Adaptive strategies comparison for interference suppression in linear arrays

L. Poli, P. Rocca, M. Salucci, A. Massa

Abstract

Dealing with the adaptive nulling of the array radiation pattern, two strategies are investigated in this report. The first one is aimed at maximizing the signal-to-noise-plus-interference ratio whereas the second one is aimed at minimizing the total power received at the output of the array. The performance analysis is proposed in correspondence with a time-varying interference scenario.

TEST CASE 11 - SINR-max-based Approach - 32 Elements - Time-Varying Scenario

Goal

Maximization of the SINR using genetic algorithms (GA) to determine the optimal thinned array configuration, considering a time-varying scenario.

Test Case Description

- Number of Elements $N = 32$
- Elements Spacing: $d = 0.5\lambda$
- Max Gain Pattern Direction : $\theta^d = 90°$, $\phi^d = 90°$
- Desired Signal Power: $0\,dB$
- Interference Power: $30\,dB$
- Noise Power: $-30\,dB$
- Timesteps: $T = 900$
- Number of Interferences: $N_t^I \in [1-5]$; $t = 1, ..., T$
- Interference Direction Of Arrival: $\theta_j^i = 90°$, $\phi_j^i \in [0° - 180°]$; $j = 1, ..., N_t^I$

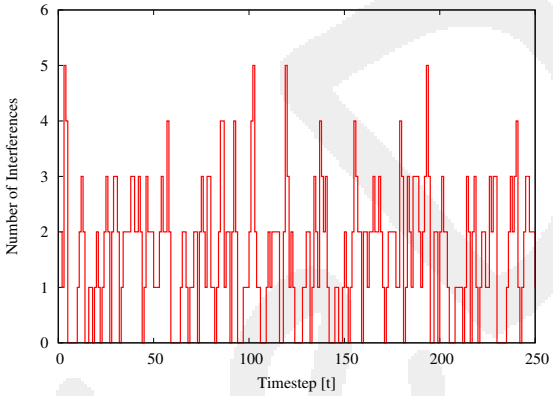

Fig.205 - Number of Interferences

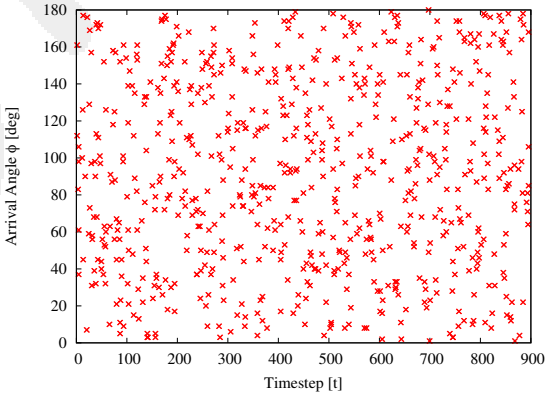

Fig.206 - Arrival Angle

Optimization Approach: GA

- Number of Variables: $X = 32$ (α_n, $n = 1, ..., N$)
- Population: 16
- Crossover Probability: 0.9
- Mutation Probability: 0.01
- Number of Generations: 200
- Thinning Coefficient Range: $\eta \in [0.00 - 1.00]$, $\eta \in [0.40 - 0.80]$, $\eta \in [0.50 - 0.70]$, $\eta \in [0.55 - 0.65]$, $\eta = 0.50$, $\eta = 0.55$, $\eta = 0.60$, $\eta = 0.65$

GA - 32 Elements - Time-Varying Scenario

	$av\{SINR\,[dB]\}$	$var\{SINR\,[dB]\}$	$min\{SINR\,[dB]\}$	$max\{SINR\,[dB]\}$
$GA\ -\ \eta \in [0.00 - 1.00]$	16.66	393.26	-30.01	45.05
$GA\ -\ \eta \in [0.40 - 0.80]$	17.24	392.68	-30.01	43.98
$GA\ -\ \eta \in [0.50 - 0.70]$	16.62	403.00	-30.02	43.42
$GA\ -\ \eta \in [0.55 - 0.65]$	15.30	402.10	-30.03	43.01
$GA\ -\ \eta = 0.50$	11.24	424.60	-30.07	42.04
$GA\ -\ \eta = 0.55$	10.11	446.70	-30.07	42.30
$GA\ -\ \eta = 0.60$	10.93	437.06	-30.03	42.79
$GA\ -\ \eta = 0.65$	13.41	433.55	-30.03	43.01

Tab.33 - Statistical analysis of the signal-to-noise-plus-interference-ration expressed in dB values $SINR\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

