Synthesis of Fibre Gratings

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Outline

- Introduction (Analysis / Synthesis)
- Grating Synthesis (Design) Methods
  - Fourier-Transform Methods
  - Integral Methods
  - Differential Methods
- Layer-Peeling IS Method
- Grating Designs
  - Square Dispersionless Filters
  - Dispersion Compensators
    - 2nd & 3rd order
- Conclusions

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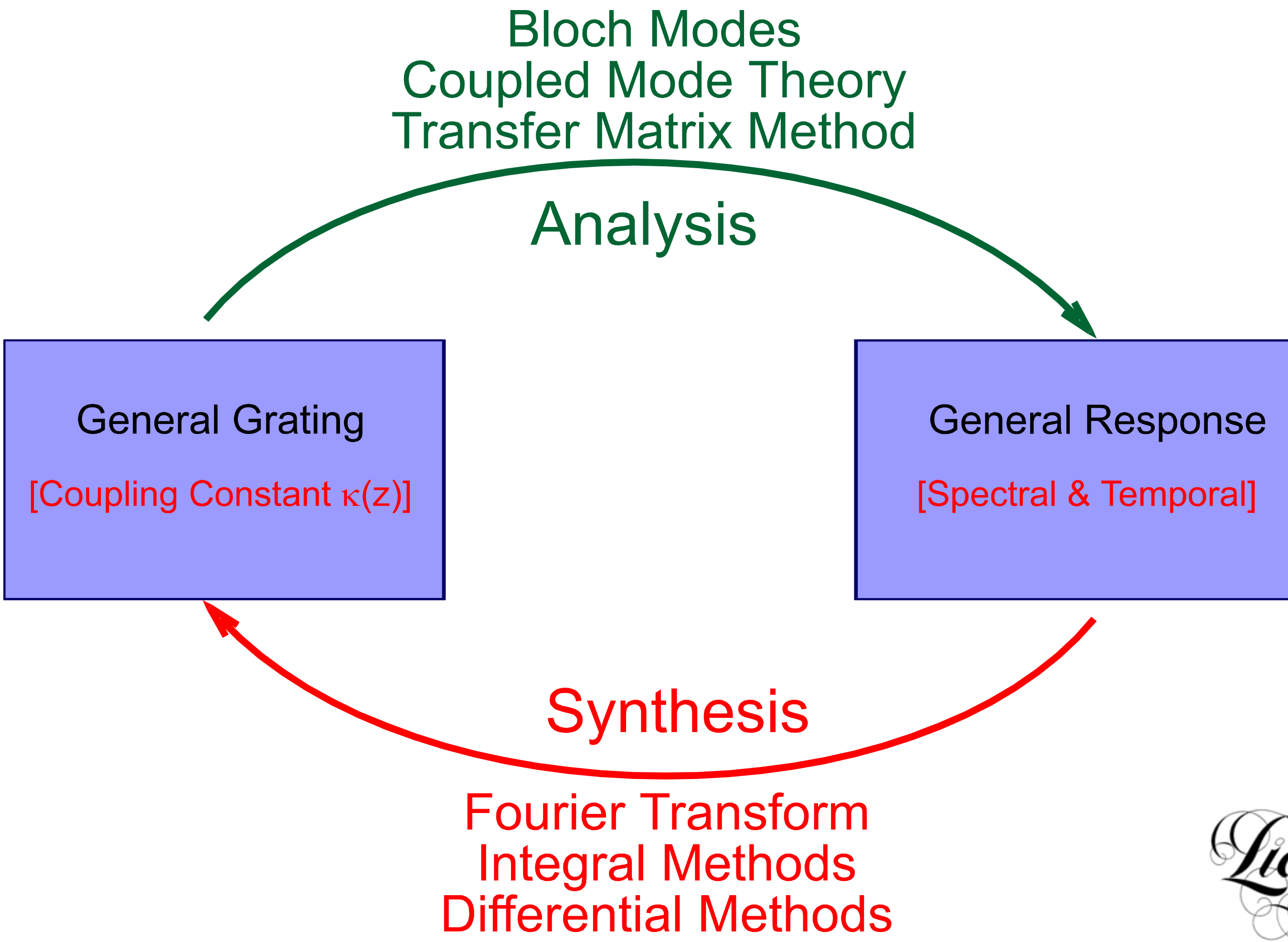
Grating Analysis - Synthesis



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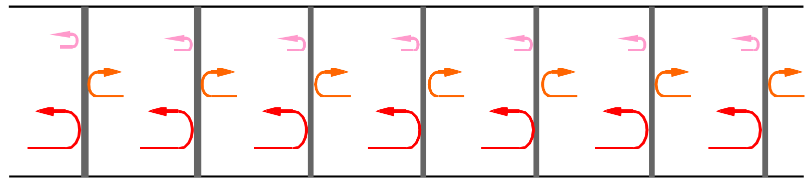
Grating Reflection

