Synthesis of Compromise Monopulse Time-Modulated Planar Arrays through Pulse Matching-based Strategies

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Abstract

In this report, a comparison between two pulse matching-based strategies for the synthesis of monopulse time-modulated planar arrays is proposed. The mixed architecture composed by a static independent BFN for the sum beam and a sub-arrayed TMA for the difference one is used for both the approaches. In the first approach, the sub-array configuration is determined by only minimising both the mismatch between the optimal/desired difference pattern and the actual one, whereas in the second approach the joint minimization of the SR power has been additionally carried out. A set of representative numerical results is reported to illustrate the effectiveness and the numerical efficiency of the proposed approaches.

TEST CASE 1 - Taylor -20dB switched to Bayliss -20dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -20dB$, $\overline{n} = 2$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -20\,dB$, $\overline{n} = 4$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 1$

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Taylor SLL=-20dB switched to Bayliss SLL=-20 dB

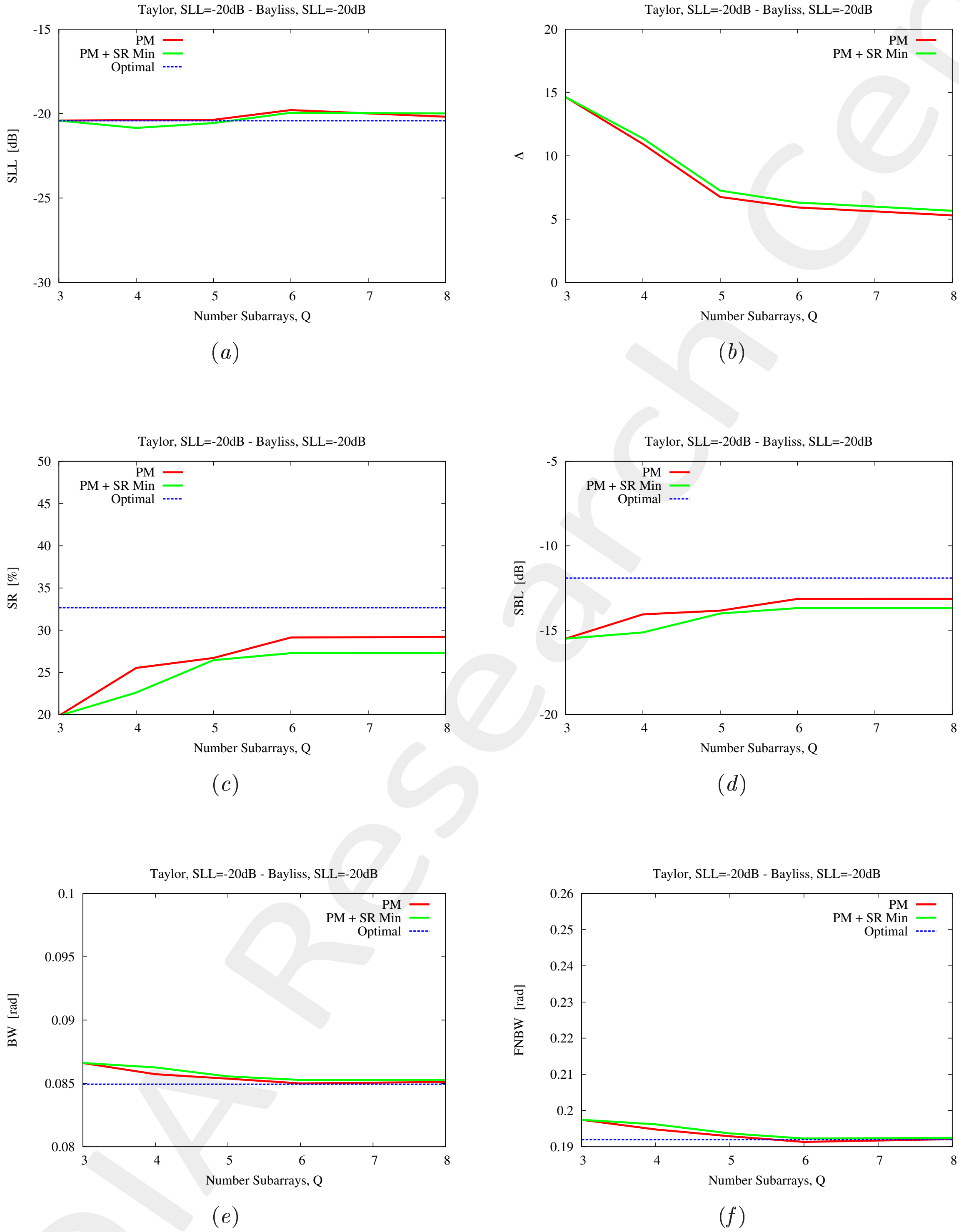

Fig.1 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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TEST CASE 2 - Taylor -20dB switched to Bayliss -25dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n;\, n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -20dB$, $\overline{n} = 2$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n;\, n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -25\,dB$, $\overline{n} = 5$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\, 4,\, 5,\, 6,\, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\, 4,\, 5,\, 6,\, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 1$

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Taylor SLL=-20dB switched to Bayliss SLL=-25 dB

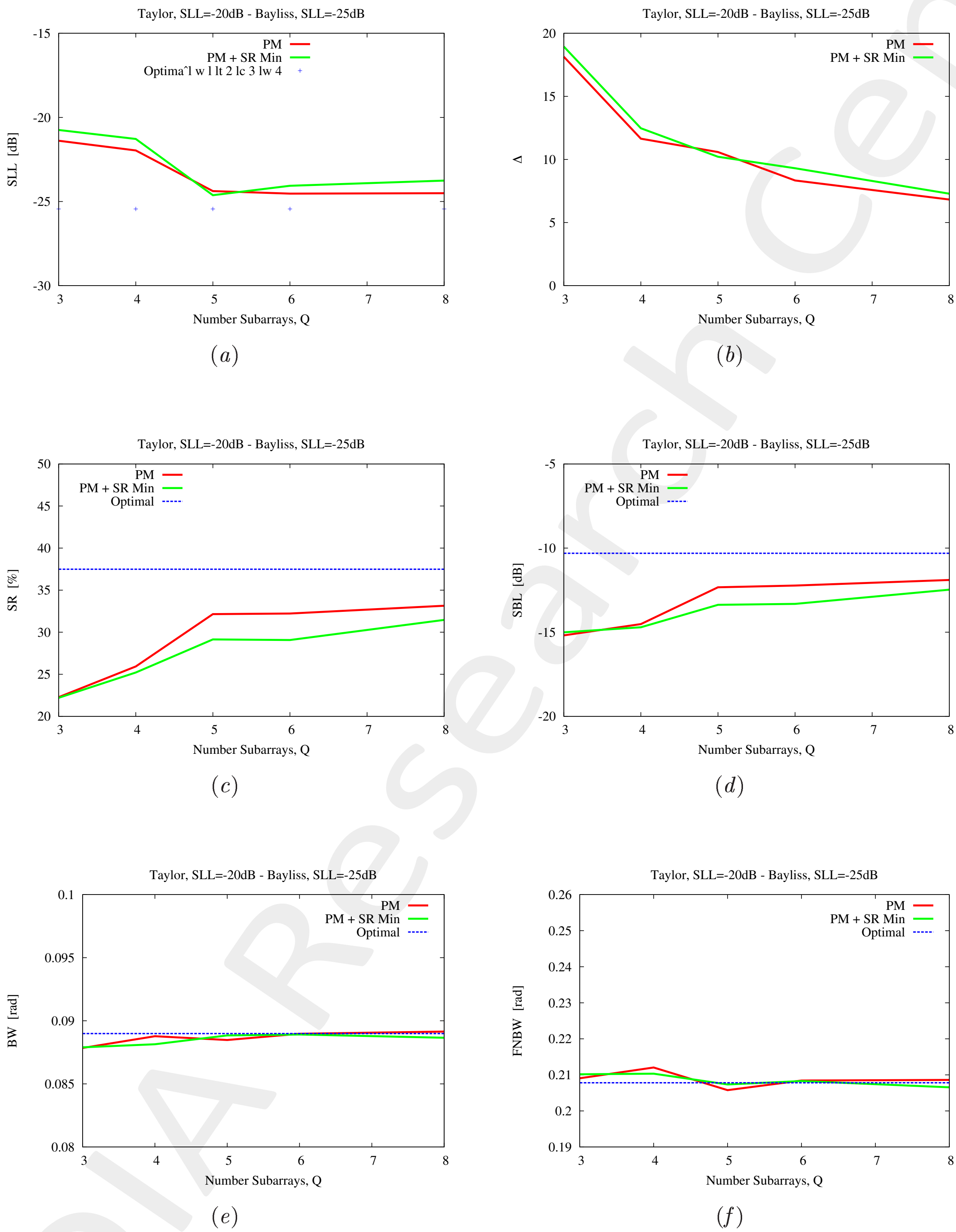

Fig.2 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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TEST CASE 3 - Taylor -20dB switched to Bayliss -30dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -20dB$, $\overline{n} = 2$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -30\,dB$, $\overline{n} = 7$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\ 4,\ 5,\ 6,\ 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\ 4,\ 5,\ 6,\ 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 1$

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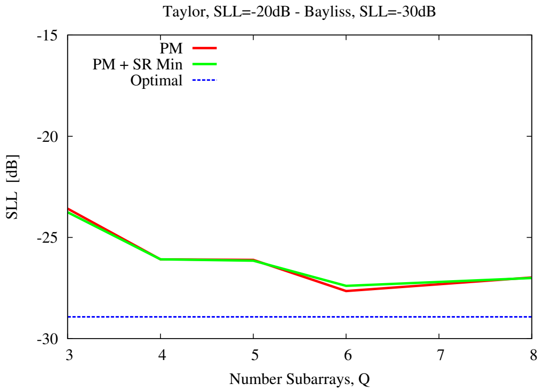
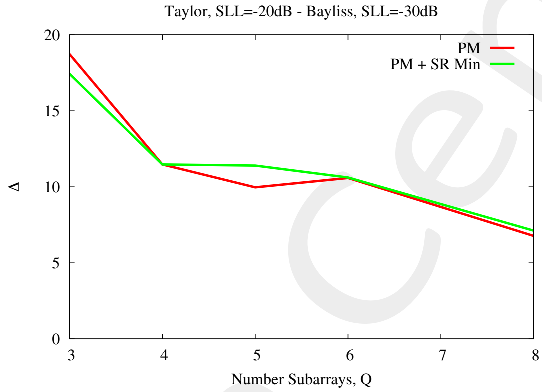
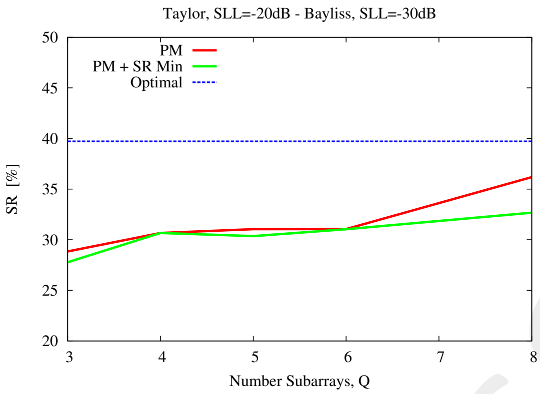
Taylor SLL=-20dB switched to Bayliss SLL=-30 dB



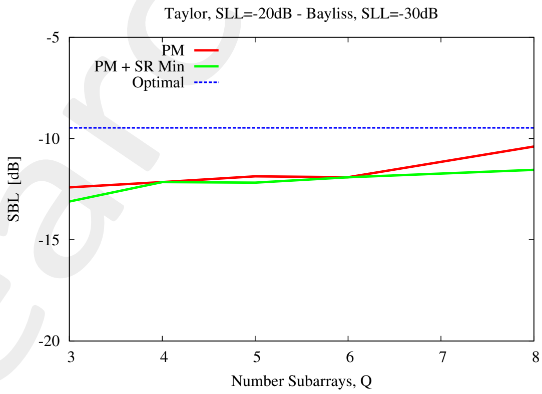
(*a*)



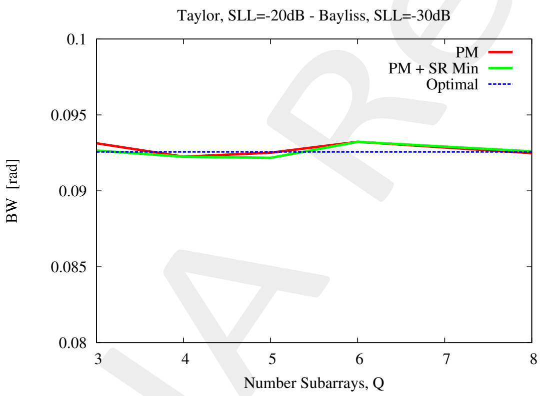
(*b*)



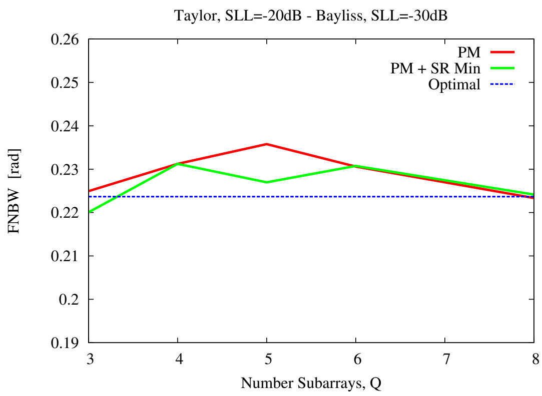
(*c*)



(*d*)



(*e*)



(*f*)

Fig.3 - Comparison of approaches [1.a] and [1.b]: (*a*) Sidelobe Level (SLL), (*b*) Pattern Matching Error (Δ), (*c*) Sideband Radiation (P_{SR}), (*d*) Sideband Level (SBL), (*e*) -3dB Beamwidth (BW) and (*f*) First Null Beamwidth ($FNBW$).

