Simultaneous control of instantaneous and average pattern features in time-modulated linear arrays

P. Rocca, L. Poli, A. Massa

Abstract

In this report, the simultaneous control of both instantaneous and average features of the TMAs patterns generated at the frequency of the receiving signal just exploiting the available time-based DoFs is investigated. The directivity of the main beam has been kept constant within the modulation period by means of the joint optimisation of both pulse-sequence descriptors (i.e., 'switch-on times' and 'switch-on instants') in order to avoid undesired fluctuation of the energy delivered at the receiver, which cause a non-negligible waste of the desired signal power in the SR, while synthesising a desired average pattern at the working frequency.

Optimization Approach

PSO, Directivity Opt.

Il processo di ottimizzazione mediante algoritmo PSO agisce sia sulle durate che sugli shift temporali degli impulsi; l'ottimizzazione è applicata su metà elementi dell'array, l'altra metà viene considerata simmetrica.

Cost Function:

$$\Psi^{PSO}\left[\tau_n(i_k),\, \tau'_n(i_k)\right] = \sum_{l=1}^{L}\left[(D_l^{act,(i_k)} - D_{av})\Delta t_l^{act,(i_k)}\right]/D_{av} + \frac{\left|SLL^{act,(i_k)} - SLL^{target}\right|}{SLL^{target}} + \frac{\left|BW^{act,(i_k)} - BW^{target}\right|}{BW^{target}}$$

dove L è il numero di intervalli di variazione della direttività all'interno del periodo di modulazione, D_{av} è la direttività media sul periodo di modulazione, D_l è la direttività istantanea all'interno dell'intervallo l-esimo, Δt_l è la durata del l-esimo intervallo normalizzata rispetto al periodo di modulazione T_p, SLL^{target} è il target relativo al pattern di riferimento e BW^{target} è il beamwidth relativo al pattern di riferimento.

TEST CASE 2.a - Dolph-Chebyshev -20dB

Goal

Sintesi di un array con eccitazioni modulate nel dominio del tempo al fine di riprodurre un pattern di Dolph-Chebyshev alla frequenza centrale di lavoro e un pattern istantaneo con massima direttività costante.

Analogies and Differences wrt Previous Cases

A: Geometria dell'array, numero di elementi, algoritmo di ottimizzazione (PSO), funzione di costo implementata, configurazione statica dell'array.

D: Configurazione degli impulsi di eccitazione degli elementi (durate degli impulsi).

Test Case Description

- Number of Elements: $N = 16$
- Elements Spacing: $d = 0.5\lambda$
- Static Array Configuration: $\alpha_n = 1,\ n = 0, ..., N-1$
- Pattern at Central Frequency: $Dolph - Chebyshev$, $SLL = -20\,dB$
- Max Gain Pattern Direction : $\theta^{max} = 90°$

Optimization Approach: PS-PSO, Directivity Opt.

- Number of Variables: $X = 8$
- Number of Particles: $S = 20$
- Number of Iterations: $I = 100$
- Inertial Weight: Linearly varying: $0.9\,to\,0.4$
- Swarm Initialization: *Random*

Optimization Approach: PS-PSO, Directivity Opt.

- Number of Variables: $X = 8$
- Number of Particles: $S = 20$
- Number of Iterations: $I = 100$
- Inertial Weight: Linearly varying: $0.9\,to\,0.4$
- Swarm Initialization: *Random*

