Analysis of Variation Sources in Ring Oscillator Layouts

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6.780 Term Project

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Agenda

- Acknowledgment of Original work
- Methods
- Areas for Exploration
    - Polysilicon Density Effects
    - Single chips vs. 'superchip'
    - Two way effects
- Results
- Conclusions

Acknowledgement of Original Work

- Based on Karen M. Gonzalez-Valentin's Master thesis: "Extraction of Variation Sources due to Layout Practices"
- Multiple ring oscillator structures on 35 chips
- Conclusions:
    - Poly Density changes frequency by 2.5%
    - Finger spacing has significant effect
   - Vertical ring oscillators also significant
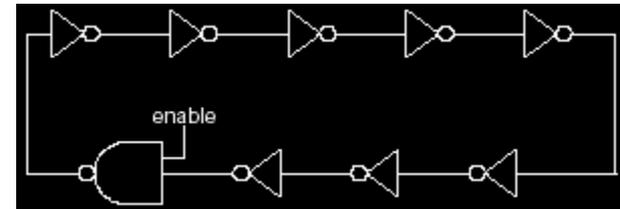
Methods

- Compiled data for aggregate 'superchip'
- Used JMP-IN
  - Fit model for polysilicon density
  - Two way interactions – least squares regression
- Compared whether individual results within 'superchip' confidence interval
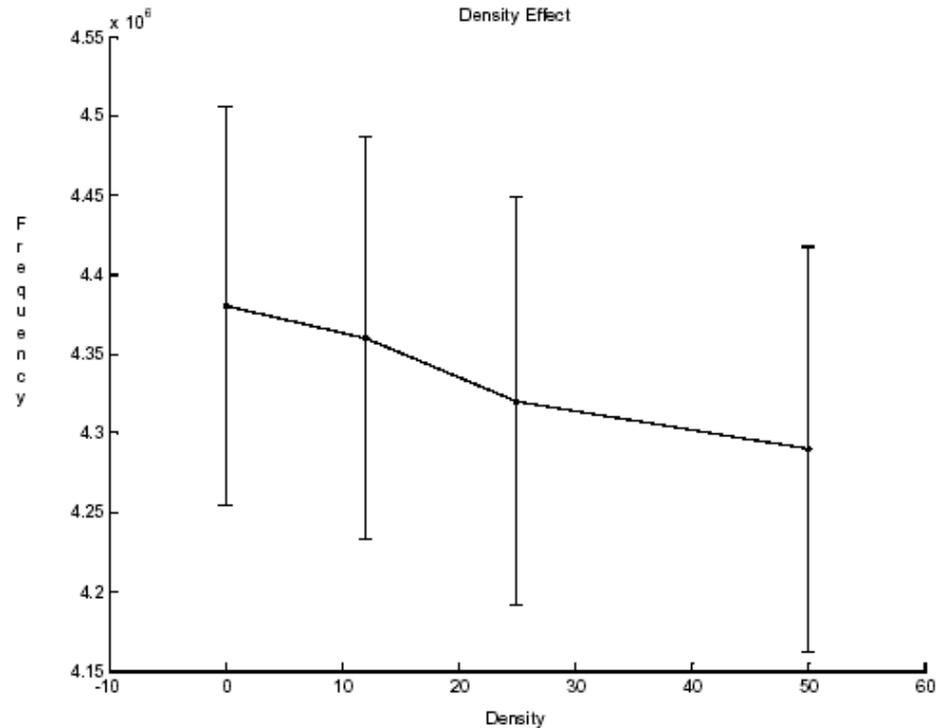
Areas for Exploration – Poly Density Effects

