



Retarding Potential Analyzer Design: Documentation for Summer 2020 Pathways Rotation:

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TECHNOLOGY DRIVES EXPLORATION



Outline



- 1. Introduction**
- 2. Goals**
- 3. Critical Challenges**
- 4. Design Evolution**
- 5. PDR Model**
- 6. PDR Summary**
- 7. CDR/Final Model**
- 8. Solution to Challenges**
- 9. Key Take Aways/Forward Plan**
- 10. Detailed Design Documentation**

Introduction: Project Description



Introduction

Goals

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Design Evolution

PDR Model

PDR Summary

Final Model

Solutions to Challenges

Key Take Aways

- Complete design of a new Retarding Potential Analyzer (RPA)
- Using the current GRC design as reference, address design deficiencies of the current probe and incorporate lessons learned by LTS researches
- Design shall be scalable (specifically to small sizes) to make it more amenable to cathode studies
- **The overall goal is to make a new RPA that is smaller than its baseline**

Why Scale an RPA?



Introduction

Why Scale an RPA?

Overall Objectives

Goal Objectives

Critical Challenges

Evolution

PDR Model

PDR/IDR Results

CDR Model

CDR Results

Solutions to Challenges

Key Take Aways

- **Existing AFRL design has many good features**
 - Grid spacing appears to be well-designed for EP plasmas
 - General mechanical design is robust and simple to build
 - No overly expensive or complicated parts
- **But challenges exist:**
 - Design already uses 4-40 screws, so going much smaller becomes problematic
 - There is a lot of “wasted space” in the design (compare “actual diameter” to “measurement diameter”: 3” compared to 0.5”)

Why is Designing an RPA Challenging?



Let's understand the physics challenges in designing an RPA

Introduction

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PDR Model

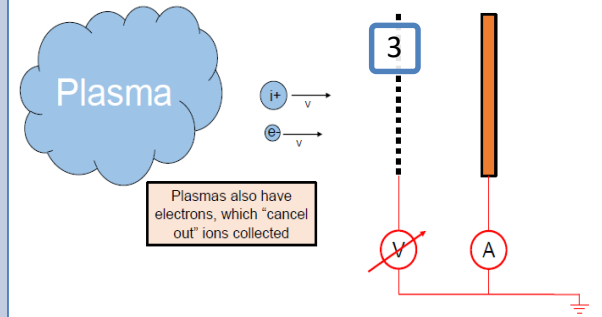
PDR Summary

Final Model

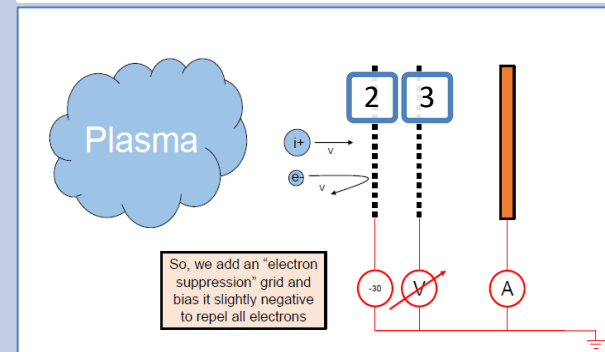
Solutions to Challenges

Key Take Aways

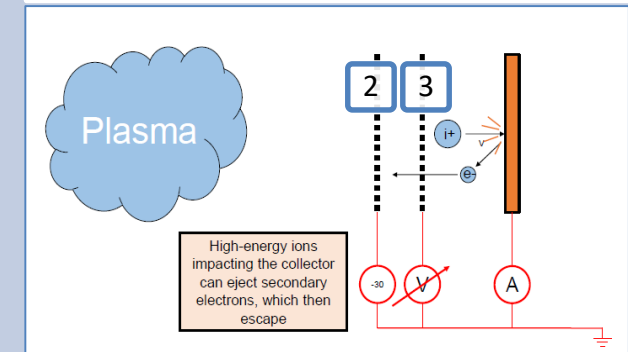
Grid 3



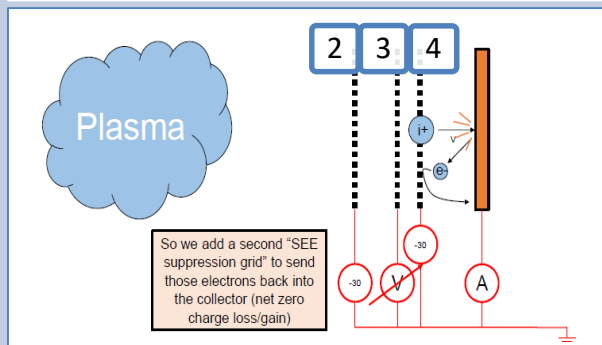
Grid 2 and 3



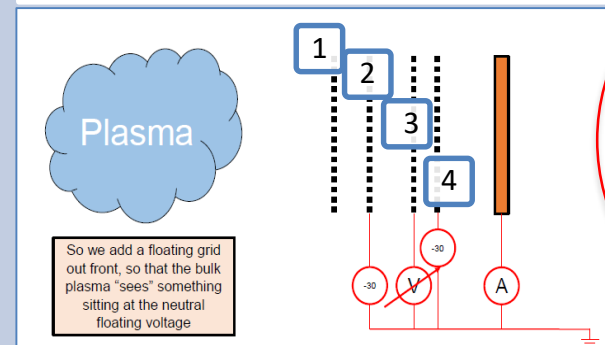
Grid 2 and 3



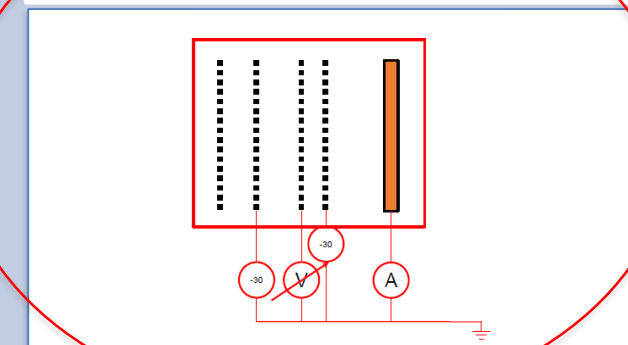
Grid 2, 3, and 4



Grid 1-4



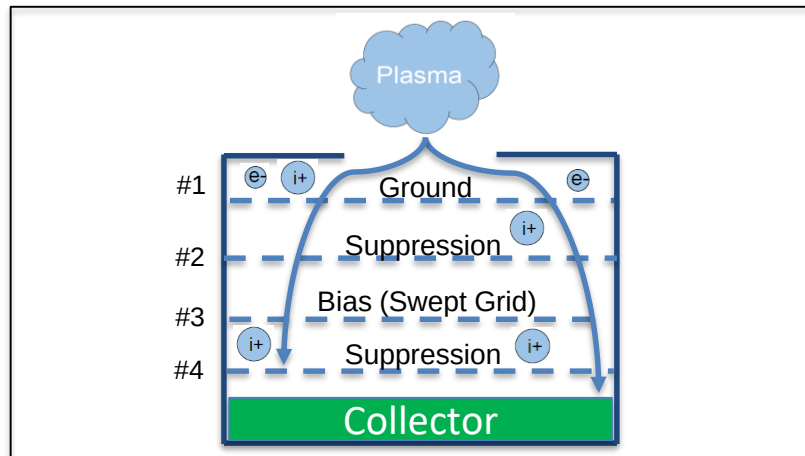
Results in a 4-grid RPA



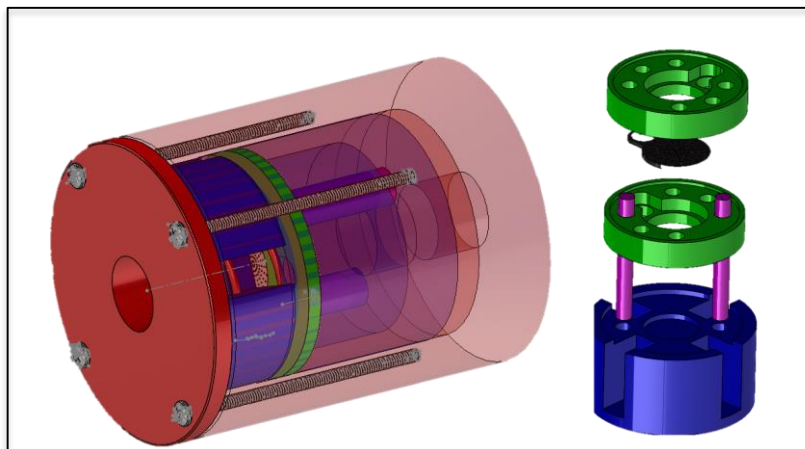
Critical Design Challenges

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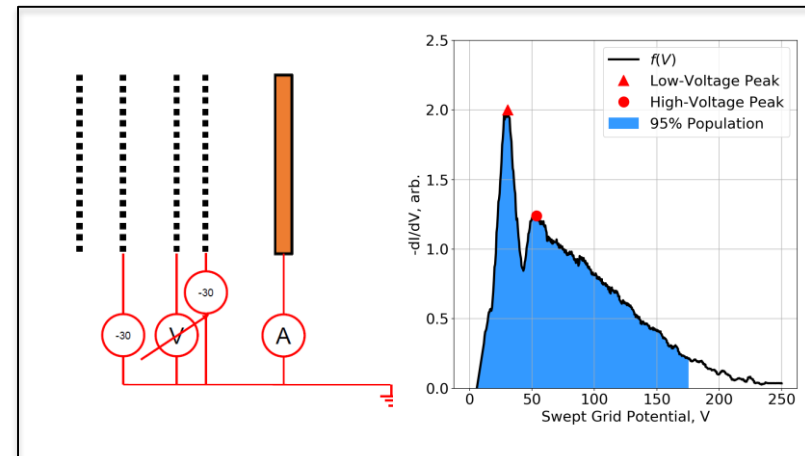
Plasma Physics and Material Interaction



Mechanical Design



Electrical Design



Unknown?