Dolph-Chebyshev Pattern, SLL=-20 dB

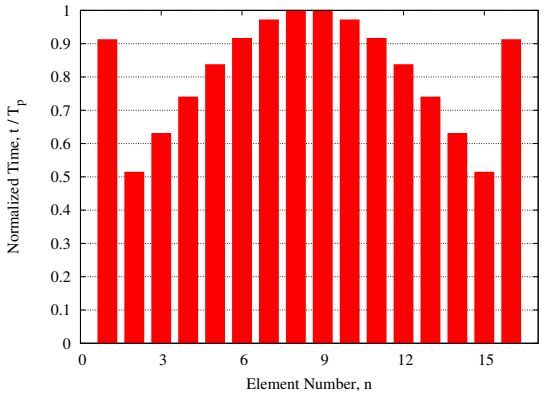

Fig.74 - Pulse Sequence

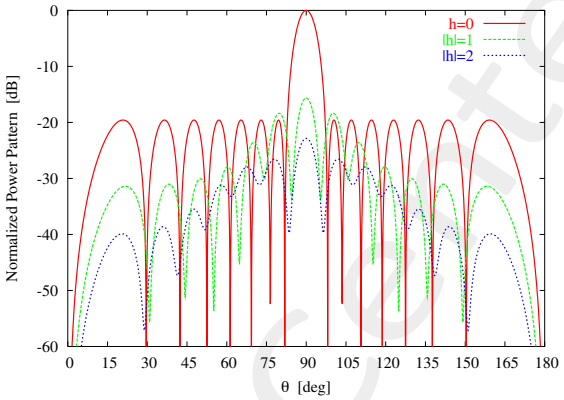

Fig.75 - Patterns

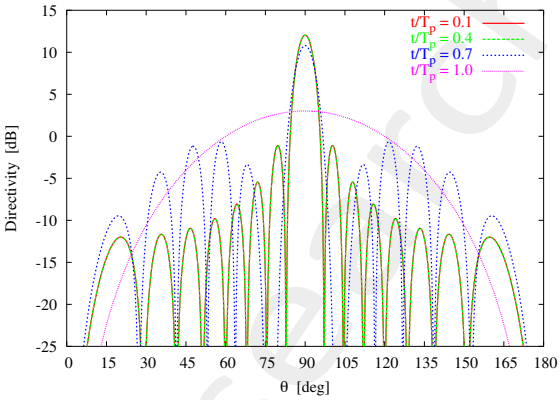

Fig.76 - Directivity

PS-PSO, Directivity Opt. - Dolph-Chebyshev Pattern, SLL=-20 dB

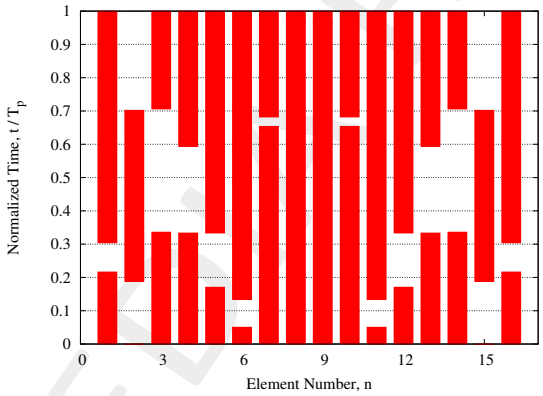

Fig.77 - Pulse Sequence

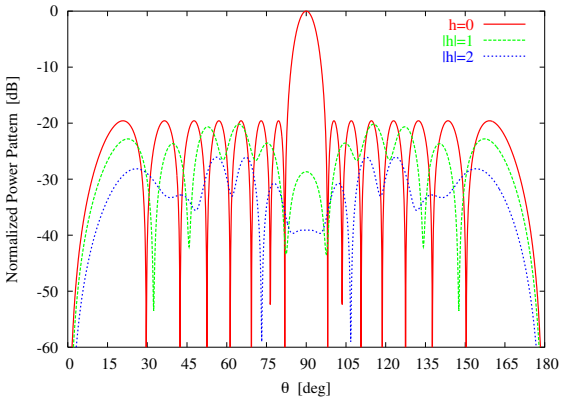

Fig.78 - Patterns

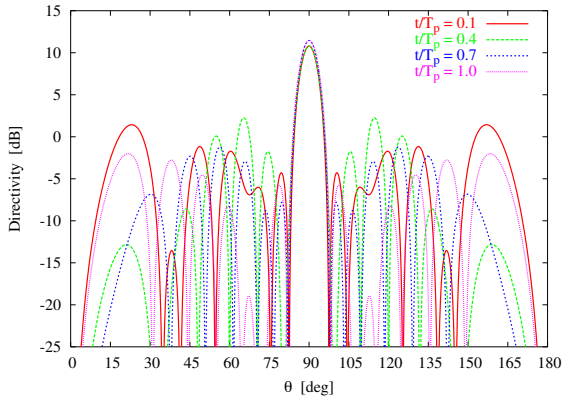

Fig.79 - Directivity

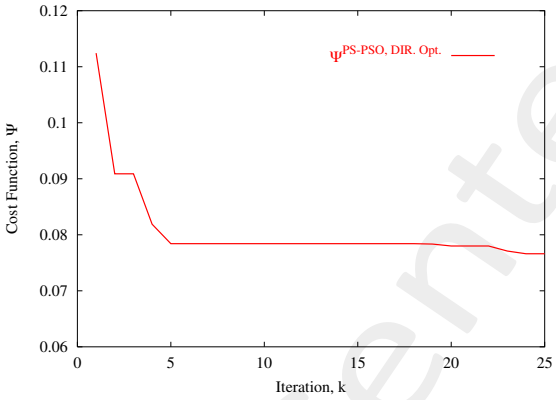

Fig.80 - Fitness

PSO, Directivity Opt. - SLL=-20 dB, BW 6.8

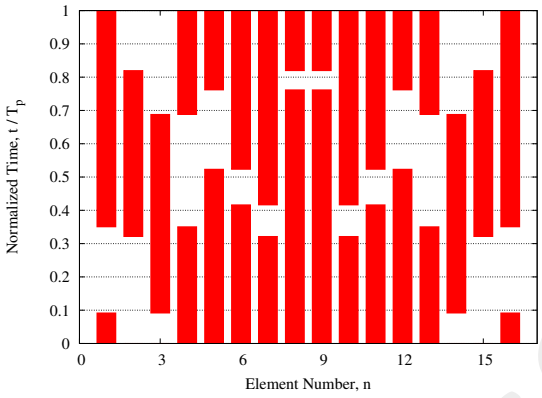

Fig.81 - Pulse Sequence

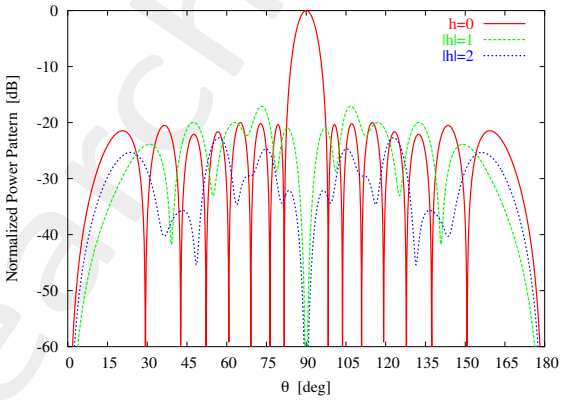

Fig.82 - Patterns

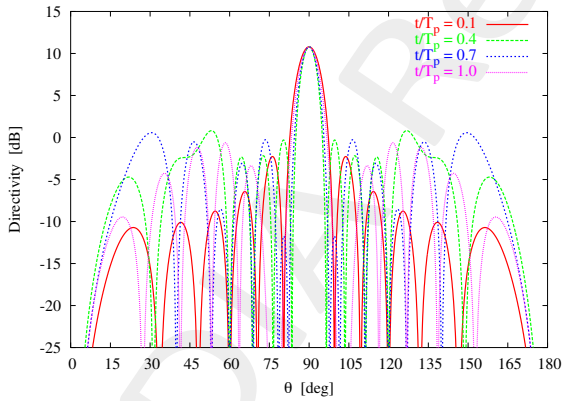

Fig.83 - Directivity

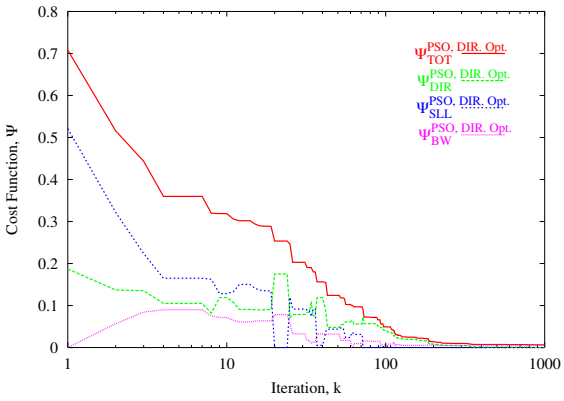

Fig.84 - Fitness

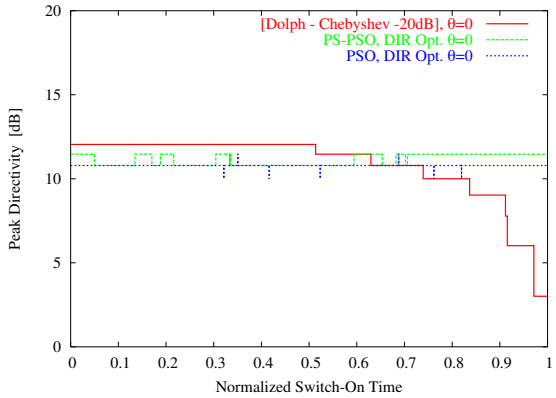

Fig.85 - Peak Directivity

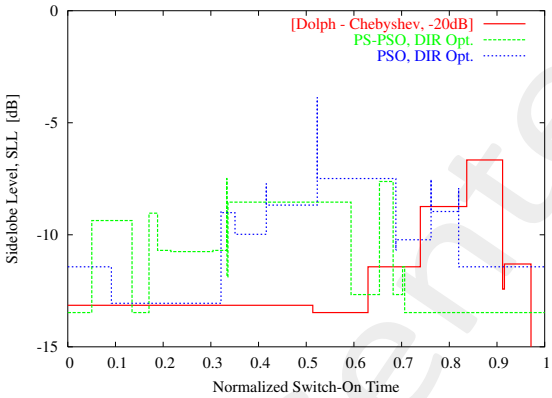

Fig.86 - Sidelobe Level

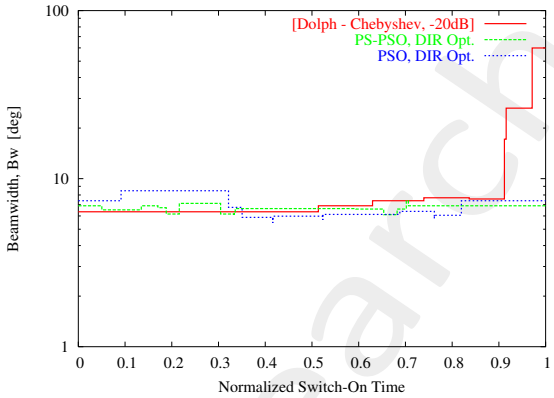

Fig.87 - Beamwidth

	$SLL_{av}\,[dB]$	$SBL\,[dB]$	$BW_{av}\,[°]$	$P_{SR}\,[\%]$
$Dolph,\ SLL = -20\,dB$	-19.57	-15.64	6.74	15.32
$PS-PSO,\ DIR\ Opt.$	-19.57	-20.18	6.71	15.31
$PSO,\ DIR\ Opt$	-20.00	-17.09	6.84	22.06

Tab.37 - Average Pattern Parameters: Sidelobe Level (SLL), Sideband Level (SBL), -3 dB Beamwidth (BW), Sideband Radiation (P_{SR})

	$av^*\{D_{max}(t)\}$	$av\{D_{max}(t)\}$	$\sigma^2\{D_{max}(t)\}$	$Min\{D_{max}(t)\}$	$Max\{D_{max}(t)\}$
Dolph, $SLL = -20\,dB$	10.80	8.76	8.17	3.01	12.04
$PS - PSO$, *DIR Opt.*	11.13	11.15	0.11	10.79	11.46
PSO, *DIR Opt*	10.79	10.63	0.23	3.00	11.46

Tab.38 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of Peak Directivity (D_{max}) in [dB]

	$av^*\{SLL(t)\}$	$av\{SLL(t)\}$	$\sigma^2\{SLL(t)]\}$	$Min\{SLL(t)\}$	$Max\{SLL(t)\}$
Dolph, $SLL = -20\,dB$	–	–	–	$-\infty$	-
$PS - PSO$, *DIR Opt.*	−11.13	−10.88	4.08	−13.47	−7.49
PSO, *DIR Opt*	−10.46	−9.13	4.19	−13.06	−3.87

Tab.39 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of Sidelobe Level (SLL) in [dB]

	$av^*\{BW(t)\}$	$av\{BW(t)\}$	$\sigma^2\{BW(t)\}$	$Min\{BW(t)\}$	$Max\{BW(t)\}$
Dolph, $SLL = -20\,dB$	9.44	17.40	301.10	6.35	59.90
$PS - PSO$, *DIR Opt.*	6.72	6.61	0.14	6.11	7.39
PSO, *DIR Opt*	7.01	6.50	0.69	5.46	8.48

Tab.40 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of -3 dB Beamwidth (BW) in [deg]

TEST CASE 2.b - Dolph-Chebyshev -25dB

Goal

Sintesi di un array con eccitazioni modulate nel dominio del tempo al fine di riprodurre un pattern di Dolph-Chebyshev alla frequenza centrale di lavoro e un pattern istantaneo con massima direttività costante.

Analogies and Differences wrt Previous Cases

A: Geometria dell'array, numero di elementi, algoritmo di ottimizzazione (PSO), funzione di costo implementata, configurazione statica dell'array.

D: Configurazione degli impulsi di eccitazione degli elementi (durate degli impulsi).

Test Case Description

- Number of Elements: $N = 16$
- Elements Spacing: $d = 0.5\lambda$
- Static Array Configuration: $\alpha_n = 1,\ n = 0, ..., N-1$
- Pattern at Central Frequency: $Dolph - Chebyshev$, $SLL = -25\,dB$
- Max Gain Pattern Direction : $\theta^{max} = 90°$

Optimization Approach: PS-PSO, Directivity Opt.

- Number of Variables: $X = 8$
- Number of Particles: $S = 20$
- Number of Iterations: $I = 100$
- Inertial Weight: Linearly varying: $0.9\,to\,0.4$
- Swarm Initialization: *Random*

Optimization Approach: PSO, Directivity Opt.