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TEST CASE 4 - Taylor -25dB switched to Bayliss -20dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -25dB$, $\overline{n} = 3$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -20\,dB$, $\overline{n} = 4$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 1$

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Taylor SLL=-25dB switched to Bayliss SLL=-20 dB

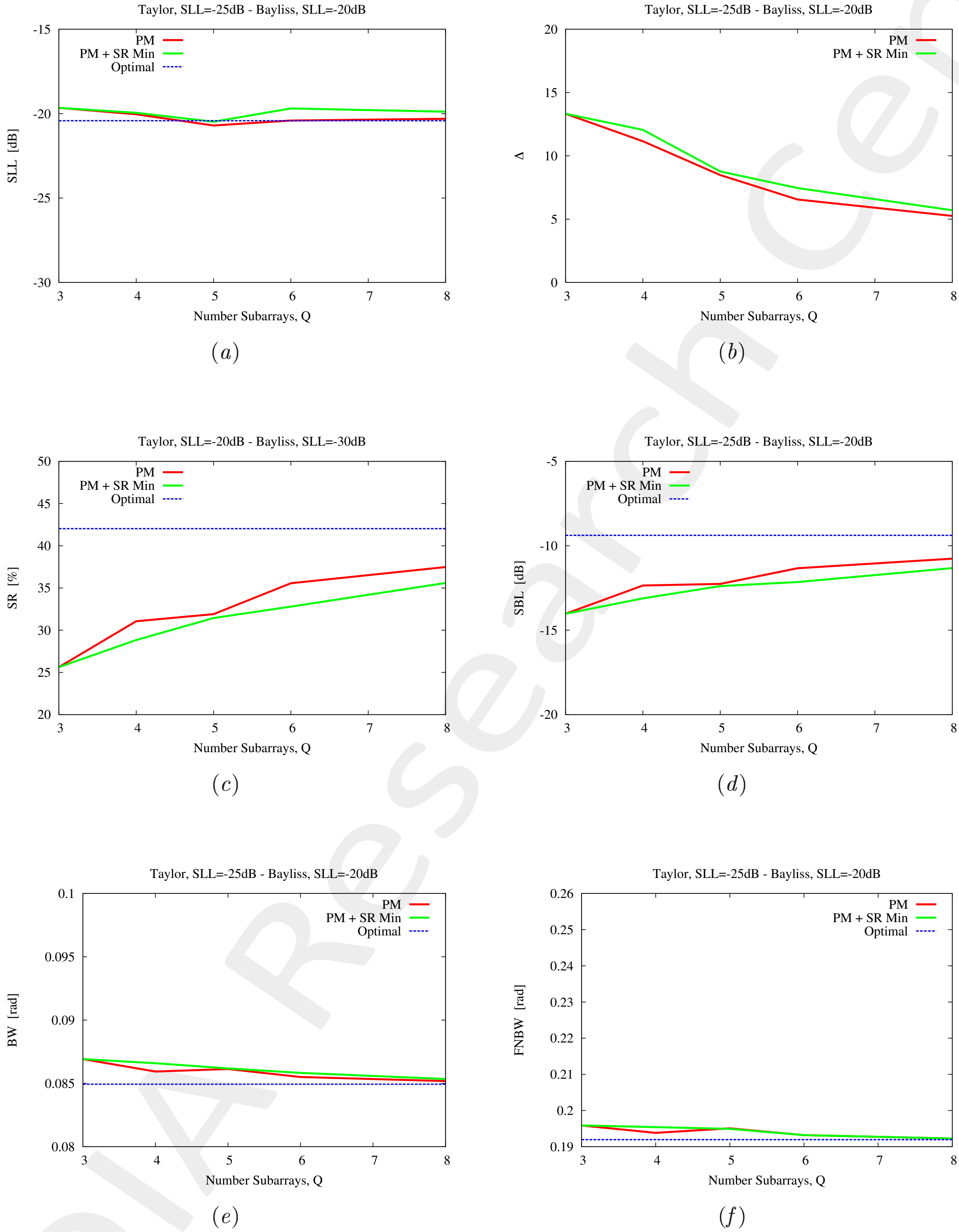

Fig.4 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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TEST CASE 5 - Taylor -25dB switched to Bayliss -25dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -25dB$, $\overline{n} = 3$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -25\,dB$, $\overline{n} = 5$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 1$

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Taylor SLL=-25dB switched to Bayliss SLL=-25 dB

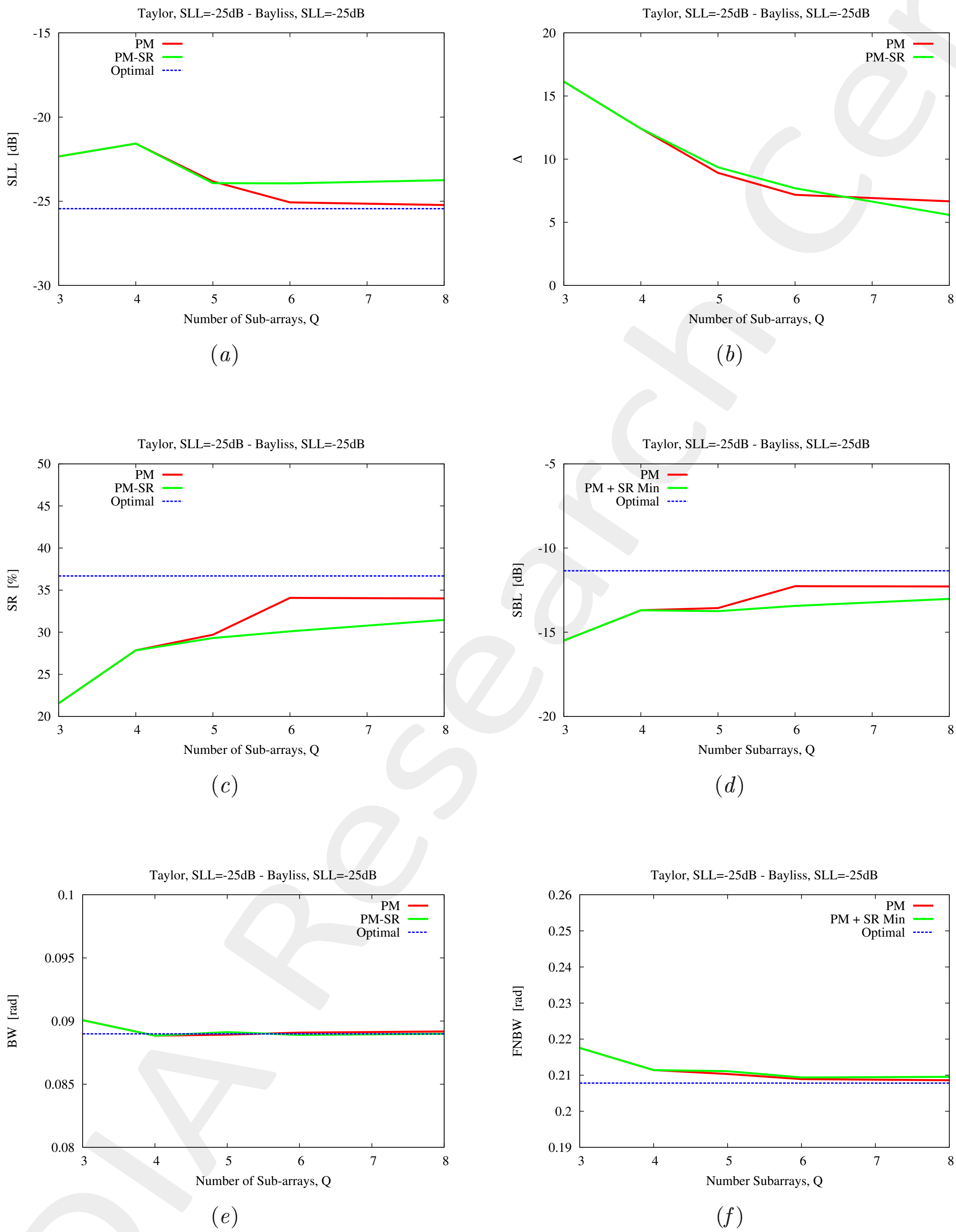

Fig.5 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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TEST CASE 6 - Taylor -25dB switched to Bayliss -30dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -25dB$, $\overline{n} = 3$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -30\,dB$, $\overline{n} = 7$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 1$

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Taylor SLL=-25dB switched to Bayliss SLL=-30 dB

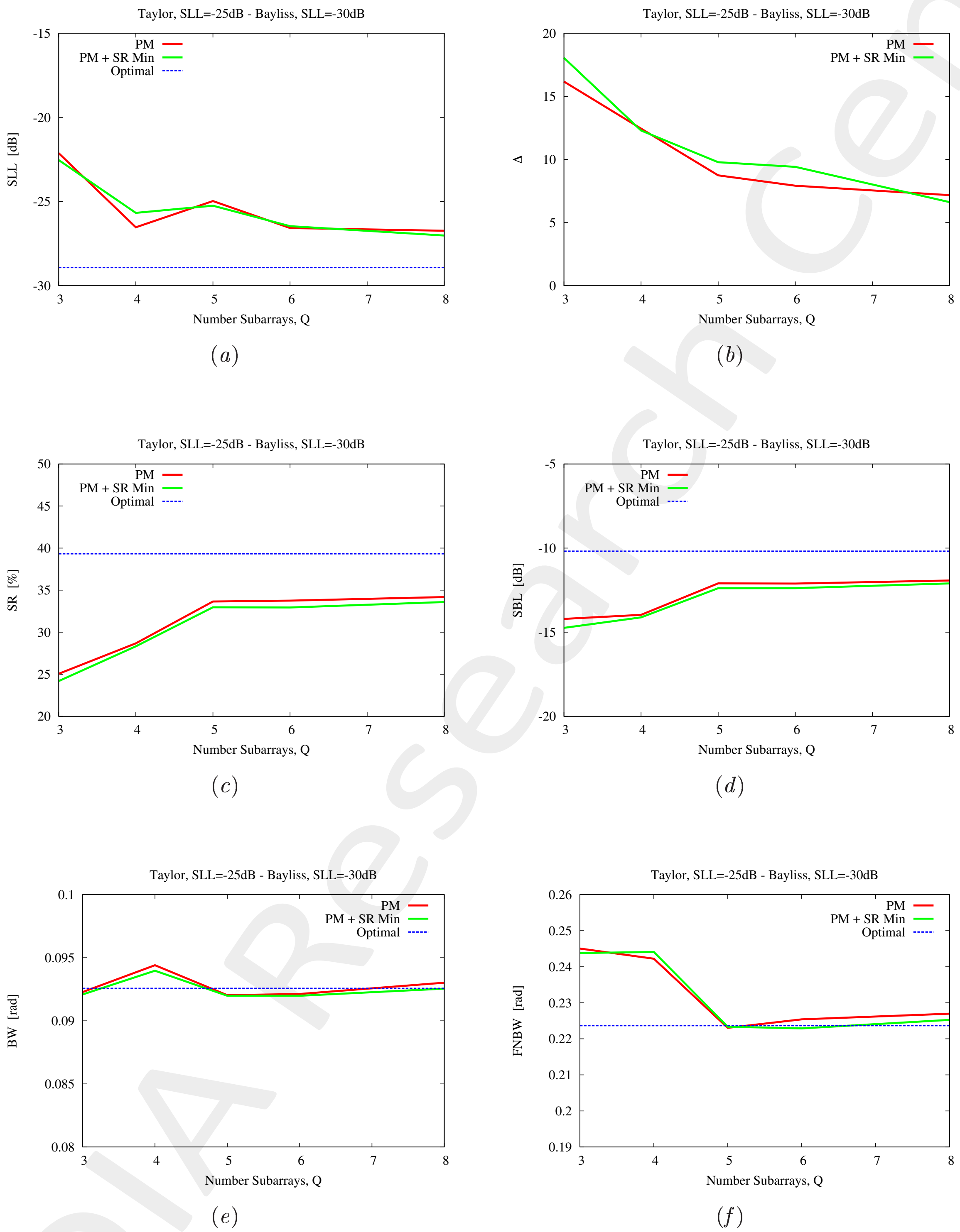

Fig.6 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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TEST CASE 7 - Taylor -30dB switched to Bayliss -20dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -30dB$, $\overline{n} = 5$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -20\,dB$, $\overline{n} = 4$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 1$