Manufacturing and Cost Analysis



Goals: Overall Goals

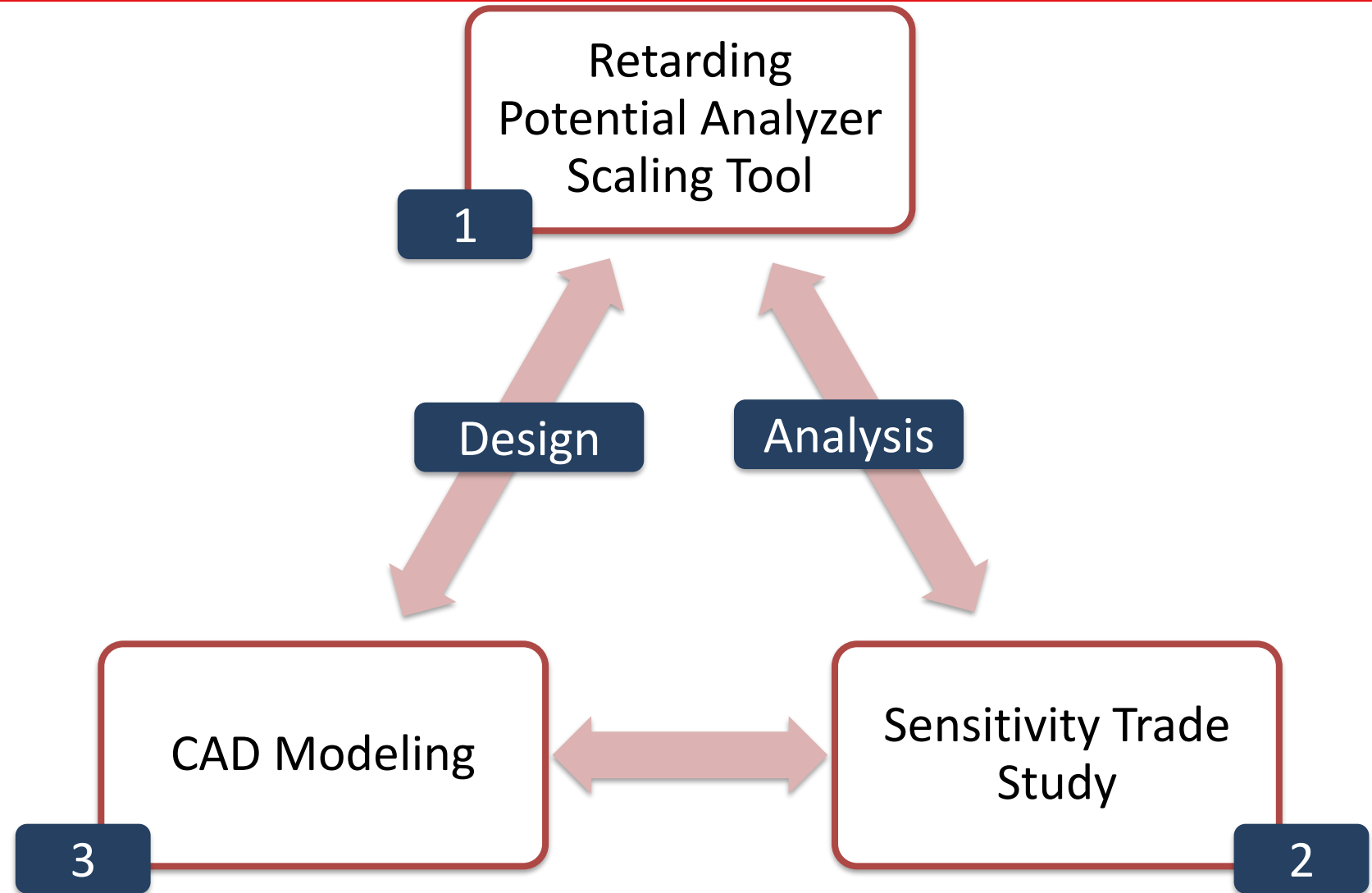
[Introduction](#)[Goals](#)[Critical Challenges](#)[Design Evolution](#)[PDR Model](#)[PDR Summary](#)[Final Model](#)[Solutions to Challenges](#)[Key Take Aways](#)

- **Design and deliver a scaling calculator tool for sizing of RPAs**
 - Flexible RPA tool to help decision makers to explore design envelope
- **Design a smaller Retarding Potential Analyzer**
 - Leverage existing designs to make improvements
 - Apply lessons learned from AFRL and other plasma diagnostics experience
 - Reduce size of new design compared to it's baseline (at least 15%)
 - Insure ease to assemble and manufacture
 - Capable of operating in cathode plasma
- **Deliver final design package with:**
 - Engineering drawings
 - Design document
 - Assembly/work instructions

Multi-Point Approach



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Current Design
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RPA Scaling Tool



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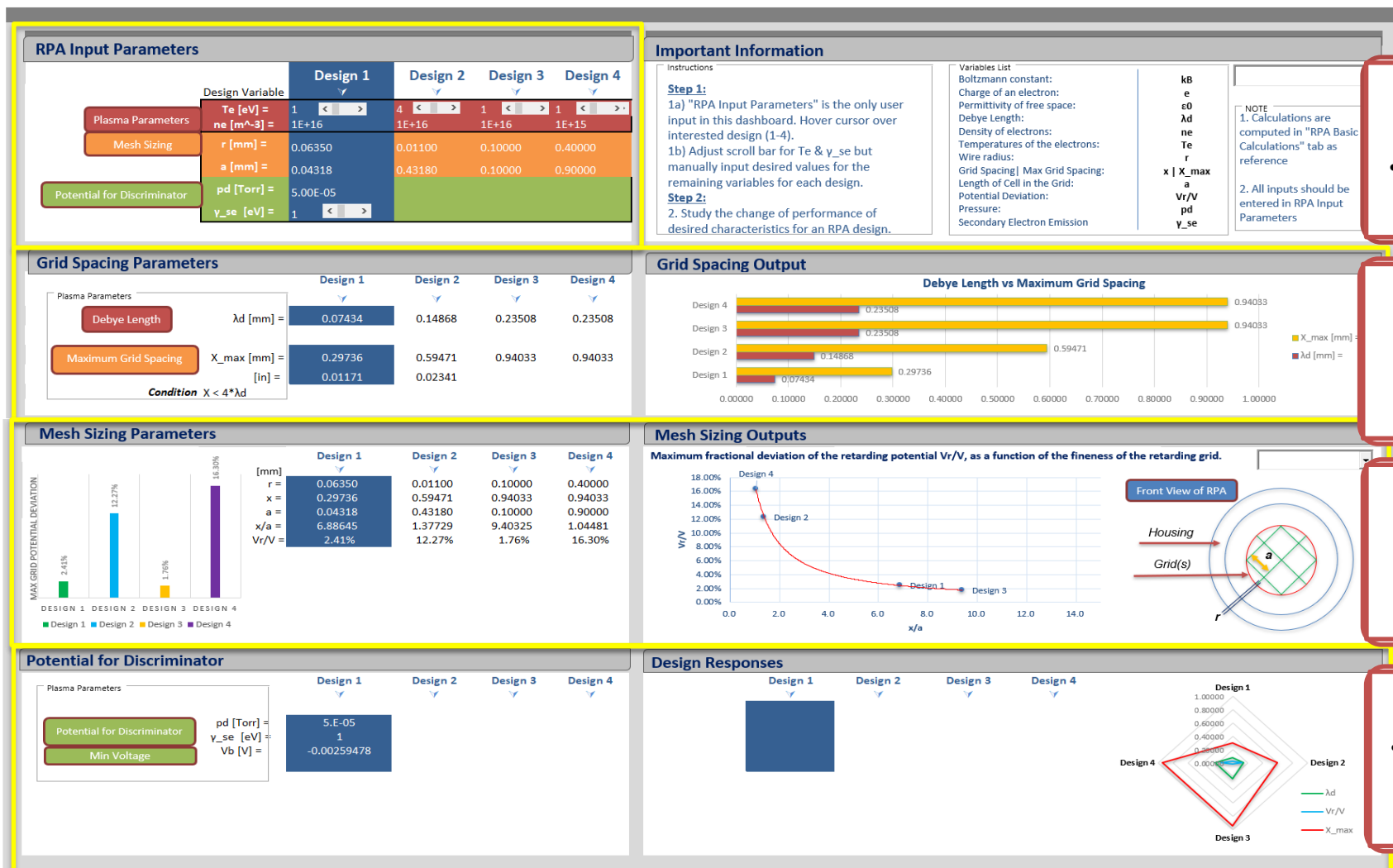
RPA Scaling Tool

Trade Study

Design/Analysis

References

Retarding Potential Analyzer (RPA) Concept Tool





Sensitivity Study



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RPA Scaling Tool

Trade Study

Design/Analysis

References

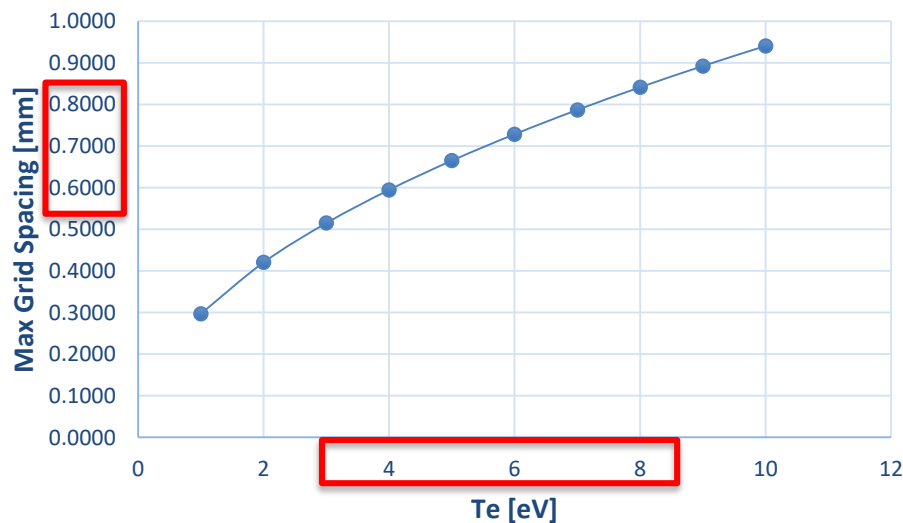
RPA Overall Length Factor

- **Scaling:** Grid Spacing (length) – Debye length
- **Driving factor:** Function of temperature (T_e) and plasma electron density (n_e)
- **Condition:** Must satisfy the condition of $x < 4\lambda_d$