- Number of Variables: $X = 16$
- Number of Particles: $S = 30$
- Number of Iterations: $I = 1000$
- Inertial Weight: Linearly varying: $0.9\,to\,0.4$
- Swarm Initialization: *Random*

Dolph-Chebyshev Pattern, SLL=-25 dB

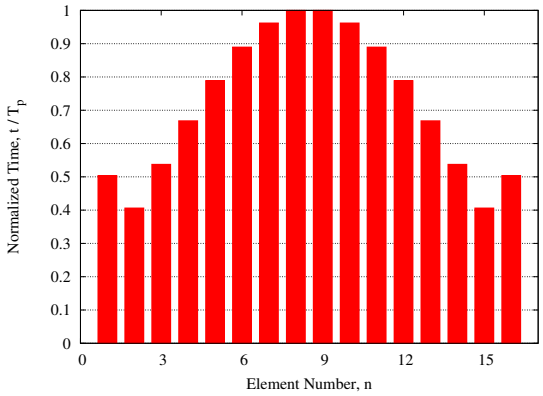

Fig.88 - Pulse Sequence

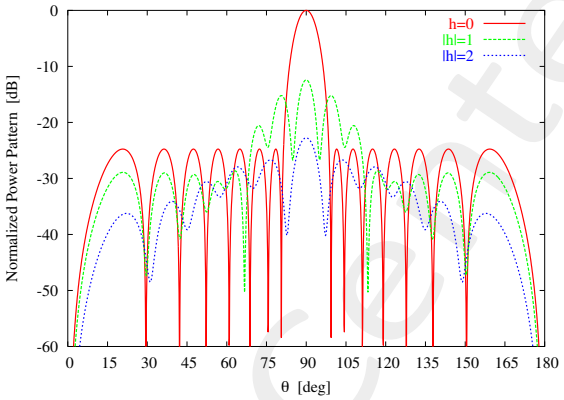

Fig.89 - Patterns

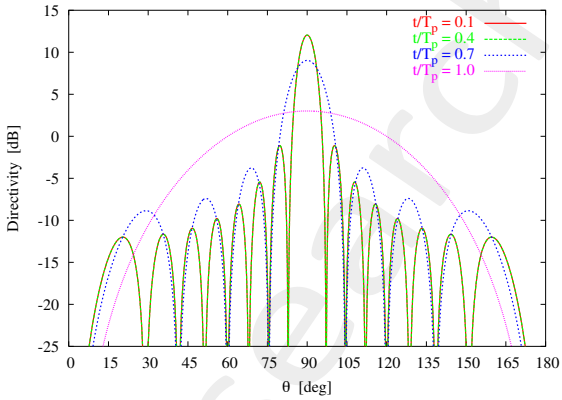

Fig.90 - Directivity

PS-PSO, Directivity Opt. - Dolph-Chebyshev Pattern, SLL=-25 dB

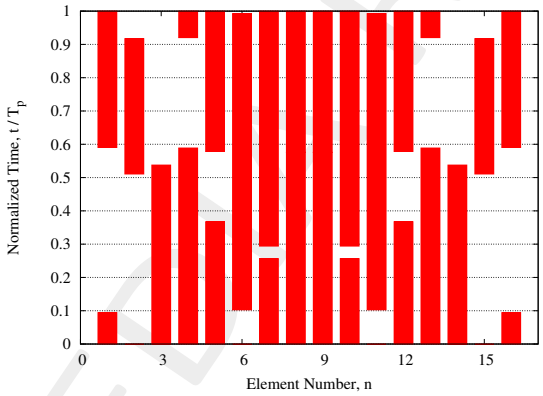

Fig.91 - Pulse Sequence

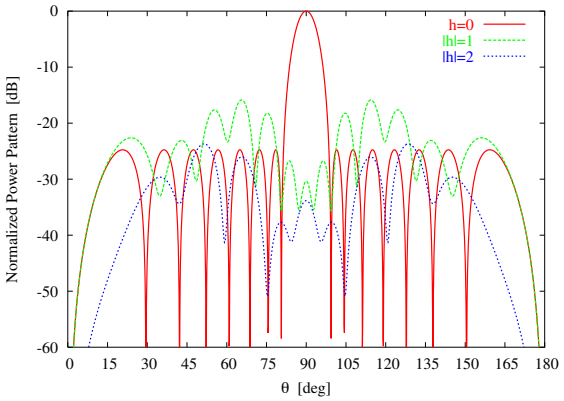

Fig.92 - Patterns

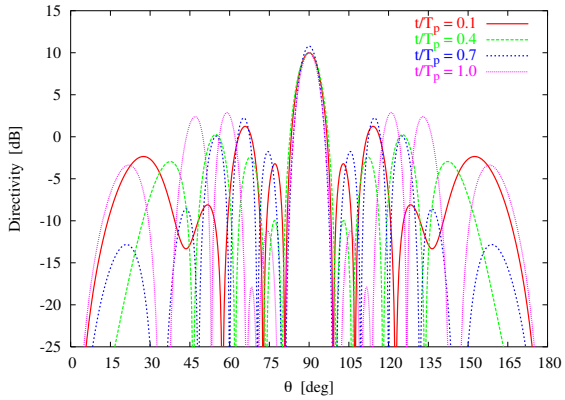

Fig.93 - Directivity

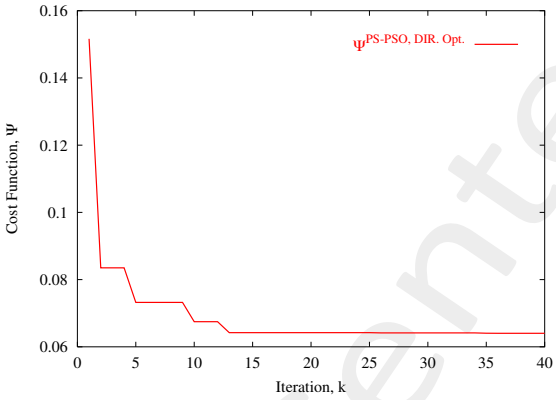

Fig.94 - Fitness

PSO, Directivity Opt. - SLL=-25 dB, BW=7.4

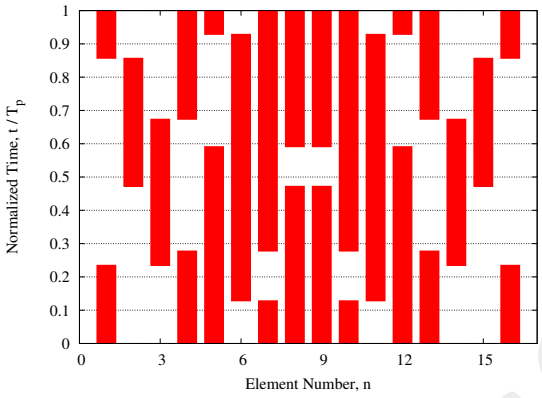

Fig.95 - Pulse Sequence

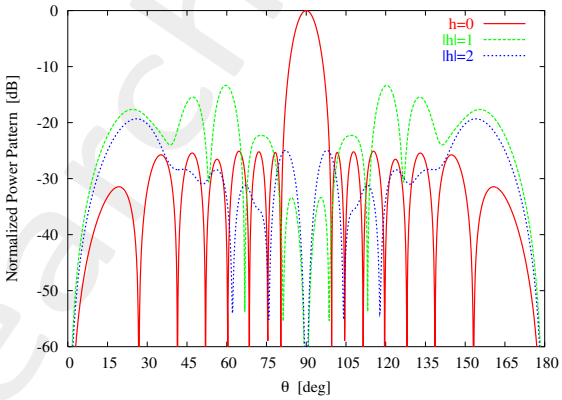

Fig.96 - Patterns

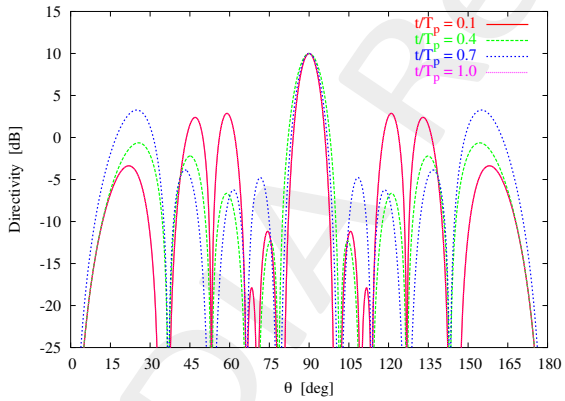

Fig.97 - Directivity

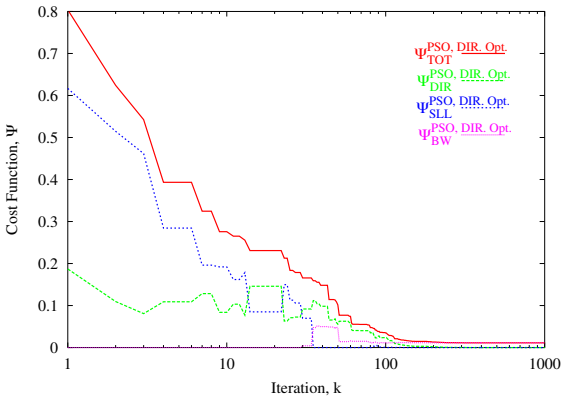

Fig.98 - Fitness

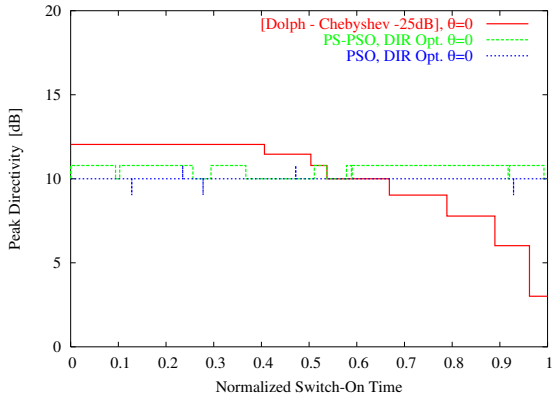

Fig.99 - Peak Directivity

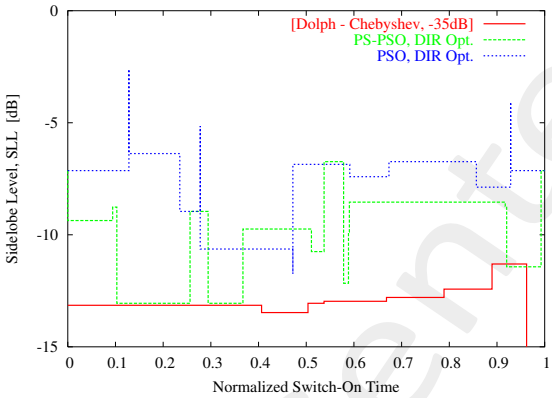

Fig.100 - Sidelobe Level

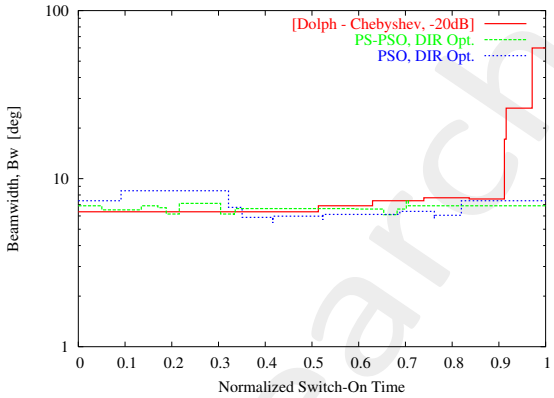

Fig.101 - Beamwidth

	$SLL_{av}\,[dB]$	$SBL\,[dB]$	$BW_{av}\,[°]$	$P_{SR}\,[\%]$
$Dolph,\ SLL = -25\,dB$	-24.76	-12.42	7.37	21.93
$PS-PSO,\ DIR\ Opt.$	-24.76	-15.86	7.36	21.93
$PSO,\ DIR\ Opt$	-25.10	-13.35	7.48	31.45

