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Negative Feedback Tuning of Arrayed Waveguide Gratings

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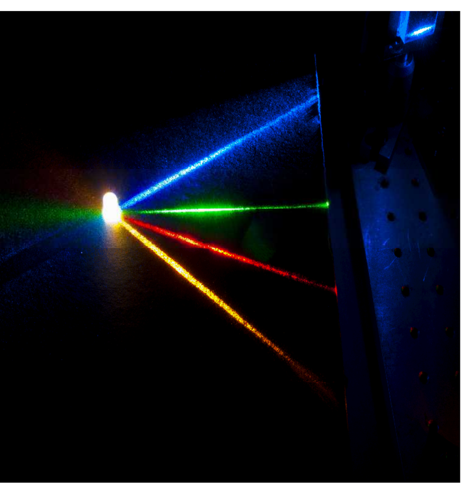
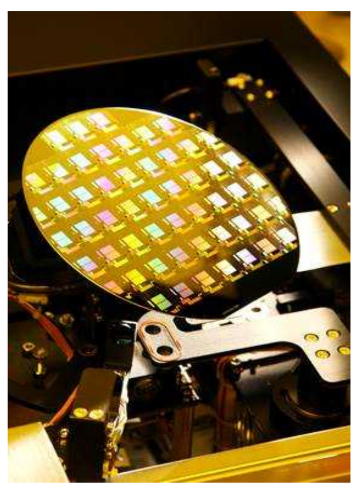
Organization: Applied Photonic Microsystems (#01765)