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Taylor SLL=-30dB switched to Bayliss SLL=-20 dB

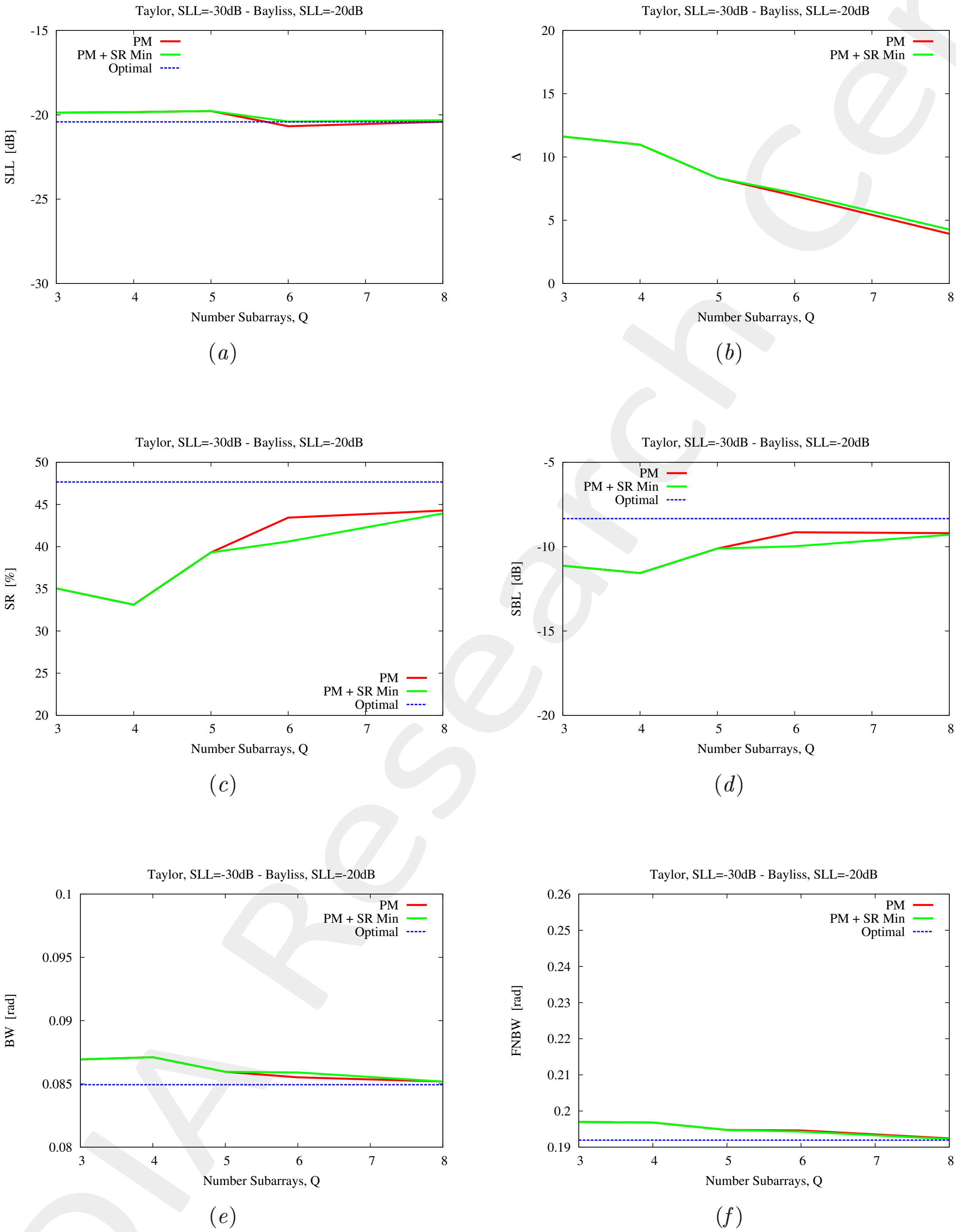

Fig.7 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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TEST CASE 8 - Taylor -30dB switched to Bayliss -25dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -30dB$, $\overline{n} = 5$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -25\,dB$, $\overline{n} = 5$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\ 4,\ 5,\ 6,\ 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\ 4,\ 5,\ 6,\ 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 1$

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Taylor SLL=-30dB switched to Bayliss SLL=-25 dB

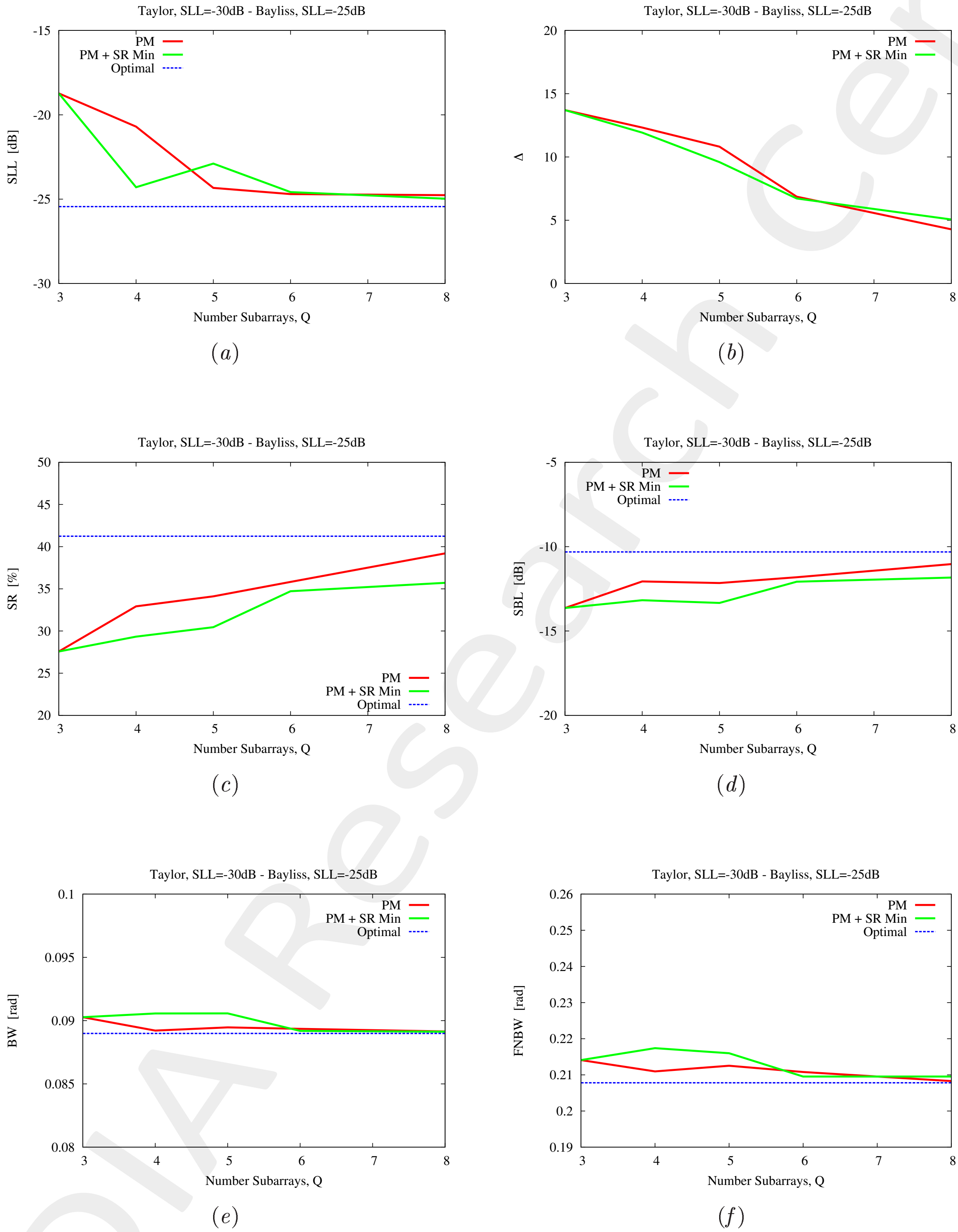

Fig.8 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth ($FNBW$).

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TEST CASE 9 - Taylor -30dB switched to Bayliss -30dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n;\, n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -30dB$, $\overline{n} = 5$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n;\, n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -30\,dB$, $\overline{n} = 7$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 1$

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Taylor SLL=-30dB switched to Bayliss SLL=-30 dB

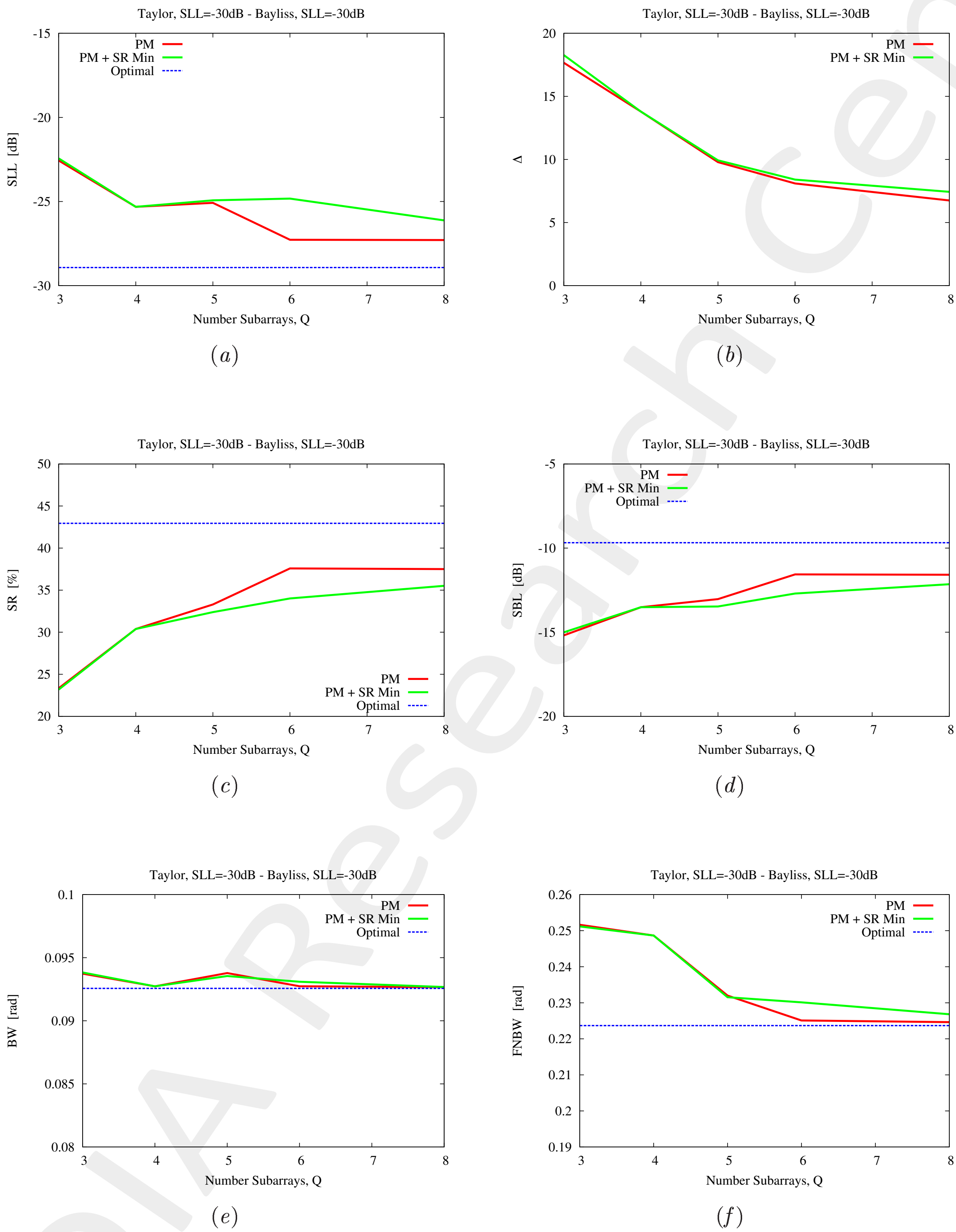

Fig.9 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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Part I