Tab.29 - Average Pattern Parameters: Sidelobe Level (SLL), Sideband Level (SBL), -3 dB Beamwidth (BW), Sideband Radiation (P_{SR})

	$av^*\{D_{max}(t)\}$	$av\{D_{max}(t)\}$	$\sigma^2\{D_{max}(t)\}$	$Min\{D_{max}(t)\}$	$Max\{D_{max}(t)\}$
Dolph, $SLL = -25\,dB$	10.10	8.77	8.1	3.01	12.04
$PS-PSO$, *DIR Opt.*	10.60	10.37	0.16	10	10.79
PSO, *DIR Opt*	10	9.91	0.28	9.03	10.79

Tab.30 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of Peak Directivity (D_{max}) in [dB]

	$av^*\{SLL(t)\}$	$av\{SLL(t)\}$	$\sigma^2\{SLL(t)]\}$	$Min\{SLL(t)\}$	$Max\{SLL(t)\}$
Dolph, $SLL = -25\,dB$	–	–	–	$-\infty$	–
$PS-PSO$, *DIR Opt.*	−10.05	−9.70	3.90	−13.06	−6.74
PSO, *DIR Opt*	−7.78	−7.24	5.30	−11.74	−2.61

Tab.31 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of Sidelobe Level (SLL) in [dB]

	$av^*\{BW(t)\}$	$av\{BW(t)\}$	$\sigma^2\{BW(t)\}$	$Min\{BW(t)\}$	$Max\{BW(t)\}$
Dolph, $SLL = -25\,dB$	12.32	18.55	282.60	6.35	59.90
$PS-PSO$, *DIR Opt.*	7.12	7.65	0.45	6.52	8.55
PSO, *DIR Opt*	7.60	7.02	2.07	2.55	9.23

Tab.32 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of -3 dB Beamwidth (BW) in [deg]

TEST CASE 2.3 - Dolph-Chebyshev -30dB

Goal

Sintesi di un array con eccitazioni modulate nel dominio del tempo al fine di riprodurre un pattern di Dolph-Chebyshev alla frequenza centrale di lavoro e un pattern istantaneo con massima direttività costante.

Test Case Description

- Number of Elements: $N = 16$
- Elements Spacing: $d = 0.5\lambda$
- Static Array Configuration: $\alpha_n = 1,\ n = 0, ..., N-1$
- Pattern at Central Frequency: $Dolph - Chebyshev$, $SLL = -30\,dB$
- Max Gain Pattern Direction : $\theta^{max} = 90°$

Optimization Approach: PS-PSO, Directivity Opt.

- Number of Variables: $X = 8$
- Number of Particles: $S = 20$
- Number of Iterations: $I = 100$
- Inertial Weight: Linearly varying: $0.9\,to\,0.4$
- Swarm Initialization: *Random*

Optimization Approach: PSO, Directivity Opt.

- Number of Variables: $X = 16$
- Number of Particles: $S = 30$
- Number of Iterations: $I = 1000$
- Inertial Weight: Linearly varying: $0.9\,to\,0.4$
- Swarm Initialization: *Random*