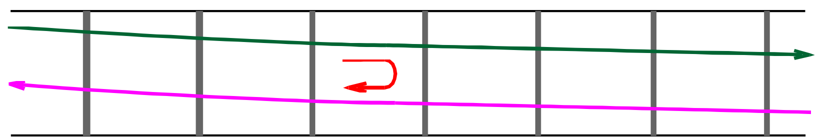
Multiple Distributed Scattering



Coupling Constant $\kappa(z)$

equivalent to

Two opposite-travelling waves



Local Reflection Coefficient

$$r(z) = \frac{B(z)}{A(z)}$$

Ricatti Equation

$$\frac{dr}{dz} = -i2\beta r + \kappa - \kappa^* r^2$$

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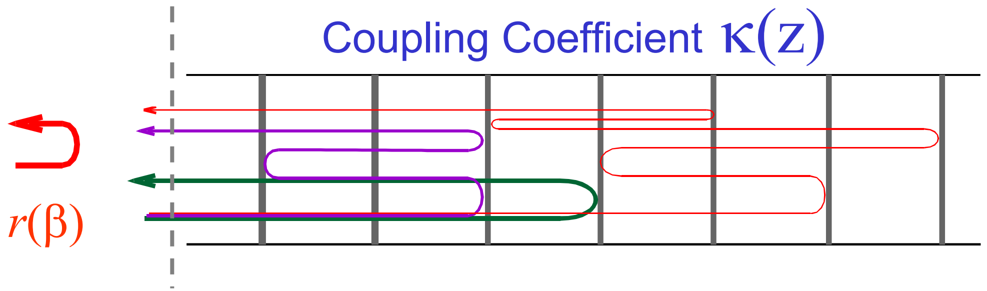
General Grating Reflection Coefficient



$$r(\beta) = -\int_{z_1=0}^{L} dz_1\, \kappa(z_1) e^{i\beta 2 z_1}$$

$$+ \int_{z_1=0}^{L} dz_1 \int_{z_2=0}^{z_1} dz_2 \int_{z_3=z_2}^{L} dz_3\, \kappa(z_1)\kappa^*(z_2)\kappa(z_3)\, e^{i\beta 2(z_1 - z_2 + z_3)}$$

$$- \int_{z_1=0}^{L} dz_1 \int_{z_2=0}^{z_1} dz_2 \int_{z_3=z_2}^{L} dz_3 \int_{z_4=0}^{z_3} dz_4 \int_{z_5=z_4}^{L} dz_5\, \kappa(z_1)\kappa^*(z_2)\kappa(z_3)\kappa^*(z_4)\kappa(z_5)\, e^{i\beta 2(z_1 - z_2 + z_3 - z_4 + z_5)}$$

+ …. (Higher Order Reflections)

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Main Grating Design Methods

- Fourier Method
- Integral Methods
- Differential Methods

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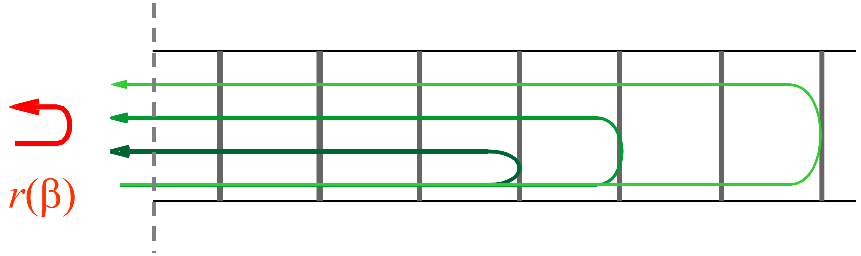
Grating Design - Fourier Method

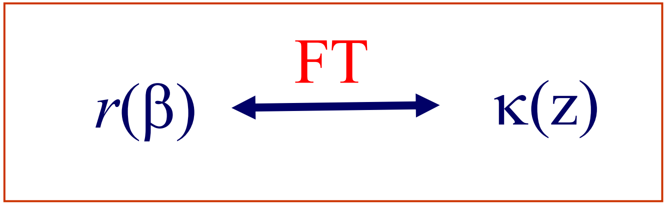


For weak gratings

$(r << 1)$

$$r(\beta) = -\int_{z_1=0}^{L} dz_1 \kappa(z_1) e^{i\beta 2 z_1}$$

$$\kappa(z) = -\frac{1}{\pi}\int_{-\infty}^{+\infty} r(\beta) e^{-i2\beta z}\, d\beta$$



- Accurate only for low reflectivities
- Limited but quite useful

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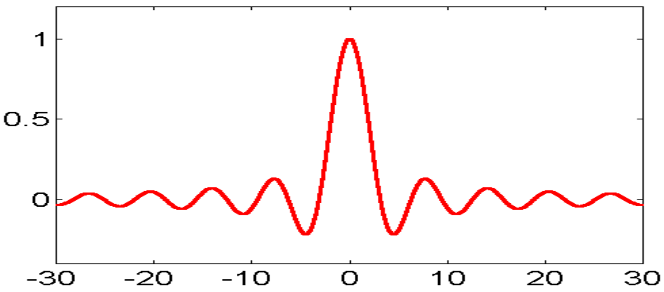
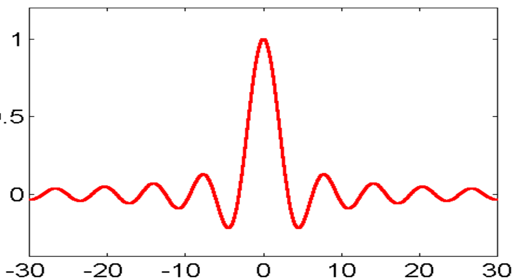
Grating Design - Fourier Method

Coupling Constant

Reflection Coefficient





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Integral IS Methods

[Gelfand-Levitan & Marchenko (GLM) Method]

- Invert Grating Response in Fourier Domain
- Coupling Constant in terms of Generalised FT Integral
- Exact Method - Multiple reflections accounted for
- Solution of Integral Equations
- Analytic solution exists when $r(\beta)$ is rational function
- Solution usually involves (NxN) matrices
- Iterative solutions have been proposed
- High Algorithmic Complexity: $O(N^3)$

Light

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Differential IS Methods

[Layer-Peeling Methods]

- Invert Grating Response in Time Domain
- Rely on Causality
- Exact Method - Multiple reflections accounted for
- Solution of Difference Equations
- Layer-by-layer medium identification
- Replicate Scattering Physical Process
- Low Algorithmic Complexity: $O(N^2)$