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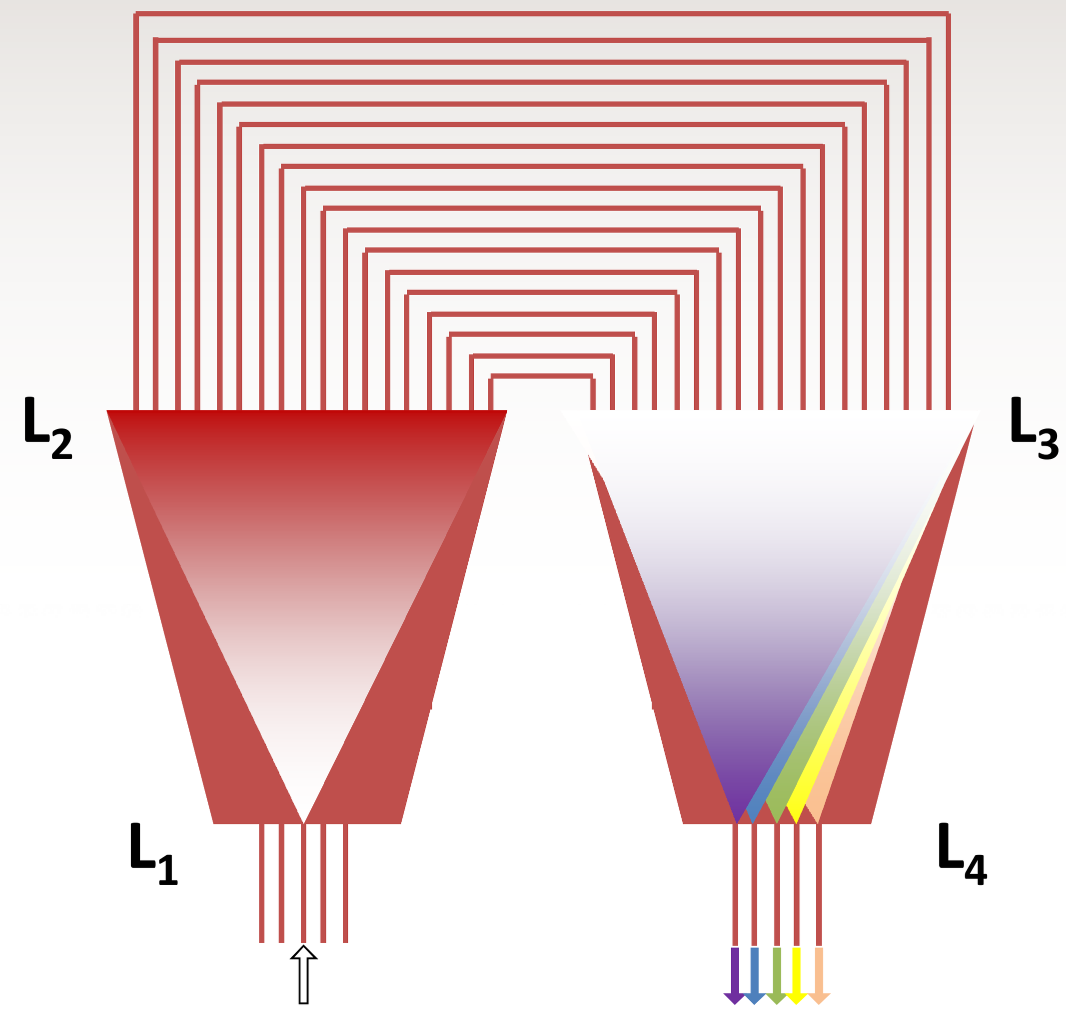