Numerical Validation - Different Weights

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TEST CASE 10 - Taylor -20dB - Bayliss -20dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -20dB$, $\overline{n} = 2$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -20\,dB$, $\overline{n} = 4$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = Q$

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Taylor SLL=-20dB switched to Bayliss SLL=-20 dB

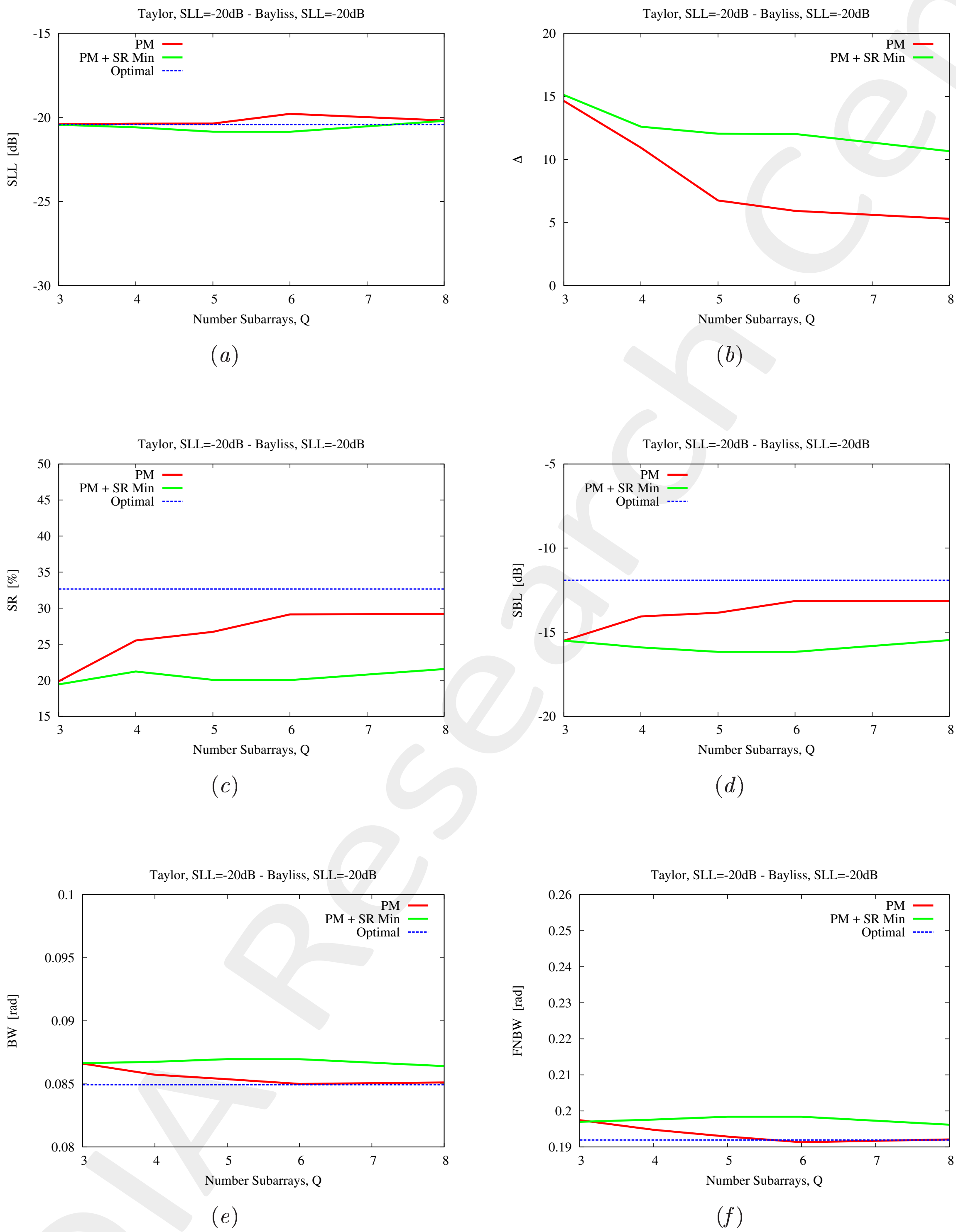

Fig.10 - Comparison of approaches [1.a] and [1.b]: (*a*) Sidelobe Level (SLL), (*b*) Pattern Matching Error (Δ), (*c*) Sideband Radiation (P_{SR}), (*d*) Sideband Level (SBL), (*e*) -3dB Beamwidth (BW) and (*f*) First Null Beamwidth ($FNBW$).

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TEST CASE 11 - Taylor -20dB switched to Bayliss -25dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n;\, n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -20dB$, $\overline{n} = 2$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n;\, n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -25\,dB$, $\overline{n} = 5$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = Q$

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Taylor SLL=-20dB switched to Bayliss SLL=-25 dB

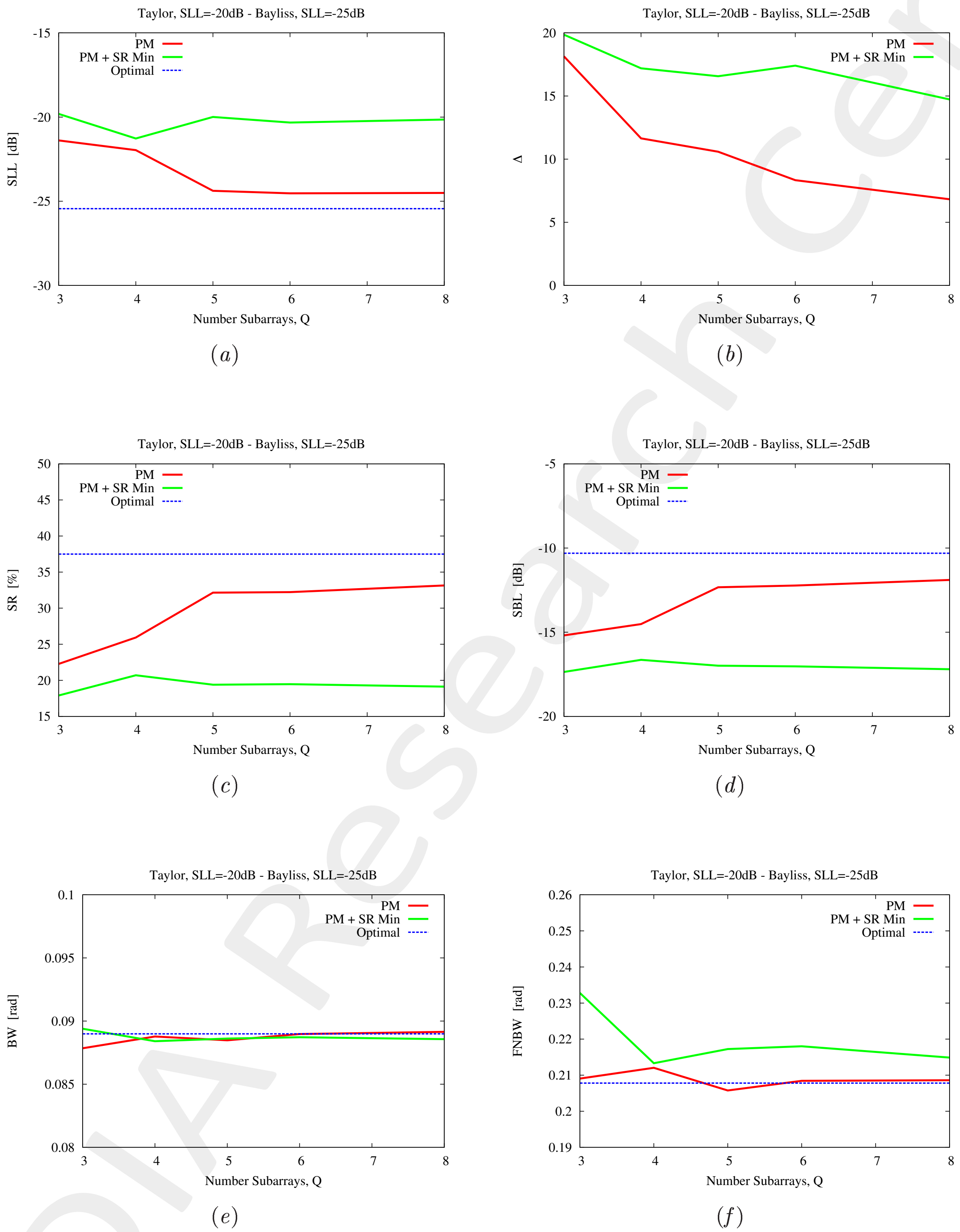

Fig.11 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth ($FNBW$).

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TEST CASE 12 - Taylor -20dB switched to Bayliss -30dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -20dB$, $\overline{n} = 2$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -30\,dB$, $\overline{n} = 7$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = Q$

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Taylor SLL=-20dB switched to Bayliss SLL=-30 dB

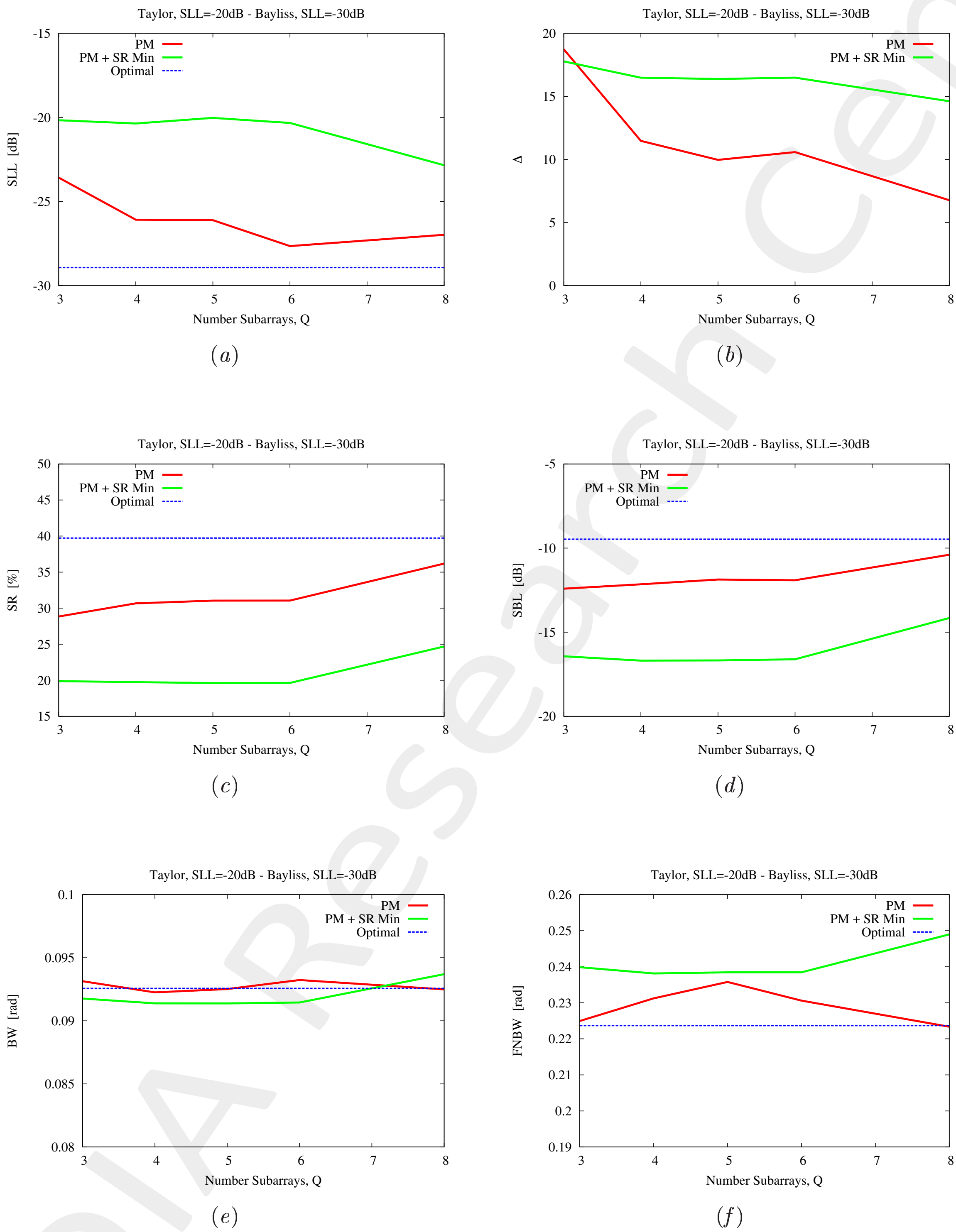

Fig.12 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth ($FNBW$).