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Layer-Peeling Grating Design Method

- General Description
- Space-Time Diagrams

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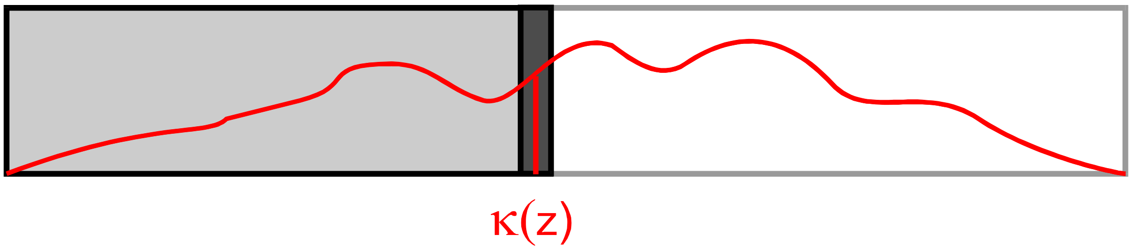
Layer-Peeling IS Algorithm



Step: 1) Impulse Response [$h_R(\tau)$] of Desired Medium [→ FT of $r(\beta)$]

2) Impulse Response [$h_T(\tau)$] of Identified Medium [→ FT of $r_T(\beta)$]

3) $\kappa(\tau/2) = -2\,[h_R(\tau) - h_T(\tau)]$

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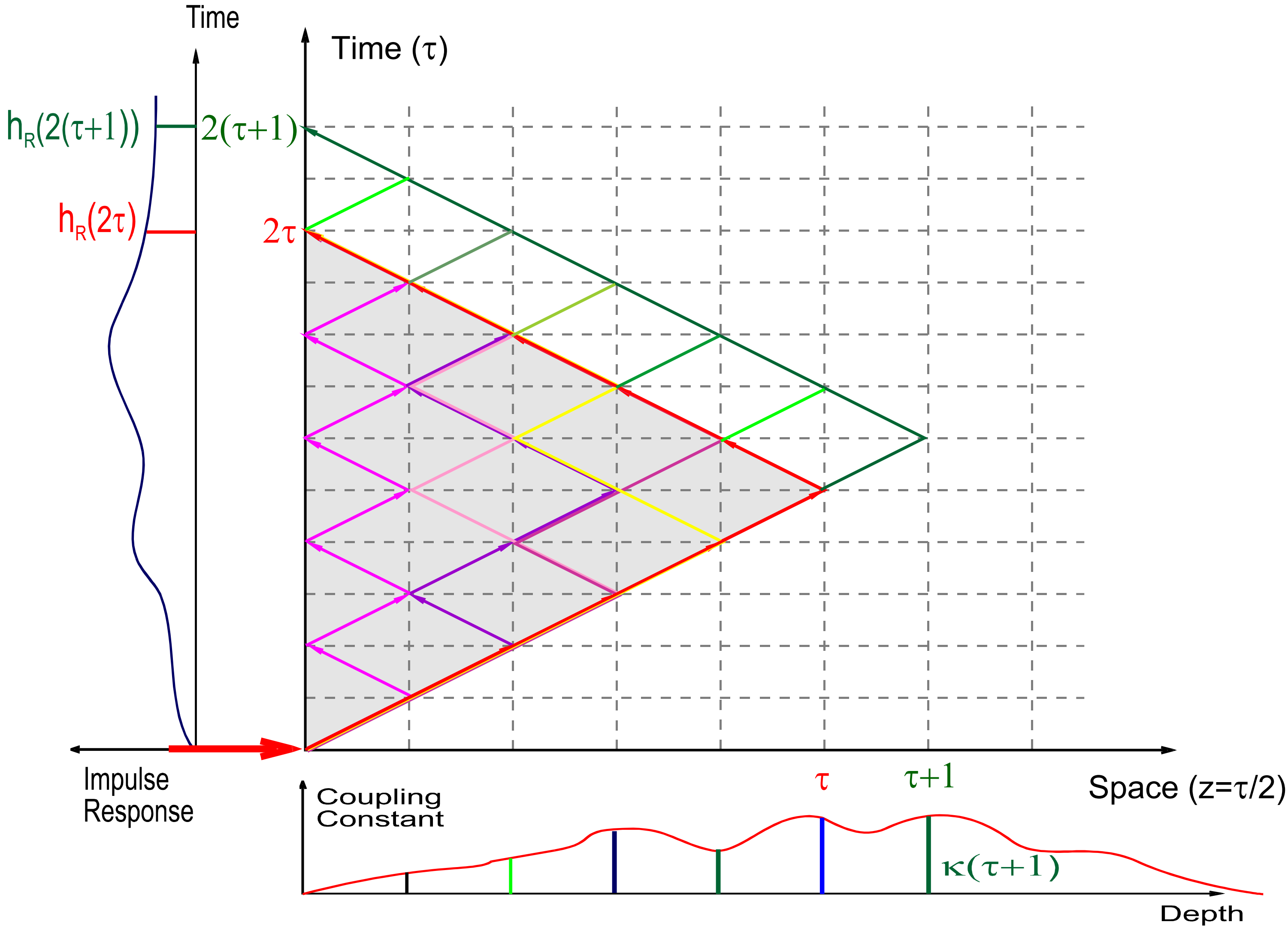
Multiple Scattering Reflection



