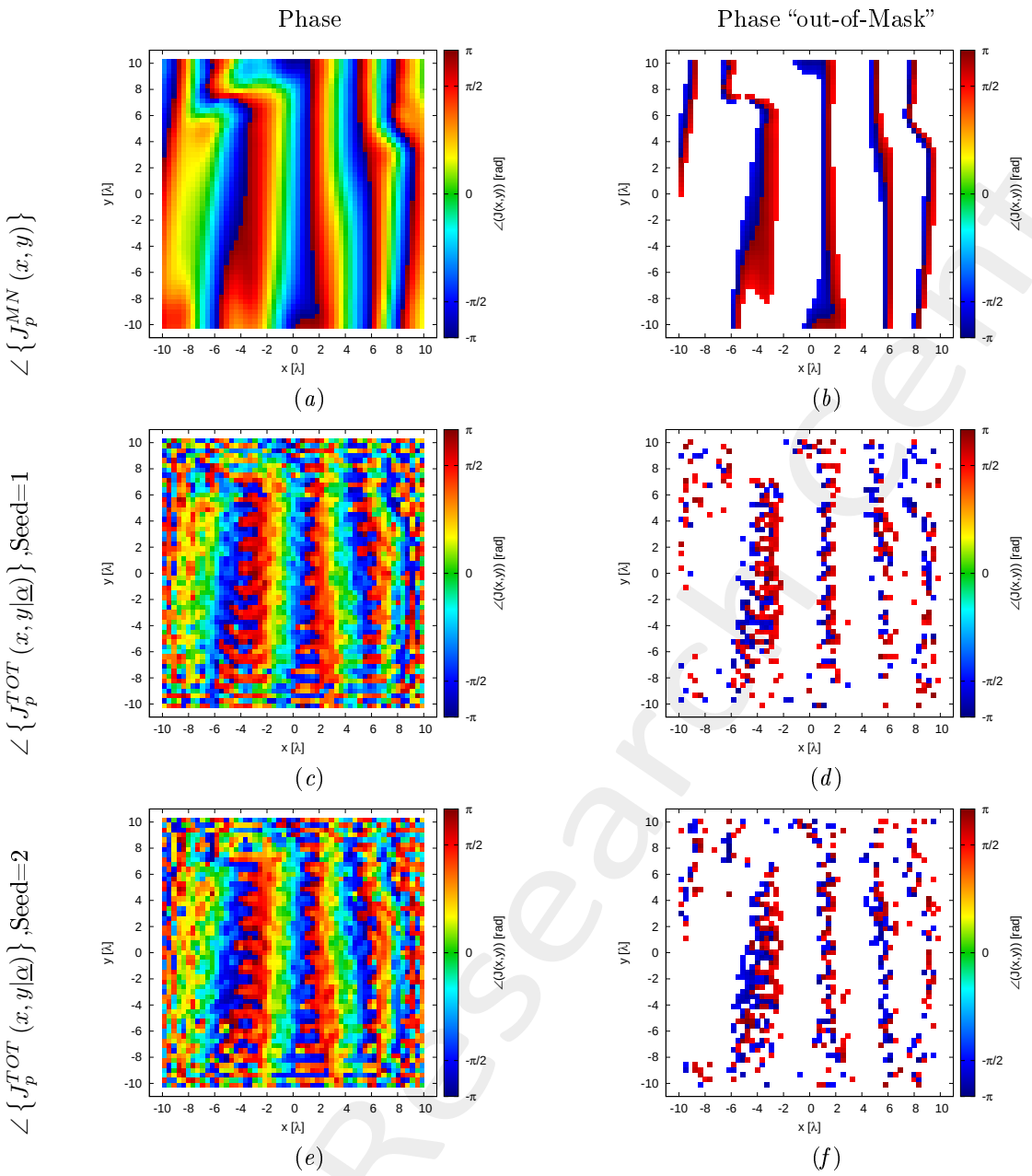
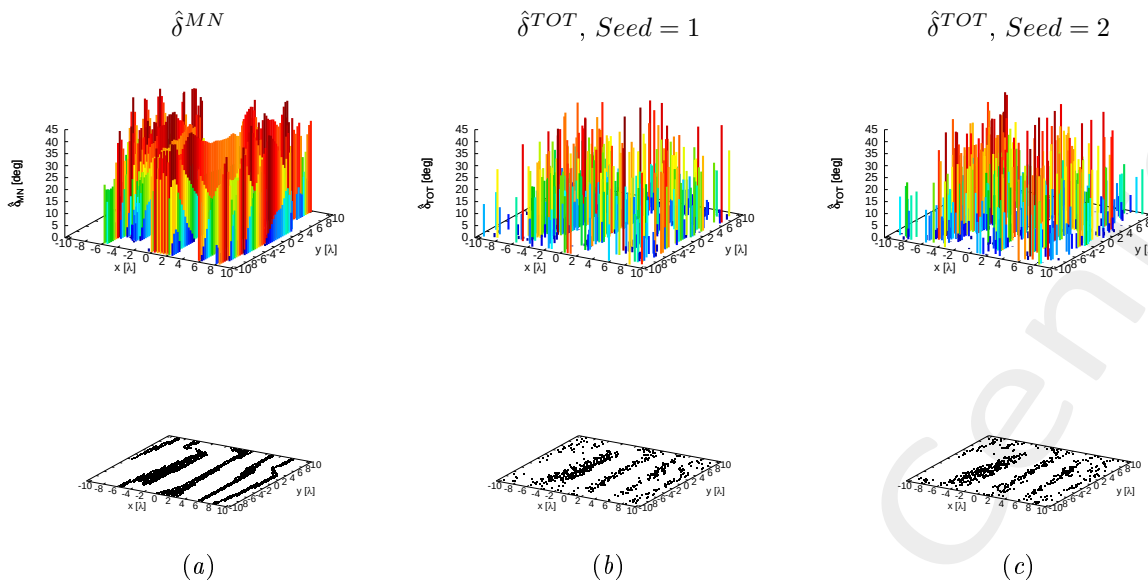


Figure 8: Phase $(a)(c)(e)$ and value of the phase out of the minimization range $(b)(d)(f)$ of the Minimum-Norm current ($\angle\{J_p^{MN}(x,y)\}$)$(a)(b)$, of the total current for the random seed $= 1(c)(d)$ and for the random seed $= 2(e)(f)$.