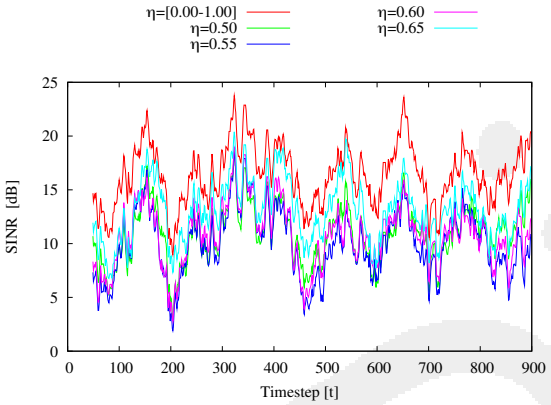

Fig.207 - SINR average comparison

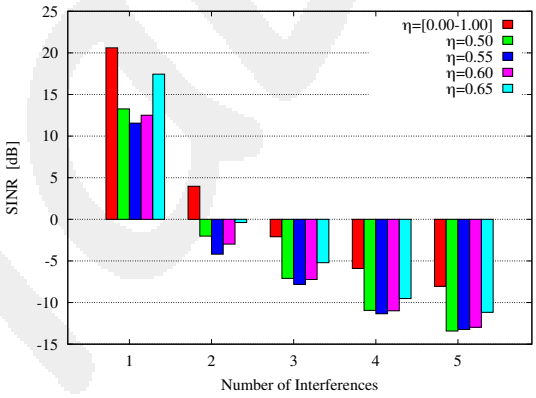

Fig.208 - SINR average comparison

	$av\{N_{ON}\}$	$var\{N_{ON}\}$	$min\{N_{ON}\}$	$max\{N_{ON}\}$
$GA\ -\ \eta \in [0.00 - 1.00]$	22.45	39.28	4	32
$GA\ -\ \eta \in [0.40 - 0.80]$	20.82	12.33	12	25
$GA\ -\ \eta \in [0.50 - 0.70]$	20.15	3.52	16	22
$GA\ -\ \eta \in [0.55 - 0.65]$	18.95	1.33	17	20
$GA\ -\ \eta = 0.50$	16	0	16	16
$GA\ -\ \eta = 0.55$	17	0	17	17
$GA\ -\ \eta = 0.60$	19	0	19	19
$GA\ -\ \eta = 0.65$	20	0	20	20

Tab.34 - Statistical analysis of the number of active elements N_{ON}: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

	$av\{D\,dB\}$	$var\{D\,[dB]\}$	$min\{D\,[dB]\}$	$max\{D\,[dB]\}$
$GA\ -\ \eta \in [0.00-1.00]$	13.32	1.79	6.02	15.05
$GA\ -\ \eta \in [0.40-0.80]$	13.12	0.64	10.79	13.98
$GA\ -\ \eta \in [0.50-0.70]$	13.02	0.18	12.04	13.42
$GA\ -\ \eta \in [0.55-0.65]$	12.77	0.07	12.30	13.01
$GA\ -\ \eta = 0.50$	12.04	0	12.04	12.04
$GA\ -\ \eta = 0.55$	12.30	0	12.30	12.30
$GA\ -\ \eta = 0.60$	12.79	0	12.79	12.79
$GA\ -\ \eta = 0.65$	13.01	0	13.01	13.01

Tab.35 - Statistical analysis of the directivity $D\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

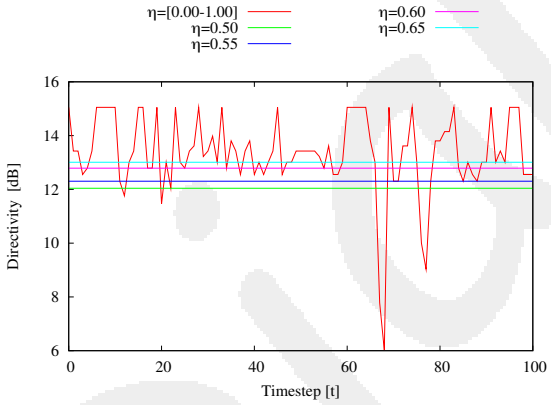

Fig.209 - Directivity comparison

Observations:

- Fig.207 riporta l'andamento medio del $SINR$ in dB mediato sui 50 timesteps precedenti;
- Fig.208 riporta il valore medio del $SINR$ in dB calcolato distinguendo i timesteps con 1,2,3,4, e 5 interferenze;
- Le prestazioni della tecnica sono buone anche per casi constrained: il valore del SINR medio risulta sempre superiore ai $10dB$;

TEST CASE 12 - SINR-max-based - 64 Elements - Time-Varying Scenario

Goal

Maximization of the SINR using genetic algorithms (GA) to determine the optimal thinned array configuration, considering a time-varying scenario.

Test Case Description

- Number of Elements $N = 64$
- Elements Spacing: $d = 0.5\lambda$
- Max Gain Pattern Direction : $\theta^d = 90°$, $\phi^d = 90°$
- Desired Signal Power: $0\,dB$
- Interference Power: $30\,dB$
- Noise Power: $-30\,dB$
- Timesteps: $T = 900$
- Number of Interferences: $N_t^I \in [1-5]\ \ t = 1, ..., T$
- Interference Direction Of Arrival: $\theta_j^i = 90°$, $\phi_j^i = 42°$

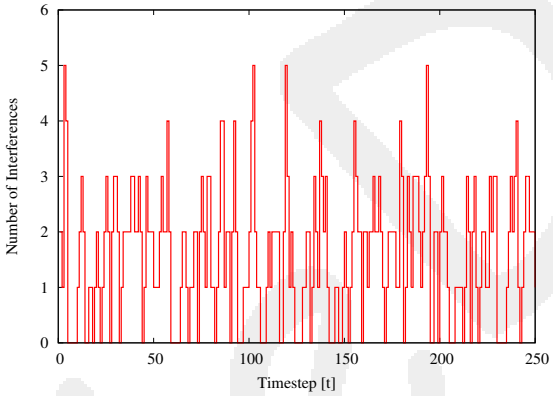

Fig.210 - Number of Interferences

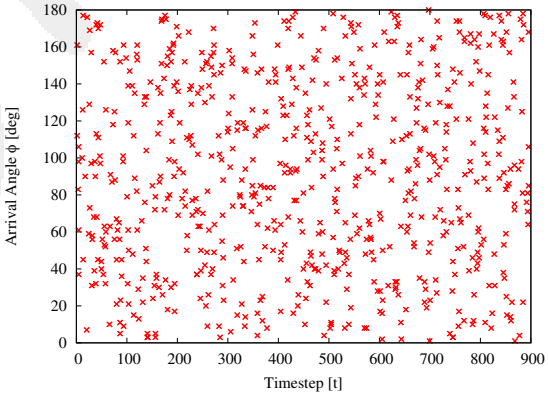

Fig.211 - Arrival Angle

Optimization Approach: GA

- Number of Variables: $X = 64$ (α_n, $n = 1, ..., N$)
- Population: 32
- Crossover Probability: 0.9
- Mutation Probability: 0.01
- Number of Generations: 200
- Thinning Coefficient Range: $\eta \in [0.00 - 1.00]$, $\eta \in [0.40 - 0.80]$, $\eta \in [0.50 - 0.70]$, $\eta \in [0.55 - 0.65]$, $\eta = 0.50$, $\eta = 0.55$, $\eta = 0.60$