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TEST CASE 13 - Taylor -25dB switched to Bayliss -20dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -25dB$, $\overline{n} = 3$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -20\,dB$, $\overline{n} = 4$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\ 4,\ 5,\ 6,\ 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\ 4,\ 5,\ 6,\ 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = Q$

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Taylor SLL=-25dB switched to Bayliss SLL=-20 dB

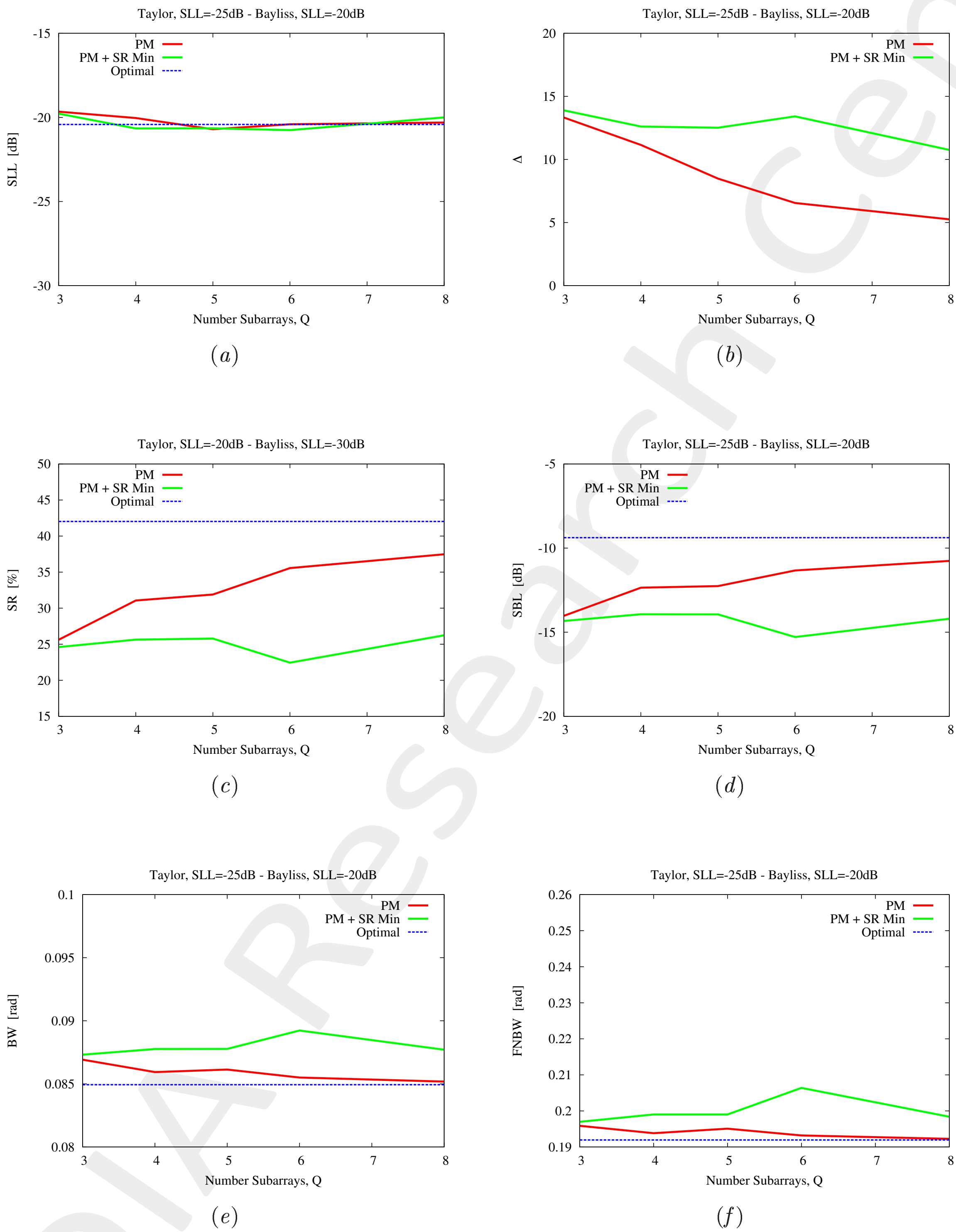

Fig.13 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth ($FNBW$).

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TEST CASE 14 - Taylor -25dB switched to Bayliss -25dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -25dB$, $\overline{n} = 3$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -25\,dB$, $\overline{n} = 5$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\ 4,\ 5,\ 6,\ 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\ 4,\ 5,\ 6,\ 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = Q$

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Taylor SLL=-25dB switched to Bayliss SLL=-25 dB

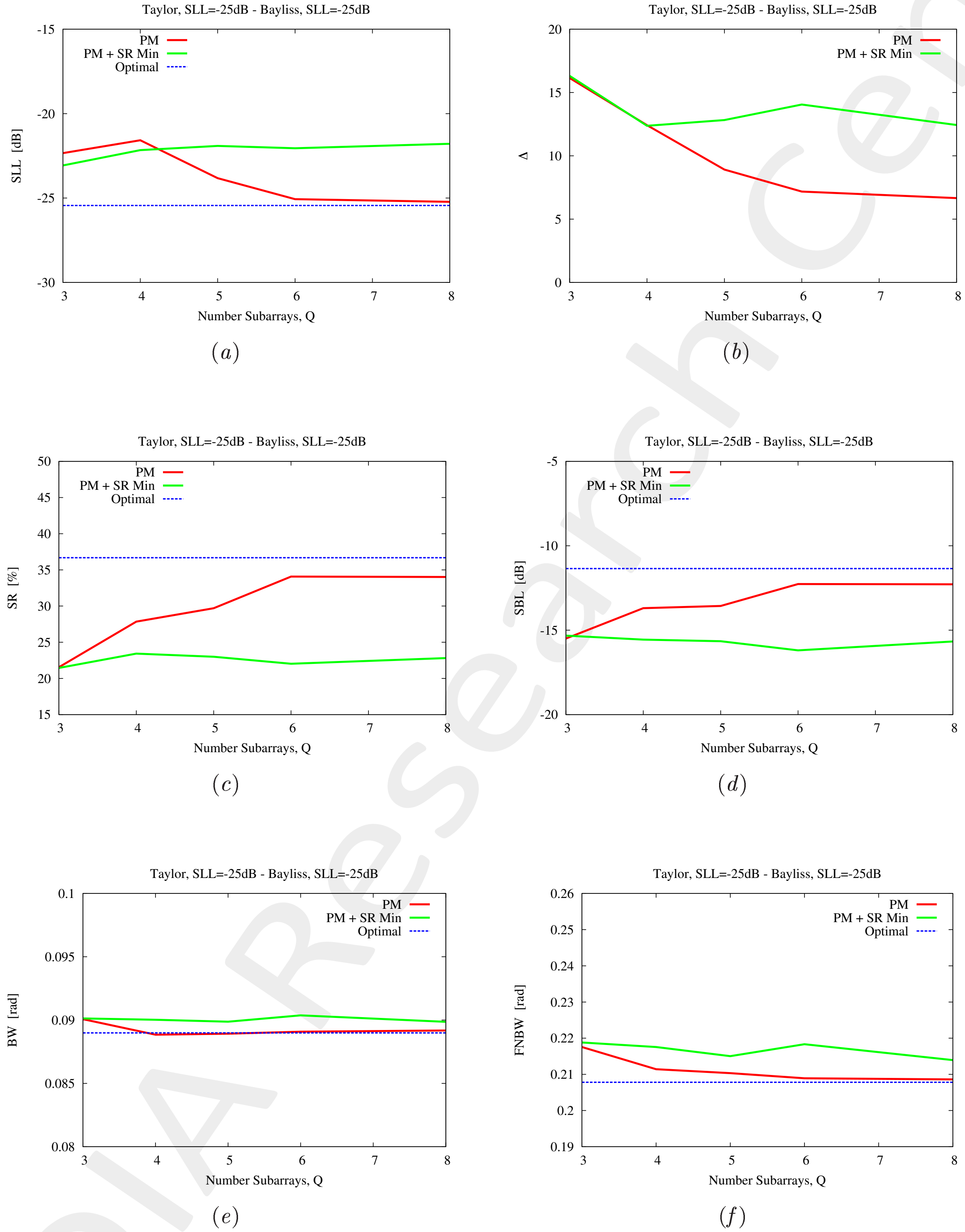

Fig.14 - Comparison of approaches [1.a] and [1.b]: (*a*) Sidelobe Level (SLL), (*b*) Pattern Matching Error (Δ), (*c*) Sideband Radiation (P_{SR}), (*d*) Sideband Level (SBL), (*e*) -3dB Beamwidth (BW) and (*f*) First Null Beamwidth ($FNBW$).

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TEST CASE 15 - Taylor -25dB switched to Bayliss -30dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -25dB$, $\overline{n} = 3$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -30\,dB$, $\overline{n} = 7$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = Q$

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Taylor SLL=-25dB switched to Bayliss SLL=-30 dB

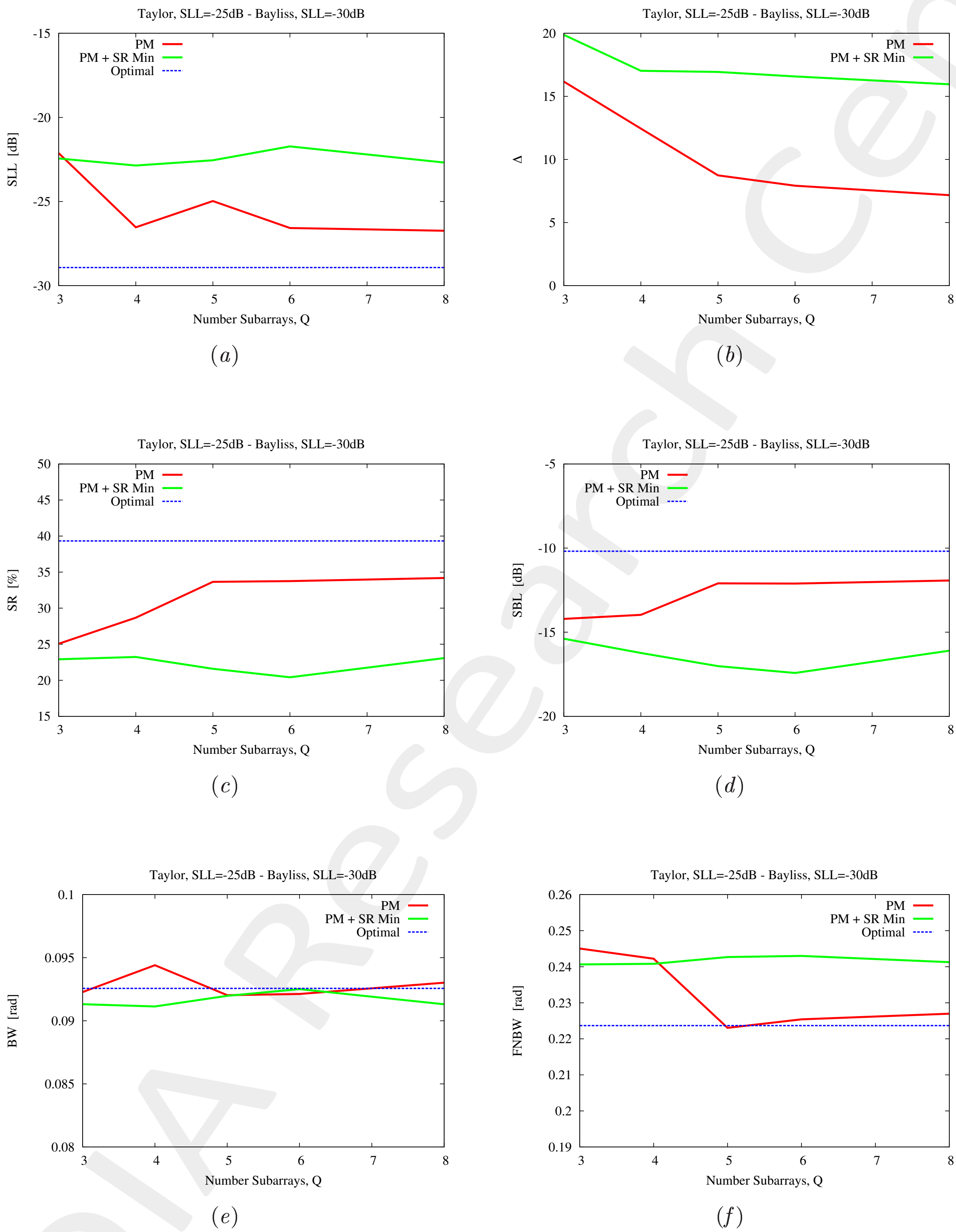

Fig.15 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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TEST CASE 16 - Taylor -30dB switched to Bayliss -20dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -30dB$, $\overline{n} = 5$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -20\,dB$, $\overline{n} = 4$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\ 4,\ 5,\ 6,\ 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\ 4,\ 5,\ 6,\ 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = Q$

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Taylor SLL=-30dB switched to Bayliss SLL=-20dB