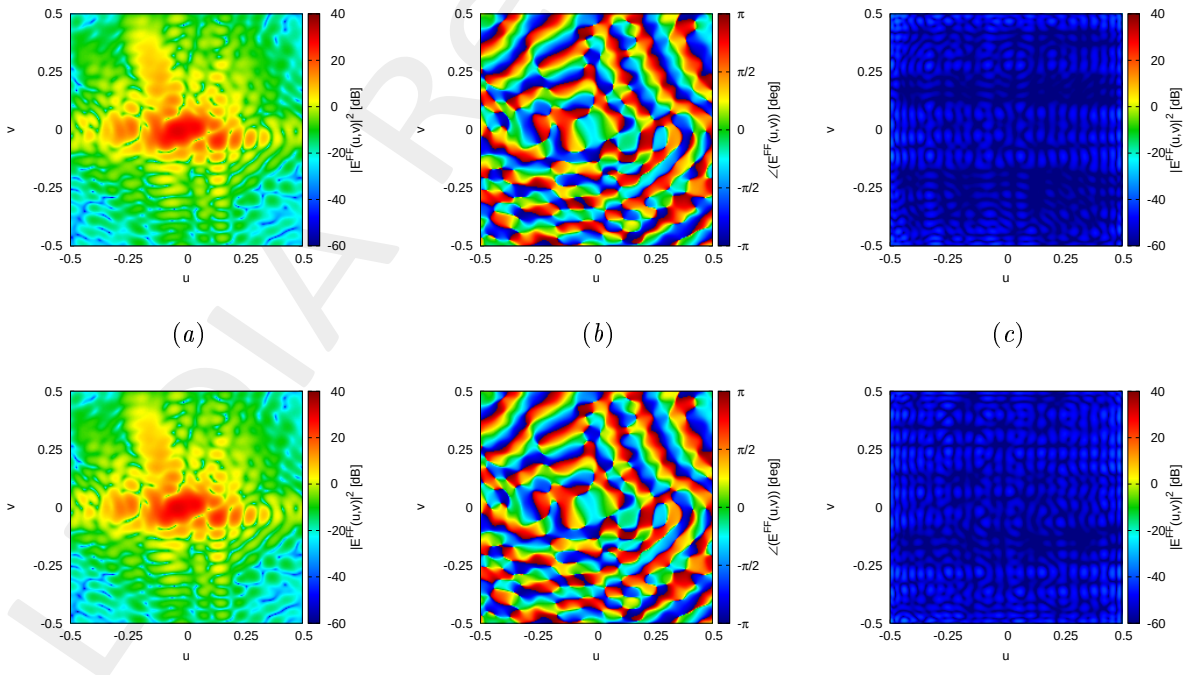
(a) (b) (c)

Figure 9: Phase Mask mismatch for the Minimum-Norm current (a), the total current for the random seed $= 1(b)$, and for the random seed $= 2(c)$.

Case	Φ	Number of value $> \phi_p^{MAX}(x,y)$	Number of value $< \phi_p^{MIN}(x,y)$	Phase Range		Time $[s]$
				Min $[deg]$	Max $[deg]$	
MN	1.0	451	358	-179.87	179.63	
Seed=1	4.253×10^{-1}	300	221	-179.92	179.80	2.54×10^4
Seed=2	4.794×10^{-1}	269	269	-179.82	179.19	3.98×10^4

Table V: Cost Function value and statistics about the result.

The verification of the radiated field is showed in Fig. 10 and numerically in table VI.



(a) (b) (c)

(d) (e) (f)

Figure 10: Magnitude $(a)(d)$, Phase $(b)(e)$ and Magnitude of the difference with respect to the original field $(c)(f)$ of the seed=1 $(a)(b)(c)$ and seed=2 $(d)(e)(f)$.

Seed	ξ
1	1.79×10^{-3}
2	2.07×10^{-3}

Table VI: Integral error of the difference between the original field and the one radiated by the total current.

1.5 K=100, P=40, I=100000

In the Fig. 11 is depicted the behaviour of the Cost Function varying the random seed. The best value of cost function is achieved by Seed=1 and is $\Phi = 4.340 \times 10^{-1}$.

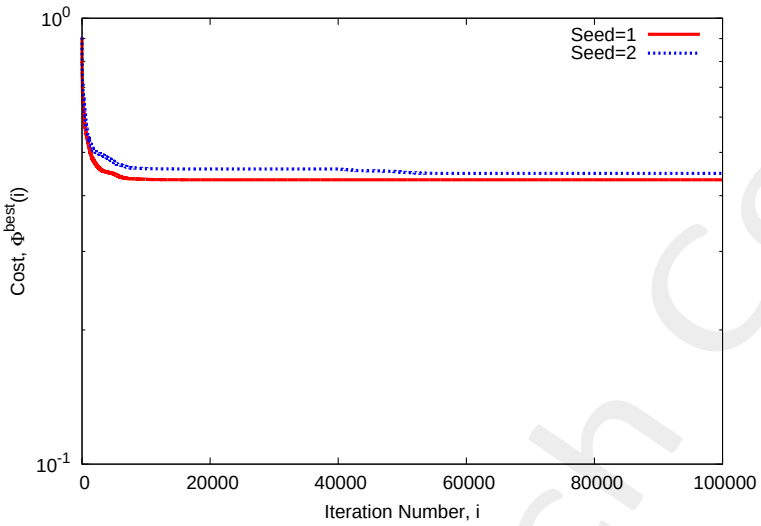


Figure 11: Cost Function behaviour at different random seed.

At this value of cost function the achieved performance on the Phase are showed in Fig. 12 and are numerically showed in table VII.

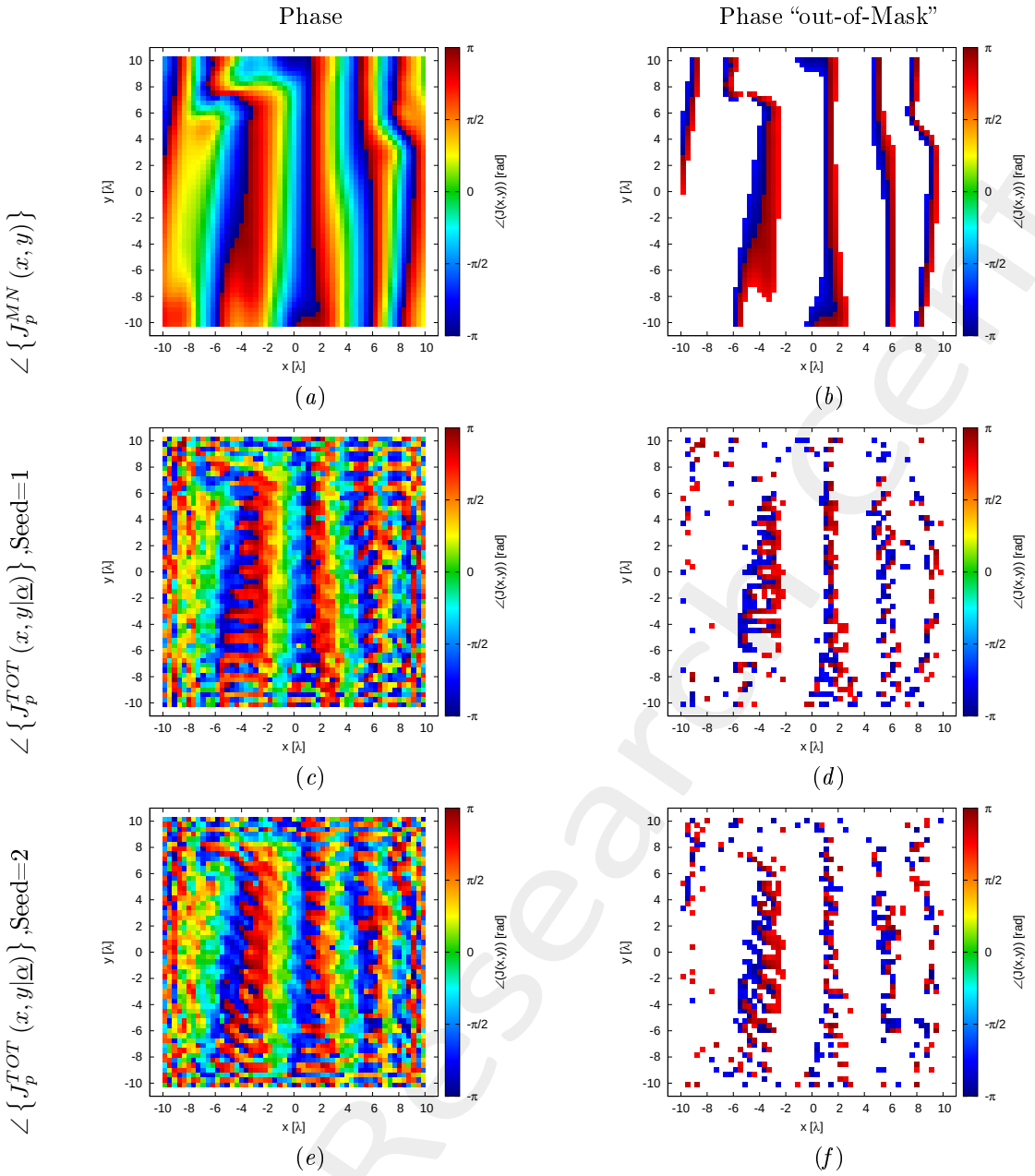


Figure 12: Phase $(a)(c)(e)$ and value of the phase out of the minimization range $(b)(d)(f)$ of the Minimum-Norm current ($\angle\{J_p^{MN}(x,y)\}$)$(a)(b)$, of the total current for the random seed $= 1(c)(d)$ and for the random seed $= 2(e)(f)$.