GA - 64 Elements - Time-Varying Scenario

	$av\{SINR[dB]\}$	$var\{SINR[dB]\}$	$min\{SINR[dB]\}$	$max\{SINR[dB]\}$
$GA - \eta \in [0.00 - 1.00]$	26.80	308.50	-30.00	48.06
$GA - \eta \in [0.40 - 0.80]$	26.20	307.21	-30.00	47.08
$GA - \eta \in [0.50 - 0.70]$	25.43	312.29	-30.00	46.43
$GA - \eta \in [0.55 - 0.65]$	25.34	314.51	-30.00	46.13
$GA - \eta = 0.50$	20.98	335.61	-30.00	45.05
$GA - \eta = 0.55$	20.26	360.73	-30.00	45.44
$GA - \eta = 0.60$	22.52	337.94	-30.00	45.80

Tab.36 - Statistical analysis of the signal-to-noise-plus-interference-ration expressed in dB values $SINR[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

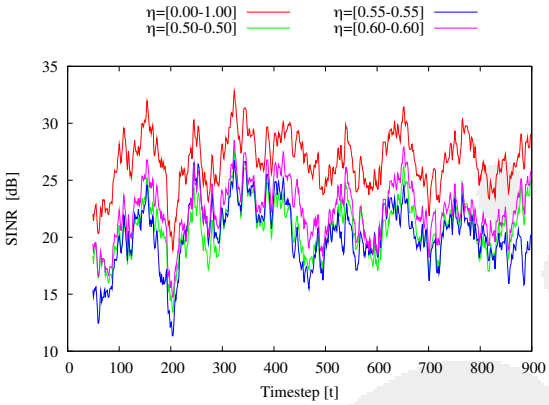

Fig.212 - SINR average comparison

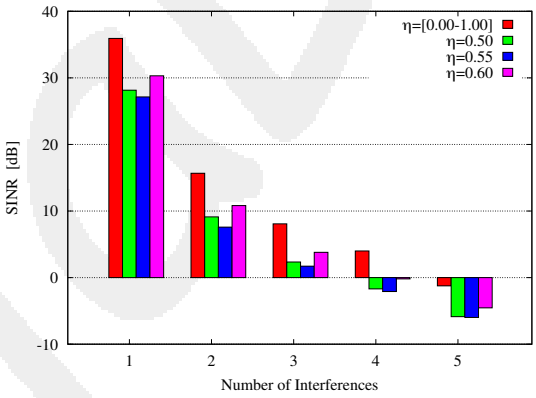

Fig.213 - SINR average comparison

	$av\{N_{ON}\}$	$var\{N_{ON}\}$	$min\{N_{ON}\}$	$max\{N_{ON}\}$
$GA - \eta \in [0.00 - 1.00]$	47.18	114.85	12	64
$GA - \eta \in [0.40 - 0.80]$	44.50	29.21	25	51
$GA - \eta \in [0.50 - 0.70]$	40.64	9.27	32	44
$GA - \eta \in [0.55 - 0.65]$	38.92	3.32	35	41
$GA - \eta = 0.50$	32	0	32	32
$GA - \eta = 0.55$	35	0	35	35
$GA - \eta = 0.60$	38	0	38	38

Tab.37 - Statistical analysis of the number of active elements N_{ON}: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

	$av\{D\,dB\}$	$var\{D\,[dB]\}$	$min\{D\,[dB]\}$	$max\{D\,[dB]\}$
$GA\ -\ \eta \in [0.00-1.00]$	16.62	1.10	10.79	18.06
$GA\ -\ \eta \in [0.40-0.80]$	16.45	0.33	13.98	17.08
$GA\ -\ \eta \in [0.50-0.70]$	16.08	0.11	15.05	16.43
$GA\ -\ \eta \in [0.55-0.65]$	15.90	0.04	15.44	16.13
$GA\ -\ \eta = 0.50$	15.05	0	15.05	15.05
$GA\ -\ \eta = 0.55$	15.44	0	15.44	15.44
$GA\ -\ \eta = 0.60$	15.80	0	15.80	15.80

Tab.38 - Statistical analysis of the directivity $D\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

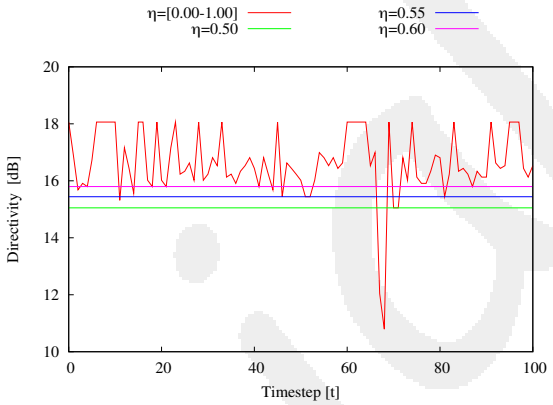

Fig.214 - Directivity comparison

Observations:

- Fig.212 riporta l'andamento medio del $SINR$ in dB mediato sui 50 timesteps precedenti;
- Fig.213 riporta il valore medio del $SINR$ in dB calcolato distinguendo i timesteps con 1,2,3,4, e 5 interferenze;
- Le prestazioni della tecnica sono buone anche per casi constrained: il valore del SINR medio risulta sempre superiore ai $20dB$;

TEST CASE 13 - SINR-max-based - 128 Elements - Time-Varying Scenario

Goal

Maximization of the SINR using genetic algorithms (GA) to determine the optimal thinned array configuration, considering a time-varying scenario.