Tennant 2008 - Dolph-Chebyshev Pattern, SLL=-30 dB

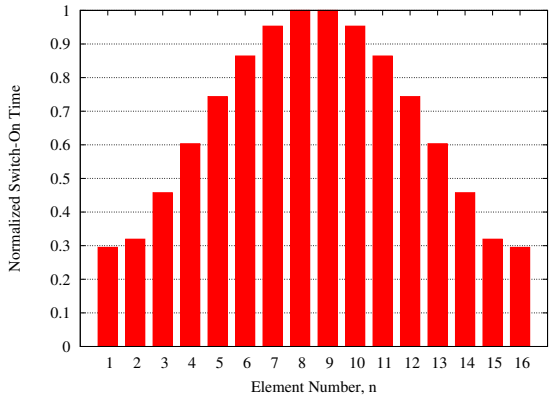

Fig.102 - Pulse Sequence

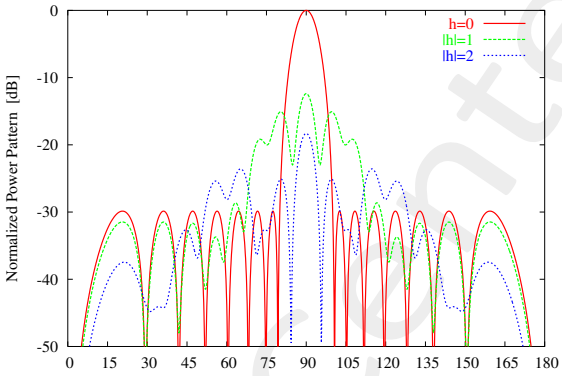

Fig.103 - Patterns

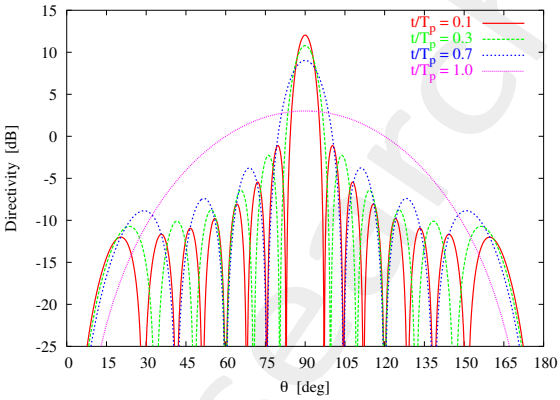

Fig.104 - Directivity

PS-PSO, Directivity Opt. - Tennant 2008 - Dolph-Chebyshev Pattern, SLL=-30 dB

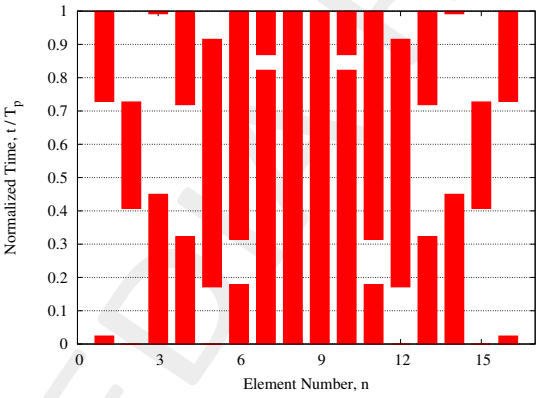

Fig.105 - Pulse Sequence

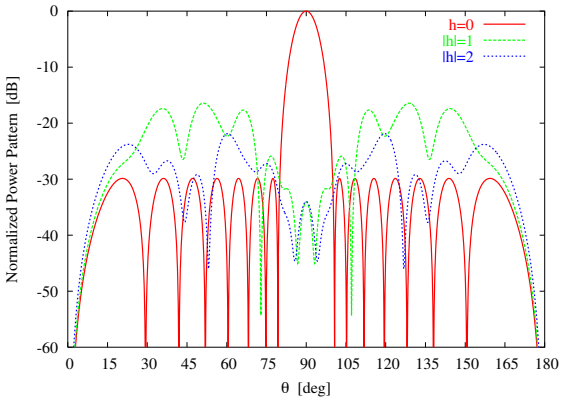

Fig.106 - Patterns

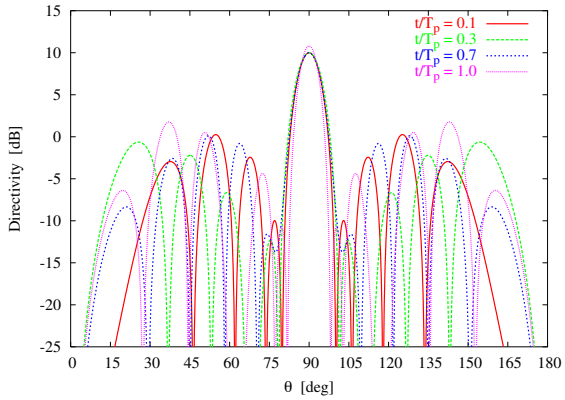

Fig.107 - Directivity

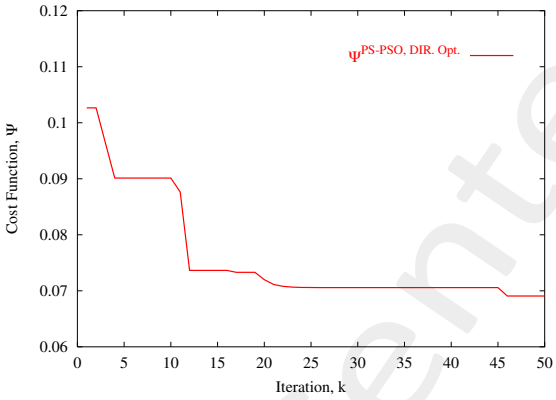

Fig.108 - Fitness

PSO, Directivity Opt. - SLL=-30 dB, BW=8.0

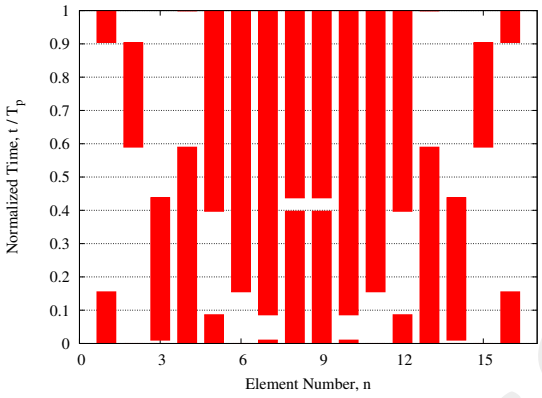

Fig.109 - Pulse Sequence

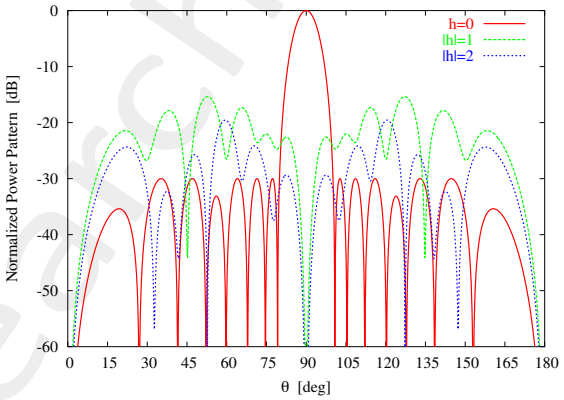

Fig.110 - Patterns

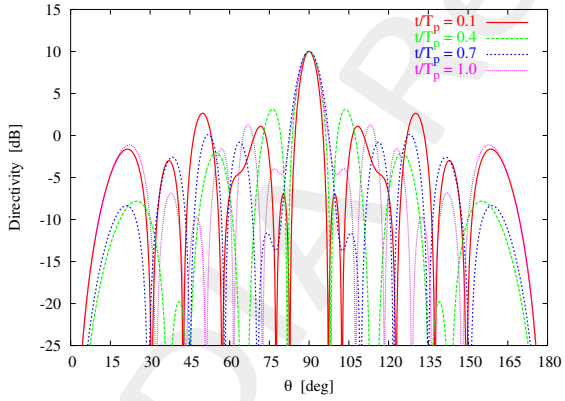

Fig.111 - Directivity

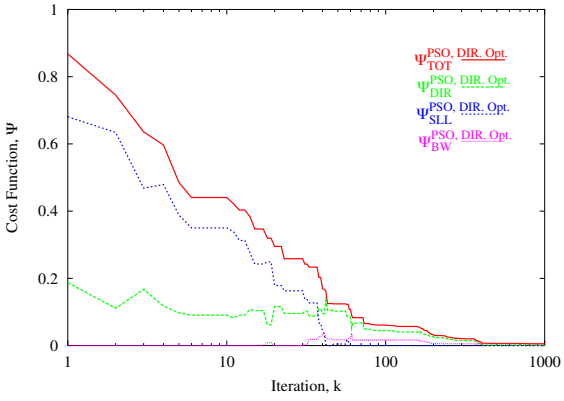

Fig.112 - Patterns

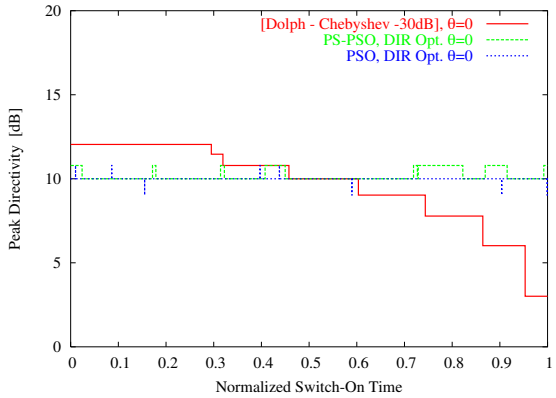

Fig.113 - Peak Directivity

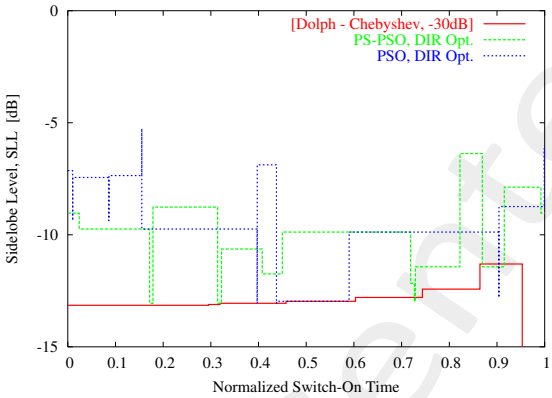

Fig.114 - Sidelobe Level

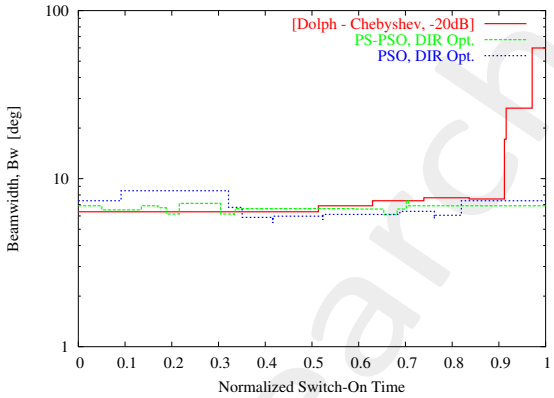

Fig.115 - Beamwidth

	$SLL_{av}\,[dB]$	$SBL\,[dB]$	$BW_{av}\,[°]$	$P_{SR}\,[\%]$
$[Tennant\,2008]$	-29.86	-12.39	7.95	24.17
$PS-PSO,\,DIR\,Opt.$	-29.86	-16.43	7.95	24.17
$PSO,\,DIR\,Opt$	-30.00	-15.37	8.04	26.89

Tab.33 - Average Pattern Parameters: Sidelobe Level (SLL), Sideband Level (SBL), -3 dB Beamwidth (BW), Sideband Radiation (P_{SR})

	$av^*\{D_{max}(t)\}$	$av\{D_{max}(t)\}$	$\sigma^2\{D_{max}(t)\}$	$Min\{D_{max}(t)\}$	$Max\{D_{max}(t)\}$
$[Tennant\,2008]$	9.66	8.76	8.17	3.01	12.04
$PS-PSO,\,DIR\,Opt.$	10.19	10.42	0.16	10	10.79
$PSO,\,DIR\,Opt$	10	9.96	0.37	9.03	10.79

Tab.34 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of Peak Directivity (D_{max}) in [dB]

	$av^*\{SLL(t)\}$	$av\{SLL(t)\}$	$\sigma^2\{SLL(t)]\}$	$Min\{SLL(t)\}$	$Max\{SLL(t)\}$
$[Tennant\,2008]$	–	–	–	$-\infty$	-11.30
$PS-PSO,\,DIR\,Opt.$	-9.79	-10.48	3.83	-13.06	-6.38
$PSO,\,DIR\,Opt$	-9.70	-9.36	6.80	-13.06	-5.26

Tab.35 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of Sidelobe Level (SLL) in [dB]

	$av^*\{BW(t)\}$	$av\{BW(t)\}$	$\sigma^2\{BW(t)\}$	$Min\{BW(t)\}$	$Max\{BW(t)\}$
$[Tennant\,2008]$	13.72	18.55	281.55	6.35	59.90
$PS-PSO,\,DIR\,Opt.$	8.05	7.93	0.91	6.72	10.19
$PS-PSO,\,DIR\,Opt$	8.27	8.20	3.85	5.96	12.78

Tab.36 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of -3 dB Beamwidth (BW) in [deg]

TEST CASE 2.4 - Dolph-Chebyshev -35dB

Goal

Sintesi di un array con eccitazioni modulate nel dominio del tempo al fine di riprodurre un pattern di Dolph-Chebyshev alla frequenza centrale di lavoro e un pattern istantaneo con massima direttività costante.

Analogies and Differences wrt Previous Cases

A: Geometria dell'array, numero di elementi, algoritmo di ottimizzazione (PSO), funzione di costo implementata, configurazione statica dell'array.

D: Configurazione degli impulsi di eccitazione degli elementi (durate degli impulsi).

Test Case Description

- Number of Elements: $N = 16$
- Elements Spacing: $d = 0.5\lambda$
- Static Array Configuration: $\alpha_n = 1,\ n = 0, ..., N-1$
- Pattern at Central Frequency: $Dolph - Chebyshev\,,\ SLL = -35\,dB$
- Max Gain Pattern Direction : $\theta^{max} = 90°$

Optimization Approach: PS-PSO, Directivity Opt.

- Number of Variables: $X = 8$
- Number of Particles: $S = 20$
- Number of Iterations: $I = 100$
- Inertial Weight: Linearly varying: $0.9\,to\,0.4$
- Swarm Initialization: *Random*

Optimization Approach: PSO, Directivity Opt.