Case	Φ	Number of value $> \phi_p^{MAX}(x,y)$	Number of value $< \phi_p^{MIN}(x,y)$	Phase Range		Time $[s]$
				Min $[deg]$	Max $[deg]$	
MN	1.0	451	358	-179.87	179.63	
Seed=1	4.340×10^{-1}	257	259	-178.21	177.25	1.33×10^4
Seed=2	4.486×10^{-1}	251	251	-179.95	179.36	1.27×10^4

Table VII: Cost Function value and statistics about the result.

The verification of the radiated field is showed in Fig. 13 and numerically in table VIII.

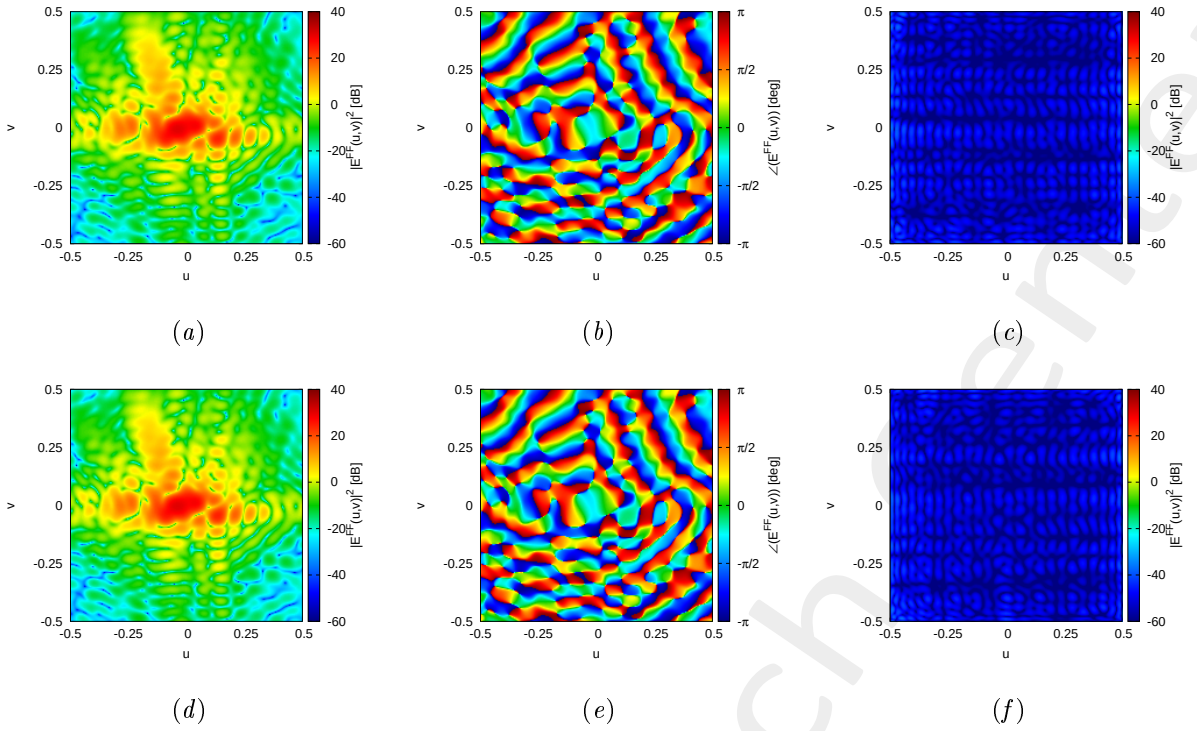


Figure 13: Magnitude $(a)(d)$, Phase $(b)(e)$ and Magnitude of the difference with respect to the original field $(c)(f)$ of the seed=1 $(a)(b)(c)$ and seed=2 $(d)(e)(f)$.

Seed	ξ
1	2.01×10^{-3}
2	1.95×10^{-3}

Table VIII: Integral error of the difference between the original field and the one radiated by the total current.

1.6 K=200, P=10, I=100000

In the Fig. 14 is depicted the behaviour of the Cost Function varying the random seed. The best value of cost function is achieved by Seed=1 and is $\Phi = 4.020 \times 10^{-1}$.

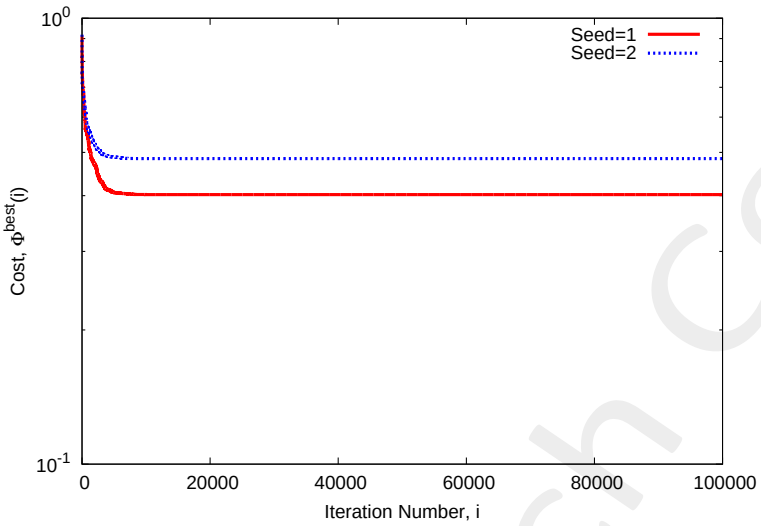


Figure 14: Cost Function behaviour at different random seed.

At this value of cost function the achieved performance on the Phase are showed in Fig. 15 and are numerically showed in table IX.