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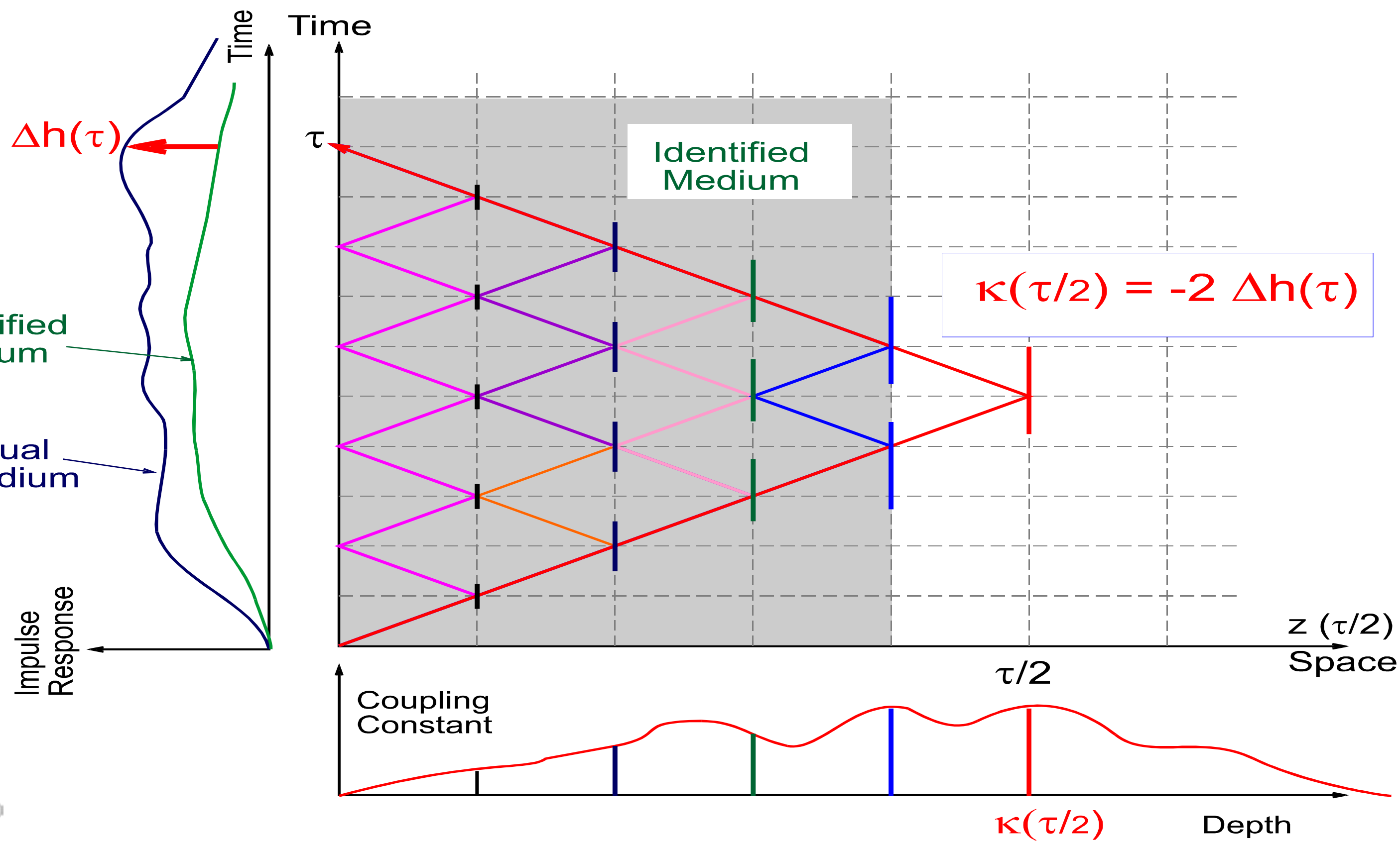
Layer-Peeling Inverse Scattering Method



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Layer-Peeling Method
Grating-Design Examples

- Uniform Grating Reconstruction
- Square Dispersionless Filters
- 2nd-order Dispersion Compensators
- 3rd-order Dispersion Compensators

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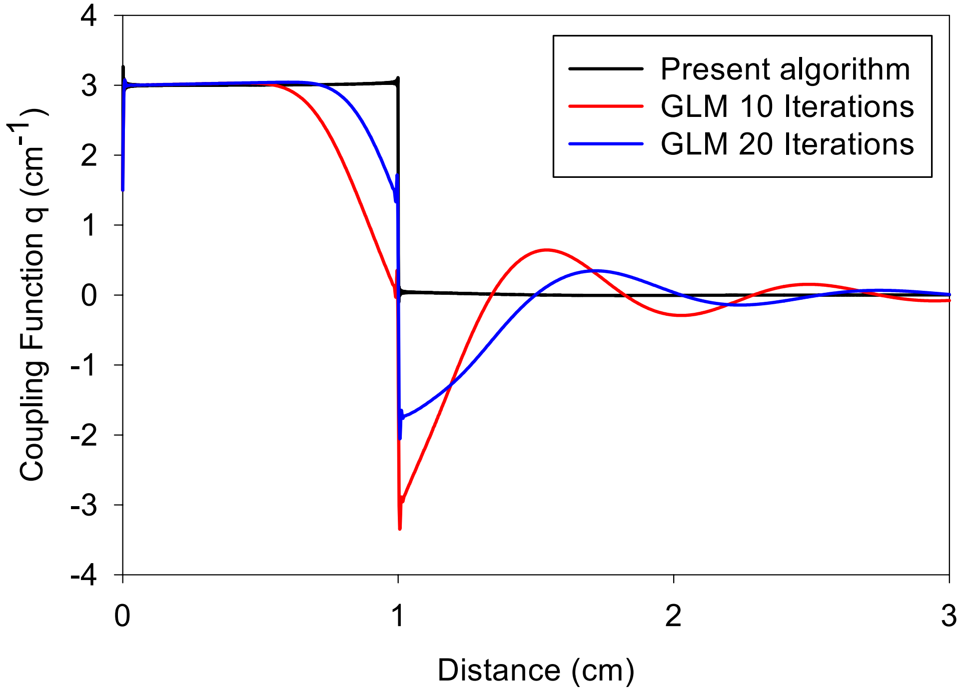
Uniform Grating Reconstruction