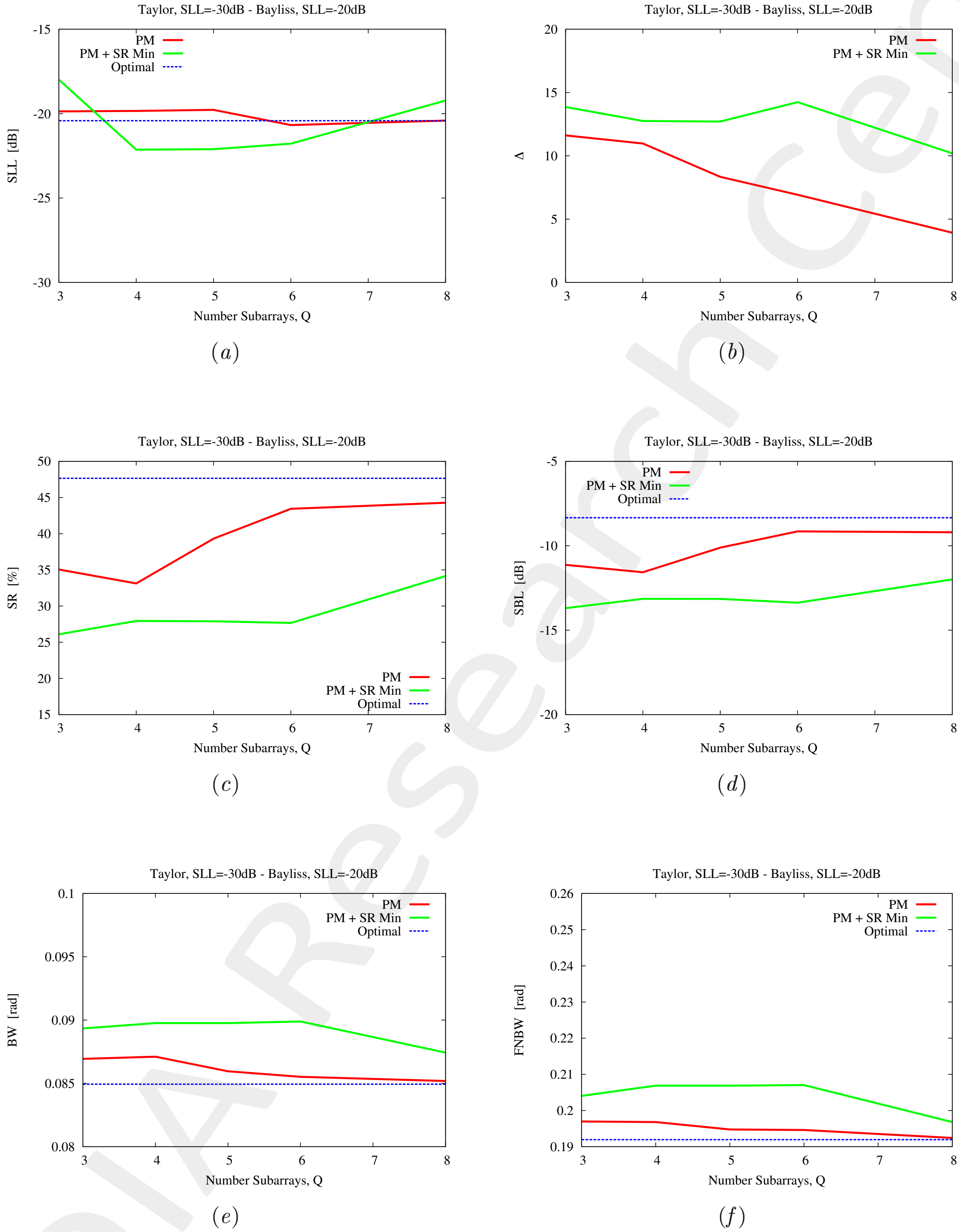

Fig.16 - Comparison of approaches [1.a] and [1.b]: (*a*) Sidelobe Level (SLL), (*b*) Pattern Matching Error (Δ), (*c*) Sideband Radiation (P_{SR}), (*d*) Sideband Level (SBL), (*e*) -3dB Beamwidth (BW) and (*f*) First Null Beamwidth ($FNBW$).

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TEST CASE 17 - Taylor -30dB switched to Bayliss -25dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n;\, n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -30dB$, $\overline{n} = 5$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n;\, n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -25\, dB$, $\overline{n} = 5$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\, 4,\, 5,\, 6,\, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3,\, 4,\, 5,\, 6,\, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = Q$

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Taylor SLL=-30dB switched to Bayliss SLL=-25 dB

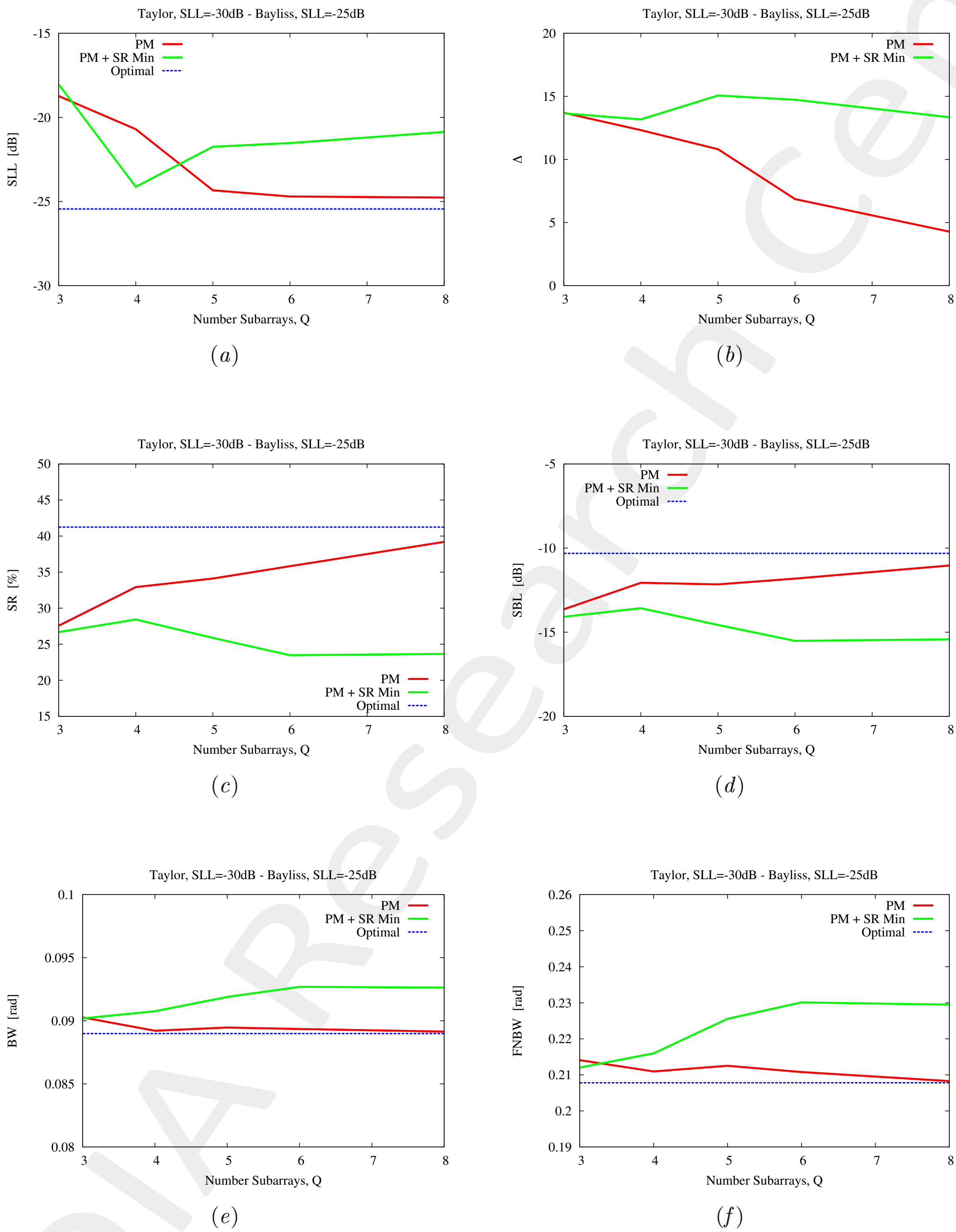

Fig.17 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth ($FNBW$).

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TEST CASE 18 - Taylor -30dB switched to Bayliss -30dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -30dB$, $\overline{n} = 5$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -30\,dB$, $\overline{n} = 7$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = Q$

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Taylor SLL=-30dB switched to Bayliss SLL=-30 dB

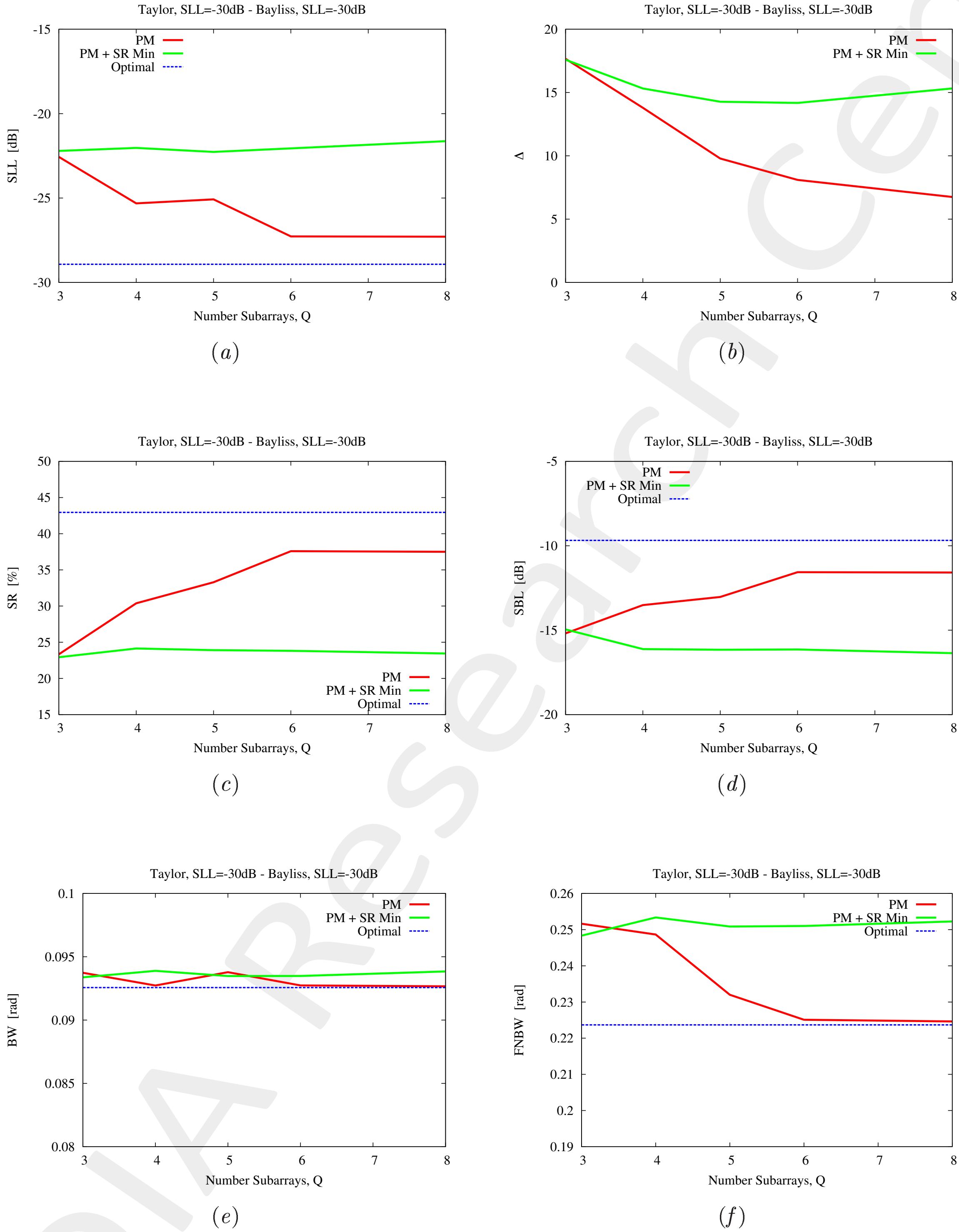

Fig.18 - Comparison of approaches [1.a] and [1.b]: (*a*) Sidelobe Level (SLL), (*b*) Pattern Matching Error (Δ), (*c*) Sideband Radiation (P_{SR}), (*d*) Sideband Level (SBL), (*e*) -3dB Beamwidth (BW) and (*f*) First Null Beamwidth ($FNBW$).