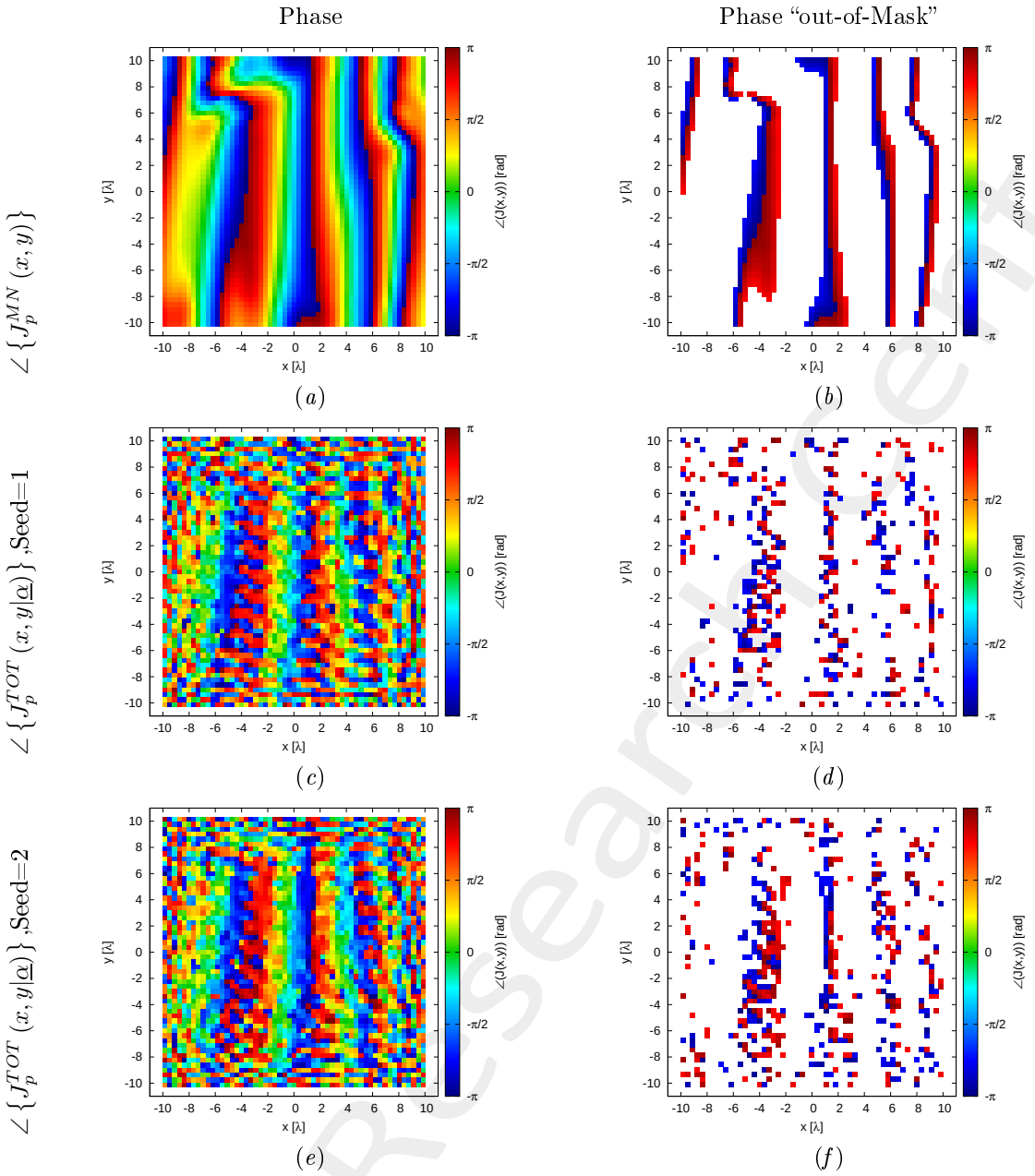


Figure 15: Phase $(a)(c)(e)$ and value of the phase out of the minimization range $(b)(d)(f)$ of the Minimum-Norm current $(\angle\{J_p^{MN}(x,y)\})(a)(b)$, of the total current for the random seed $= 1(c)(d)$ and for the random seed $= 2(e)(f)$.

Case	Φ	Number of value $> \phi_p^{MAX}(x,y)$	Number of value $< \phi_p^{MIN}(x,y)$	Phase Range		Time $[s]$
				Min $[deg]$	Max $[deg]$	
MN	1.0	451	358	-179.87	179.63	
Seed=1	4.020×10^{-1}	229	235	-179.46	178.45	6.45×10^3
Seed=2	4.843×10^{-1}	286	265	-179.93	178.90	5.64×10^3

Table IX: Cost Function value and statistics about the result.

The verification of the radiated field is showed in Fig. 16 and numerically in table X.

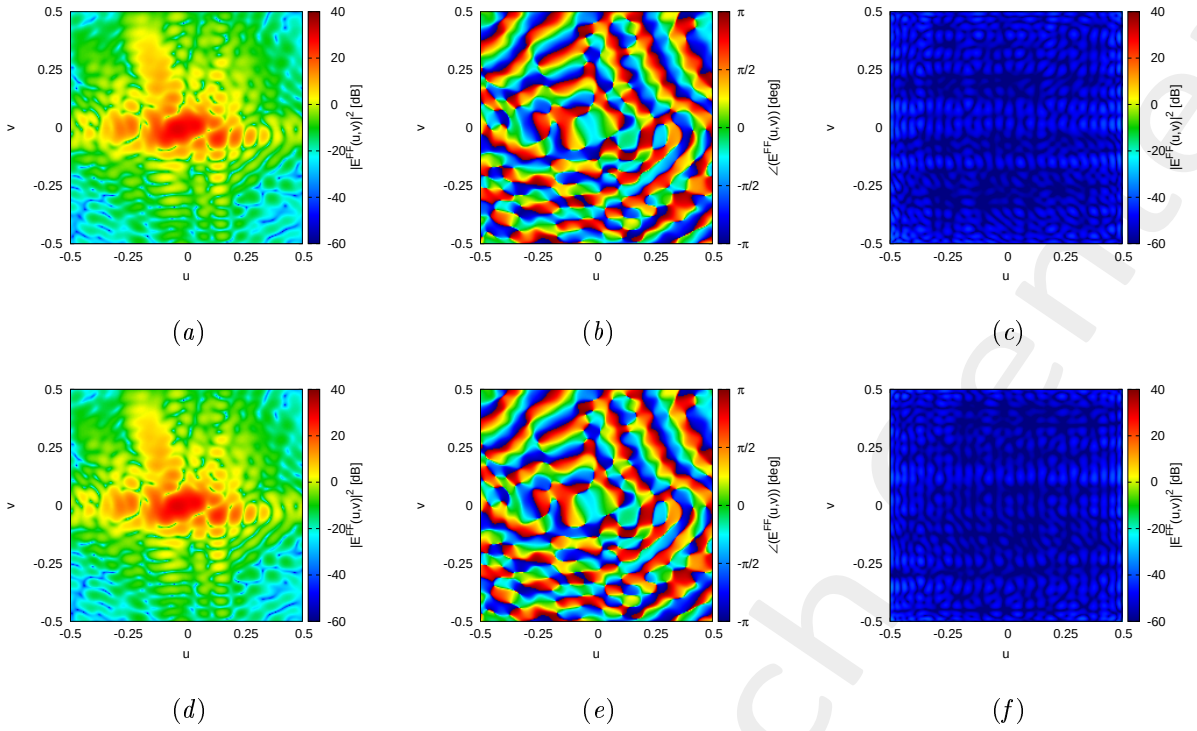


Figure 16: Magnitude $(a)(d)$, Phase $(b)(e)$ and Magnitude of the difference with respect to the original field $(c)(f)$ of the seed=1 $(a)(b)(c)$ and seed=2 $(d)(e)(f)$.

Seed	ξ
1	2.11×10^{-3}
2	1.91×10^{-3}

Table X: Integral error of the difference between the original field and the one radiated by the total current.

1.7 K=200, P=20, I=100000

In the Fig. 17 is depicted the behaviour of the Cost Function varying the random seed. The best value of cost function is achieved by Seed=1 and is $\Phi = 3.737 \times 10^{-1}$.

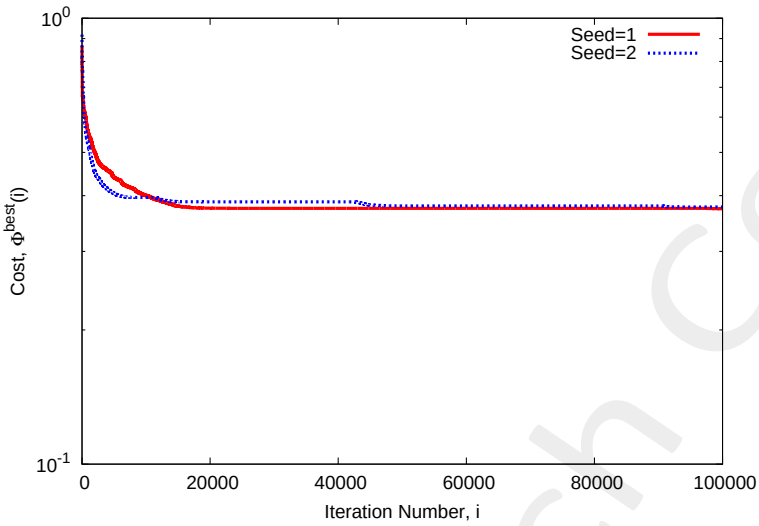


Figure 17: Cost Function behaviour at different random seed.