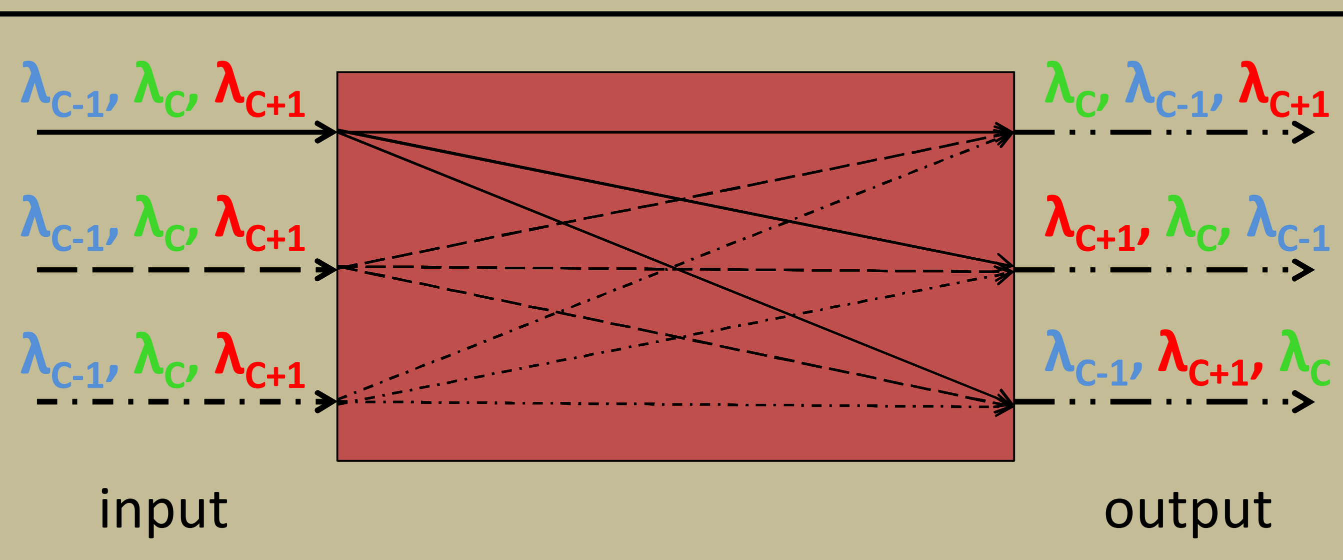
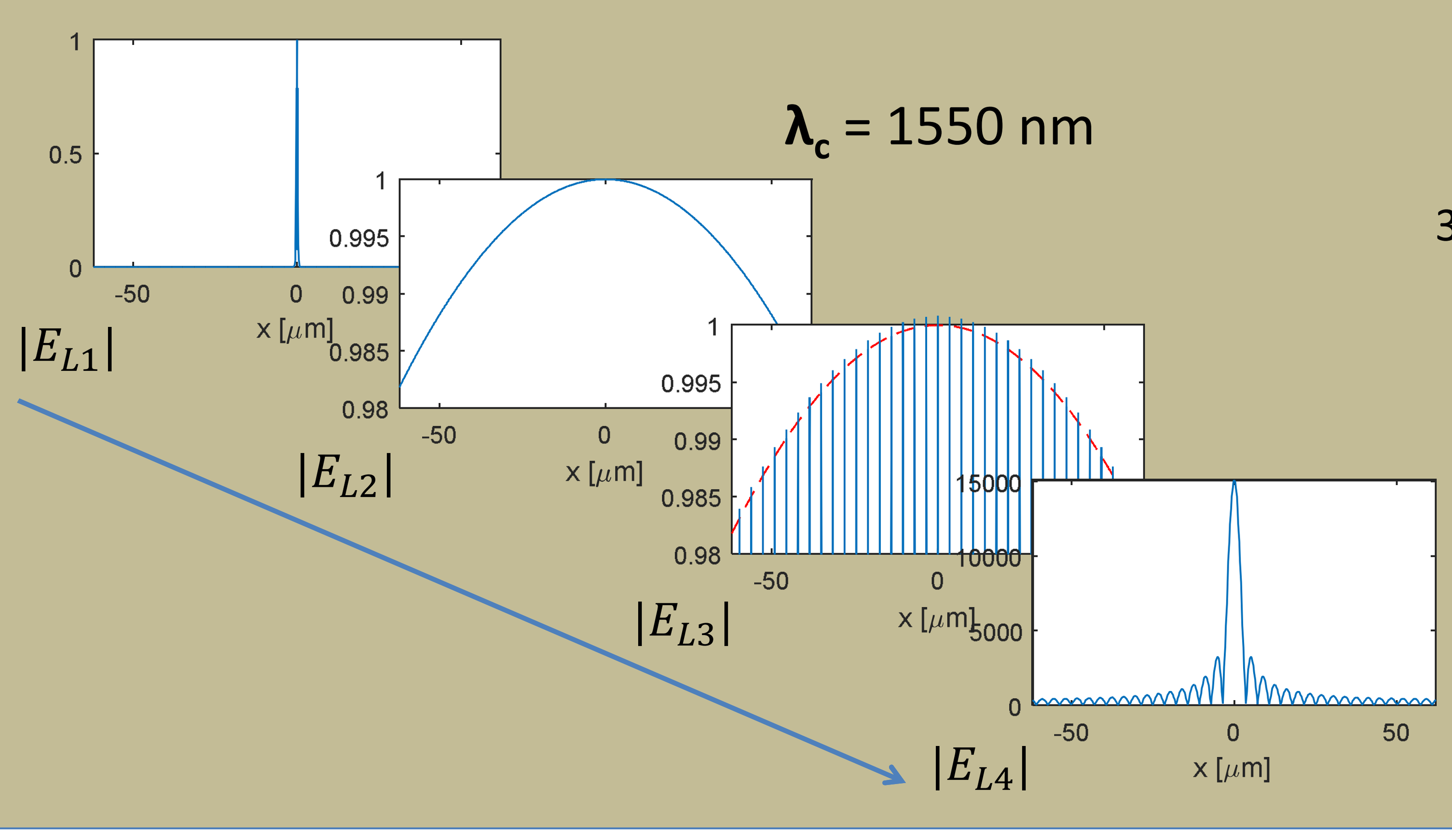
Abstract:

Arrayed waveguide gratings (AWGs) are a substantial component in integrated silicon photonics technology, enabling high bit rates due to wavelength division multiplexing (WDM). However, realistic applications show that these devices are susceptible to bit errors due to unavoidable phase changes in the densely-packed waveguide (WG) region. To resolve this issue, we propose a negative feedback system to detect and correct the phase errors utilizing the Gerchberg-Saxton (GS) algorithm and its legacies.



Arrayed Waveguide Grating:





- AWG can be viewed as an NxN router.
- Basic operation:
  1. Input light defocuses from **L_1** and couples into dense WG region at **L_2**. All light is in phase.
  2. Each WG output at **L_3** is in phase with each other at **λ_C**. At other wavelengths, there is a phase difference **$\Delta\phi(\lambda)$** between adjacent WGs due to dispersion.
  3. Light refocuses at **L_4**. Due to **$\Delta\phi(\lambda)$**, the focal point is different for each wavelength.

Assuming Fraunhofer regime $\left(\frac{n_{FPR}\pi w_{WG}^2}{4\lambda_C L_{FPR}} \ll 1\right)$:

$$E_{L2} = \mathcal{F}\{E_{L1}\}$$
$$E_{L4} = \mathcal{F}\{E_{L3}\}$$

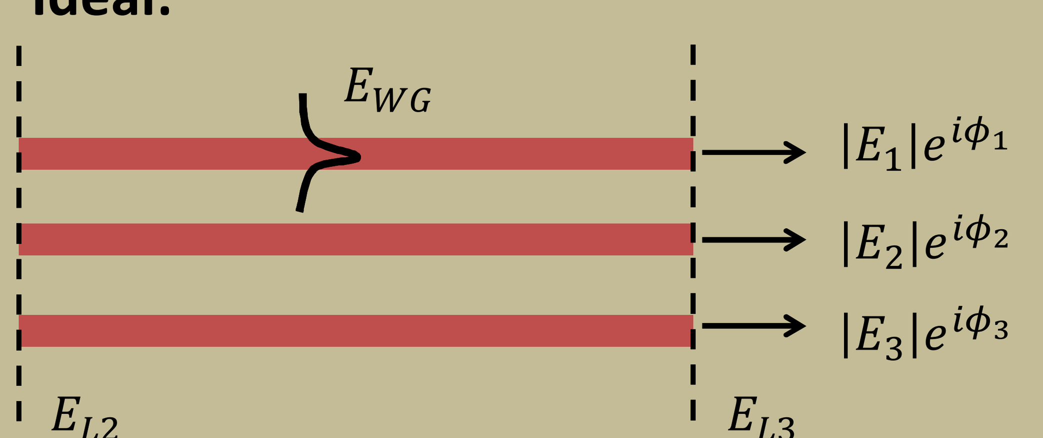
Eqn. [1]

Imperfection-Induced Phase Errors in Dense WG Region:

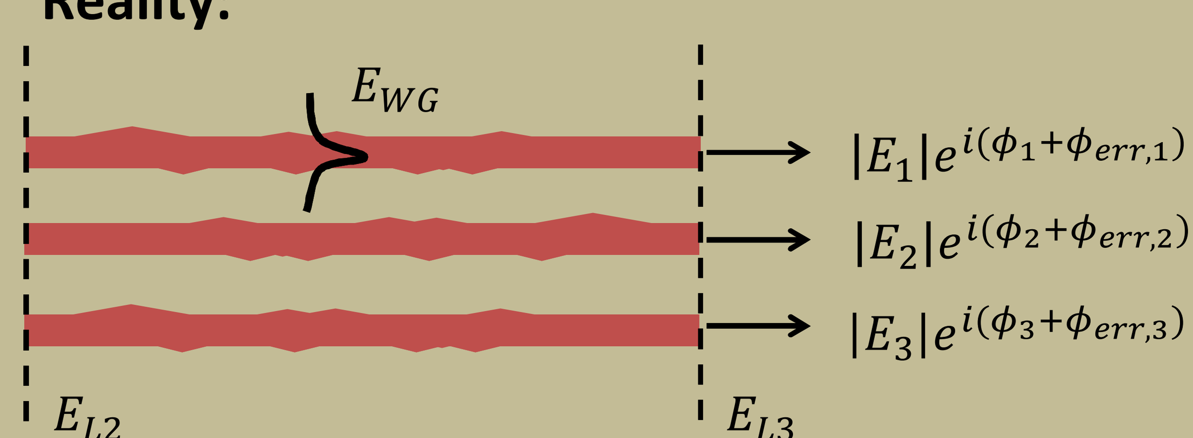
$$E_{L3} = E_{WG} * \left[E_{L2} \sum_{m=-N/2}^{N/2} \delta(x - md_a) \times \exp\left(i\left\{\underbrace{\frac{2\pi}{\lambda} n_{eff}(\lambda)\left[L_0 + \Delta L\left(m + \frac{N}{2}\right)\right]}_{\phi_m} + \phi_{err,m}\right\}\right)\right]$$