- Determine a model for the effect of polysilicon density on frequency

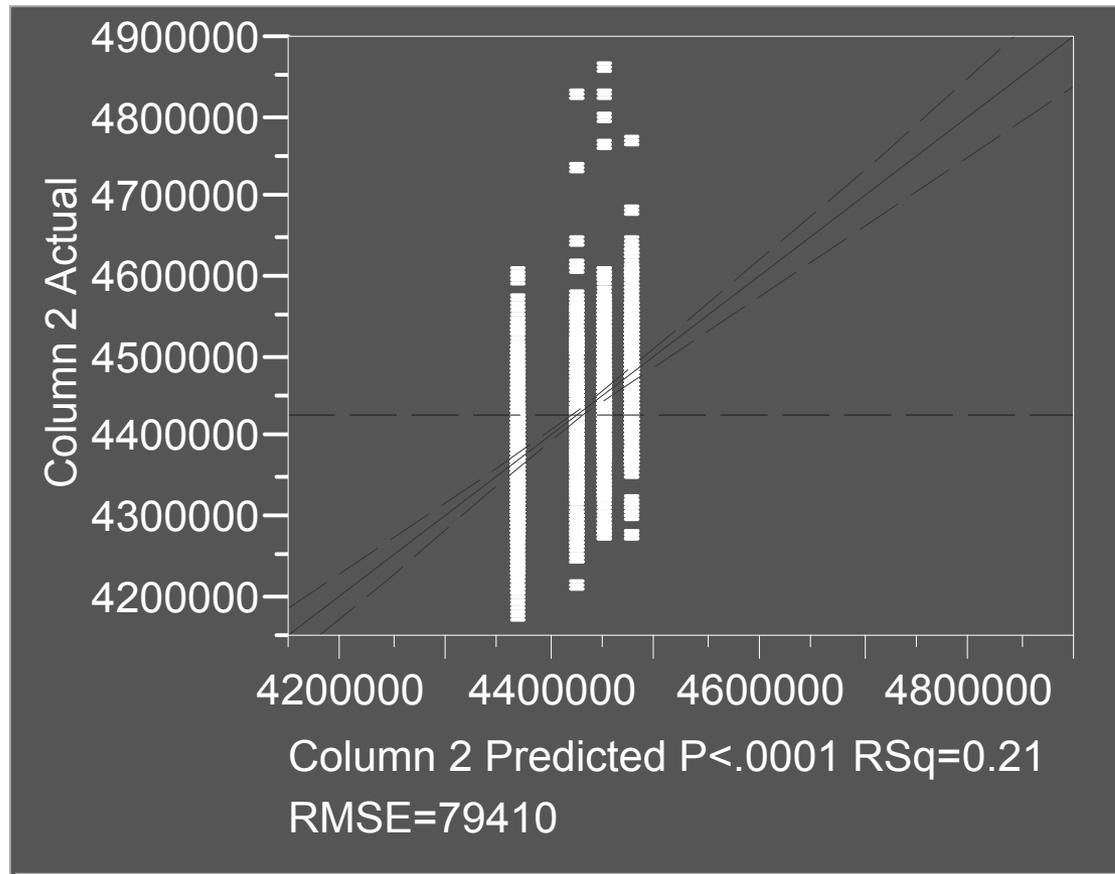| Poly	Poly	Poly
Poly	Ring Oscillator	Poly
Poly	Poly	Poly
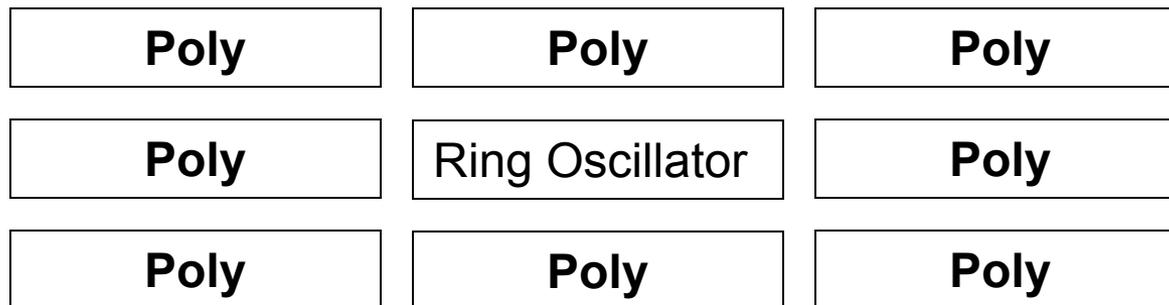
- Based on measurements for poly density = 0%, 12.5%, 25%, 50%