- Number of Variables: $X = 16$
- Number of Particles: $S = 30$
- Number of Iterations: $I = 1000$
- Inertial Weight: Linearly varying: $0.9\,to\,0.4$
- Swarm Initialization: *Random*

Dolph-Chebyshev Pattern, SLL=-35 dB

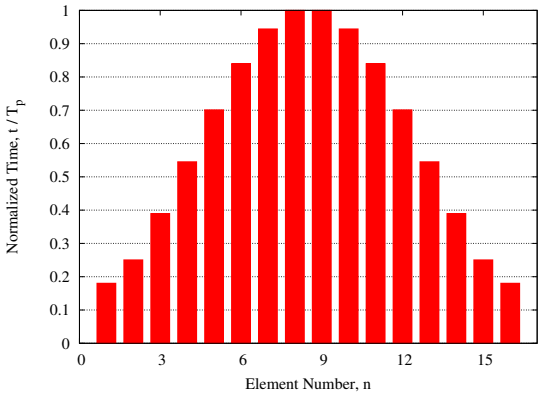

Fig.116 - Pulse Sequence

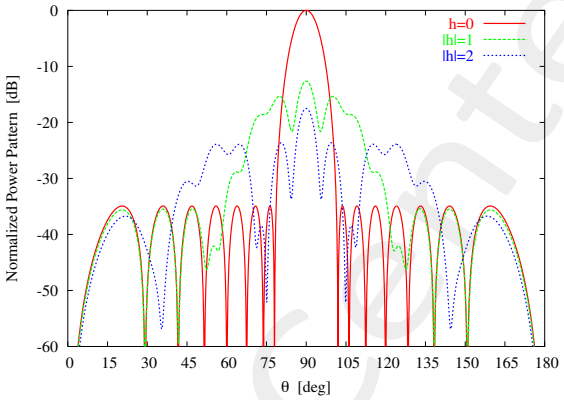

Fig.117 - Patterns

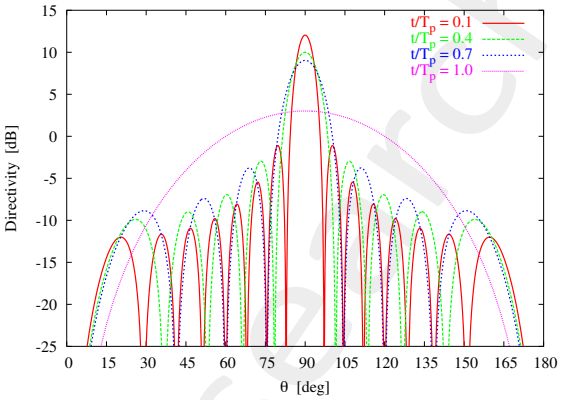

Fig.118 - Directivity

Dolph-Chebyshev Pattern, SLL=-35 dB - PS-PSO, Directivity Opt.

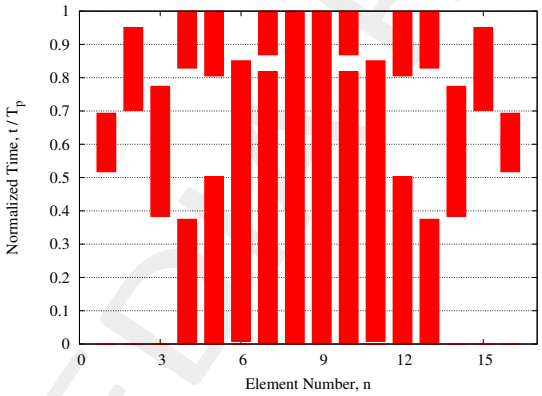

Fig.119 - Pulse Sequence

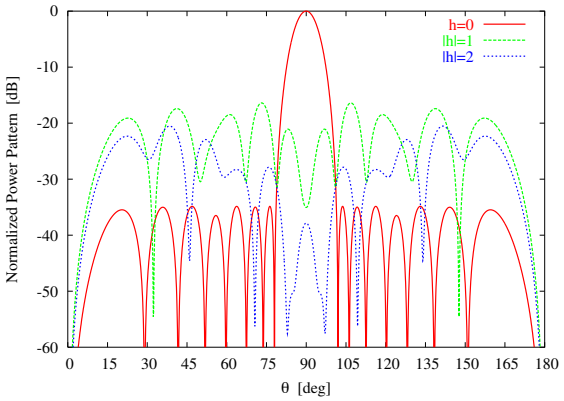

Fig.120 - Patterns

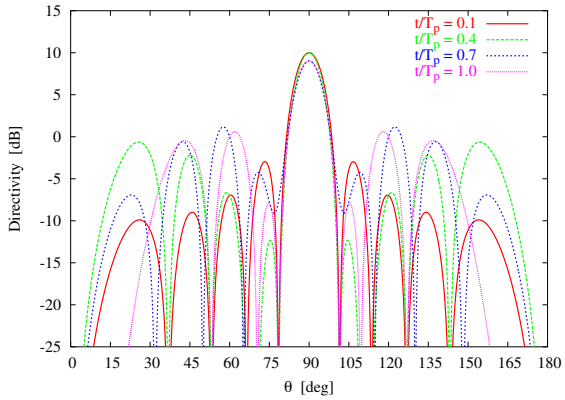

Fig.121 - Directivity

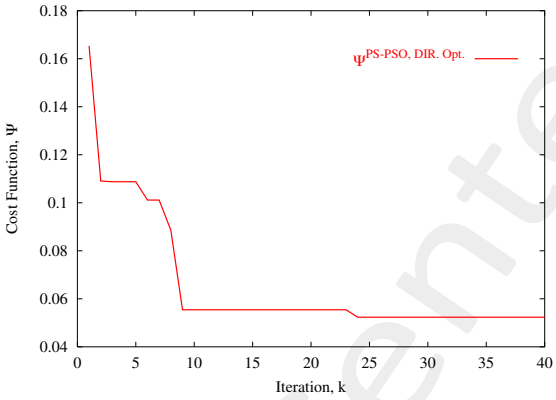

Fig.122 - Fitness

Dolph-Chebyshev Pattern, SLL=-35 dB BW= 8.5 PSO, Directivity Opt.