Layer-Peeling -vs- Iterative GLM



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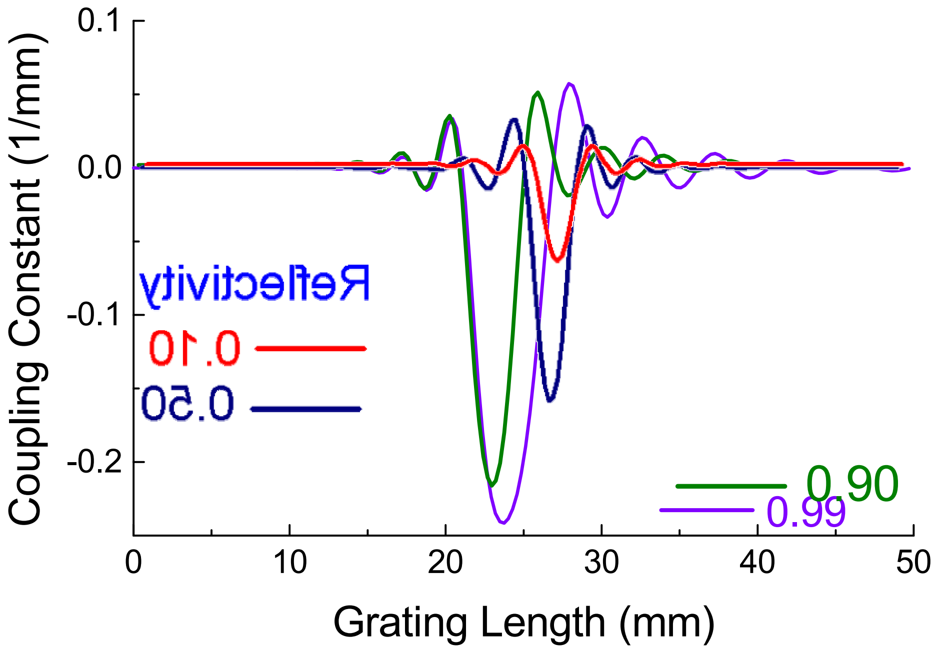
Square Dispersionless Filter Design

BW_{-1dB} = 0.45nm
BW_{-30dB} = 0.60nm
→ 75% Bandwidth Use



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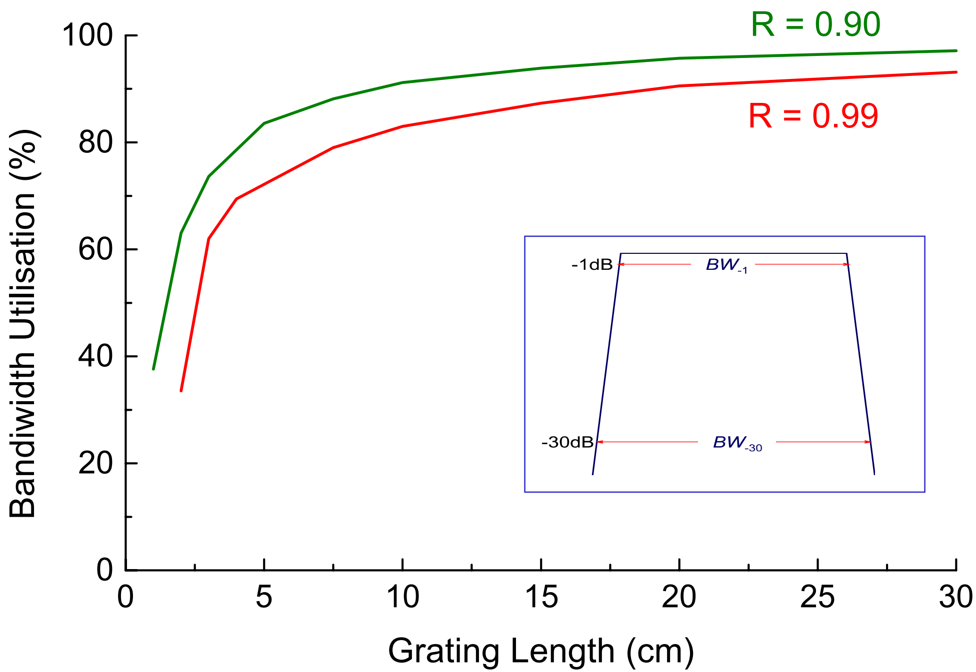
Square Dispersionless Filters