Eqn. [2]

Ideal:



Reality:



We can compensate for the phase error by implementing a correction factor that cancels it out. The equation above can be rewritten as:

$$E_{L3} = E_{WG} * \left[E_{L2} \sum_{m=-N/2}^{N/2} \delta(x - md_a) \times \exp\left(i\{\phi_m + \phi_{err,m} + \phi_{PEC}\}\right)\right]$$

Eqn. [3]

NOTE: We currently assume that there is negligible loss induced from the imperfections.

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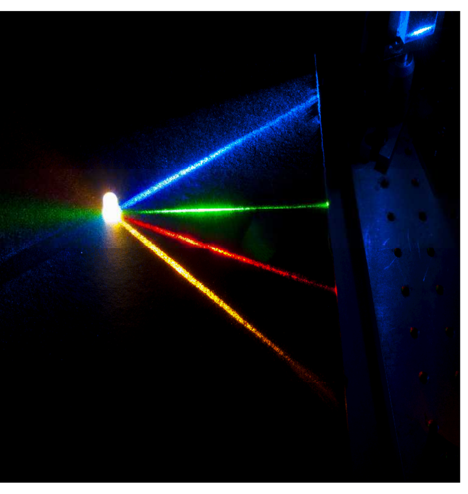

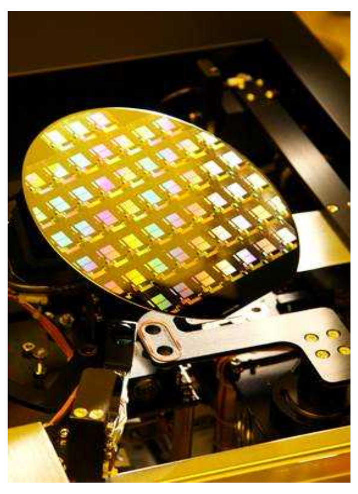

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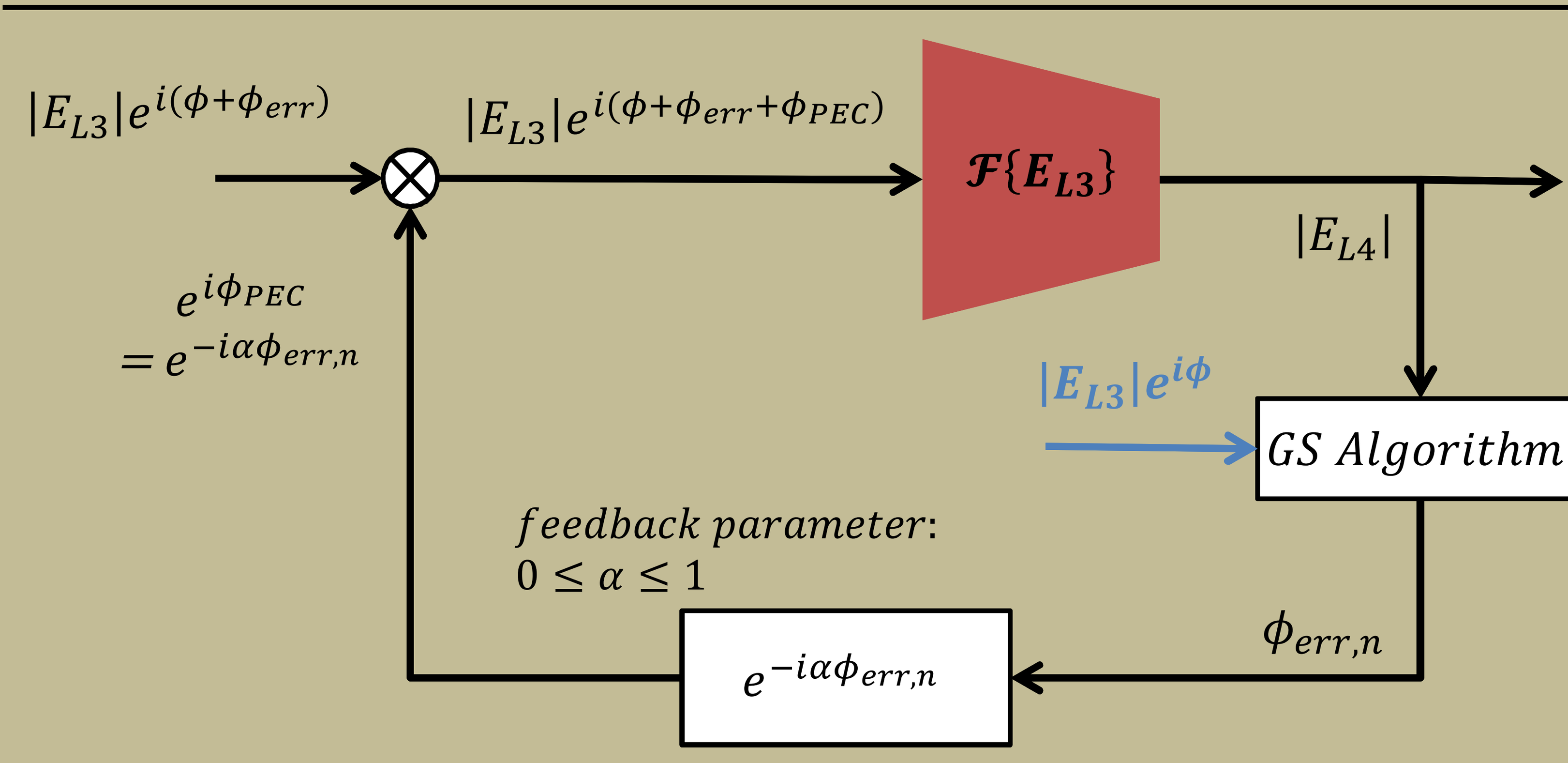
Phase Error Correction via Negative Feedback Tuning:



$|E_{L4}|$ can be measured directly via NSOM or approximately calculated by transmission spectra measurements.

By implementing P-N junctions or ohmic heaters on each WG on the array, we can tune the phase by electro-optic or thermo-optic tuning.

Gerchberg-Saxton Phase Retrieval Algorithm:

In experimental measurements, the phase information is lost. However, methods such as GS-based algorithms allow the phase information to be closely approximated.

$$G_n(u) = \mathcal{F}\{g_n(x)\} = |G_n(u)|e^{i\phi_{G_n}(u)}$$

$$G_n'(u) = |F(u)|e^{i\phi_{G_n}(u)}$$

$$g_n'(x) = \mathcal{F}^{-1}\{G_n'(u)\} = |g_n'(x)|e^{i\phi_{g_n'}(x)}$$

$$g_{n+1}(x) = |f(x)|e^{i\phi_{g_n'}(x)}$$

Inputs:

$$f(x) = |E_{L3}|e^{i\phi}$$
$$|F(u)| = |E_{L4}|$$
$$g_1(x) = |f(x)|e^{i\phi_{rand}(x)}$$