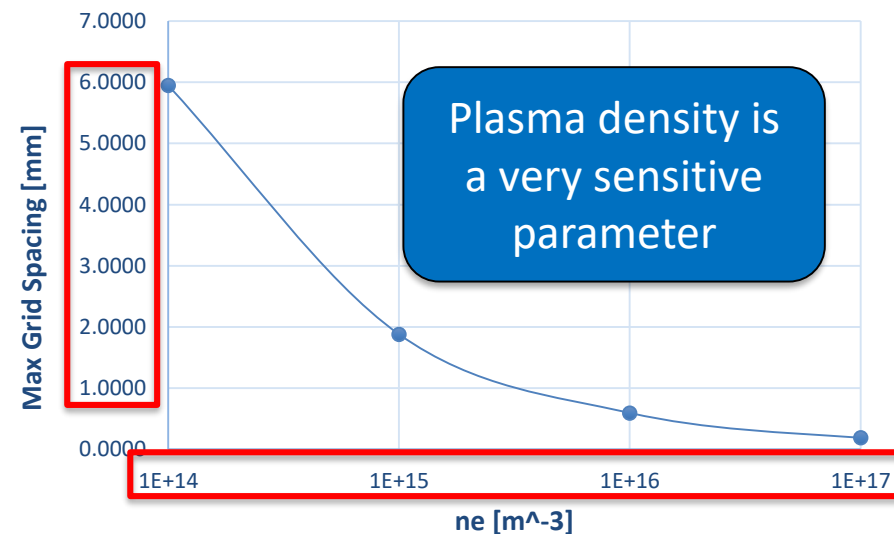
RPA Overall Diameter Factor

- **Scaling:** Mesh Wire Spacing – Debye length
- **Driving factor:** Function of temperature (T_e), plasma electron density (n_e), wire radius (r), grid spacing (x), and length of cell in the grid (a)
- **Condition:** Largest deviation in the potential field surround grid:

Max Grid Spacing vs Plasma Temperature
[Fixed Plasma Density $n_e = 1.0E16 \text{ m}^{-3}$]



Max Grid Spacing vs Plasma Density
[Fixed Plasma Temperature = 4eV]



Primary Design Concepts



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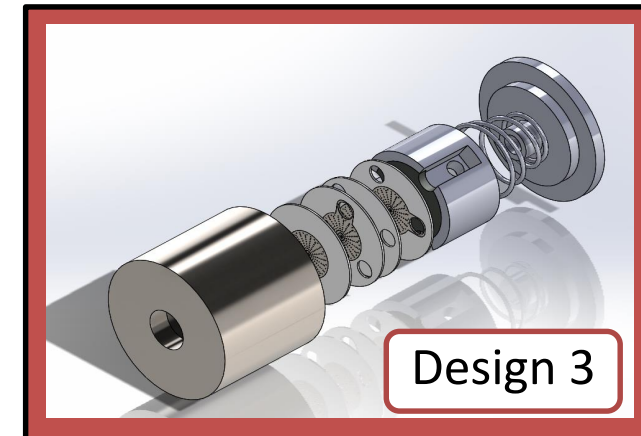
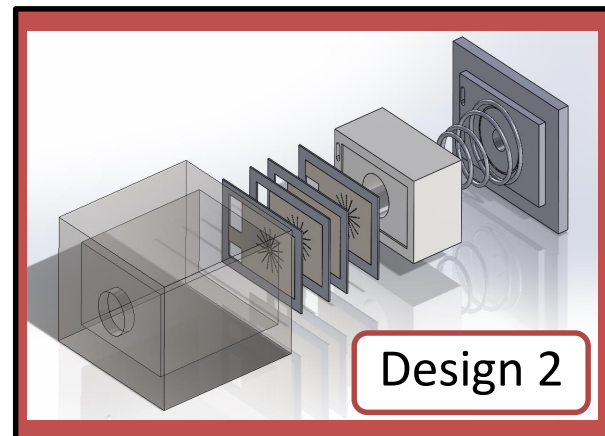
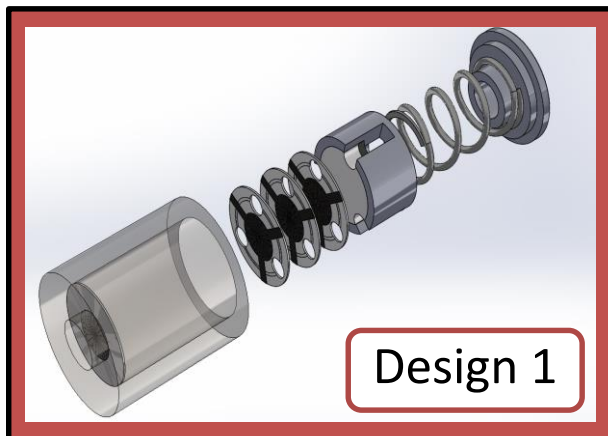
Problem

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Design Concepts Overview for Each Model

- Basic specifications
- Unique Characteristics
- Critical Parts
- Assembly Outlook
- Decision Matrix
- Next Steps



Design 1



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Design 1

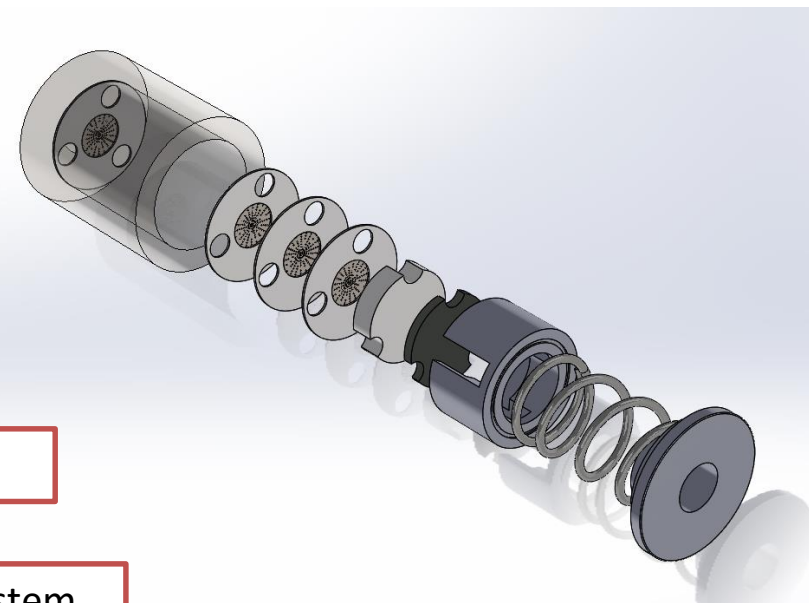
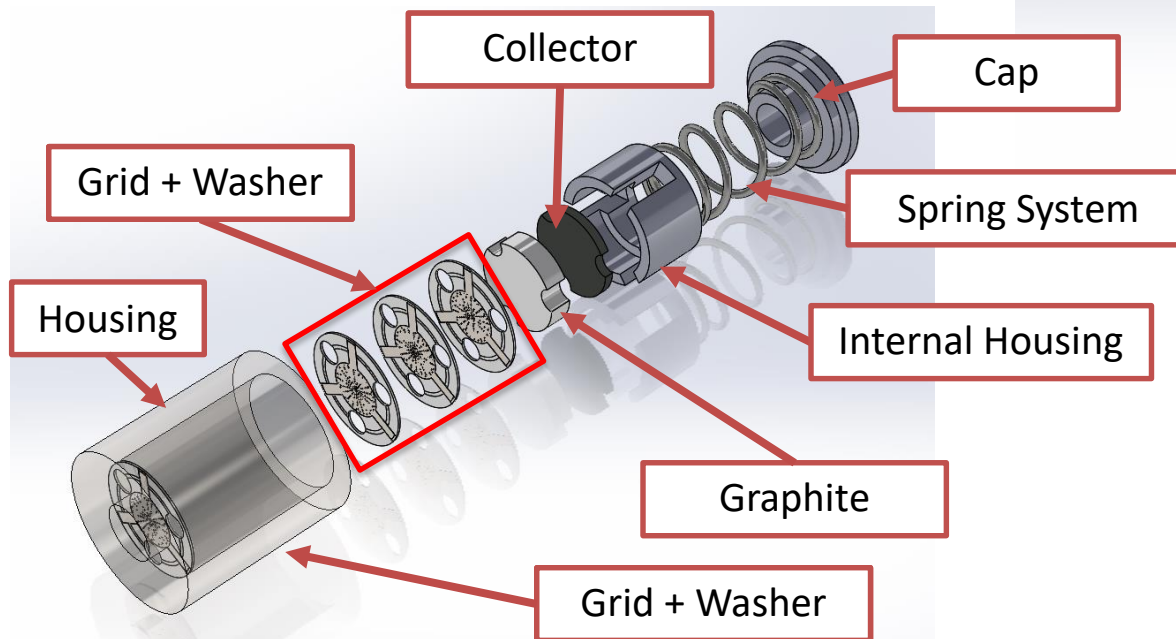
Design 2

Design 3

References

Specifications of Design 1: “The Star”

- Overall Length/Overall Width: 2.13in x 1.75in
- Could use 2-56 fasteners
- Aperture Hole: 0.61in
- Grids sit flushed into washer, with “star” like tabs for electrical connections
- Collector has own “assembly” that is multi-purposed
 - Housing holds both a graphite (sputtering) and conductor (collector) piece
 - Flushes washers together at correct distances with help of spring