At this value of cost function the achieved performance on the Phase are showed in Fig. 18 and are numerically showed in table XI.

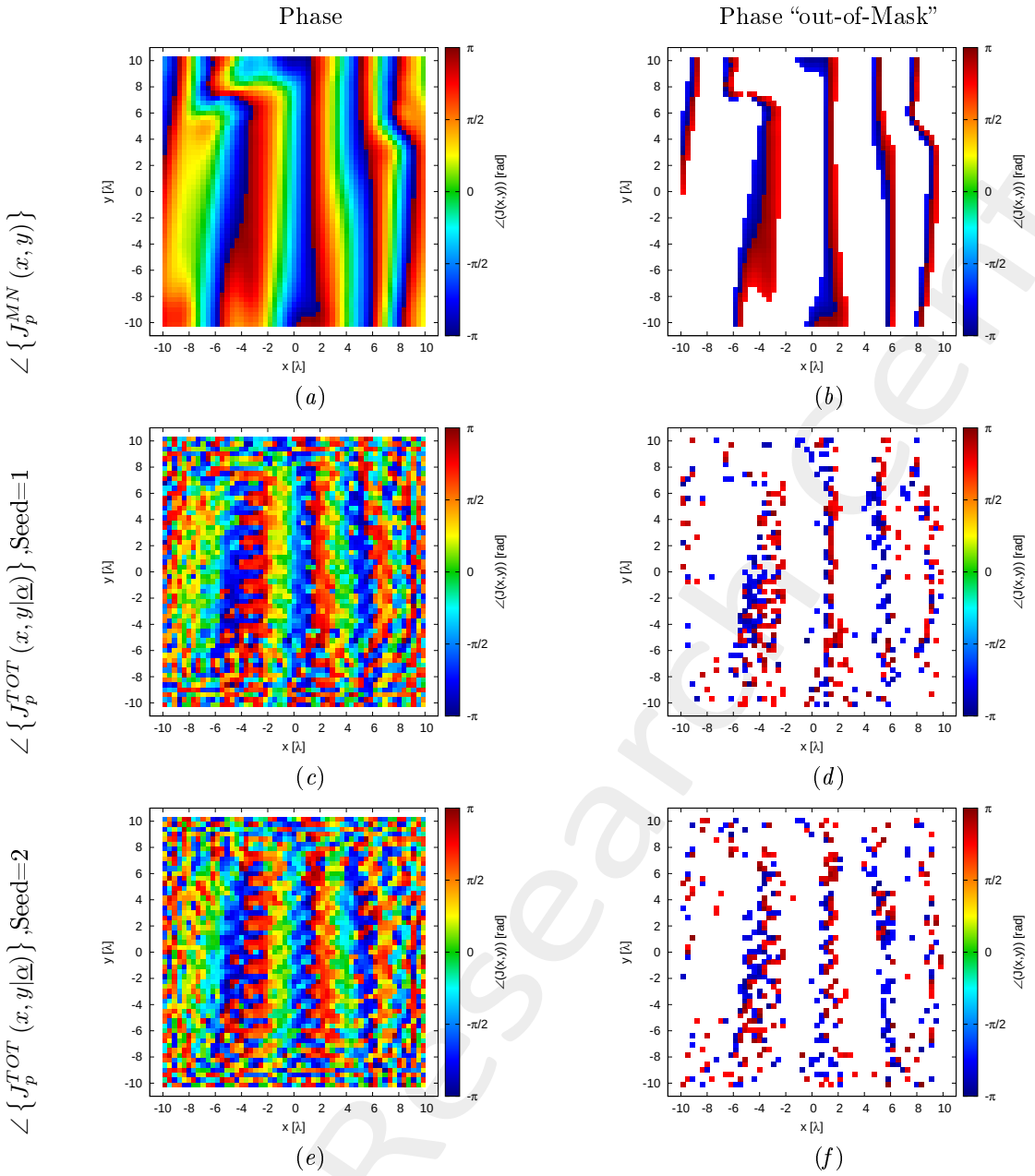


Figure 18: Phase $(a)(c)(e)$ and value of the phase out of the minimization range $(b)(d)(f)$ of the Minimum-Norm current $(\angle\{J_p^{MN}(x,y)\})(a)(b)$, of the total current for the random seed $= 1(c)(d)$ and for the random seed $= 2(e)(f)$.

Case	Φ	Number of value $> \phi_p^{MAX}(x,y)$	Number of value $< \phi_p^{MIN}(x,y)$	Phase Range		Time $[s]$
				Min $[deg]$	Max $[deg]$	
MN	1.0	451	358	-179.87	179.63	
Seed=1	3.737×10^{-1}	241	231	-179.49	179.22	1.22×10^4
Seed=2	3.772×10^{-1}	229	229	-176.58	179.35	1.30×10^4

Table XI: Cost Function value and statistics about the result.

The verification of the radiated field is showed in Fig. 19 and numerically in table XII.

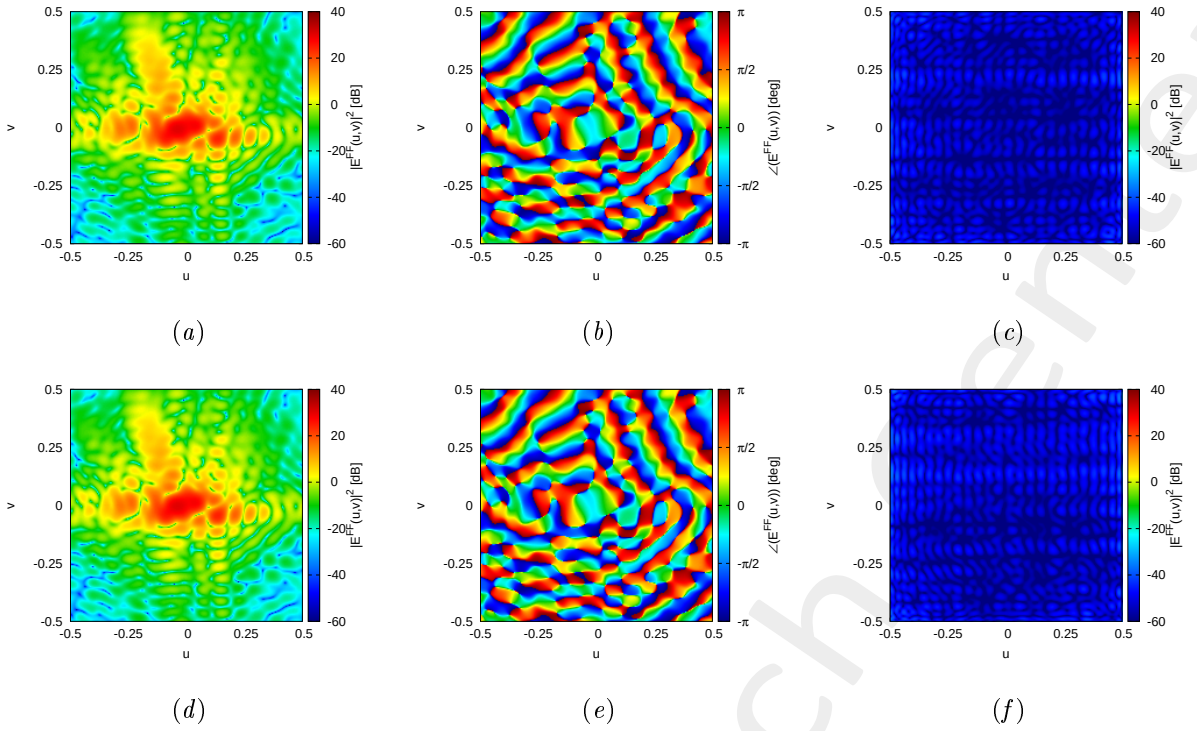


Figure 19: Magnitude $(a)(d)$, Phase $(b)(e)$ and Magnitude of the difference with respect to the original field $(c)(f)$ of the seed=1 $(a)(b)(c)$ and seed=2 $(d)(e)(f)$.