Fit Model for Poly Density

$$frequency = 4.477 - 0.213 * density$$
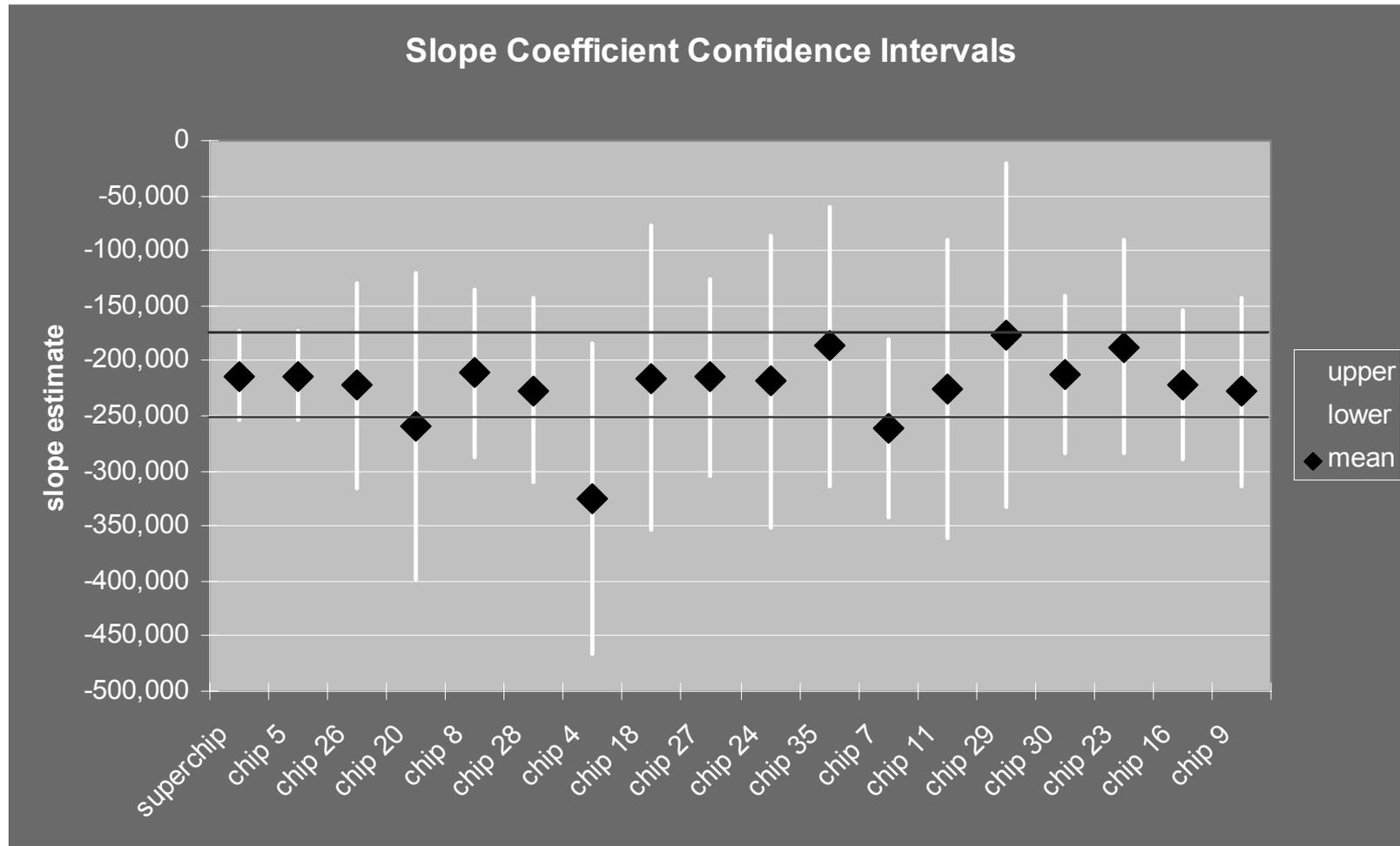