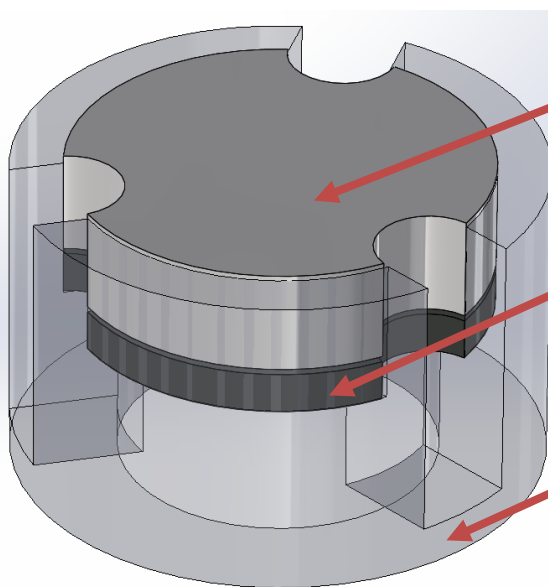
Design 1 – Critical Parts

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- **Collector and Housing:**

- **Housing**

- Contains housing to enforce correct spacing
 - Further insulates sensitive electrical components
 - Guides wiring for assembly
 - Supports spring tension/compression from rear



Detector Graphite

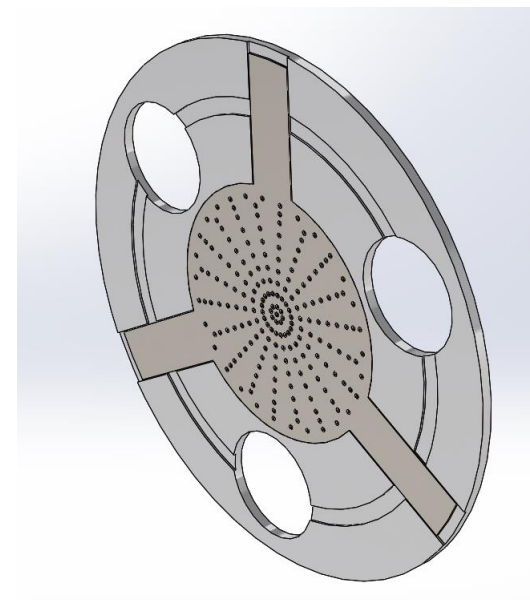
Conductor Lead

Macor

- **Washer and Grid:**

- **Collector**

- Grid is flushed into washer
 - Grooves contain path for wire/solder



Design 1 – Critical Assembly



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Design 1

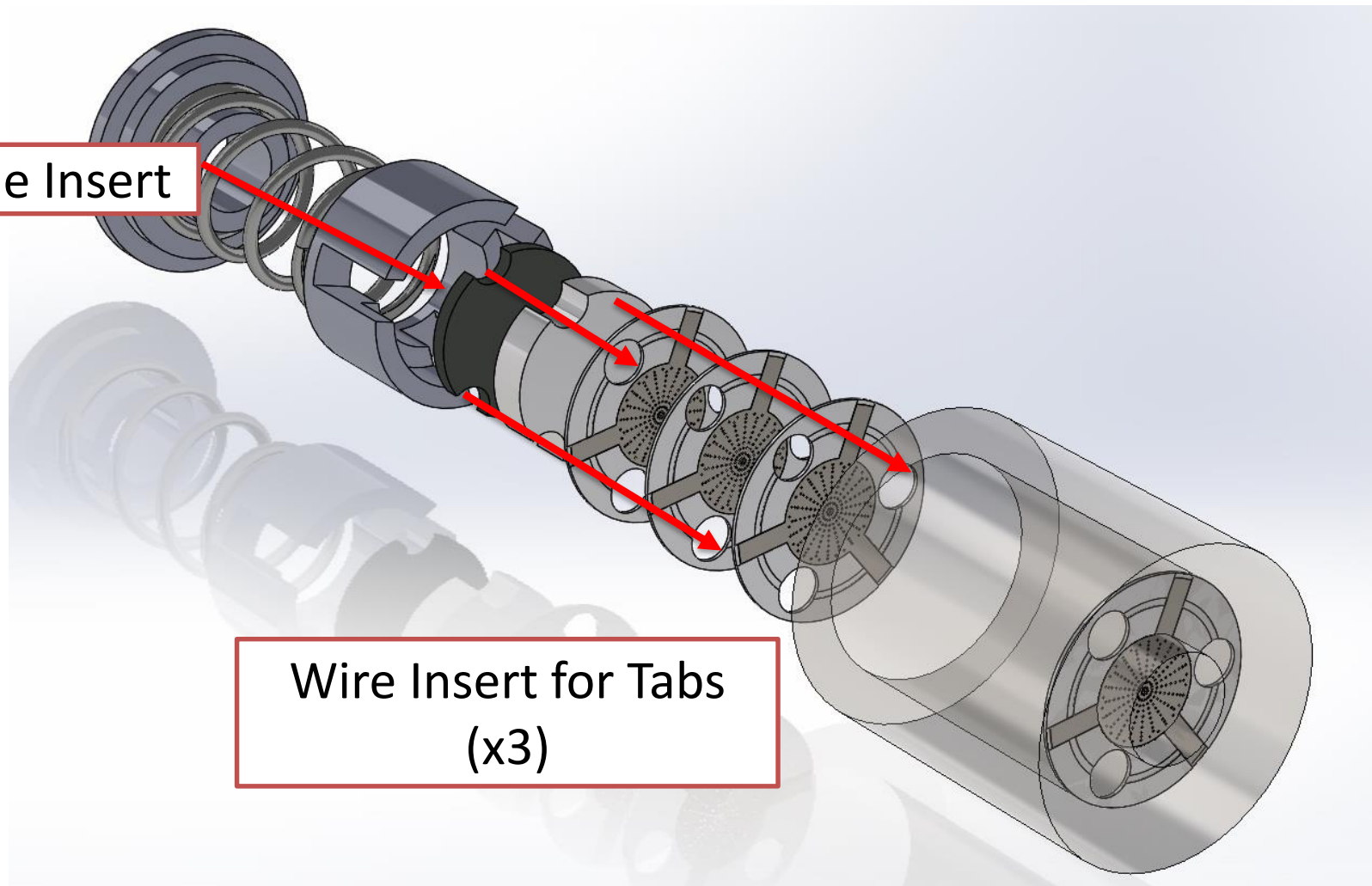
Design 2

Design 3

References

Cable Insert

Wire Insert for Tabs
(x3)



Design 1 Decision Matrix

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	[%]	Design 1 - Star	
Design Factor	Weight (W)	Value (V)	Weighted Value (V x W)
1. Ease of Manufacturing	20	5	1
2. Ability to Meet Performance	20	6	1.2
3. Size efficiency (ratio of aperture to overall size)	10	7	0.7
4. Ability to be scaled up/down	30	6	1.8
5. Risk	20	3	0.6
Weighted Total Value	100		5.3



Design 2



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Design 1

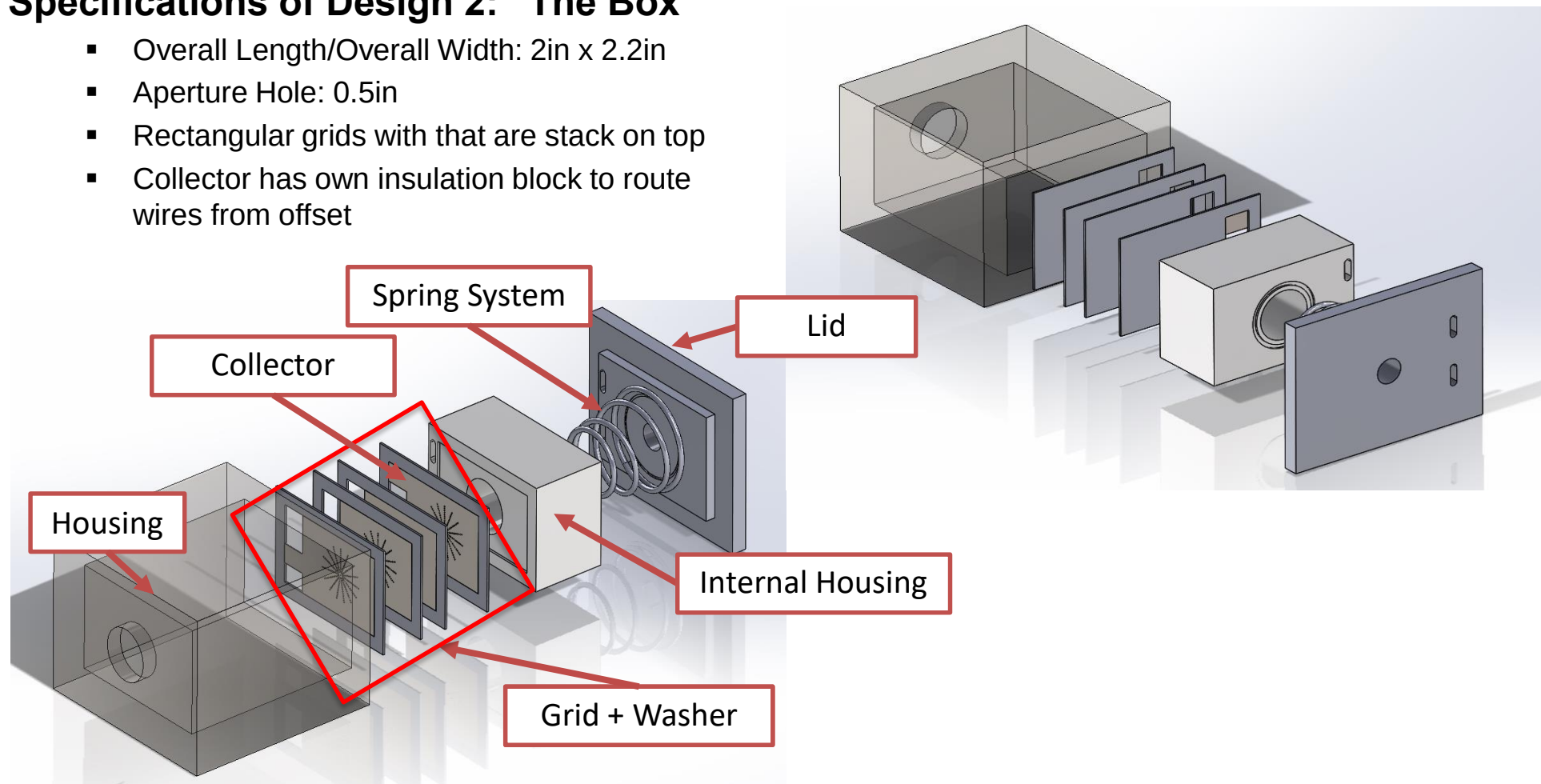
Design 2

Design 3

References

Specifications of Design 2: “The Box”

