An Alternative Laser-Speckle-Smoothing Scheme for the NIF

1.5-MJ CH-foam target; end of acceleration

1-D SSD, 10.8 Å

1-D MultiFM, 8 Å

2-D SSD, 11 Å

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Multiple FM modulators in 1-D reduces imprint to 2-D SSD levels

- Multiple FM modulators in 1-D (1-D MultiFM SSD*)
  - reduced complexity, i.e., no second dimension
  - applied in a fiber within a rack-mounted unit, so layout impact is minimal because bulk optics are not needed
  - takes advantage of multiple color cycles without the disadvantage of coherence maxima in the spectrum
  - simulations show that imprint levels are comparable to 2-D SSD in direct drive and should apply to polar direct drive

Collaborators

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Implementing 2-D SSD on the NIF will be expensive and technically challenging

- 2-D SSD is required for igniting 1-MJ and 1.5-MJ direct-drive designs*
- This result assumed single FM modulators
- Bulk optics modulators are required for the second SSD dimension
  - space constraints in the NIF PAM’s
- 1 THz (12 Å) of 2-D SSD requires dual-frequency triplers
- Simulations show that imprint from multiple FM SSD modulators in 1-D is comparable to 2-D SSD
- Less bandwidth is used; 650 GHz (8 Å)
- Potentially can get to 0.5 THz (6 Å) with a single-frequency-conversion crystal using multiple FM modulators in 1-D

*Testable on OMEGA EP

Laser-speckle smoothing is characterized by the coherence time and the angular divergence.

Both the coherence time and asymptotic level are functions of ℓ-mode.

\[ \Delta \theta_{\text{SSD}} \equiv \text{Angular divergence} \]

\[ t_c \equiv \text{Coherence time} \]

\[ \log(\sigma_{\text{rms}}) \approx \log(\sigma_0) + \frac{1}{2} \left[ \log(t_c) - \log(t) \right] \]

\[ t_c < t < t_{\text{asym}} \]

Asymptotic level \( \propto (\ell \cdot \Delta \theta_{\text{SSD}})^{-2} \)
SSD smoothing can be improved by increasing the divergence and/or the inverse coherence time.

- Increasing divergence
  - allowing divergence to be closer to the existing pinhole
    \( \Delta \theta_{SSD} = 100 \, \mu\text{rad}, \Delta \theta_{\text{pinhole}} = 300 \, \mu\text{rad} \)
  - dynamic bandwidth reduction* can make this possible without risk of pinhole closure

- Increasing the inverse coherence time

- Increasing \( N_{cc} \) and/or \( \Delta \lambda \) does both

Increasing the inverse coherence time, $t_c^{-1}$, allows the target to experience a smoother spot for a longer period.

\[ \Delta\theta_{\text{SSD}}, \Delta\lambda \]

\[ t_c^{-1} \propto \ell \cdot \Delta\lambda \cdot N_{cc} \]

\[ \Delta\theta_{\text{SSD}} \propto \frac{\Delta\lambda \cdot N_{cc}}{v_m} \]

- Implies $v_m$ increases as $N_{cc}$ increases.
Increasing the color cycles increases $t_c^{-1}$ for the lower $\ell$-modes and produces resonances for the higher $\ell$-modes.

- Improved smoothing in the lower $\ell$-modes occurs at the expense of higher $\ell$-mode uniformity.
Employing multiple FM modulators in 1-D reduces the peak-to-peak variations in the inverse coherence time.

\[ \Delta \theta_{SSD} \propto \frac{\Delta \lambda \cdot N_{cc}}{v_m} \]

1-D SSD, \( N_{cc} = 8 \)

\( \Delta \theta_{SSD} \) fixed

\( 4 \times v_m \)
Employing multiple FM modulators in 1-D reduces the peak-to-peak variations in the inverse coherence time

- $t_c^{-1}$ decreased by $4\times$, and $\Delta\theta_{\text{SSD}}$ increased by $2\times$ relative to 1-D SSD
Employing multiple FM modulators in 1-D reduces the peak-to-peak variations in the inverse coherence time $t_c^{-1}$.

$\Delta t_c^{-1} \propto \ell \cdot \Delta \lambda \cdot N_{cc}$

$N_{cc} = 8$

$\Delta \theta_{SSD}$ fixed

$4 \times \nu_m$

$\Delta \theta_{SSD}$ increased 2×

$\Delta \theta_{SSD} \propto \frac{\Delta \lambda \cdot N_{cc}}{\nu_m}$

$\Delta \theta_{SSD}$ increased 2× relative to 1-D SSD

- $t_c^{-1}$ decreased by 4×
Employing multiple FM modulators in 1-D reduces the peak-to-peak variations in the inverse coherence time $t_{c}^{-1}$

\[ t_{c}^{-1} \propto \ell \cdot \Delta \lambda \cdot N_{cc} \]

- $t_{c}^{-1}$ decreased by 4×, and $\Delta \theta_{SSD}$ increased by 2× relative to 1-D SSD
- Lower $\ell$-mode performance can be kept constant by keeping the product $\Delta \lambda \cdot N_{cc}$ and $\Delta \theta_{SSD}$ constant
- Targets with low IFAR are more stable to higher $\ell$-mode feedthrough
Modulator frequencies required to match the 4 color-cycle 1-D SSD are lower

\[ N_{cc} = 4 \]
Modulator frequencies required to match the 4 color-cycle 1-D SSD are lower.

- The bandwidth is reduced to 8 Å (650 GHz), the divergence is reduced to 100 μrad, and the modulator frequencies are reduced to ~50 GHz.
Simulations show that multiple FM modulators in 1-D reduces imprint to 2-D SSD levels.

1.5-MJ CH-foam target; end of acceleration

- 1-D SSD, 10.8 Å
- 1-D MultiFM, 8 Å
- 2-D SSD, 11 Å

- Simulations are in progress to confirm gain
Summary/Conclusions

Multiple FM modulators in 1-D reduces imprint to 2-D SSD levels

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