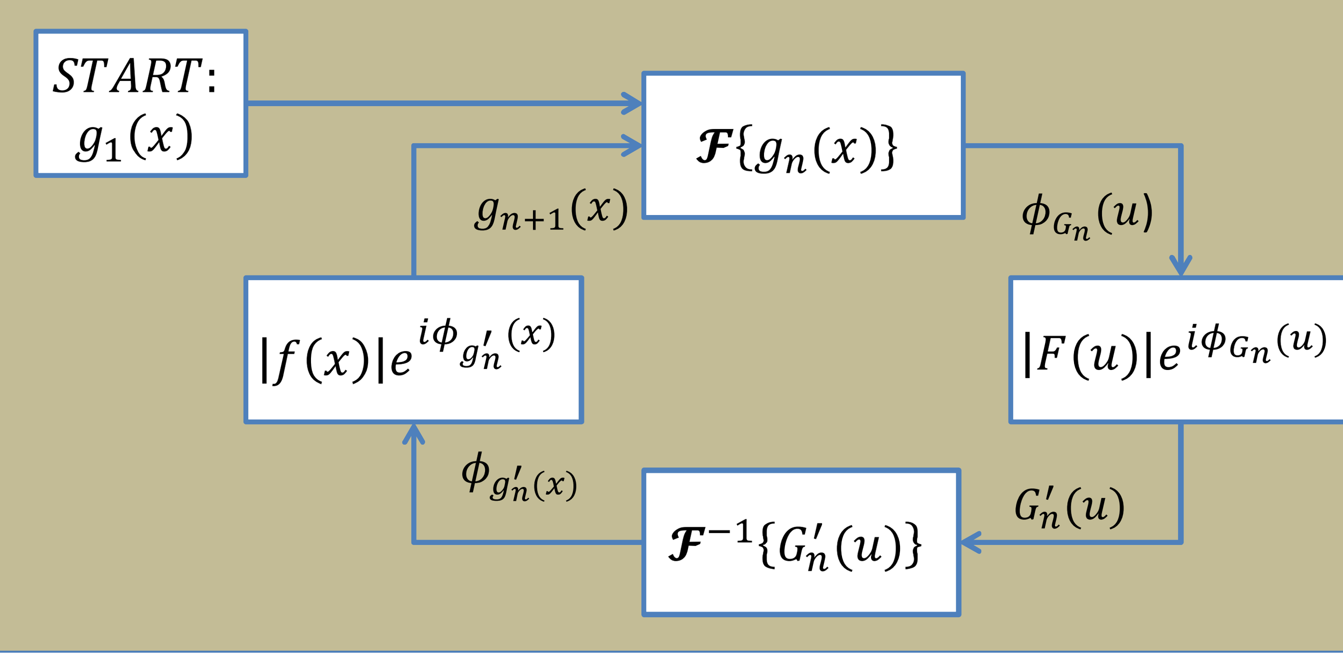
Outputs:

$$g_n(x) = |E_{L3}|e^{i(\phi+\phi_{err,n})}$$

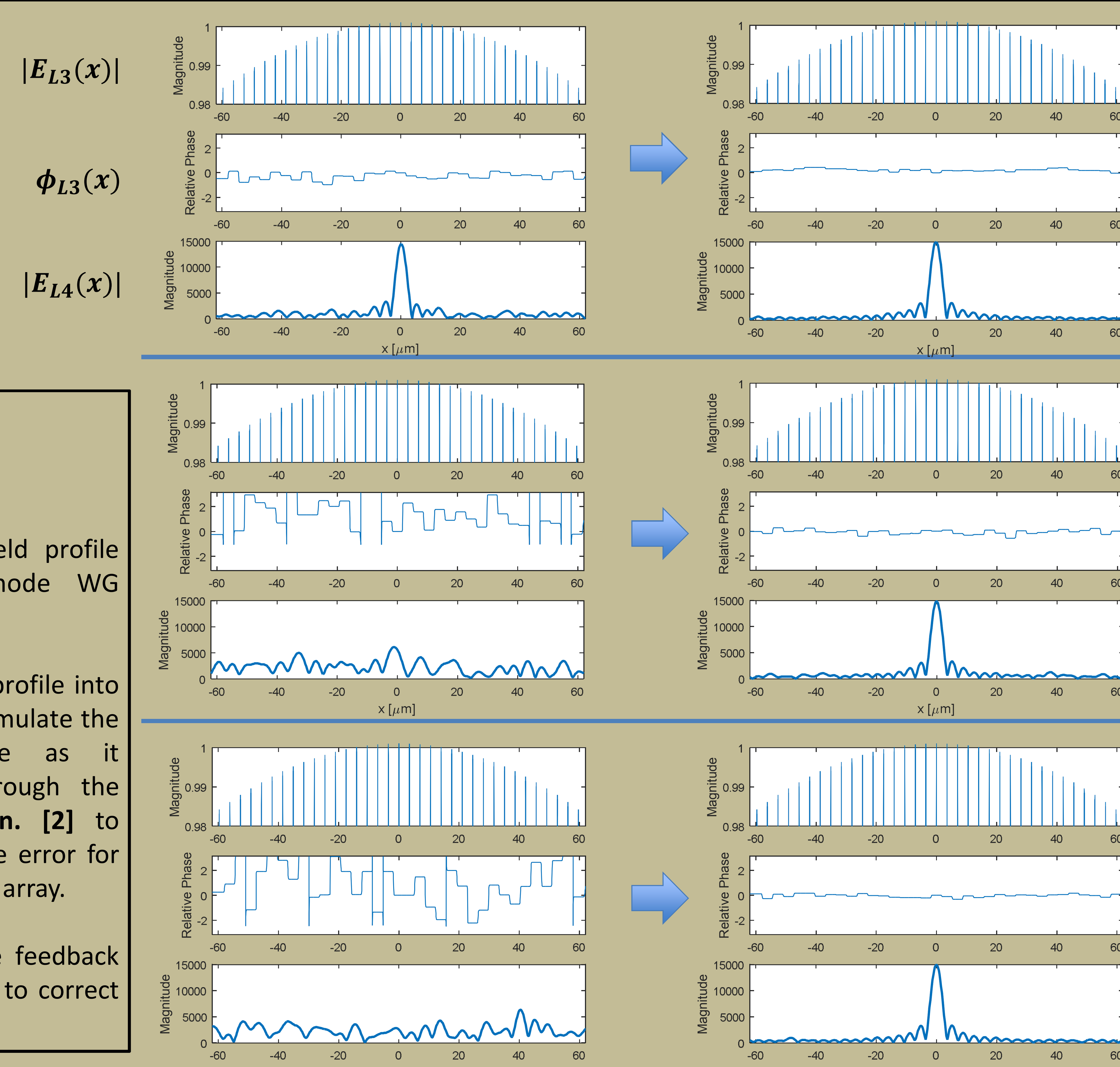
The algorithm repeats until the following square-error metric reaches a minimum.

$$M^{-2}\sum_u [|G_n(u)| - |F(u)|]^2$$

NOTE: The variable M corresponds to the M-point discrete Fourier transform.



Simulation Methods & Results:



Software Used:

- Lumerical
- MATLAB

1) Get electric field profile of a single-mode WG from Lumerical.
2) Import E-field profile into MATLAB and simulate the profile change as it propagates through the AWG. Use **Eqn. [2]** to impose a phase error for each WG in the array.
3) Utilize negative feedback tuning method to correct the phase.

References:

[1] Shibnath Pathak, "Silicon Nano-Photonics Based Arrayed Waveguide Gratings", (3/2014)
[2] Dobrusin V, Ruschin S; Design of a fast tunable wavelength filter based on an arrayed waveguide grating. Opt. Eng. 0001;44(4):044001-044001-8.
[3] S. M. Schultz; Using MATLAB to help teach Fourier optics. Proc. SPIE 6695, Optics and Photonics for Information Processing, 66950I (September 20, 2007); doi:10.1117/12.735889.
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[5] J. R. Fienup, "Phase retrieval algorithms: a comparison," Appl. Opt. **21**, 2758-2769 (1982)
[6] R. W. Gerchberg and W. O. Saxton, "A practical algorithm for the determination of the phase from image and diffraction plane pictures," Optik 35, 237 (1972)

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