- Overall Length/Overall Width: 2in x 2.2in
- Aperture Hole: 0.5in
- Rectangular grids with that are stack on top
- Collector has own insulation block to route wires from offset

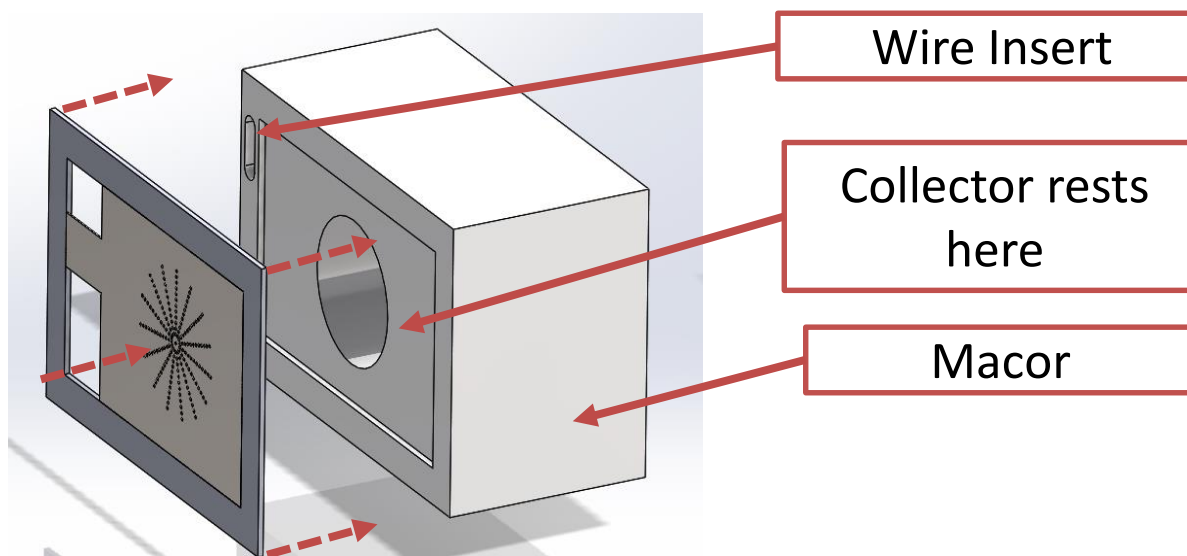


Design 2 – Critical Parts

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- **Collector and Housing:**

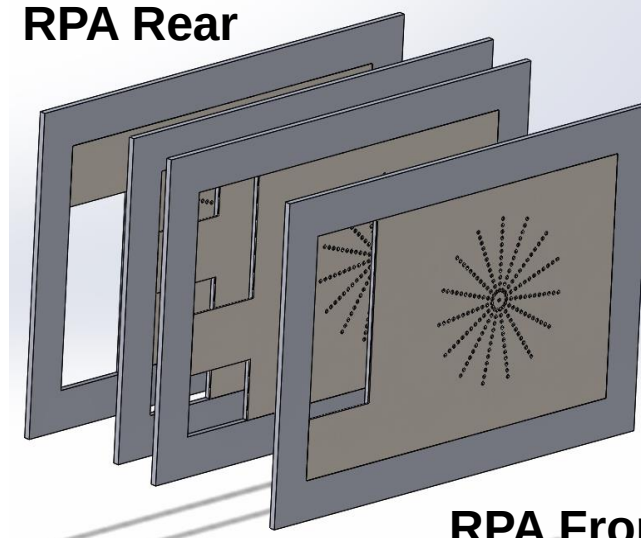
- Collector
 - Contains housing to enforce correct spacing
 - Further insulates sensitive electrical components
 - Guides wiring for assembly
 - Supports spring tension/compression from rear



- **Washer and Grid:**

- Collector
 - Grid is flushed into with rectangular tab offset

RPA Rear



RPA Front

Design 2 – Critical Assembly



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Design 1

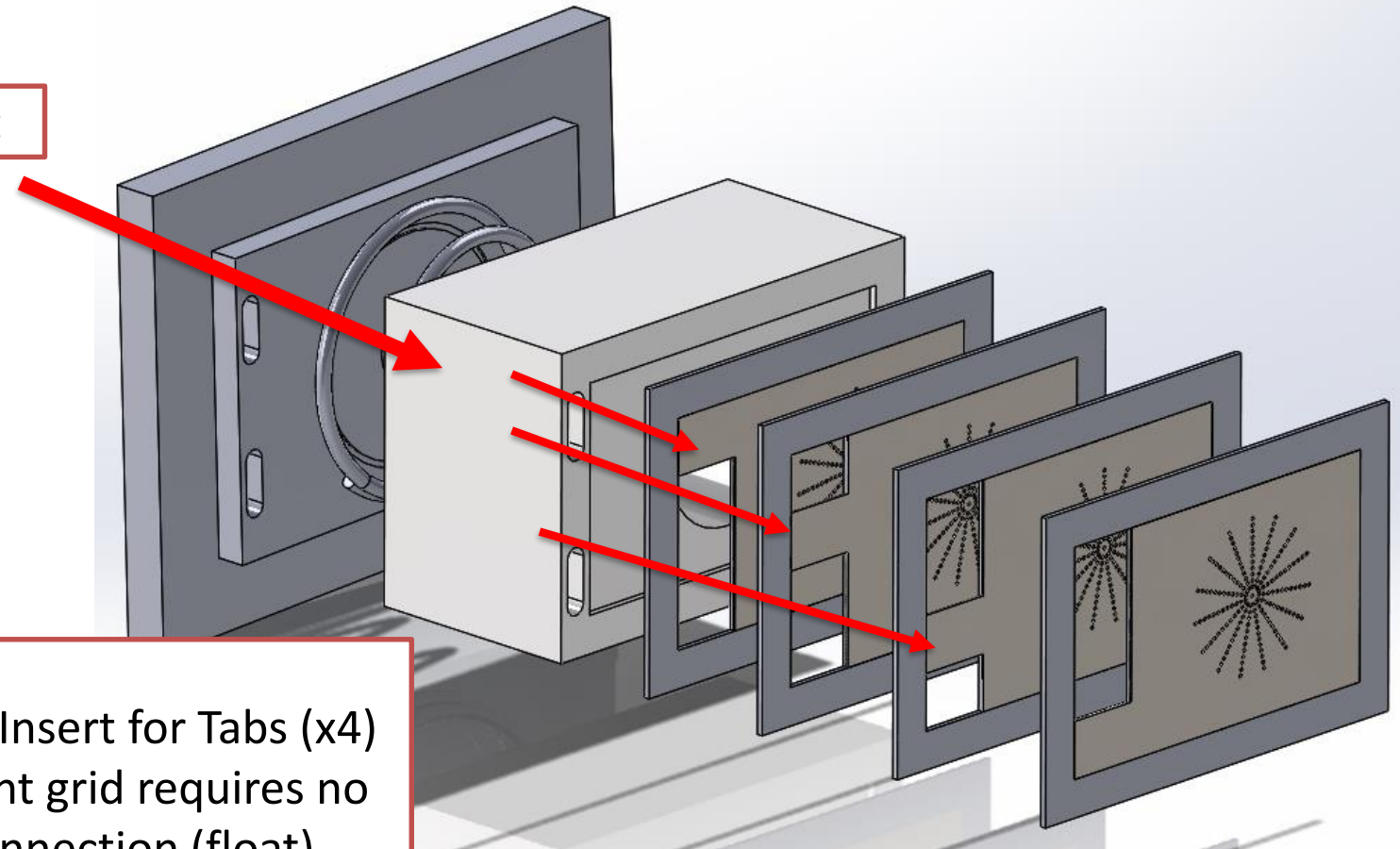
Design 2

Design 3

References

Cable Insert

Wire Insert for Tabs (x4)
– front grid requires no
connection (float)





Design 2

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	[%]	Design 2 - Box	
Design Factor	Weight (W)	Value (V)	Weighted Value (V x W)
1. Ease of Manufacturing	20	8	1.6
2. Ability to Meet Performance	20	7	1.4
3. Size efficiency (ratio of aperture to overall size)	10	9	0.9
4. Ability to be scaled up/down	30	8	2.4
5. Risk	20	4	0.8
Weighted Total Value	100		7.1