Bandwidth Utilisation = BW_{-1} / BW_{-30}



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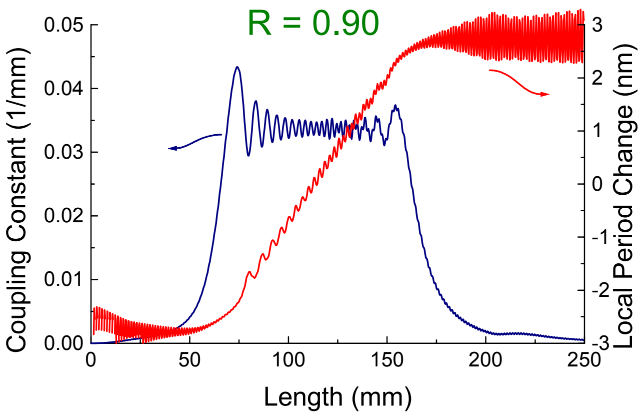
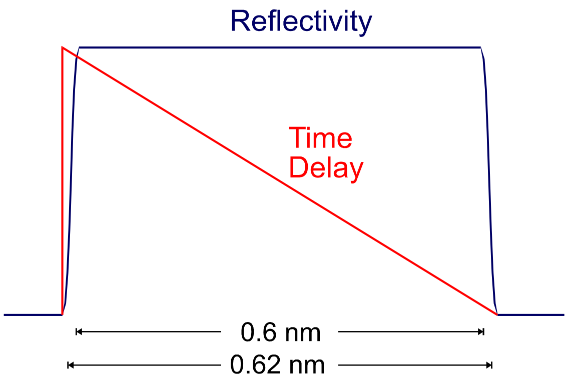
Linear Dispersion Compensator Grating Design

Layer-Peeling

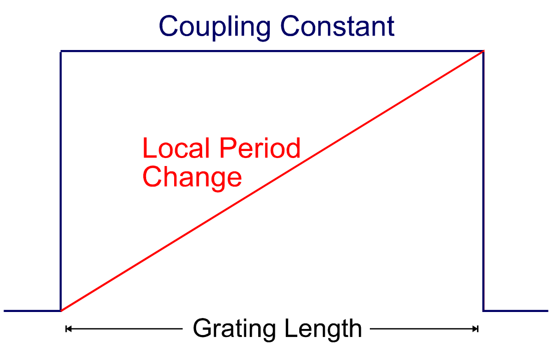
IS Design

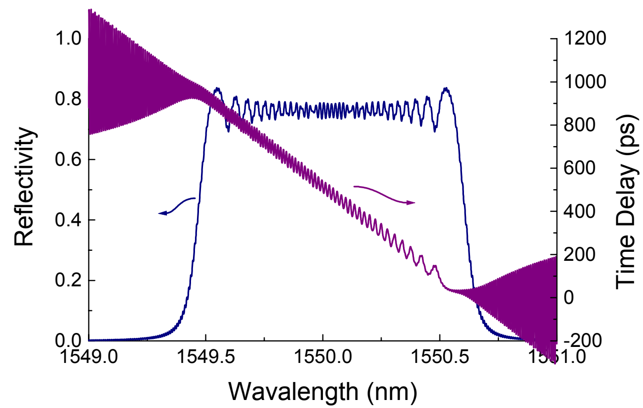




Conventional

Design





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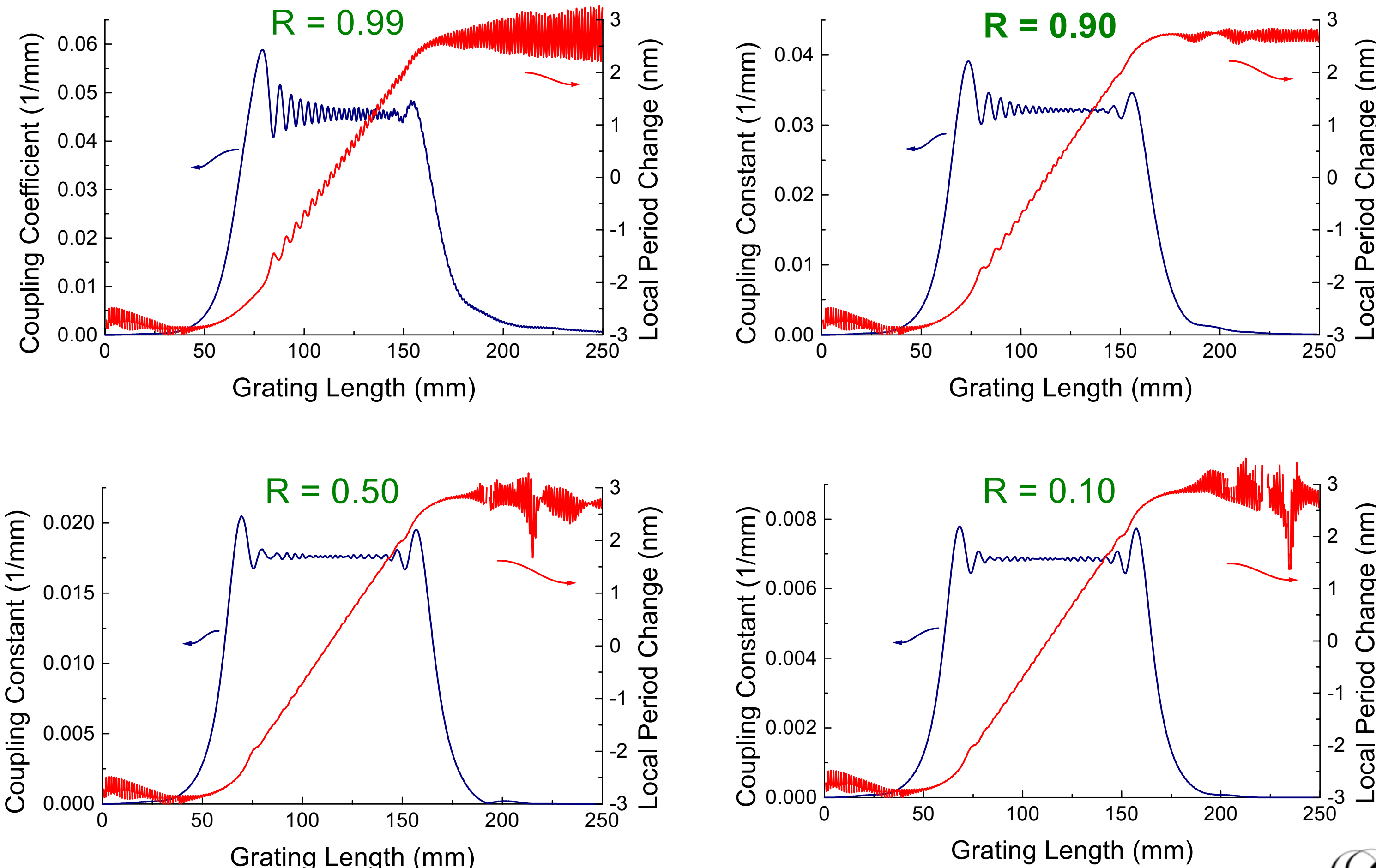
2nd order Grating Dispersion Compensator Design