Actual by Predicted Poly Density
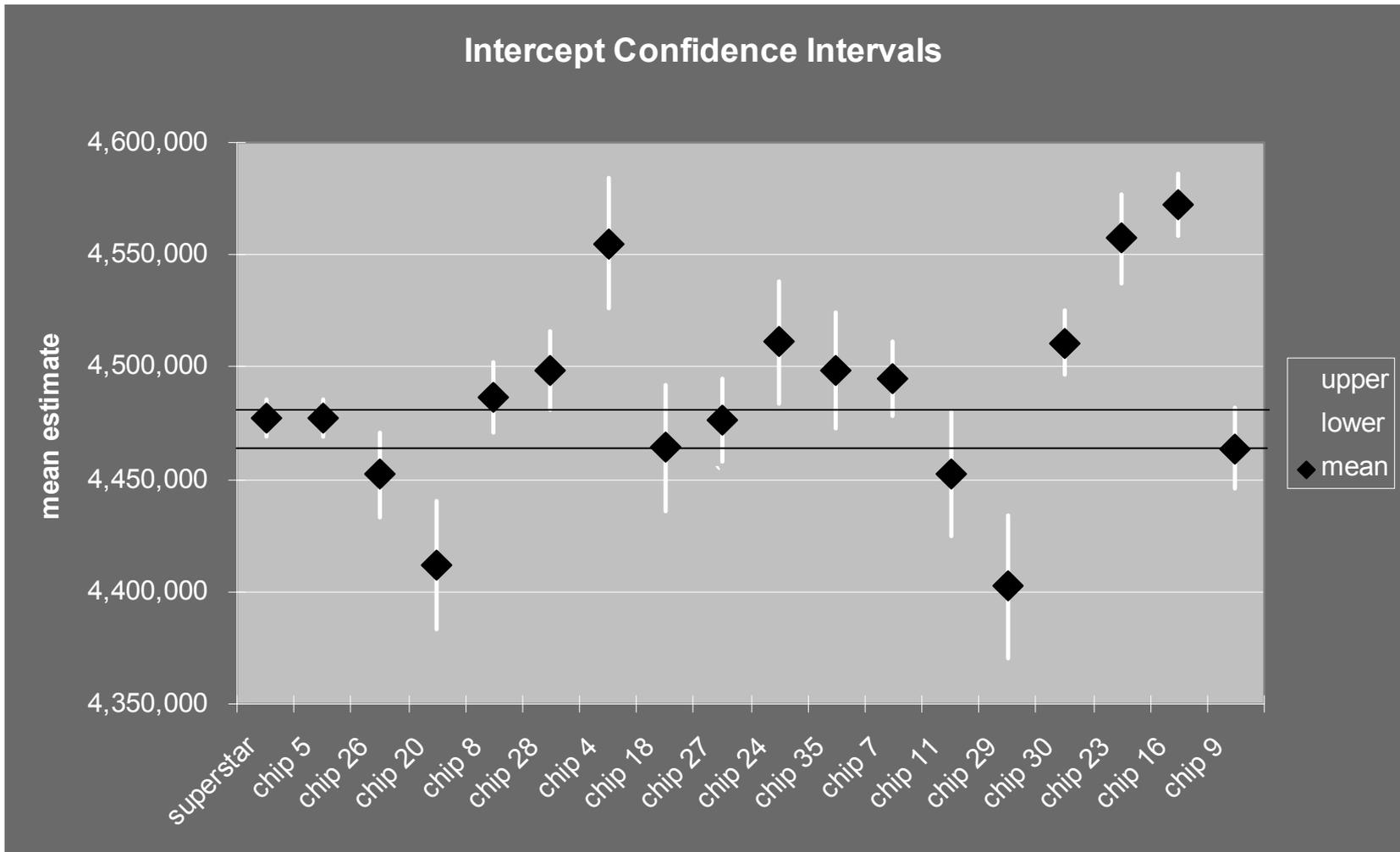
Single chips vs. 'superchip'