Design 3



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Design 1

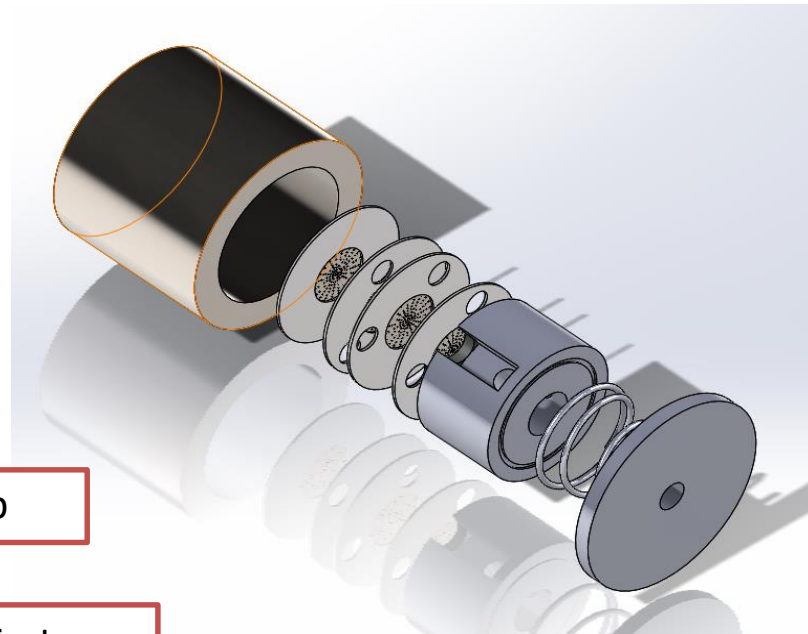
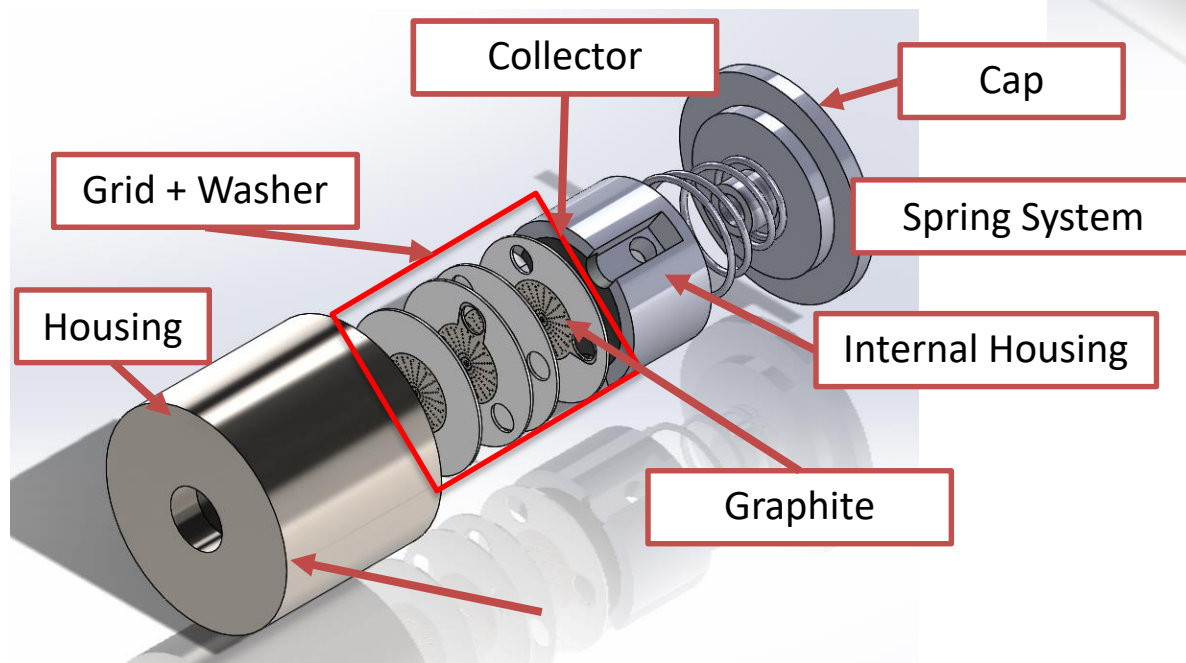
Design 2

Design 3

References

- **Specifications:**

- Overall Length/Overall Width: 1.75in x 1.5in
- Aperture Hole: 0.5in
- Grids sit flushed into washer with clock position Collector
- Macor housing is a little more complex



Design 3 – Critical Assembly



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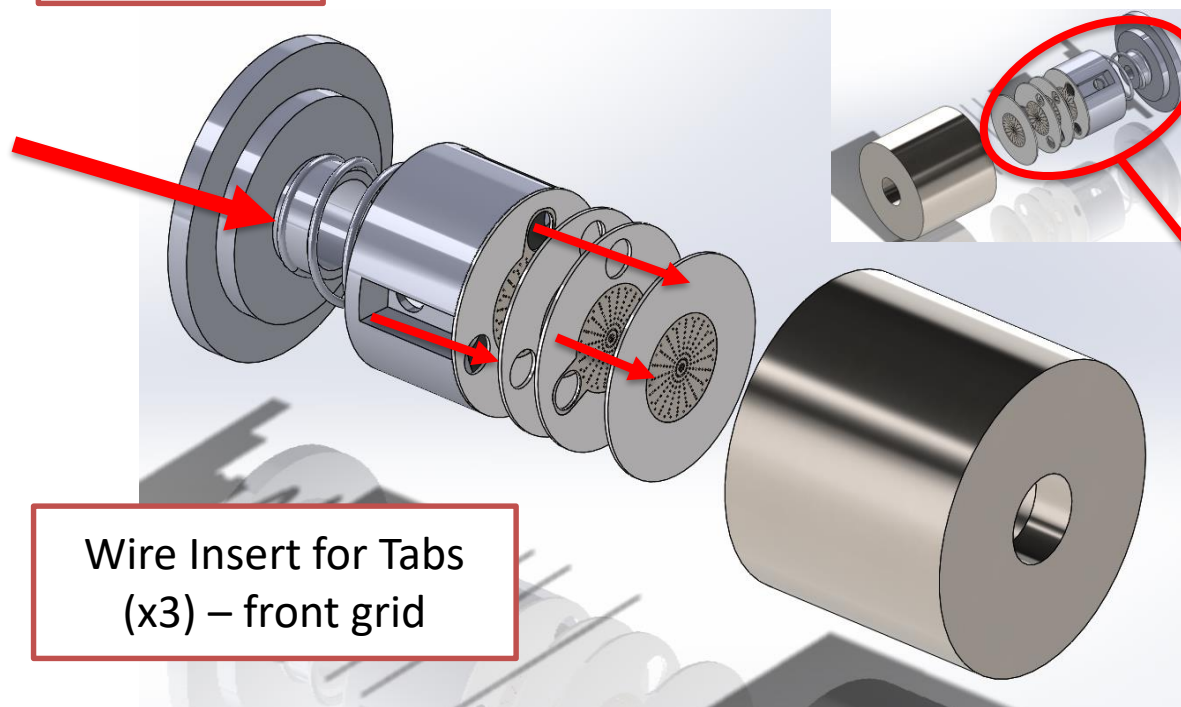
Design 1

Design 2

Design 3

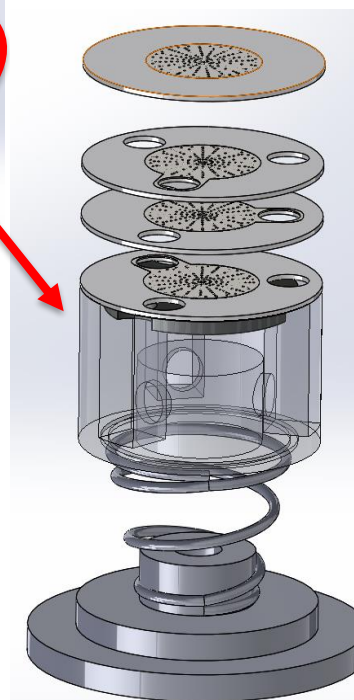
References

Cable Insert

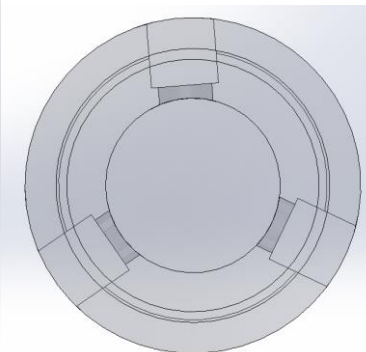


Wire Insert for Tabs
(x3) – front grid

Multi-directional path



Right side view



Under side view

Design 3 – Critical Assembly



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Design 1

Design 2

Design 3

References

	[%]	Design 3 - Stingray	
Design Factor	Weight (W)	Value (V)	Weighted Value (V x W)
1. Ease of Manufacturing	20	7	1.4
2. Ability to Meet Performance	20	8	1.6
3. Size efficiency (ratio of aperture to overall size)	10	8	0.8
4. Ability to be scaled up/down	30	9	2.7
5. Risk	20	8	1.6
Weighted Total Value	100		8.1

Recommendation

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	[%]	Design 1 - Star		Design 2 - Box		Design 3 - Stingray	
Design Factor	Weight (W)	Value (V)	Weighted Value (V x W)	Value (V)	Weighted Value (V x W)	Value (V)	Weighted Value (V x W)
1. Ease of Manufacturing	20	5	1	8	1.6	7	1.4
2. Ability to Meet Performance	20	6	1.2	7	1.4	8	1.6
3. Size efficiency (ratio of aperture to overall size)	10	7	0.7	9	0.9	8	0.8
4. Ability to be scaled up/down	30	6	1.8	8	2.4	9	2.7
5. Risk	20	3	0.6	4	0.8	8	1.6
Weighted Total Value	100		5.3		7.1		8.1

- Overall, Design 3 has the best capacity to be scaled to different sizes and is the least complex
- From design metrics shown above, **analysis recommends to proceed with Design 3, "The Stingray"**