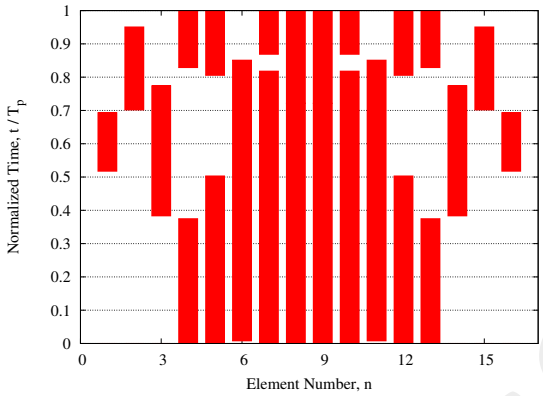

Fig.123 - Pulse Sequence

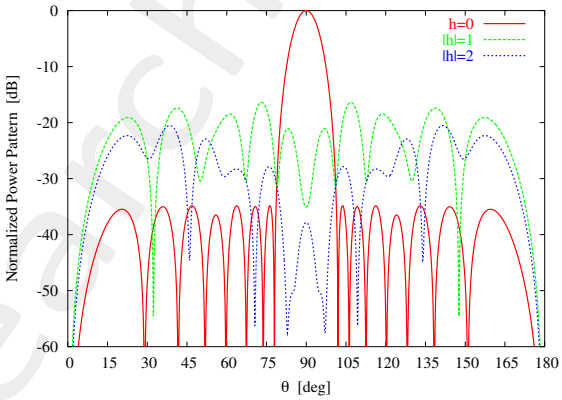

Fig.124 - Patterns

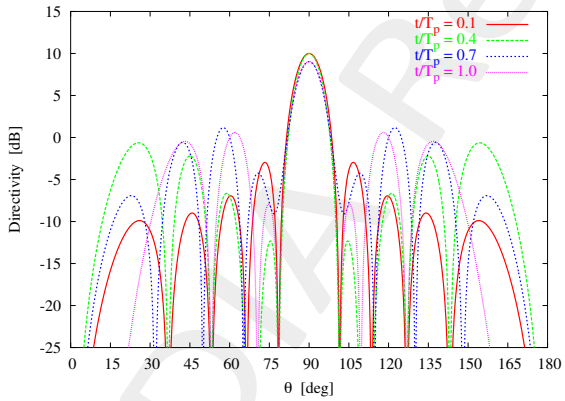

Fig.125 - Directivity

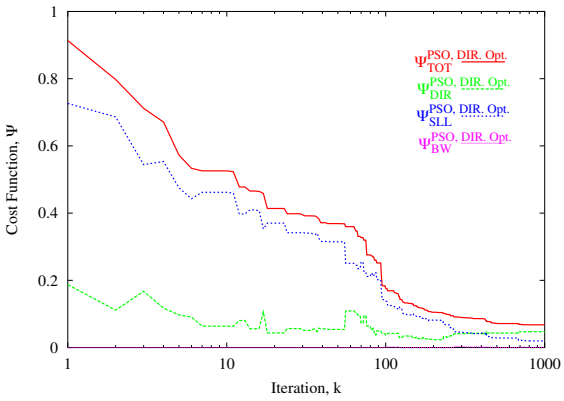

Fig.126 - Patterns

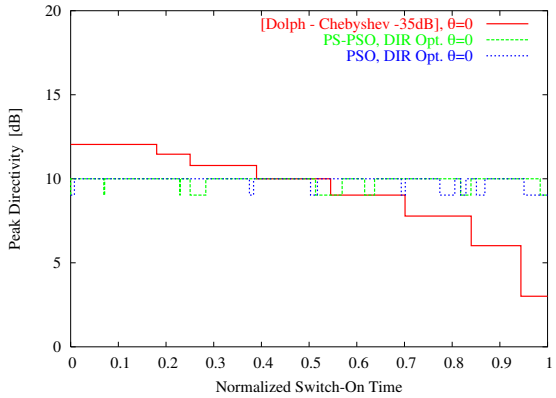

Fig.127 - Peak Directivity

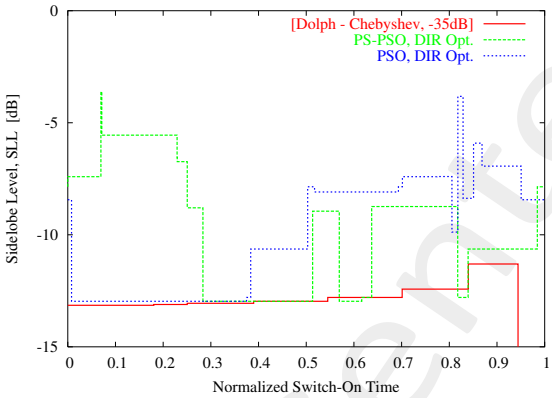

Fig.128 - Sidelobe Level

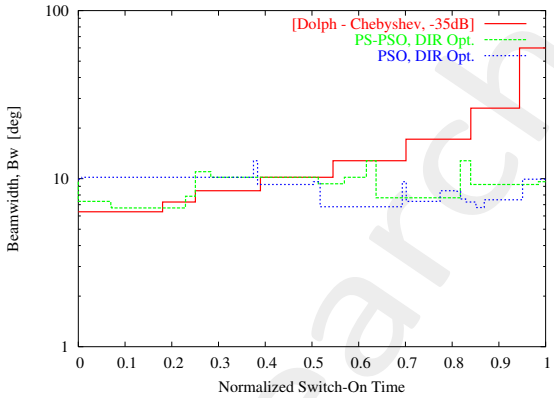

Fig.129 - Beamwidth

	$SLL_{av}\,[dB]$	$SBL\,[dB]$	$BW_{av}\,[°]$	$P_{SR}\,[\%]$
$Dolph,\ SLL = -35\,dB$	-34.92	-12.61	8.48	25.11
$PS-PSO,\ DIR\ Opt.$	-34.92	-15.76	8.48	25.11
$PSO,\ DIR\ Opt$	-34.85	-16.39	8.51	24.93

Tab.41 - Average Pattern Parameters: Sidelobe Level (SLL), Sideband Level (SBL), -3 dB Beamwidth (BW), Sideband Radiation (P_{SR})

	$av^*\{D_{max}(t)\}$	$av\{D_{max}(t)\}$	$\sigma^2\{D_{max}(t)\}$	$Min\{D_{max}(t)\}$	$Max\{D_{max}(t)\}$
Dolph, $SLL = -35\,dB$	9.31	8.77	8.17	3.01	12.04
$PS-PSO$, *DIR Opt.*	9.85	9.48	0.23	9.03	10
PSO, *DIR Opt*	9.86	9.48	0.23	9.03	10

Tab.42 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of Peak Directivity (D_{max}) in [dB]

	$av^*\{SLL(t)\}$	$av\{SLL(t)\}$	$\sigma^2\{SLL(t)]\}$	$Min\{SLL(t)\}$	$Max\{SLL(t)\}$
Dolph, $SLL = -35\,dB$	–	–	–	$-\infty$	–
$PS-PSO$, *DIR Opt.*	−9.71	−8.95	8.01	−12.96	−3.62
PSO, *DIR Op*	−10.01	−8.45	5.29	−12.97	−3.82

Tab.43 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of Sidelobe Level (SLL) in [dB]

	$av^*\{BW(t)\}$	$av\{BW(t)\}$	$\sigma^2\{BW(t)\}$	$Min\{BW(t)\}$	$Max\{BW(t)\}$
Dolph, $SLL = -35\,dB$	14.88	18.55	281.55	6.35	59.90
$PS-PSO$, *DIR Opt.*	8.87	9.22	3.63	6.69	12.78
PSO, *DIR Opt*	8.82	8.75	2.53	6.73	12.78

Tab.44 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of -3 dB Beamwidth (BW) in [deg]

TEST CASE 2.5 - Dolph-Chebyshev -40dB

Goal

Sintesi di un array con eccitazioni modulate nel dominio del tempo al fine di riprodurre un pattern di Dolph-Chebyshev alla frequenza centrale di lavoro e un pattern istantaneo con massima direttività costante.

Analogies and Differences wrt Previous Cases

A: Geometria dell'array, numero di elementi, algoritmo di ottimizzazione (PSO), funzione di costo implementata, configurazione statica dell'array.

D: Configurazione degli impulsi di eccitazione degli elementi (durate degli impulsi).

Test Case Description

- Number of Elements: $N = 16$
- Elements Spacing: $d = 0.5\lambda$
- Static Array Configuration: $\alpha_n = 1,\ n = 0, ..., N-1$
- Pattern at Central Frequency: $Dolph - Chebyshev\,,\ SLL = -40\,dB$
- Max Gain Pattern Direction : $\theta^{max} = 90°$

Optimization Approach: PS-PSO, Directivity Opt.

- Number of Variables: $X = 8$
- Number of Particles: $S = 20$
- Number of Iterations: $I = 100$
- Inertial Weight: Linearly varying: $0.9\,to\,0.4$
- Swarm Initialization: *Random*

Optimization Approach: PSO, Directivity Opt.

- Number of Variables: $X = 16$
- Number of Particles: $S = 30$
- Number of Iterations: $I = 1000$
- Inertial Weight: Linearly varying: $0.9\,to\,0.4$
- Swarm Initialization: *Random*