Seed	ξ
1	1.79×10^{-3}
2	2.02×10^{-3}

Table XII: Integral error of the difference between the original field and the one radiated by the total current.

1.8 K=200, P=40, I=100000

In the Fig. 20 is depicted the behaviour of the Cost Function varying the random seed. The best value of cost function is achieved by Seed=1 and is $\Phi = 2.684 \times 10^{-1}$.

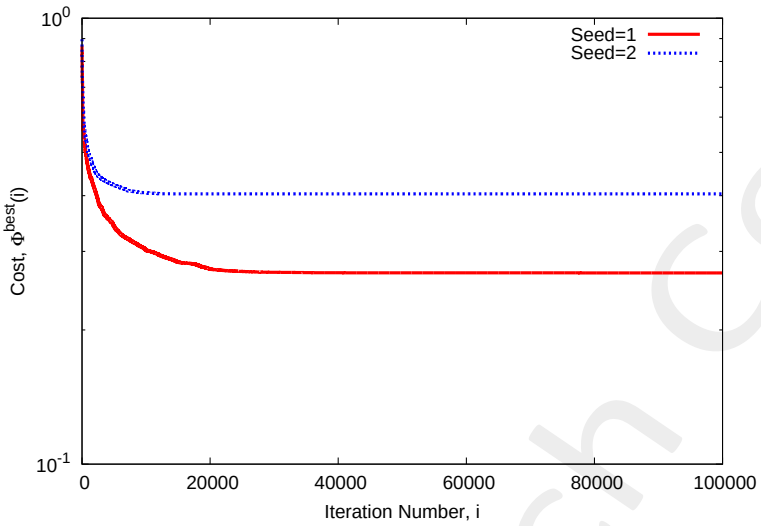


Figure 20: Cost Function behaviour at different random seed.

At this value of cost function the achieved performance on the Phase are showed in Fig. 21 and are numerically showed in table XIII.

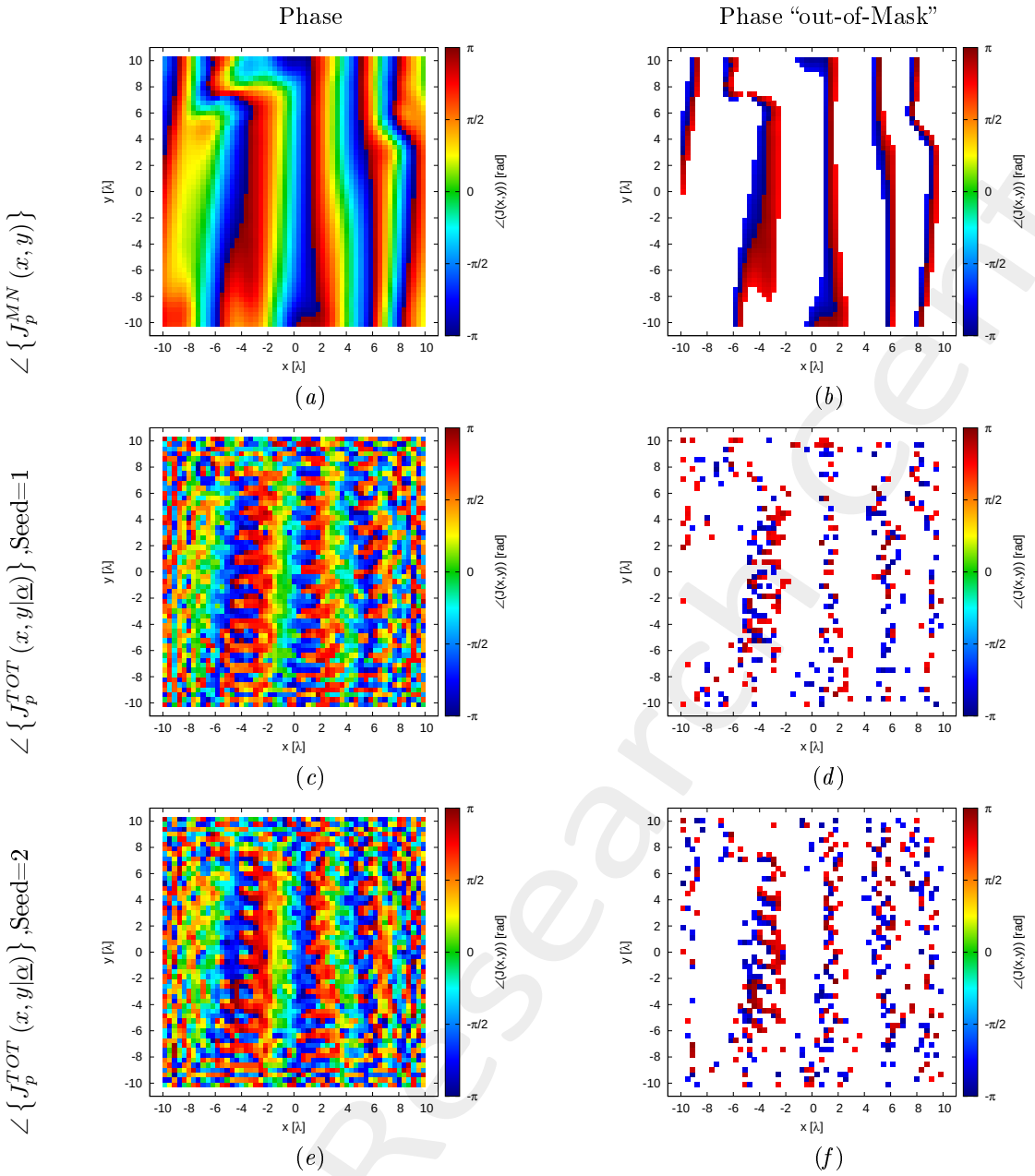


Figure 21: Phase $(a)(c)(e)$ and value of the phase out of the minimization range $(b)(d)(f)$ of the Minimum-Norm current $(\angle\{J_p^{MN}(x,y)\})(a)(b)$, of the total current for the random seed $= 1(c)(d)$ and for the random seed $= 2(e)(f)$.

Case	Φ	Number of value $> \phi_p^{MAX}(x,y)$	Number of value $< \phi_p^{MIN}(x,y)$	Phase Range		Time $[s]$
				Min $[deg]$	Max $[deg]$	
MN	1.0	451	358	-179.87	179.63	
Seed=1	2.684×10^{-1}	195	185	-176.89	177.87	2.32×10^4
Seed=2	4.036×10^{-1}	234	243	-179.49	179.64	2.81×10^4

Table XIII: Cost Function value and statistics about the result.

The verification of the radiated field is showed in Fig. 22 and numerically in table XIV.