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Part II

Numerical Validation - Analysis Varying SR-Weight

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TEST CASE 19 - Taylor -25dB switched to Bayliss -25dB

Goal

Design of a sub-arrayed monopulse planar antenna array using time-modulation technique to synthesize a compromise difference pattern at the central frequency minimizing the power losses in sideband radiation.

Test Case Description

- Number of Elements along the x-axis: $N_x = 20$
- Number of Elements along the y-axis: $N_y = 20$
- Total Number of Elements: $N_{tot} = 400$
- Elements Spacing along the x-axis: $d_x = 0.5\lambda$
- Elements Spacing along the y-axis: $d_y = 0.5\lambda$
- Static Array Configuration: $\underline{A} = \{\alpha_n; n = 1, ..., N_{tot}\}$ - $Taylor$, $SLL = -25dB$, $\overline{n} = 3$
- Reference Difference Time-Modulated Pattern at Central Frequency: $\underline{B} = \{\beta_n; n = 1, ..., N_{tot}\}$ - $Bayliss$, $SLL = -25\,dB$, $\overline{n} = 5$
- Array Aperture Radius: $r = 5\lambda$
- Total Active Elements: $N_{tot} = 316$

[1.a] Approach: Pulse Matching

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 0$

[1.b] Approach: Pulse Matching & SR Minimization

- Number of Iterations: $I = 20$
- Number of Subarrays: $Q = 3, 4, 5, 6, 8$
- Pulse Matching Weight: $w_{PM}^{CPM} = 1$
- SR Minimization Weight: $w_{SR}^{CPM} = 2, 3, 4, 5$

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Taylor SLL=-25dB switched to Bayliss SLL=-25 dB, $w_{SR} = 2$

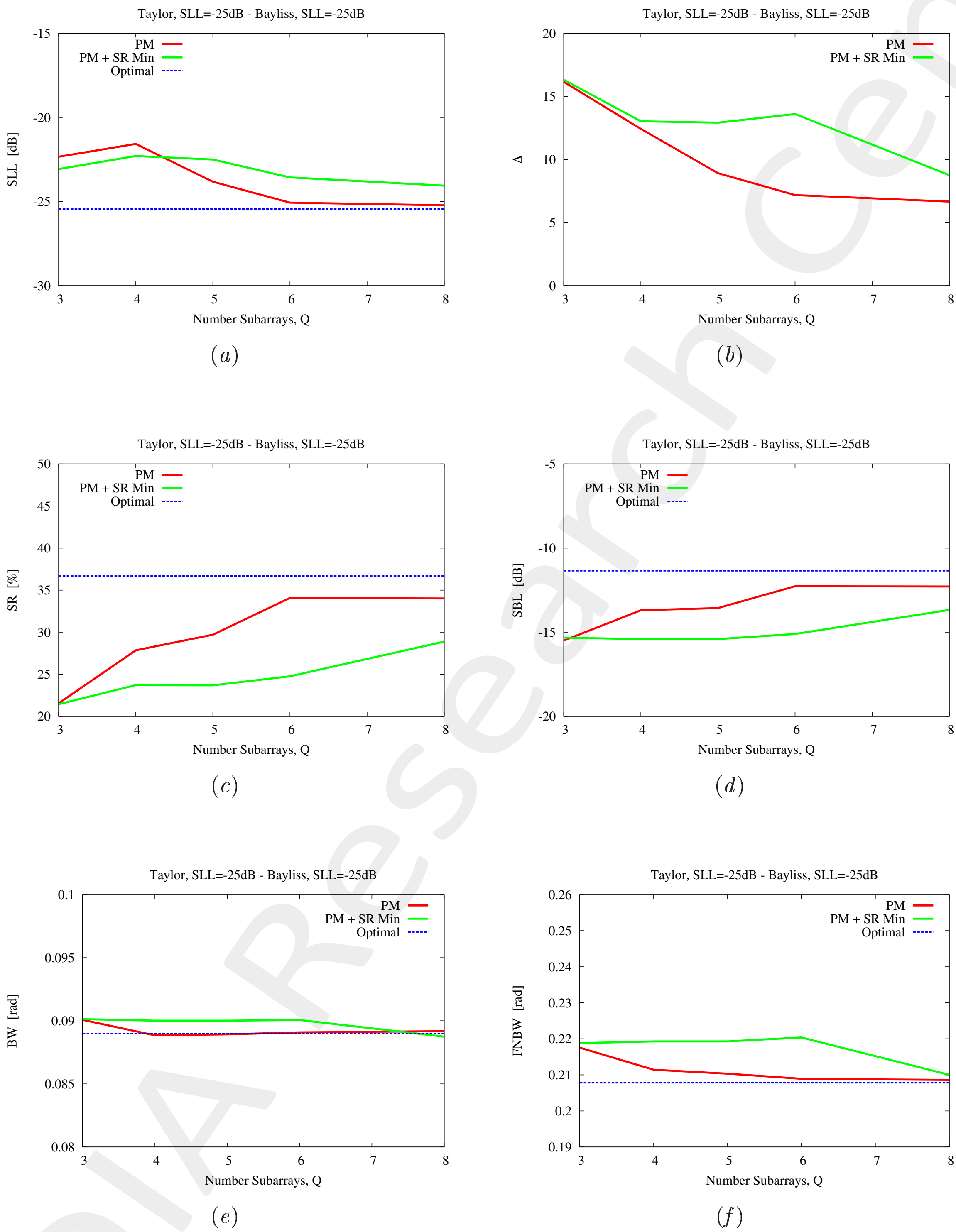

Fig.19 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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Taylor SLL=-25dB switched to Bayliss SLL=-25 dB, $w_{SR} = 3$

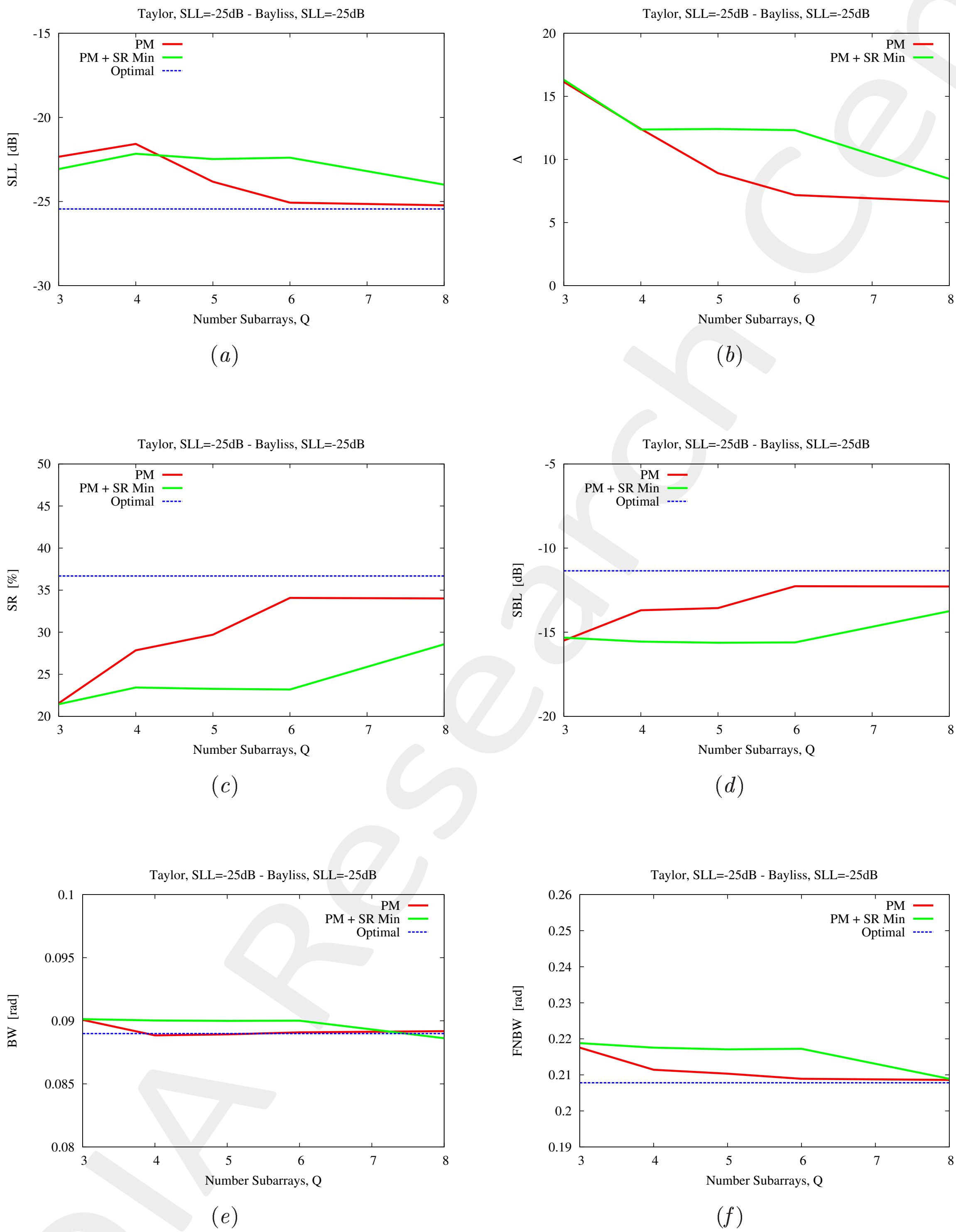

Fig.20- Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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Taylor SLL=-25dB switched to Bayliss SLL=-25 dB, $w_{SR} = 4$

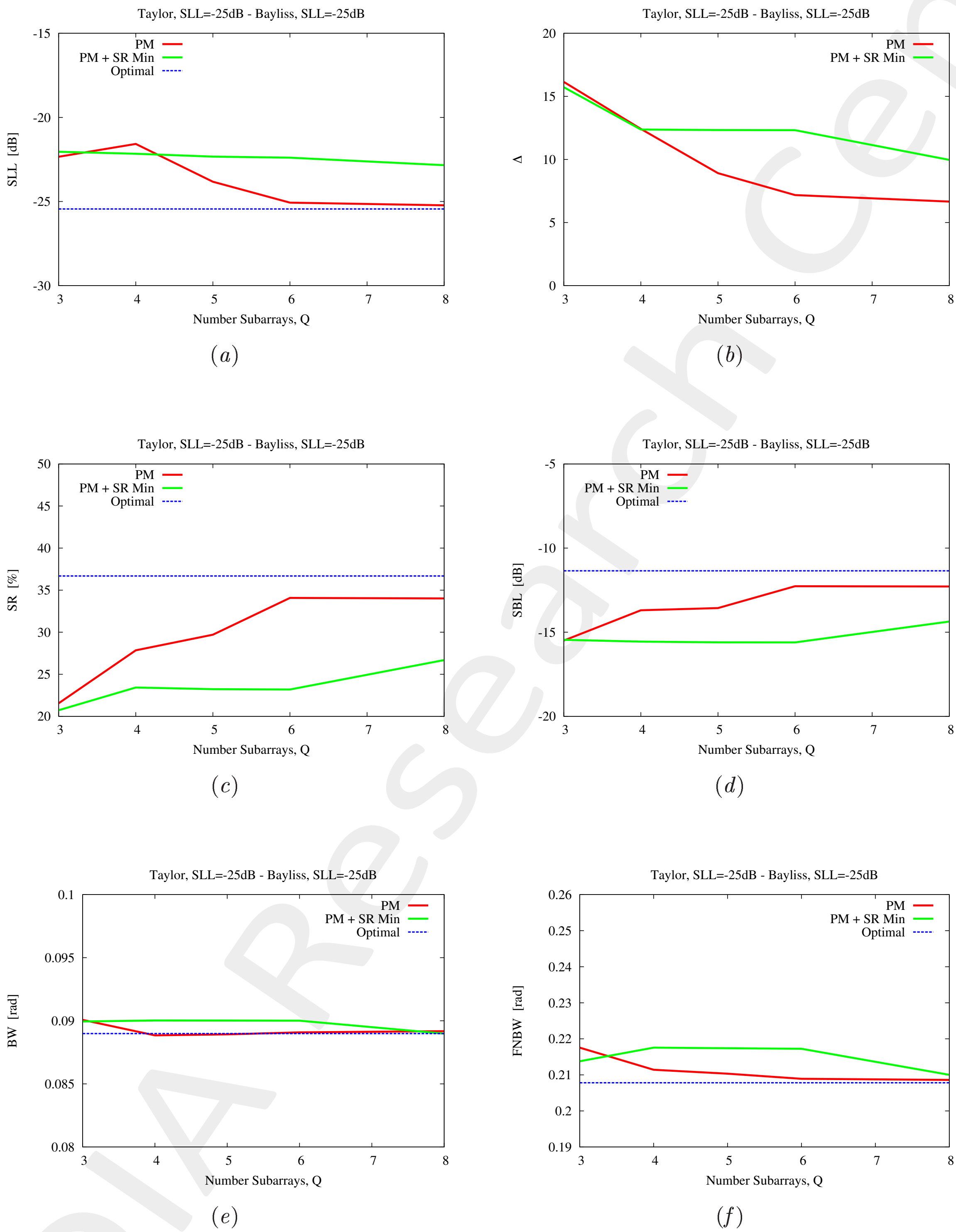

Fig.21 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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Taylor SLL=-25dB switched to Bayliss SLL=-25 dB, $w_{SR} = 5$