Design Evolution



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Design Evolution

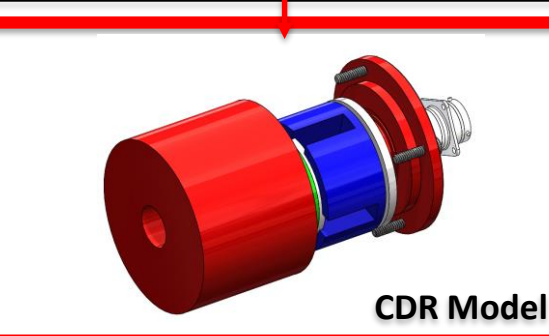
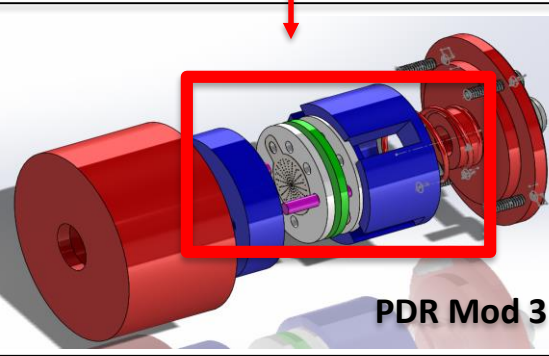
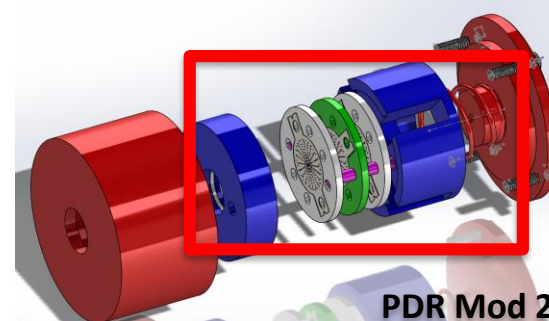
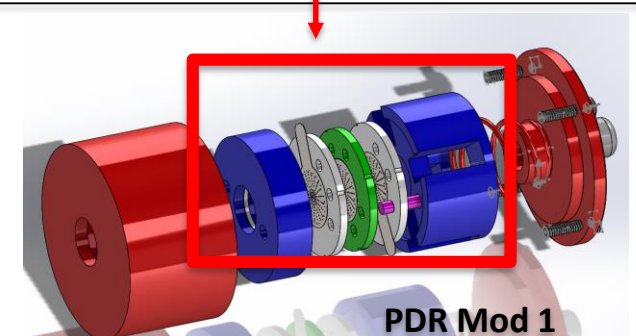
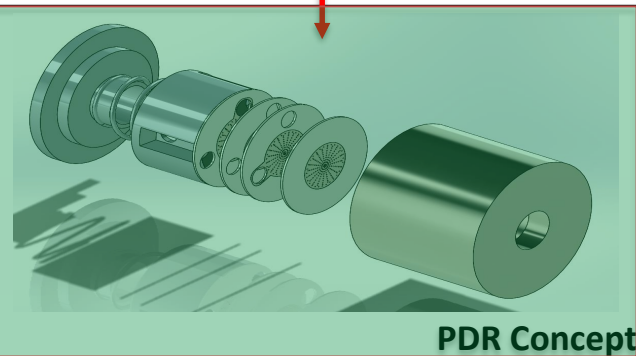
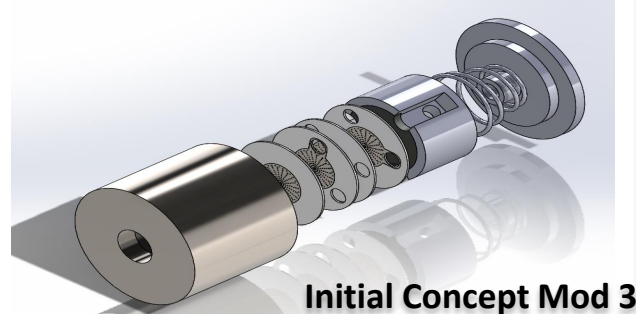
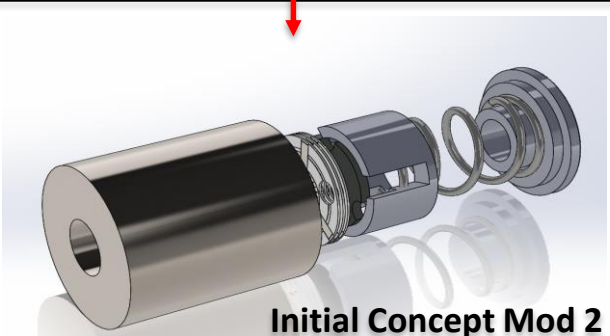
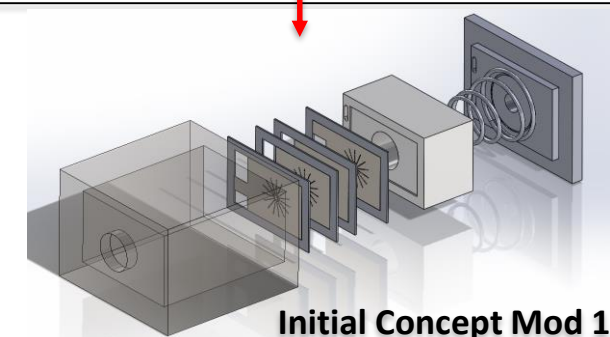
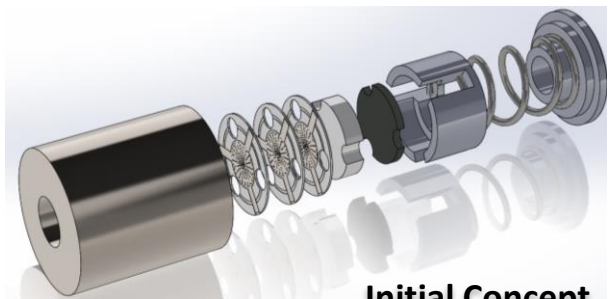
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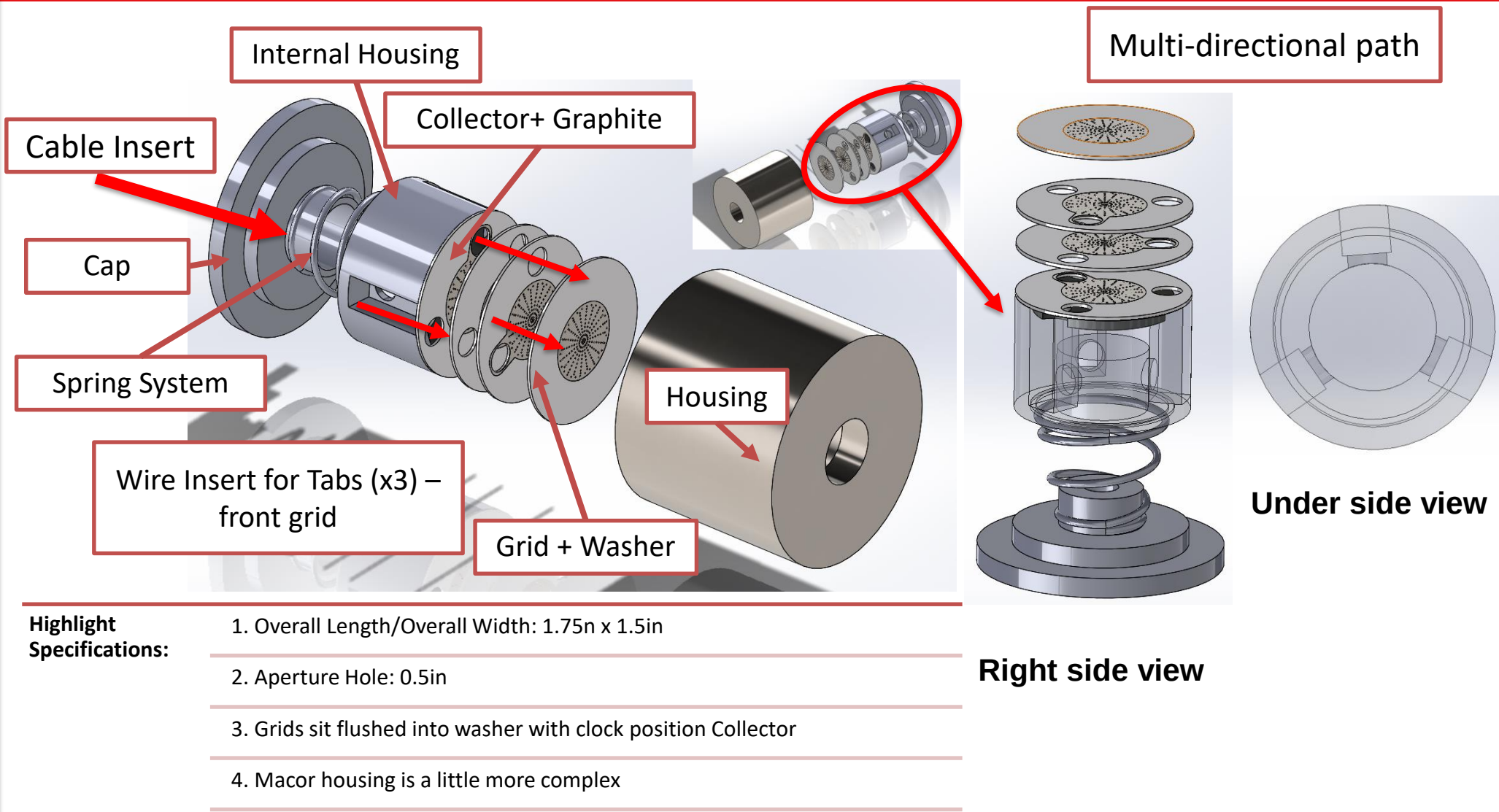
Key Take Aways