Test Case Description

- Number of Elements $N = 128$
- Elements Spacing: $d = 0.5\lambda$
- Max Gain Pattern Direction : $\theta^d = 90°$, $\phi^d = 90°$
- Desired Signal Power: $0\,dB$
- Interference Power: $30\,dB$
- Noise Power: $-30\,dB$
- Timesteps: $T = 900$
- Number of Interferences: $N_t^I \in [1-5]$; $t = 1, ..., T$
- Interference Direction Of Arrival: $\theta_j^i = 90°$, $\phi_j^i \in [0° - 180°]$; $j = 1, ..., N_t^I$

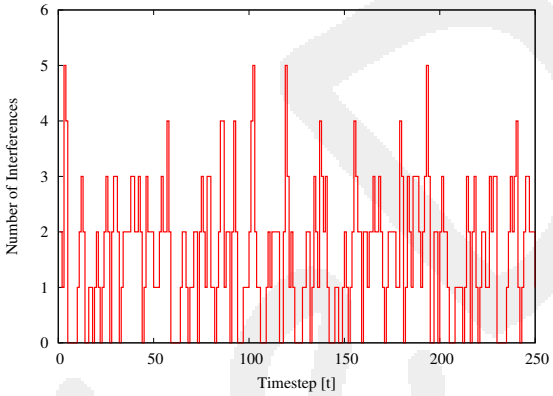

Fig.215 - Number of Interferences

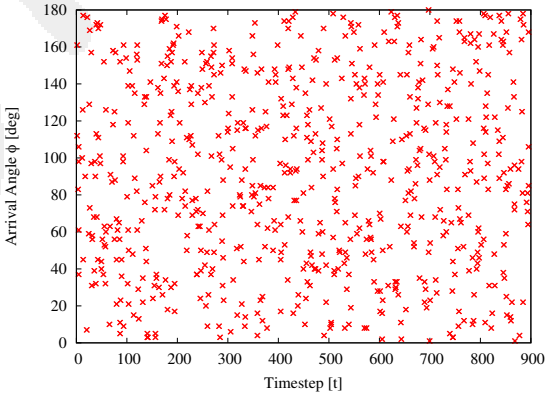

Fig.216 - Arrival Angle

Optimization Approach: GA

- Number of Variables: $X = 128$ (α_n, $n = 1, ..., N$)
- Population: 64
- Crossover Probability: 0.9
- Mutation Probability: 0.01
- Number of Generations: 200
- Thinning Coefficient Range: $\eta \in [0.00 - 1.00]$, $\eta \in [0.40 - 0.80]$, $\eta \in [0.50 - 0.70]$, $\eta \in [0.55 - 0.65]$, $\eta = 0.50$, $\eta = 0.55$, $\eta = 0.60$

GA - 128 Elements - Time-Varying Scenario

	$av\{SINR[dB]\}$	$var\{SINR[dB]\}$	$min\{SINR[dB]\}$	$max\{SINR[dB]\}$
$GA - \eta \in [0.00 - 1.00]$	29.73	322.26	-30.00	51.07
$GA - \eta \in [0.40 - 0.80]$	29.67	309.42	-30.00	50.09
$GA - \eta \in [0.50 - 0.70]$	29.46	305.78	-30.00	49.49
$GA - \eta \in [0.55 - 0.65]$	29.41	301.62	-30.00	49.19
$GA - \eta = 0.50$	30.38	275.39	-30.00	48.06
$GA - \eta = 0.55$	31.12	283.91	-30.00	48.45
$GA - \eta = 0.60$	31.63	270.89	-30.00	48.81

Tab.39 - Statistical analysis of the signal-to-noise-plus-interference-ration expressed in dB values $SINR[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

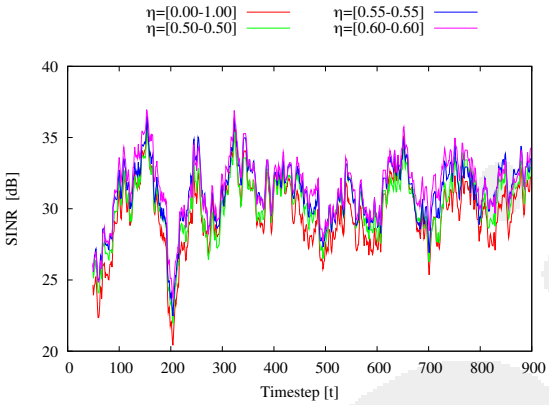

Fig.217 - SINR average comparison

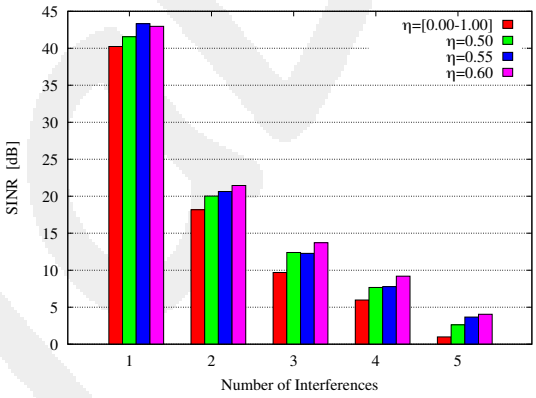

Fig.218 - SINR average comparison

	$av\{N_{ON}\}$	$var\{N_{ON}\}$	$min\{N_{ON}\}$	$max\{N_{ON}\}$
$GA - \eta \in [0.00 - 1.00]$	88.61	542.72	21	128
$GA - \eta \in [0.40 - 0.80]$	85.26	129.58	52	102
$GA - \eta \in [0.50 - 0.70]$	81.57	34.84	64	89
$GA - \eta \in [0.55 - 0.65]$	78.19	14.61	70	83
$GA - \eta = 0.50$	64	0	64	64
$GA - \eta = 0.55$	70	0	70	70
$GA - \eta = 0.60$	76	0	76	76

Tab.40 - Statistical analysis of the number of active elements N_{ON}: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