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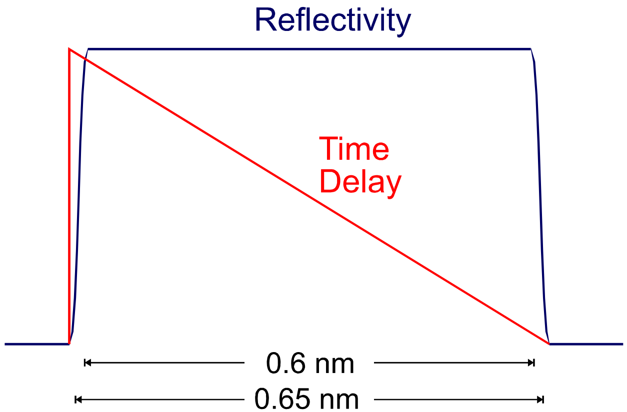
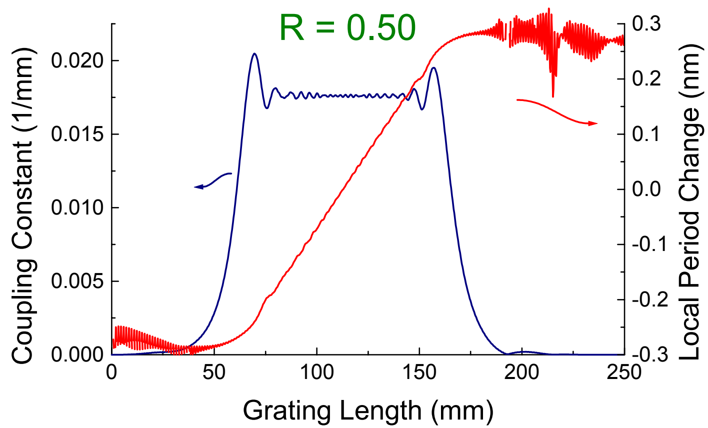
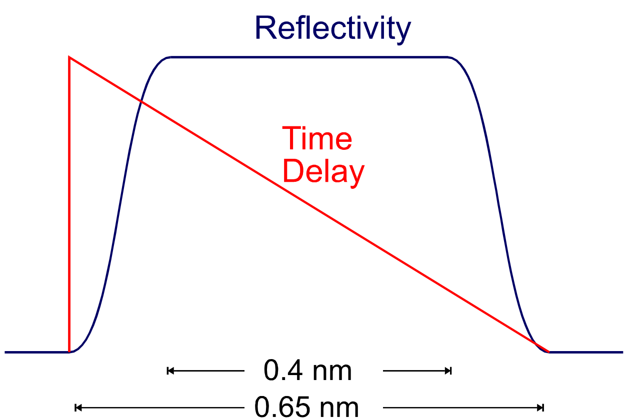
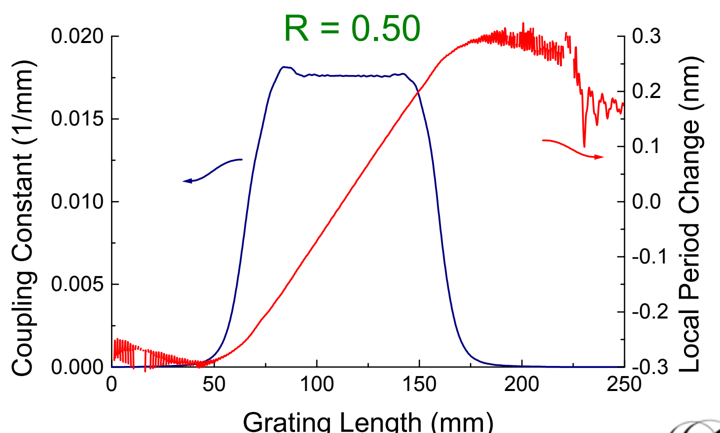
2nd order Grating Dispersion Compensator Design