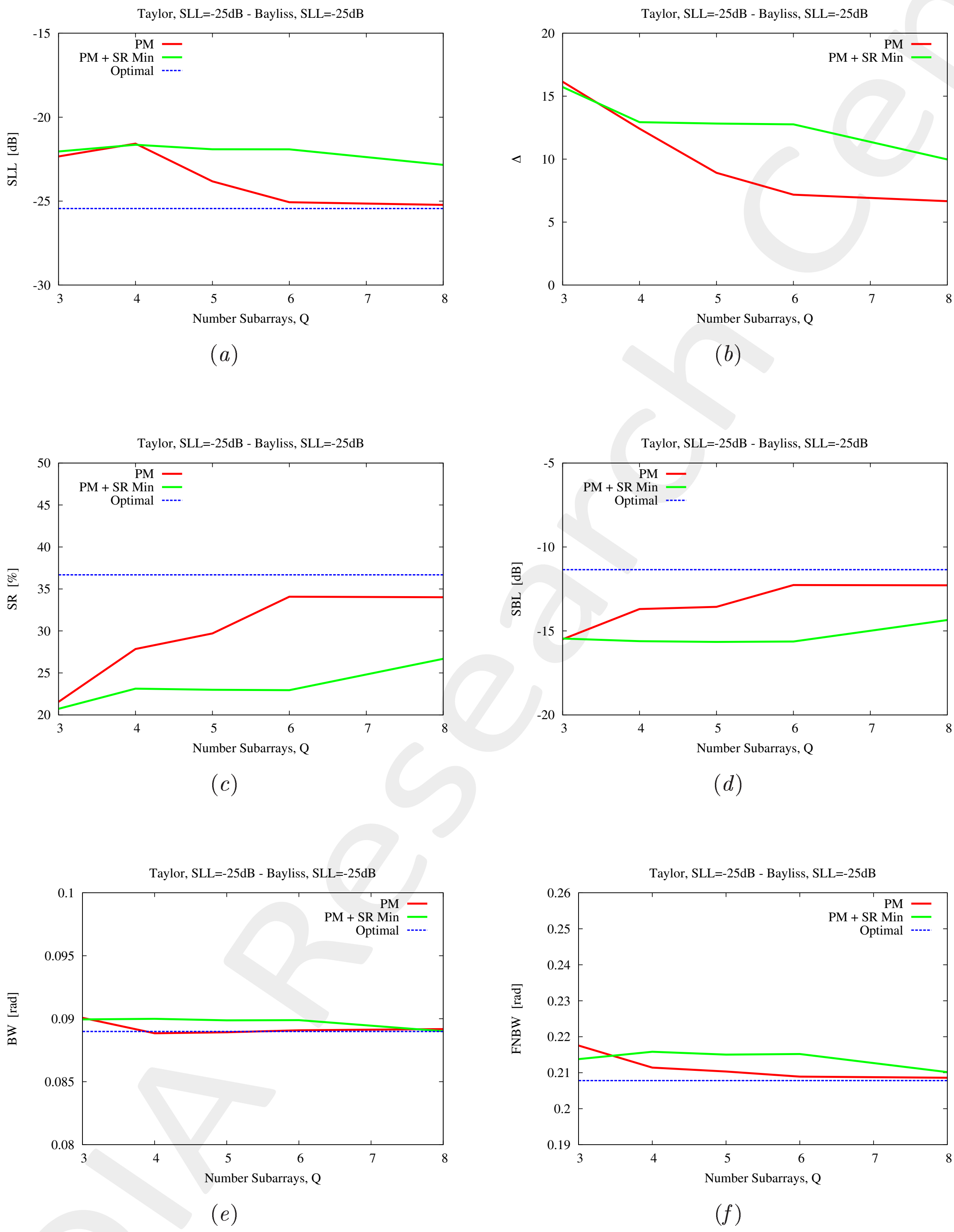

Fig.22 - Comparison of approaches [1.a] and [1.b]: (a) Sidelobe Level (SLL), (b) Pattern Matching Error (Δ), (c) Sideband Radiation (P_{SR}), (d) Sideband Level (SBL), (e) -3dB Beamwidth (BW) and (f) First Null Beamwidth $(FNBW)$.

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Taylor SLL=-25dB switched to Bayliss SLL=-25 dB, $w_{SR} \in [1, ..., 5]$

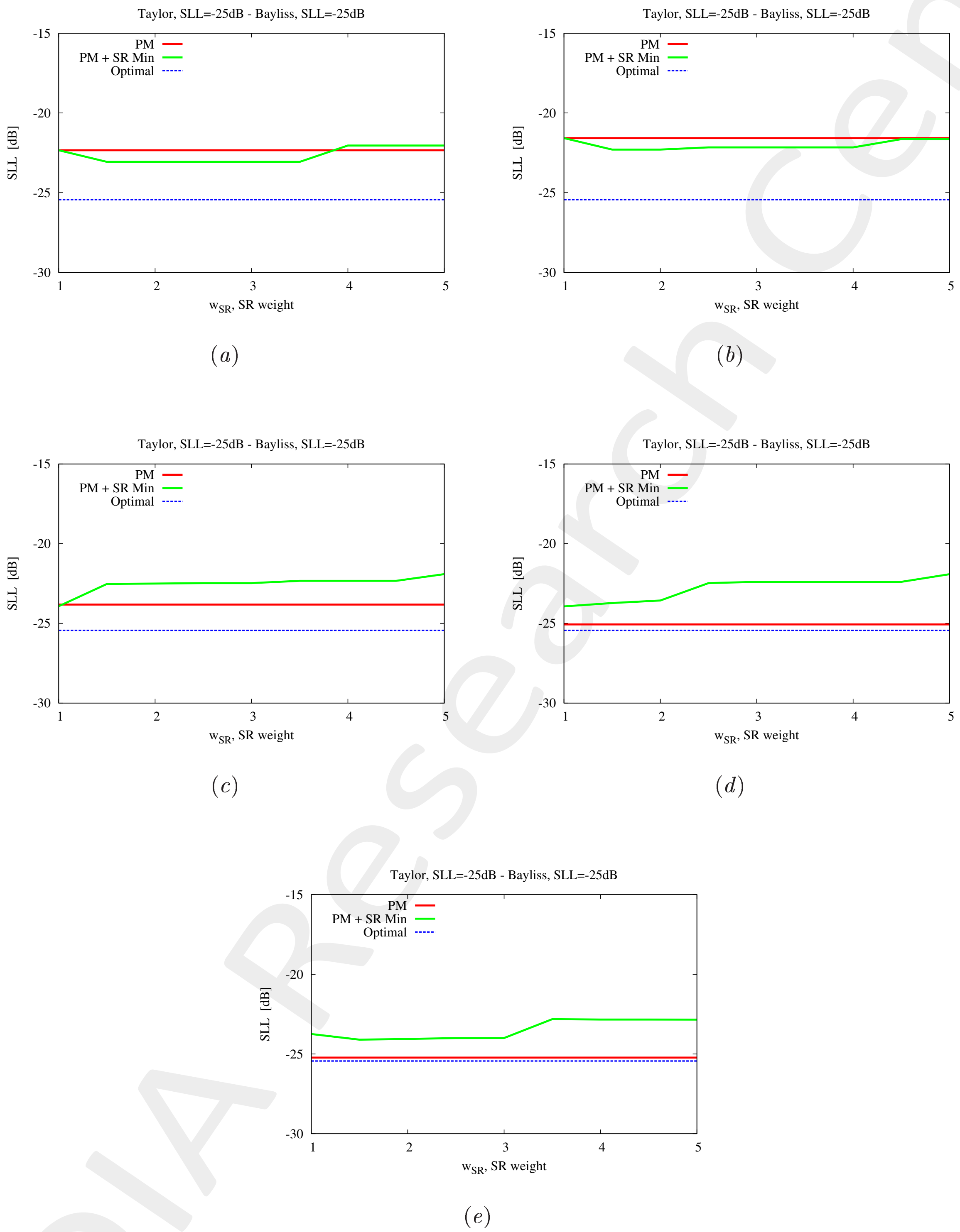

Fig.23 - Comparison of approaches [1.a] and [1.b]: Sidelobe Level (SLL) for (a) $Q = 3$, (b) $Q = 4$, (c) $Q = 5$, (d) $Q = 6$ and (e) $Q = 8$.

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Taylor SLL=-25dB switched to Bayliss SLL=-25 dB, $w_{SR} \in [1, ..., 5]$

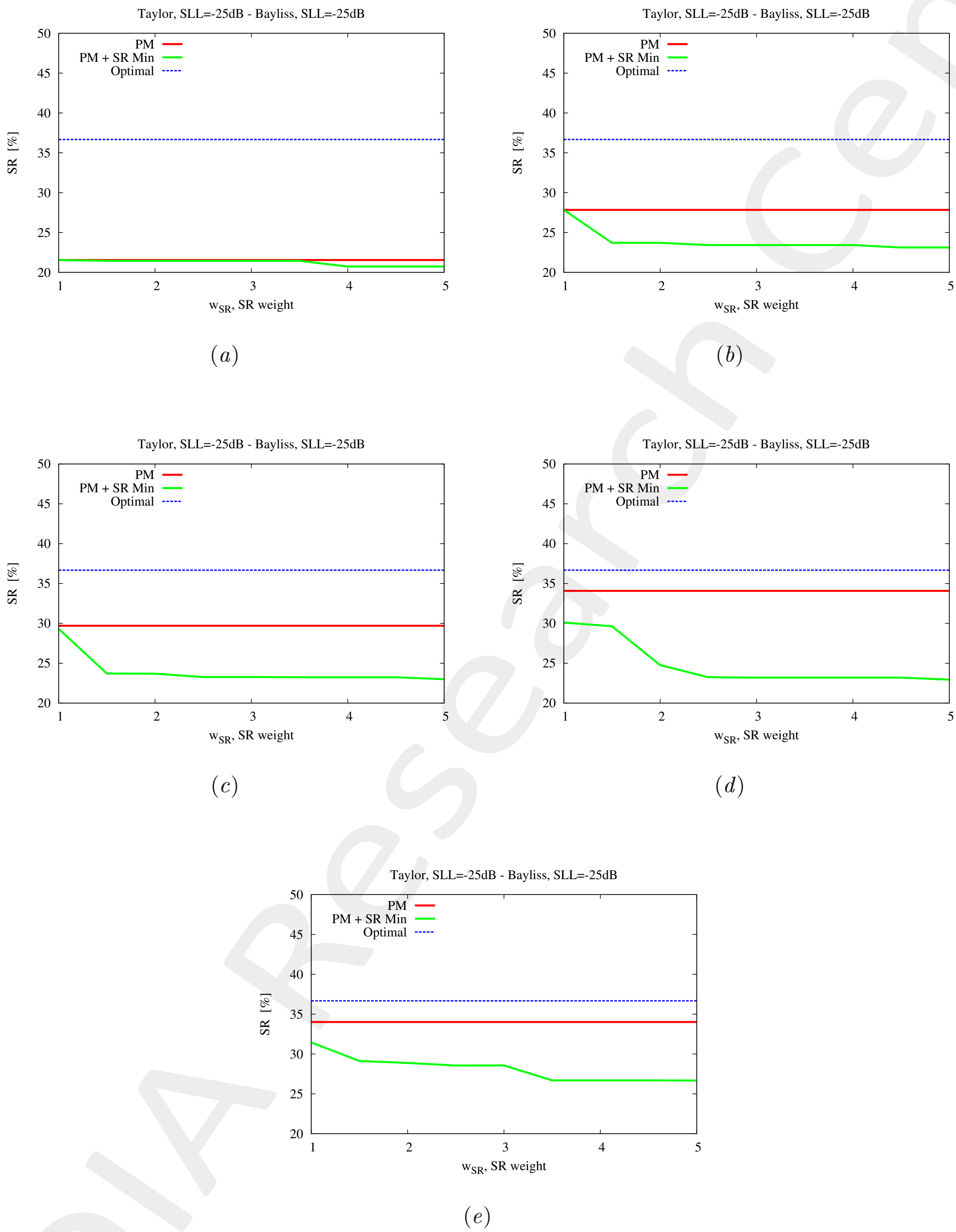

Fig.24 - Comparison of approaches [1.a] and [1.b]: Sideband Radiation (P_{SR}) for (a) $Q = 3$, (b) $Q = 4$, (c) $Q = 5$, (d) $Q = 6$ and (e) $Q = 8$.

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