	$av\{D\,dB\}$	$var\{D\,[dB]\}$	$min\{D\,[dB]\}$	$max\{D\,[dB]\}$
$GA\ -\ \eta \in [0.00-1.00]$	19.33	1.21	13.22	21.07
$GA\ -\ \eta \in [0.40-0.80]$	19.27	0.34	17.16	20.09
$GA\ -\ \eta \in [0.50-0.70]$	19.10	0.10	18.06	19.49
$GA\ -\ \eta \in [0.55-0.65]$	18.45	4.56×10^{-2}	18.93	19.19
$GA\ -\ \eta = 0.50$	18.06	0	18.06	18.06
$GA\ -\ \eta = 0.55$	18.45	0	18.45	18.45
$GA\ -\ \eta = 0.60$	18.81	0	18.81	18.81

Tab.41 - Statistical analysis of the directivity $D\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

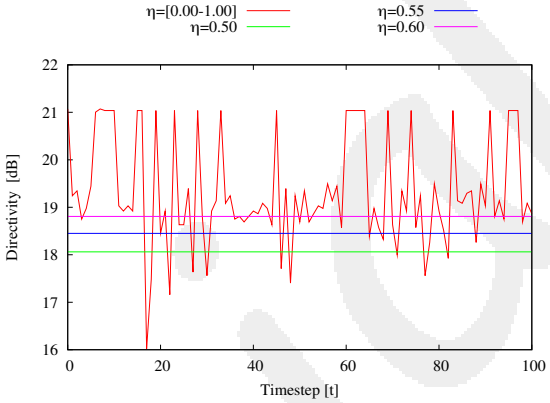

Fig.219 - Directivity comparison

Observations:

- Fig.217 riporta l'andamento medio del $SINR$ in dB mediato sui 50 timesteps precedenti;
- Fig.218 riporta il valore medio del $SINR$ in dB calcolato distinguendo i timesteps con 1,2,3,4, e 5 interferenze;
- Le prestazioni della tecnica sono buone anche per casi constrained: il valore del SINR medio risulta sempre circa uguale a $30dB$;

TEST CASE 14 - MinPwr Approach - 32 Elements - Time-Varying Scenario

Goal

Maximization of the SINR using genetic algorithms (GA) to determine the optimal thinned array configuration, considering a time-varying scenario.

Test Case Description

- Number of Elements $N = 32$
- Elements Spacing: $d = 0.5\lambda$
- Max Gain Pattern Direction : $\theta^d = 90°$, $\phi^d = 90°$
- Desired Signal Power: $0\,dB$
- Interference Power: $30\,dB$
- Noise Power: $-30\,dB$
- Timesteps: $T = 900$
- Number of Interferences: $N_t^I \in [1-5]$; $t = 1, ..., T$
- Interference Direction Of Arrival: $\theta_j^i = 90°$, $\phi_j^i \in [0° - 180°]$; $j = 1, ..., N_t^I$

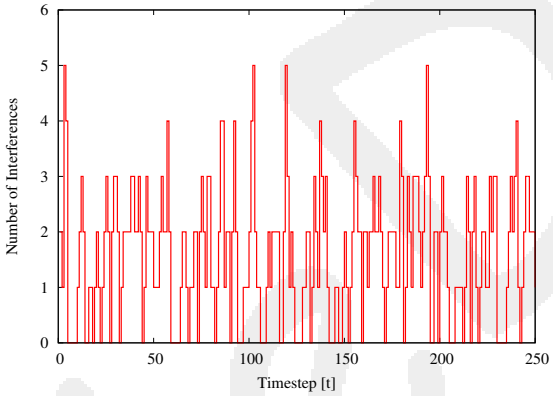

Fig.220 - Number of Interferences

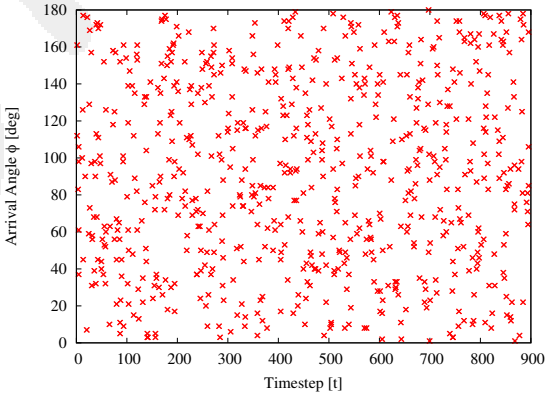

Fig.221 - Arrival Angle

Optimization Approach: GA

- Number of Variables: $X = 32$ (α_n, $n = 1, ..., N$)
- Population: 16
- Crossover Probability: 0.9
- Mutation Probability: 0.01
- Number of Generations: 200
- Thinning Coefficient Range: $\eta \in [0.40 - 0.80]$, $\eta \in [0.50 - 0.70]$, $\eta \in [0.55 - 0.65]$, $\eta = 0.50$, $\eta = 0.55$, $\eta = 0.60$, $\eta = 0.65$

GA - minPwr Approach - 32 Elements - Time-Varying Scenario

	$av\{SINR[dB]\}$	$var\{SINR[dB]\}$	$min\{SINR[dB]\}$	$max\{SINR[dB]\}$
$GA - \eta \in [0.40 - 0.80]$	12.90	372.35	-30.06	40.79
$GA - \eta \in [0.50 - 0.70]$	13.81	374.44	-30.02	42.04
$GA - \eta \in [0.55 - 0.65]$	13.84	377.14	-30.06	42.55
$GA - \eta = 0.50$	11.24	424.60	-30.07	42.04
$GA - \eta = 0.55$	10.11	446.70	-30.07	42.30
$GA - \eta = 0.60$	10.93	437.06	-30.03	42.79
$GA - \eta = 0.65$	13.41	433.55	-30.03	43.01

Tab.42 - Statistical analysis of the signal-to-noise-plus-interference-ration expressed in dB values $SINR[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