Dolph-Chebyshev Pattern, SLL=-40 dB

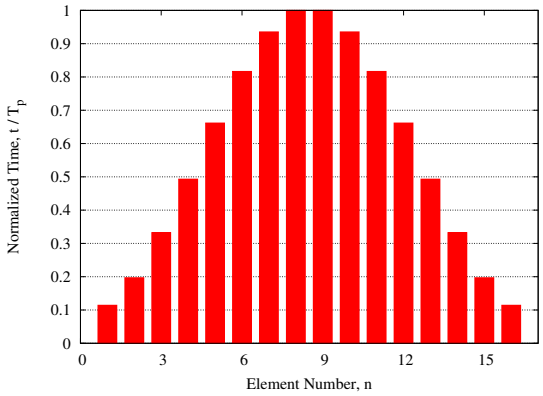

Fig.130 - Pulse Sequence

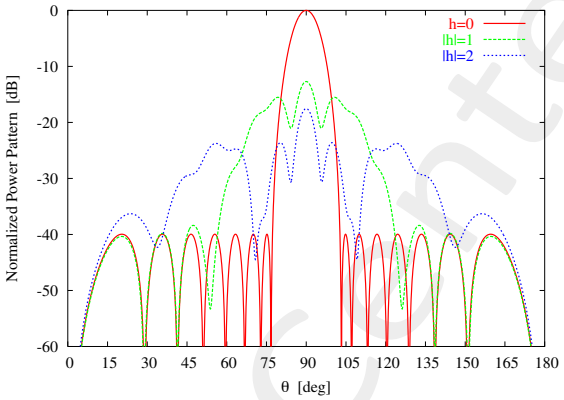

Fig.131 - Patterns

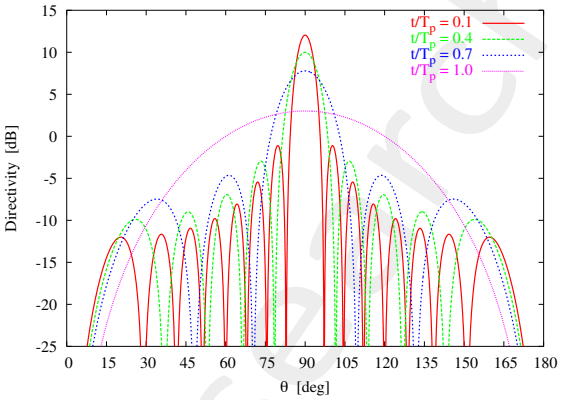

Fig.132 - Directivity

PS-PSO, Directivity Opt. - Dolph-Chebyshev Pattern, SLL=-40 dB

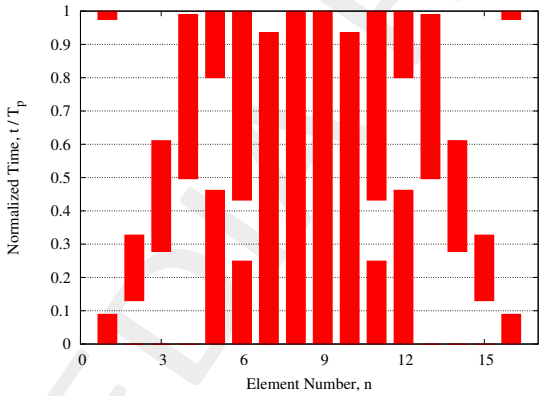

Fig.133 - Pulse Sequence

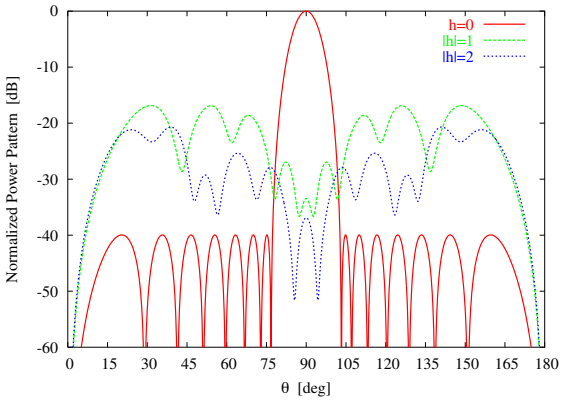

Fig.134 - Patterns

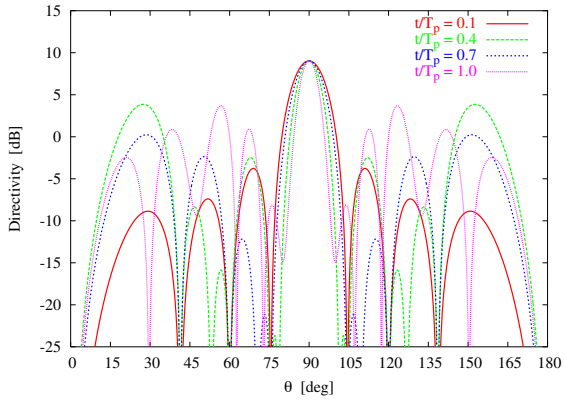

Fig.135 - Directivity

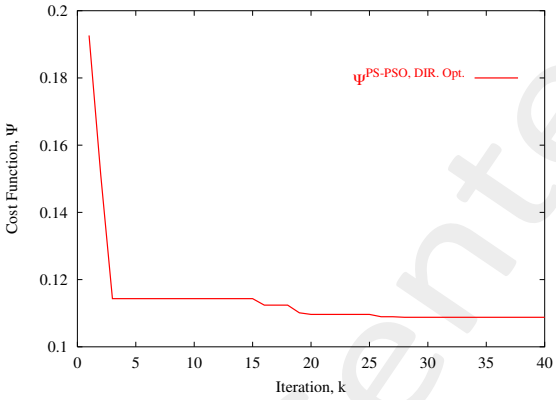

Fig.136 - Patterns

PSO, Directivity Opt. - SLL=-40 dB BW= 9.0

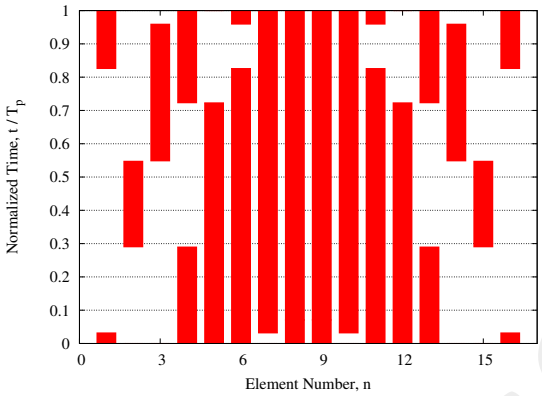

Fig.137 - Pulse Sequence

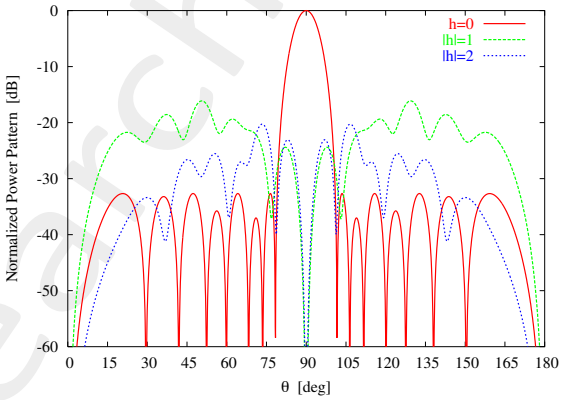

Fig.138 - Patterns

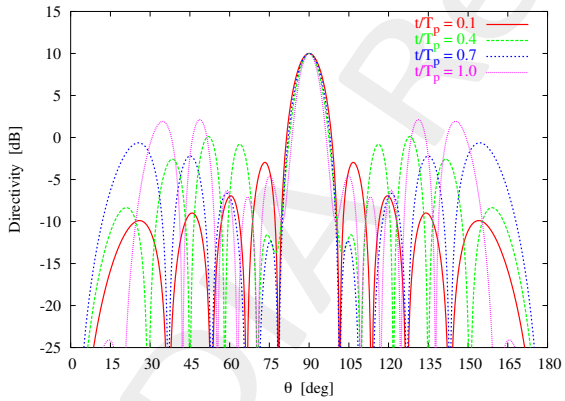

Fig.139 - Directivity

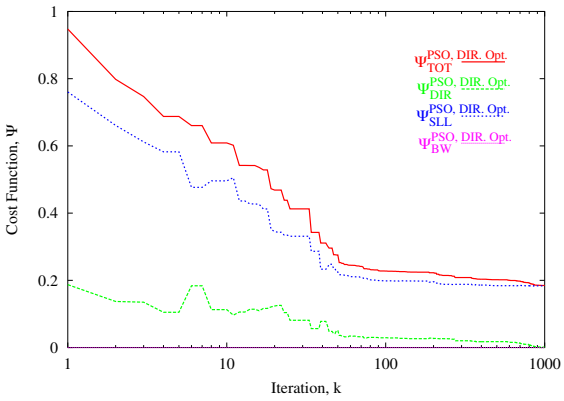

Fig.140 - Fitness

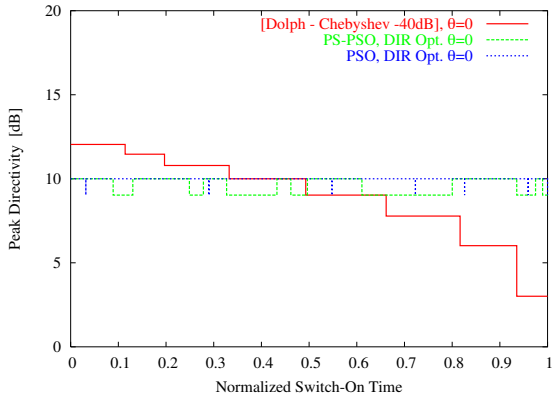

Fig.141 - Peak Directivity

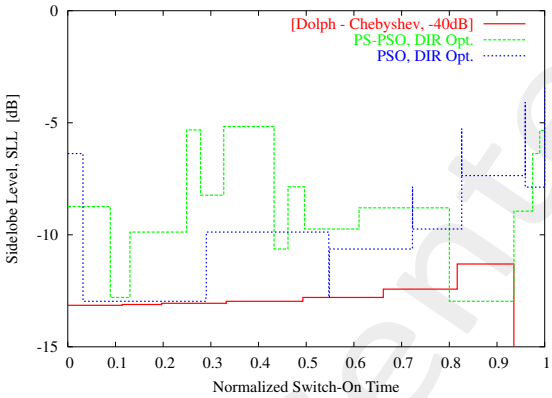

Fig.142 - Sidelobe Level

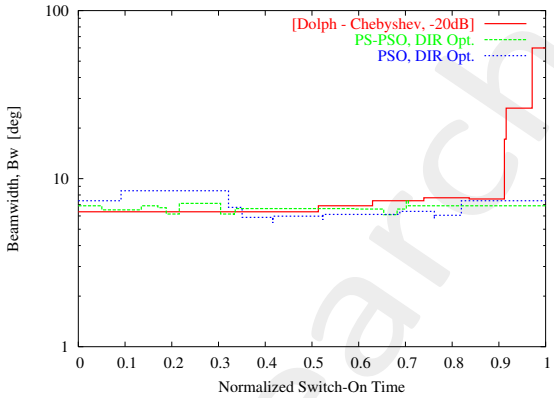

Fig.143 - Beamwidth

	$SLL_{av}\,[dB]$	$SBL\,[dB]$	$BW_{av}\,[°]$	$P_{SR}\,[\%]$
$Dolph,\ SLL = -40\,dB$	-39.96	-12.70	8.97	25.61
$PS-PSO,\ DIR\ Opt.$	-39.96	-16.86	8.97	25.61
$PSO,\ DIR\ Opt$	-32.66	-16.12	8.39	23.78

Tab.45 - Average Pattern Parameters: Sidelobe Level (SLL), Sideband Level (SBL), -3 dB Beamwidth (BW), Sideband Radiation (P_{SR})

	$av^*\{D_{max}(t)\}$	$av\{D_{max}(t)\}$	$\sigma^2\{D_{max}(t)\}$	$Min\{D_{max}(t)\}$	$Max\{D_{max}(t)\}$
Dolph, $SLL = -40\,dB$	9.03	8.77	8.17	3.01	12.04
$PS-PSO$, *DIR Opt.*	9.56	9.51	0.23	9.03	10
PSO, *DIR Opt*	10.00	9.52	0.23	9.03	10

Tab.46 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of Peak Directivity (D_{max}) in [dB]

	$av^*\{SLL(t)\}$	$av\{SLL(t)\}$	$\sigma^2\{SLL(t)]\}$	$Min\{SLL(t)\}$	$Max\{SLL(t)\}$
Dolph, $SLL = -40\,dB$	–	–	–	$-\infty$	–
$PS-PSO$, *DIR Opt.*	−9.20	−8.63	5.91	−12.97	−5.17
PSO, *DIR Opt*	−10.27	−8.56	9.16	−12.97	−3.34

Tab.47 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of Sidelobe Level (SLL) in [dB]

	$av^*\{BW(t)\}$	$av\{BW(t)\}$	$\sigma^2\{BW(t)\}$	$Min\{BW(t)\}$	$Max\{BW(t)\}$
Dolph, $SLL = -40\,dB$	15.92	18.55	281.55	6.35	59.90
$PS-PSO$, *DIR Opt.*	9.29	8.87	2.64	6.76	12.78
PSO, *DIR Opt*	8.65	8.74	4.16	6.28	12.78

Tab.48 - Istant Pattern Parameters: Weighted Average (av^*), Average (av), Variance (σ^2), Minimum (Min) and Maximum (Max) of -3 dB Beamwidth (BW) in [deg]

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