Title
Mask roughness induced LER: a rule of thumb

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**Mask Roughness LER: Random or Predictable Effect?**

When coherently illuminated, roughness on the mask couples to speckle in the aerial image. By specifying illumination conditions (coherence, \( \alpha \)), optical conditions, and mask roughness characteristics (replicated surface roughness (RSR) and correlation length), the resulting speckle statistics are largely determined.

Greater height variations (RSR) and lesser self-similarity across the mask (correlation length) mean that the mask is "rougher" in a statistical sense.

So...Can’t we push a few terms around and rearrange?  

\[
\text{ILS} = \frac{\text{mean} \cdot \text{rms}}{\text{median} \cdot \text{median}}
\]

Given the rms speckle (intensity variation), the resulting LER can be expressed in terms of the aerial image log slope (ILS). In practice, the ILS can be quickly determined using 1D aerial image simulations. To determine the illumination- and mask-specific clear-field rms speckle, a one-time 2D aerial image simulation can be performed. From these two values, the full parameter space can be reached by this analytic extension.

Image-log-slope (ILS) measures the aerial image intensity transition across an edge when features are present on a mask; e.g. from line to space.

ILS is typically used as a metric of imaging quality, and can be applied to determine the coupling from intensity variations (speckle) to line-edge movement (LER).

Larger ILS means that a given intensity variation would change line-edge position less than a smaller ILS would.

**Verification**

To verify the validity of this approach, we compared the analytic LER to the LER resulting from the full 2D aerial image simulations (extracted using SUMMIT).

Our first attempt was a poor match. A direct comparison between the clear-field speckle and feature-specific speckle at the line-edge in and the middle of the space shows great disparity. It is apparent that the presence of features affects speckle in a complex way. The simplification to clear-field speckle is thus not accurate. Another simplification is possible, however, under the long correlation limit where image plane mixing of uncorrelated elements of the mask does not occur.

For large RSR and long correlation lengths under highly coherent illumination, the LER enters a "geometric regime", whereby it is proportional to the mask slope error as it propagates through focus.

The patent disparity between clear-field and line-edge speckle provokes future research into the effect features have on coherence, as seen through speckle.

In the course of data accumulated here, simulations show that in all cases LER peaks for mid-spatial frequency roughnesses (32nm, wafer dim.), about the resolution of our optic. Simulations will be extended to higher NA to see if this is coincidental.

An analytic solution exists for mask roughness induced LER. For the case that line-edge speckle matches closely with clear-field speckle in the limit of long correlation lengths, it provides a powerful, fast method to obtain LER. Otherwise, this method provides a clean proof-of-principle.