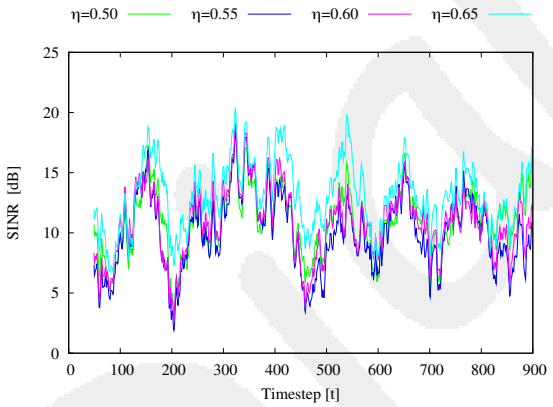

Fig.222 - SINR average comparison

	$av\{N_{ON}\}$	$var\{N_{ON}\}$	$min\{N_{ON}\}$	$max\{N_{ON}\}$
$GA - \eta \in [0.40 - 0.80]$	13.55	4.36	12	24
$GA - \eta \in [0.50 - 0.70]$	16.82	1.73	16	22
$GA - \eta \in [0.55 - 0.65]$	17.66	0.75	17	20
$GA - \eta = 0.50$	16	0	16	16
$GA - \eta = 0.55$	17	0	17	17
$GA - \eta = 0.60$	19	0	19	19
$GA - \eta = 0.65$	20	0	20	20

Tab.43 - Statistical analysis of the number of active elements N_{ON}: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

	$av\{D\,dB\}$	$var\{D\,[dB]\}$	$min\{D\,[dB]\}$	$max\{D\,[dB]\}$
$GA\ -\ \eta \in [0.40 - 0.80]$	11.27	3.73×10^{-1}	10.79	13.80
$GA\ -\ \eta \in [0.50 - 0.70]$	12.25	1.03×10^{-1}	12.04	13.42
$GA\ -\ \eta \in [0.55 - 0.65]$	12.46	4.30×10^{-2}	12.30	13.01
$GA\ -\ \eta = 0.50$	12.04	0	12.04	12.04
$GA\ -\ \eta = 0.55$	12.30	0	12.30	12.30
$GA\ -\ \eta = 0.60$	12.79	0	12.79	12.79
$GA\ -\ \eta = 0.65$	13.01	0	13.01	13.01

Tab.44 - Statistical analysis of the directivity $D\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

Observations:

- Fig.222 riporta l'andamento medio del $SINR$ in dB mediato sui 50 timesteps precedenti;
- Le prestazioni della tecnica sono di poco inferiori rispetto alla tecnica SINR-based per i casi in cui η è definito all'interno di un intervallo: tendenzialmente la tecnica cerca soluzioni con il minimo numero possibile di elementi attivi;
- E' interessante osservare che le soluzioni ricavate dalla tecnica minPwr nel caso in cui si condideri η definito da un singolo valore sono le stesse ricavate dalla tecnica SINR-based (partendo dalla stessa inizializzazione della popolazione): di conseguenza otteniamo in questo caso pari prestazioni;

TEST CASE 15 - MinPwr Approach - 64 Elements - Time-Varying Scenario

Goal

Maximization of the SINR using genetic algorithms (GA) to determine the optimal thinned array configuration, considering a time-varying scenario.

Test Case Description

- Number of Elements $N = 64$
- Elements Spacing: $d = 0.5\lambda$
- Max Gain Pattern Direction : $\theta^d = 90°$, $\phi^d = 90°$
- Desired Signal Power: $0\,dB$
- Interference Power: $30\,dB$
- Noise Power: $-30\,dB$
- Timesteps: $T = 900$
- Number of Interferences: $N_t^I \in [1-5]$; $t = 1, ..., T$
- Interference Direction Of Arrival: $\theta_j^i = 90°$, $\phi_j^i \in [0° - 180°]$; $j = 1, ..., N_t^I$

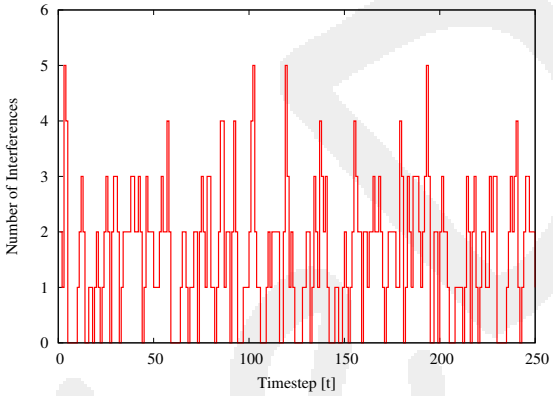

Fig.223 - Number of Interferences

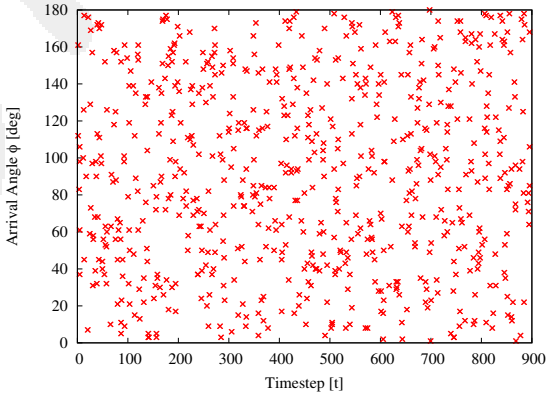

Fig.224 - Arrival Angle

Optimization Approach: GA

- Number of Variables: $X = 64$ $(\alpha_n,\ n = 1, ..., N)$
- Population: 32
- Crossover Probability: 0.9
- Mutation Probability: 0.01
- Number of Generations: 200
- Thinning Coefficient Range: $\eta \in [0.40{-}0.80], \eta \in [0.50{-}0.70], \eta \in [0.55{-}0.65], \eta = 0.50, \eta = 0.55, \eta = 0.60$