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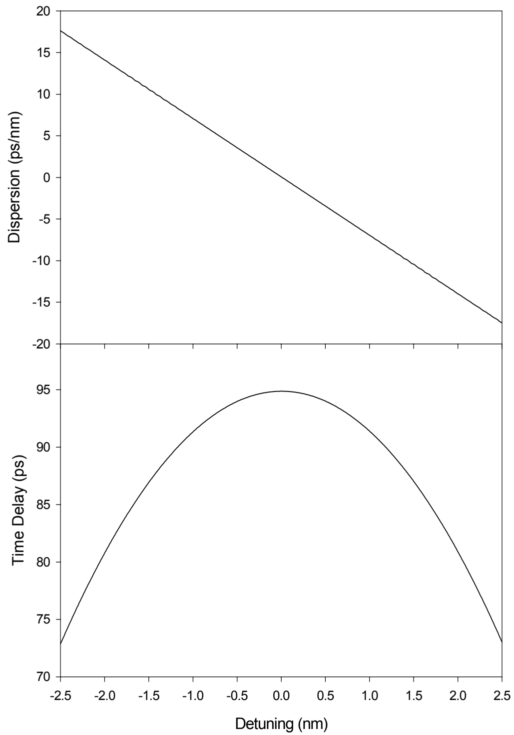
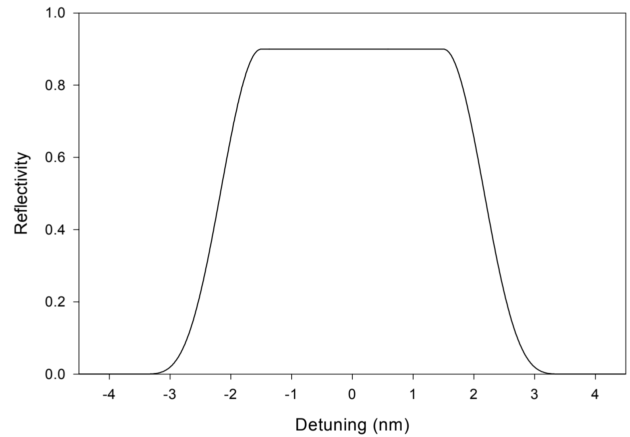
3rd Order Dispersion Compensators

Dispersion

Time Delay



Reflectivity



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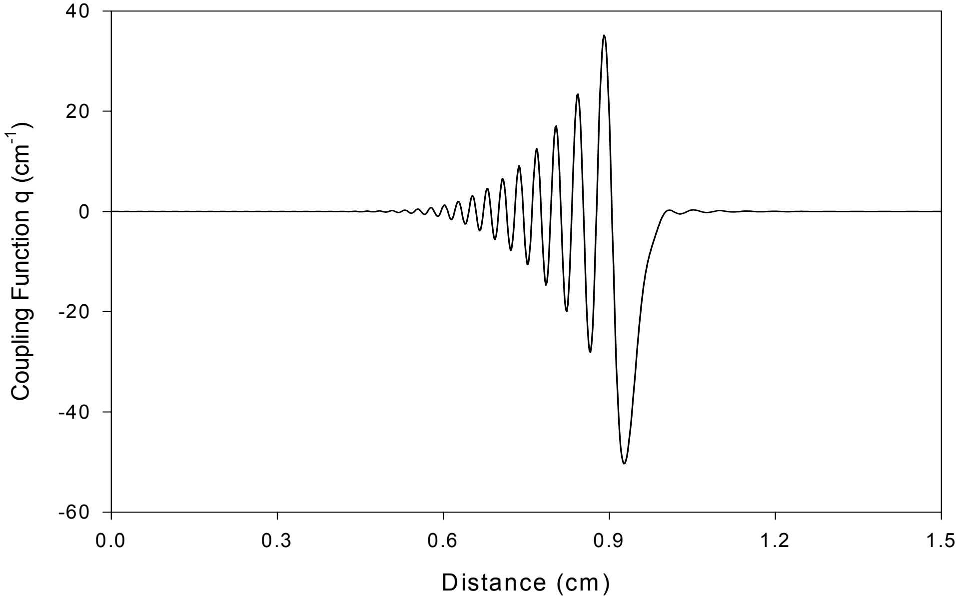
3rd Order Dispersion Compensator Design

- Real Coupling Coefficient



- Constant Period

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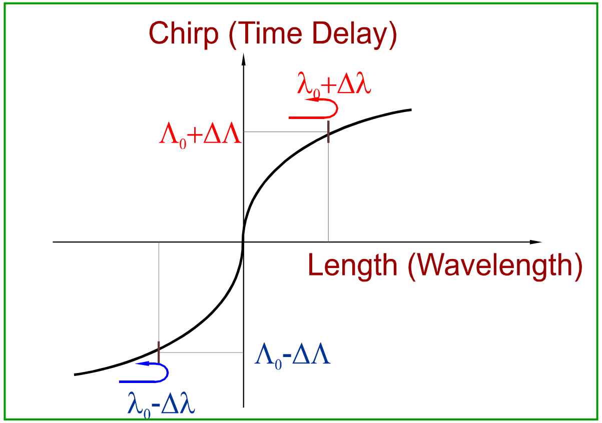
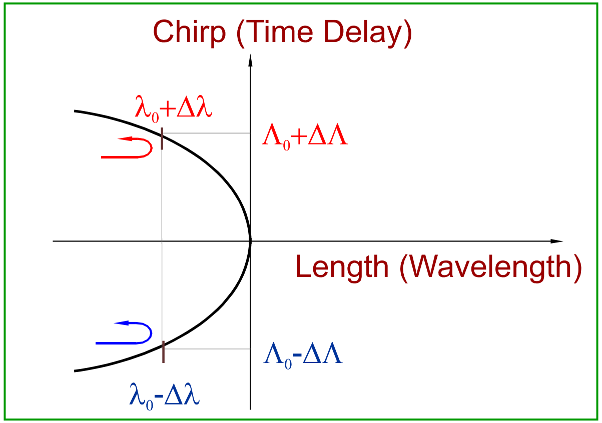
3rd order DC - Physical Picture



Chirped Compensator
(with Antisymmetric Chirp)



Folded Chirped Compensator

Unchirped

Locally Varying Moire Grating

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Conclusions

- Main grating-design techniques have been reviewed
- Differential Layer-Peeling Method presented extensively

  Extremely Powerful
  Replicates physical scattering process
  Fast & Accurate method
  Gives exact solutions to exact scattering problems

- Provides Novel Exciting Grating Designs
- Enhances Grating Design Intuition

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