- Any differences between individual chip behavior and the aggregate 'superchip'?

Results – Poly Density

Slope Coefficient Confidence Intervals
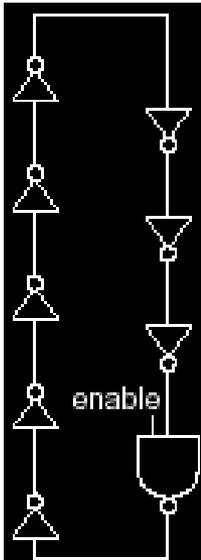
Intercept Confidence Intervals

Areas for Exploration - Two way effects with Vertical RO's

- Gonzalez-Valentin's demonstrated that Vertical RO's may be different (lower μ, larger σ)
  - May be due to mask making bias or ion implantation effect
- Next question:
  - Are these vertical effects truly significant?
  - Are there any effect interactions in the data set?

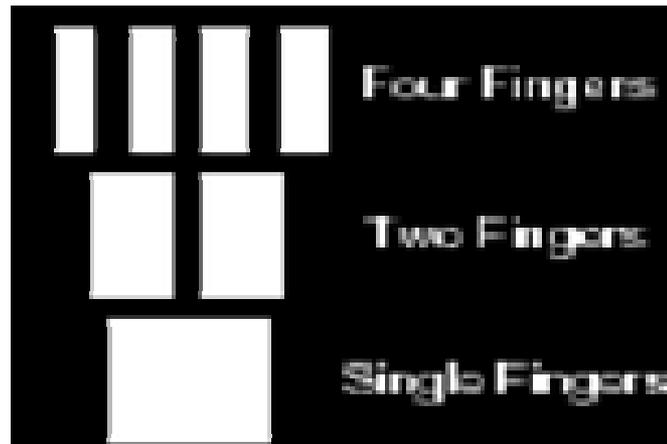# Vertical RO's versus 3x spacing

- Does line spacing have a significant effect on frequency?
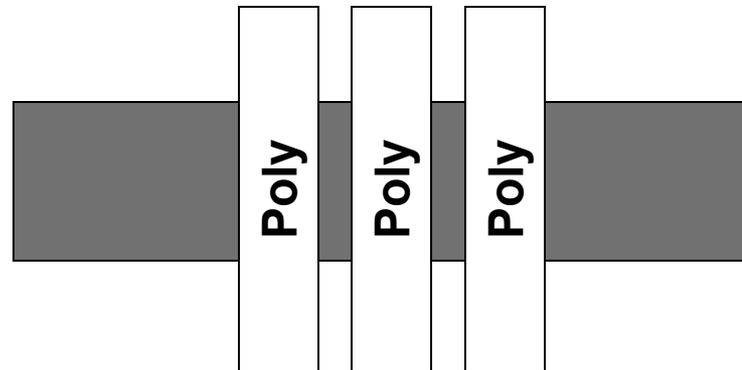
- Significant interaction with Vertical RO's?

Vertical RO's vs Single Finger

- Canonical RO has multiple fingers
  - Does a single finger with same effective gate length have a different effect?

- Significant interaction with Vertical RO's?

Two way interactions

Vertical vs. 3x spacing

- Both main effects are significant (<0.001)
- Cross term not significant

Vertical vs. single finger

- Both main effects are significant (<0.001)
- Cross term is <u>significant</u> (<0.001), but magnitude is minimal

Summary of Fit

RSquare	0.442632
RSquare Adj	0.442533
Root Mean Square Error	121798.8
Mean of Response	4411380
Observations (or Sum Wgts)	17010

Avg. RSquare for individual chips: **0.887206**

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4363792.7	1153.876	3781.9	0.0000
vertical	-22979.12	1153.876	-19.91	<.0001
single finger	-110366.5	1153.876	-95.65	0.0000
vertical*single finger	7898.9525	1153.876	6.85	<.0001

Fit of 'superchip' poor

- 'Superchip' R^2 values were much worse than the individual chips
- Fit affected by some significant outliers:

Y Actual

13142857
9857142.9
6571428.6

4000000 7000000 10000000 13000000

Y Predicted P0.0000 RSq=0.44
RMSE=121799
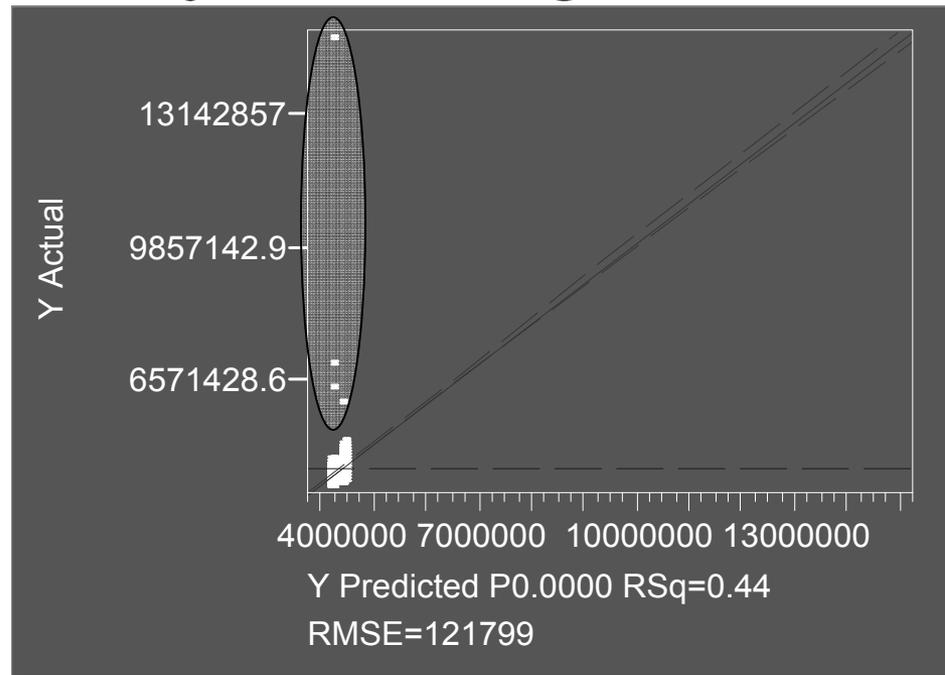
Conclusions

- All main effects inspected in paper were significant

- Model fit for polysilicon density effect
  - 50% Δ in density = 3% Δ in frequency
  - Density has a consistent effect over multiple individual chips

- Significant but small interaction between vertical RO's and single finger

Questions?