GA - minPwr Approach - 64 Elements - Time-Varying Scenario

	$av\{SINR[dB]\}$	$var\{SINR[dB]\}$	$min\{SINR[dB]\}$	$max\{SINR[dB]\}$
$GA - \eta \in [0.40 - 0.80]$	18.47	299.24	-30.01	44.15
$GA - \eta \in [0.50 - 0.70]$	20.98	303.60	-30.00	45.05
$GA - \eta \in [0.55 - 0.65]$	22.31	305.73	-30.00	45.56
$GA - \eta = 0.50$	20.98	335.61	-30.00	45.05
$GA - \eta = 0.55$	20.26	360.73	-30.00	45.44
$GA - \eta = 0.60$	22.52	337.94	-30.00	45.80

Tab.45 - Statistical analysis of the signal-to-noise-plus-interference-ration expressed in dB values $SINR[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

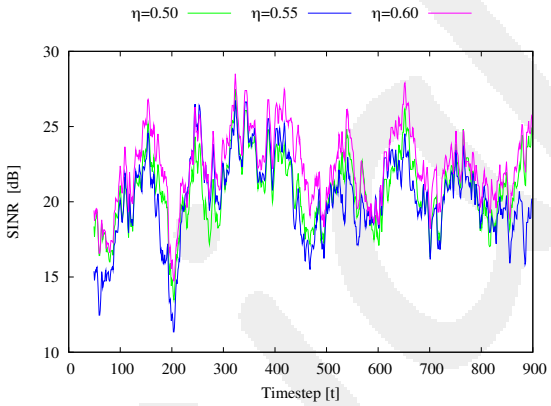

Fig.225 - SINR average comparison

	$av\{N_{ON}\}$	$var\{N_{ON}\}$	$min\{N_{ON}\}$	$max\{N_{ON}\}$
$GA - \eta \in [0.40 - 0.80]$	26.41	4.91	25	40
$GA - \eta \in [0.50 - 0.70]$	32.63	1.57	32	40
$GA - \eta \in [0.55 - 0.65]$	35.45	0.71	35	41
$GA - \eta = 0.50$	64	0	64	64
$GA - \eta = 0.55$	70	0	70	70
$GA - \eta = 0.60$	76	0	76	76

Tab.46 - Statistical analysis of the number of active elements N_{ON}: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

	$av\{D\,dB\}$	$var\{D\,[dB]\}$	$min\{D\,[dB]\}$	$max\{D\,[dB]\}$
$GA\ -\ \eta \in [0.40 - 0.80]$	14.20	1.14×10^{-1}	13.97	16.02
$GA\ -\ \eta \in [0.50 - 0.70]$	15.13	2.55×10^{-2}	15.05	16.02
$GA\ -\ \eta \in [0.55 - 0.65]$	15.49	1.00×10^{-2}	15.44	16.13
$GA\ -\ \eta = 0.50$	15.05	0	15.05	15.05
$GA\ -\ \eta = 0.55$	15.44	0	15.44	15.44
$GA\ -\ \eta = 0.60$	15.80	0	15.80	15.80

Tab.47 - Statistical analysis of the directivity $D\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

Observations:

- Fig.225 riporta l'andamento medio del $SINR$ in dB mediato sui 50 timesteps precedenti;
- Le prestazioni della tecnica sono di poco inferiori rispetto alla tecnica SINR-based per i casi in cui η è definito all'interno di un intervallo: tendenzialmente la tecnica cerca soluzioni con il minimo numero possibile di elementi attivi;
- E' interessante osservare che le soluzioni ricavate dalla tecnica minPwr nel caso in cui si condideri η definito da un singolo valore sono le stesse ricavate dalla tecnica SINR-based (partendo dalla stessa inizializzazione della popolazione): di conseguenza otteniamo in questo caso pari prestazioni;

TEST CASE 16 - MinPwr Approach - 128 Elements - Time-Varying Scenario

Goal

Maximization of the SINR using genetic algorithms (GA) to determine the optimal thinned array configuration, considering a time-varying scenario.

Test Case Description

- Number of Elements $N = 128$
- Elements Spacing: $d = 0.5\lambda$
- Max Gain Pattern Direction : $\theta^d = 90°$, $\phi^d = 90°$
- Desired Signal Power: $0\,dB$
- Interference Power: $30\,dB$
- Noise Power: $-30\,dB$
- Timesteps: $T = 900$
- Number of Interferences: $N_t^I \in [1-5]$; $t = 1, ..., T$
- Interference Direction Of Arrival: $\theta_j^i = 90°$, $\phi_j^i \in [0° - 180°]$; $j = 1, ..., N_t^I$

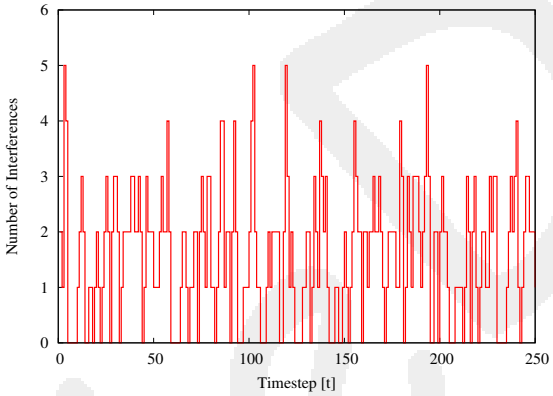

Fig.226 - Number of Interferences

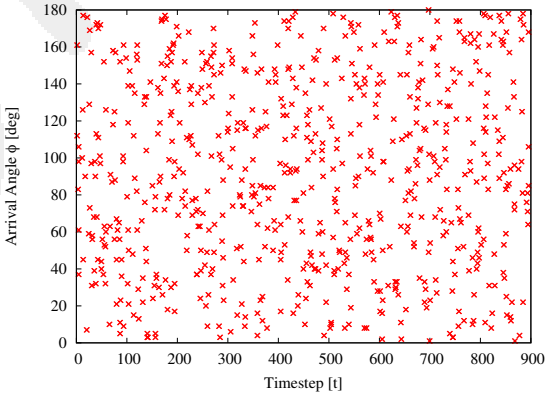

Fig.227 - Arrival Angle

Optimization Approach: GA

- Number of Variables: $X = 128$ (α_n, $n = 1, ..., N$)
- Population: 64
- Crossover Probability: 0.9
- Mutation Probability: 0.01
- Number of Generations: 200
- Thinning Coefficient Range: $\eta \in [0.40{-}0.80], \eta \in [0.50{-}0.70], \eta \in [0.55{-}0.65], \eta = 0.50, \eta = 0.55, \eta = 0.60$