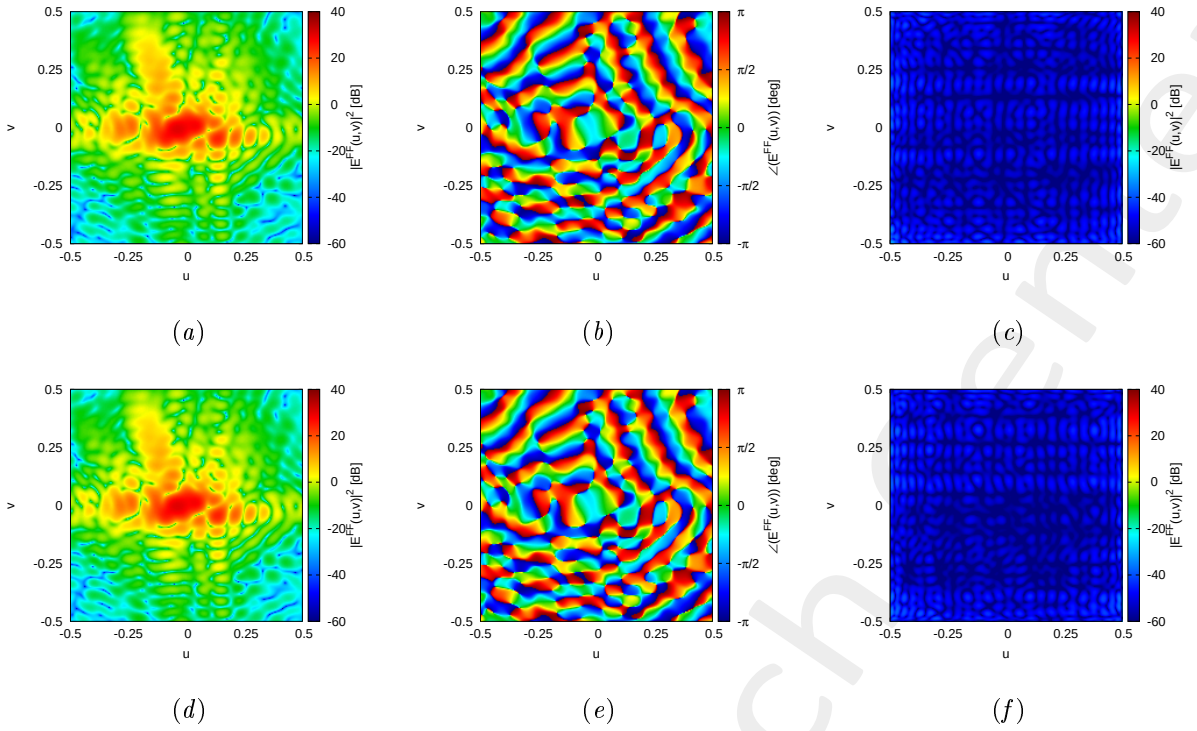


Figure 22: Magnitude $(a)(d)$, Phase $(b)(e)$ and Magnitude of the difference with respect to the original field $(c)(f)$ of the seed=1 $(a)(b)(c)$ and seed=2 $(d)(e)(f)$.

Seed	ξ
1	1.98×10^{-3}
2	1.97×10^{-3}

Table XIV: Integral error of the difference between the original field and the one radiated by the total current.

1.9 K=200, P=40, I=300000

In the Fig. 23 is depicted the behaviour of the Cost Function varying the random seed. The best value of cost function is achieved by Seed=2 and is $\Phi = 3.375 \times 10^{-1}$.

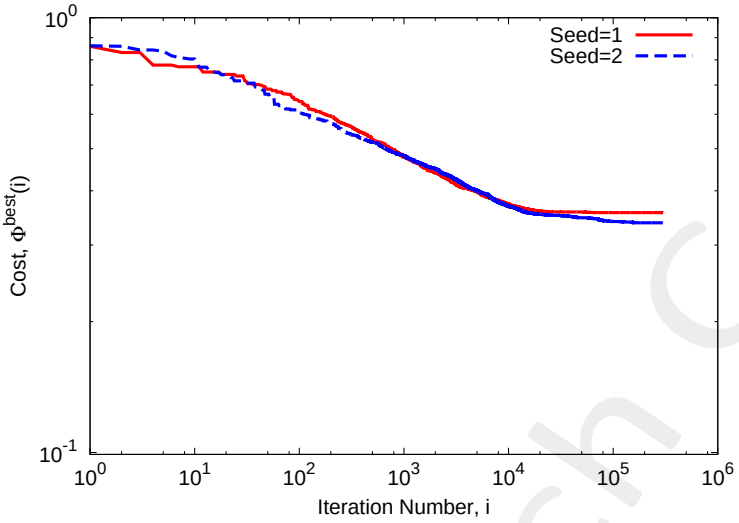


Figure 23: Cost Function behaviour at different random seed.

At this value of cost function the achieved performance on the Phase are showed in Fig. 24 and are numerically showed in table XV.

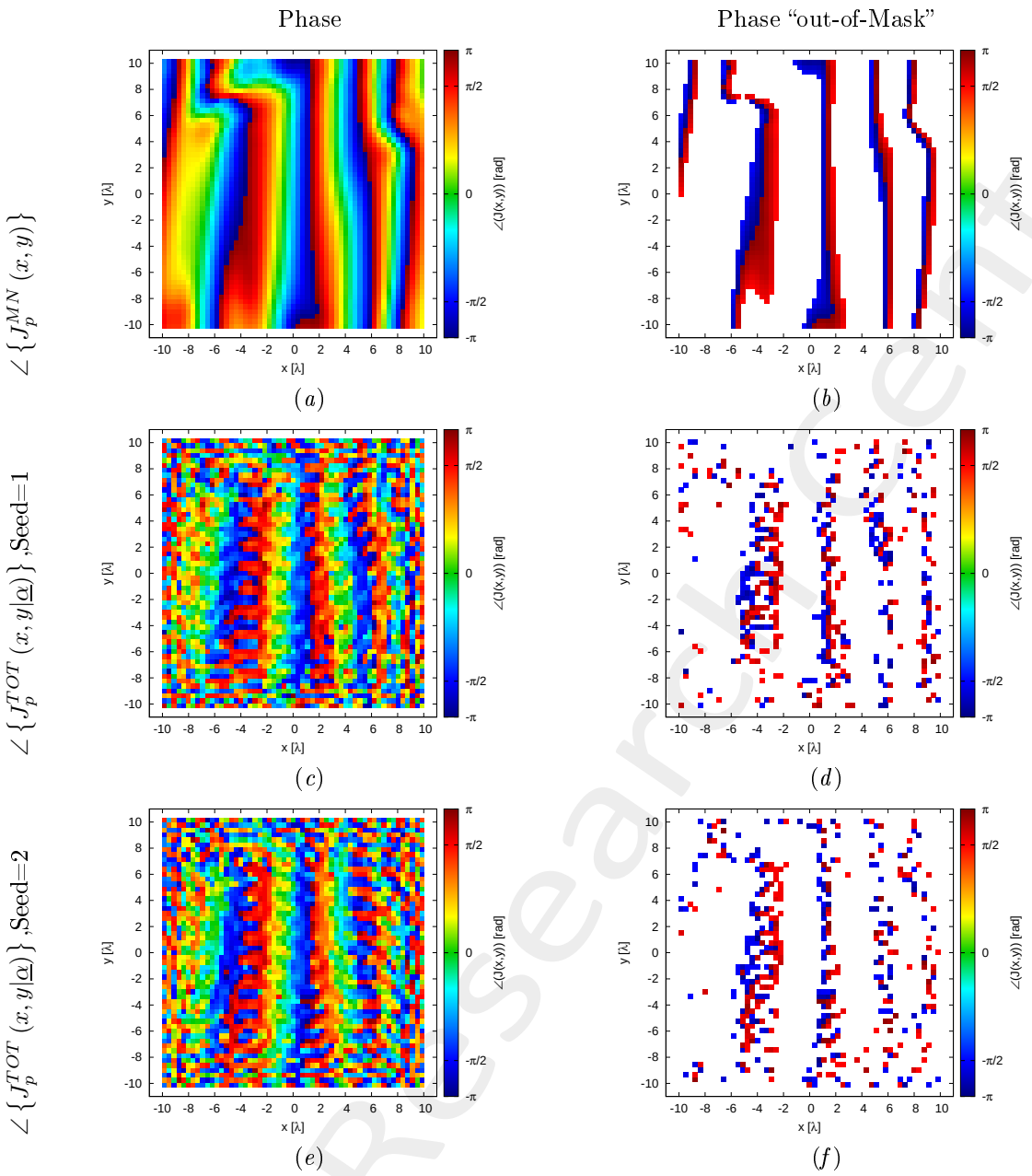
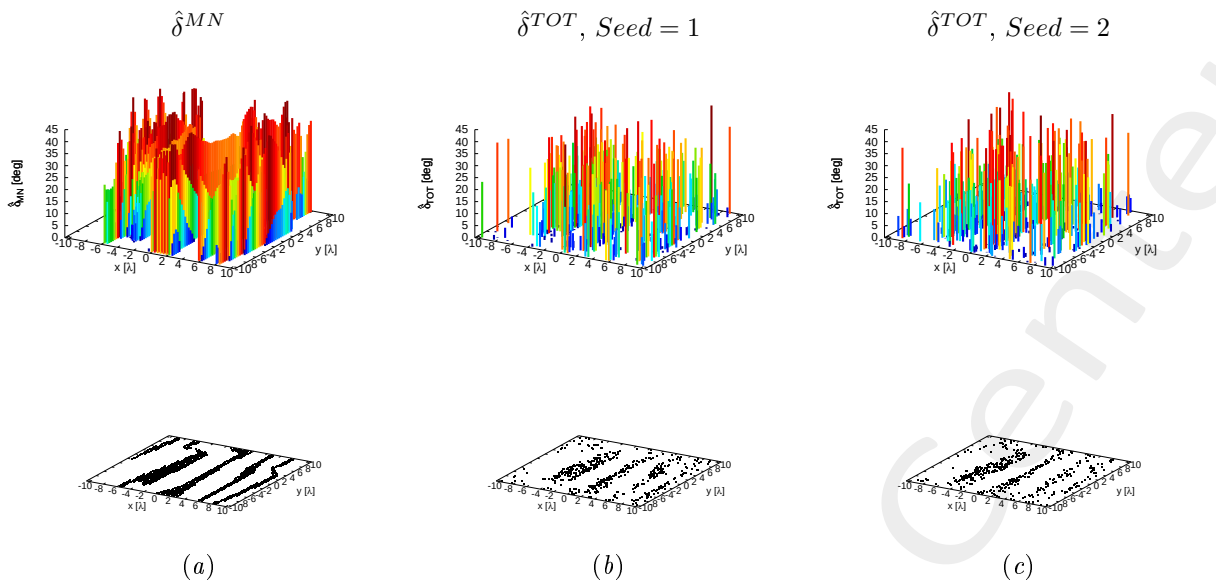


Figure 24: Phase $(a)(c)(e)$ and value of the phase out of the minimization range $(b)(d)(f)$ of the Minimum-Norm current ($\angle\{J_p^{MN}(x,y)\}$)$(a)(b)$, of the total current for the random seed $= 1(c)(d)$ and for the random seed $= 2(e)(f)$.



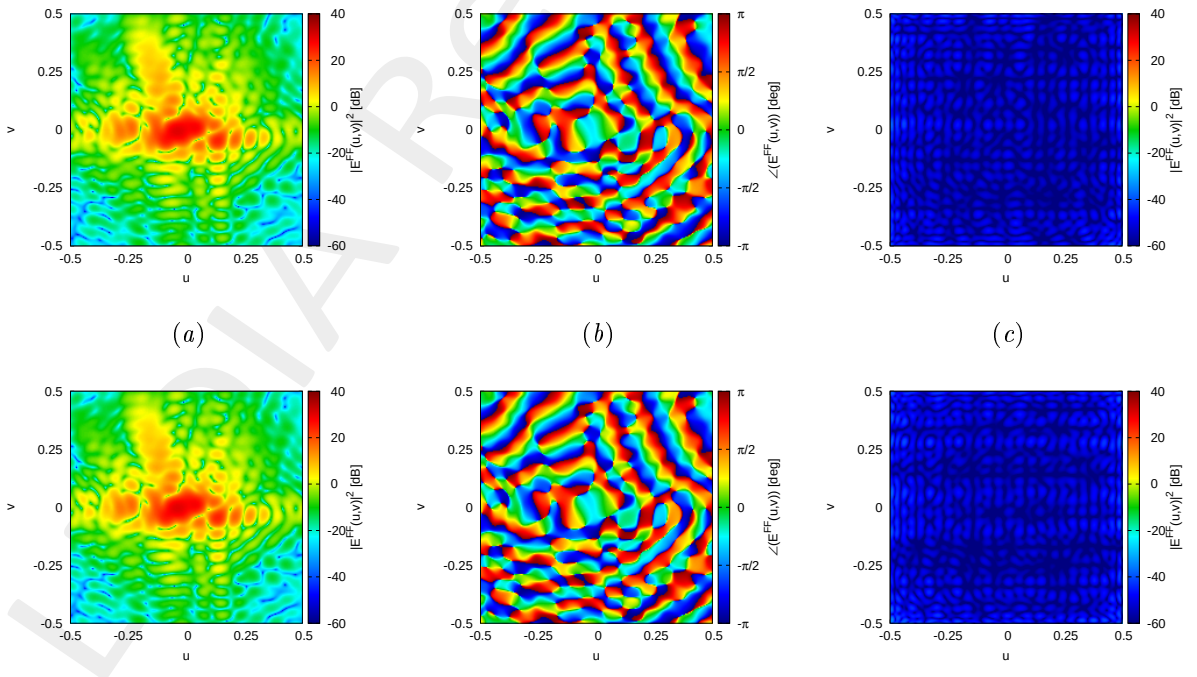
(a) (b) (c)

Figure 25: Phase Mask mismatch for the Minimum-Norm current (a), the total current for the random seed $= 1(b)$, and for the random seed $= 2(c)$.

Case	Φ	Number of value $> \phi_p^{MAX}(x,y)$	Number of value $< \phi_p^{MIN}(x,y)$	Phase Range		Time $[s]$
				Min $[deg]$	Max $[deg]$	
MN	1.0	451	358	-179.87	179.63	
Seed=1	3.560×10^{-1}	249	215	-177.56	179.82	8.48×10^4
Seed=2	3.375×10^{-1}	228	212	-178.41	179.62	8.04×10^4

Table XV: Cost Function value and statistics about the result.

The verification of the radiated field is showed in Fig. 26 and numerically in table XVI.



(a) (b) (c)

(d) (e) (f)

Figure 26: Magnitude $(a)(d)$, Phase $(b)(e)$ and Magnitude of the difference with respect to the original field $(c)(f)$ of the seed=1 $(a)(b)(c)$ and seed=2 $(d)(e)(f)$.

Seed	ξ
1	1.69×10^{-3}
2	1.87×10^{-3}

Table XVI: Integral error of the difference between the original field and the one radiated by the total current.

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

References

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