GA - minPwr Approach - 128 Elements - Time-Varying Scenario

	$av\{SINR[dB]\}$	$var\{SINR[dB]\}$	$min\{SINR[dB]\}$	$max\{SINR[dB]\}$
$GA - \eta \in [0.40 - 0.80]$	20.70	302.30	-30.01	47.16
$GA - \eta \in [0.50 - 0.70]$	23.80	295.25	-30.00	48.06
$GA - \eta \in [0.55 - 0.65]$	25.62	294.55	-30.00	48.45
$GA - \eta = 0.50$	30.38	275.39	-30.00	48.06
$GA - \eta = 0.55$	31.12	283.91	-30.00	48.45
$GA - \eta = 0.60$	31.63	270.89	-30.00	48.81

Tab.48 - Statistical analysis of the signal-to-noise-plus-interference-ration expressed in dB values $SINR[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

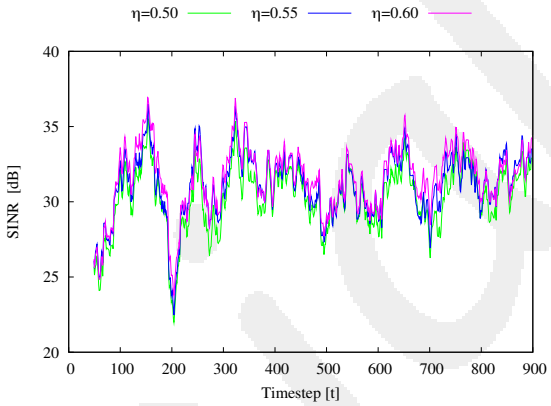

Fig.228 - SINR average comparison

	$av\{N_{ON}\}$	$var\{N_{ON}\}$	$min\{N_{ON}\}$	$max\{N_{ON}\}$
$GA - \eta \in [0.40 - 0.80]$	52.89	8.95	51	67
$GA - \eta \in [0.50 - 0.70]$	64.96	3.37	64	80
$GA - \eta \in [0.55 - 0.65]$	70.66	1.95	70	80
$GA - \eta = 0.50$	64	0	64	64
$GA - \eta = 0.55$	70	0	70	70
$GA - \eta = 0.60$	76	0	76	76

Tab.49 - Statistical analysis of the number of active elements N_{ON}: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

	$av\{D\,dB\}$	$var\{D\,[dB]\}$	$min\{D\,[dB]\}$	$max\{D\,[dB]\}$
$GA\ -\ \eta \in [0.40-0.80]$	17.23	5.47×10^{-2}	17.08	18.26
$GA\ -\ \eta \in [0.50-0.70]$	18.12	1.40×10^{-2}	18.06	19.03
$GA\ -\ \eta \in [0.55-0.65]$	18.48	6.97×10^{-3}	18.45	19.03
$GA\ -\ \eta = 0.50$	18.06	0	18.06	18.06
$GA\ -\ \eta = 0.55$	18.45	0	18.45	18.45
$GA\ -\ \eta = 0.60$	18.81	0	18.81	18.81

Tab.50 - Statistical analysis of the directivity $D\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

Observations:

- Fig.228 riporta l'andamento medio del $SINR$ in dB mediato sui 50 timesteps precedenti;
- Le prestazioni della tecnica sono inferiori rispetto alla tecnica SINR-based per i casi in cui η è definito all'interno di un intervallo: tendenzialmente la tecnica cerca soluzioni con il minimo numero possibile di elementi attivi;
- E' interessante osservare che le soluzioni ricavate dalla tecnica minPwr nel caso in cui si condideri η definito da un singolo valore sono le stesse ricavate dalla tecnica SINR-based (partendo dalla stessa inizializzazione della popolazione): di conseguenza otteniamo in questo caso pari prestazioni;

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, 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.

[4] 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.

[5] 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.

[6] 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.

[7] 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.

[8] 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.

[9] 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.

[10] F. Viani, L. Lizzi, M. Donelli, D. Pregnolato, G. Oliveri, and A. Massa, "Exploitation of smart antennas in wireless sensor networks," Journal of Electromagnetic Waves and Applications, vol. 24, no. 5/6, pp. 993-1003, 2010.

[11] L. Poli, P. Rocca, M. Salucci, and A. Massa, "Reconfigurable thinning for the adaptive control of linear arrays," IEEE Transactions on Antennas and Propagation, vol. 61, no. 10, pp. 5068-5077, October 2013.

[12] P. Rocca, R. L. Haupt, and A. Massa, "Interference suppression in uniform linear array through a dynamic thinning strategy," IEEE Trans. Antennas Propag., vol. 59, no. 12, pp. 4525-4533, Dec. 2011.

[13] G. Oliveri, L. Manica, and A. Massa, "ADS-Based guidelines for thinned planar arrays," IEEE Trans. Antennas Propag., vol. 58, no. 6, pp. 1935-1948, Jun. 2010.

[14] G. Oliveri and A. Massa, "ADS-based array design for 2D and 3D ultrasound imaging," IEEE Trans. Ultrasonics, Ferroelectrics, and Frequency Control, vol. 57, no. 7, pp. 1568-1582, Jul. 2010.