PDR Model



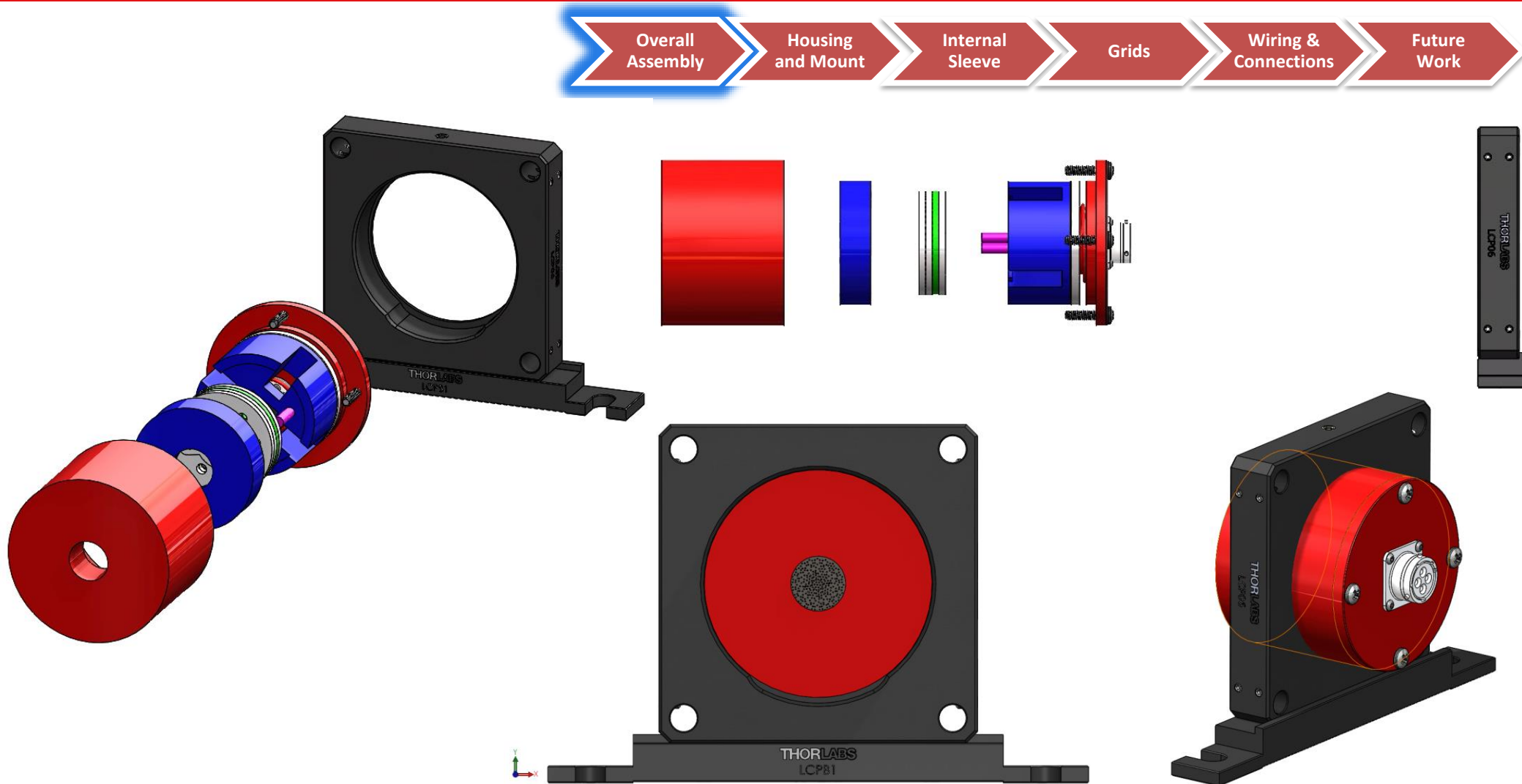
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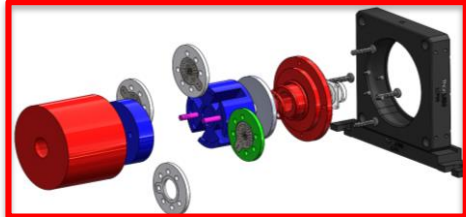
CDR Assembled Model



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CDR Model: Mechanical Design (1/2)

Overall
AssemblyHousing
and MountInternal
Sleeve

Grids

Wiring &
ConnectionsFuture
Work

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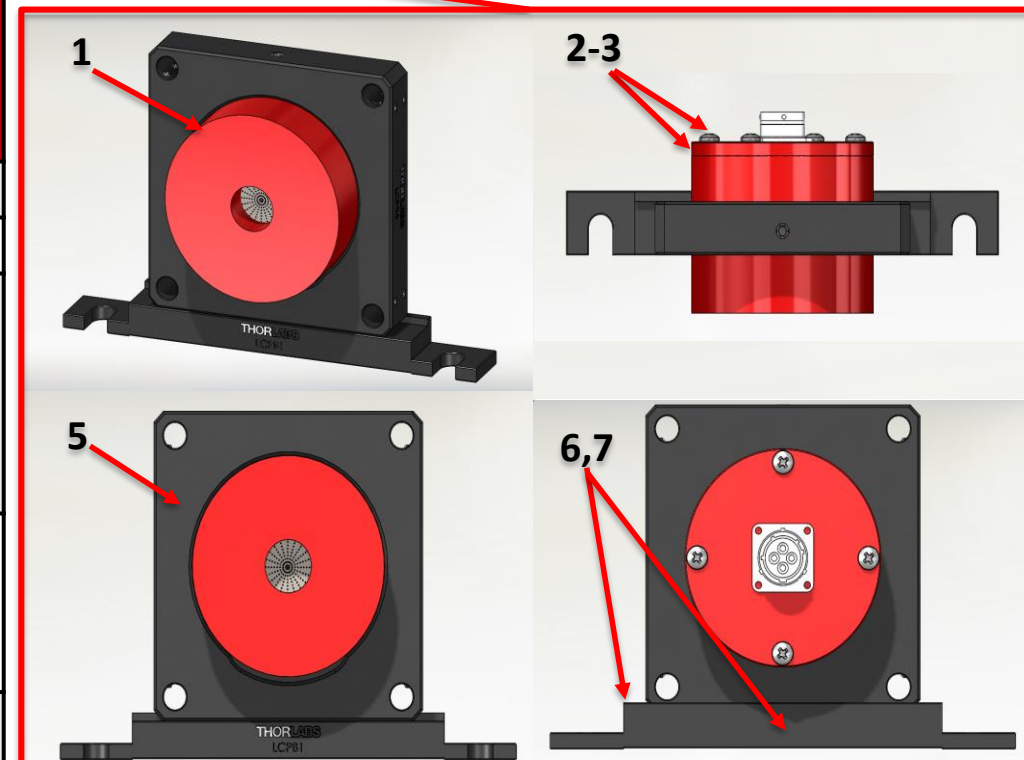
PDR Summary

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Part Parameter	Dimensions L x W [in x in] or stated	Approx. Weight [lbs]	Material	Procurement
1. RPA Housing ¹	2.0 x 1.5	0.81	SS	Custom Fab
2. RPA Cap ¹	2.0 x 0.5	0.02	SS	Custom Fab
3. RPA Housing Fasteners ¹	4-40 Thread Size, 1/2" Long, Phillips Super- Corrosion- Resistant	-	316 SS	Custom Fab
5. 60 mm Cage Plate ²	Ø2" Double- Bore Optic Mount, 8-32 Tap	0.08	Aluminu m	Thor Labs
6. Cage Plate Mounting Base ²	60 mm Cage Plate	0.03	Aluminu m	Thor Labs
7. Support Mount Fasteners ¹	#8 [M4] Cap Screw	-	316 SS	Custom Fab

****Procurement:**CF – Custom Fabrication¹TL – Thor Labs²

CDR Model: Mechanical Design (1/2)



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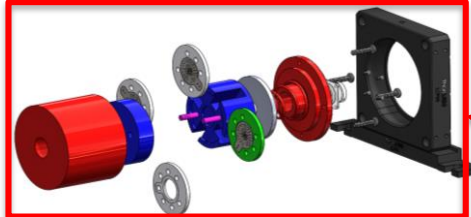
PDR Model

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Overall Assembly

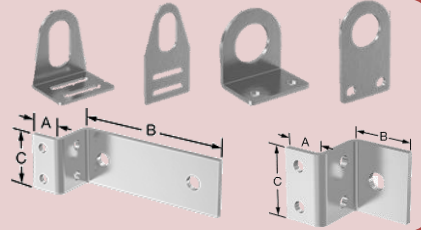
Housing and Mount

Internal Sleeve

Grids

Wiring & Connections

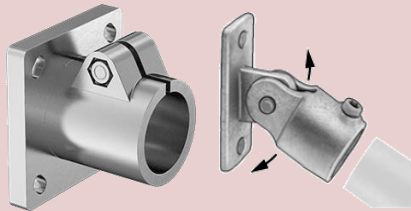
Future Work



Rectangular

Pros: Simple, easy to machine

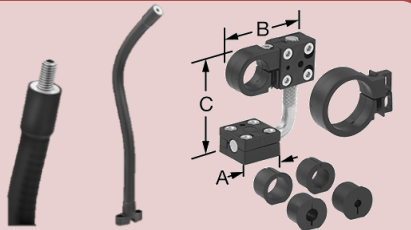
Cons: Fixed, limited adjustability



Circular

Pros: Adjustability

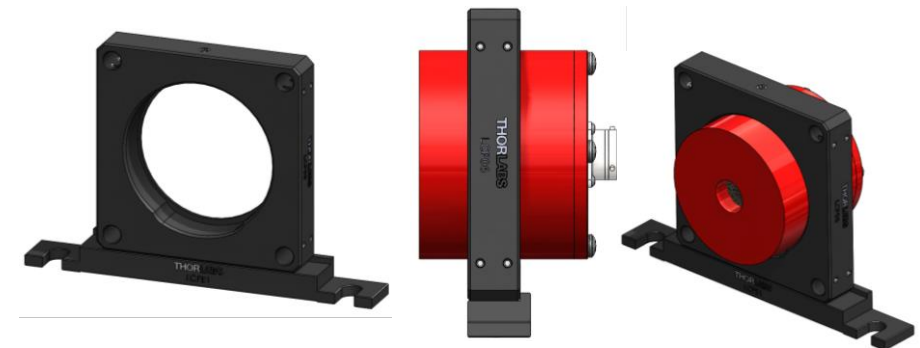
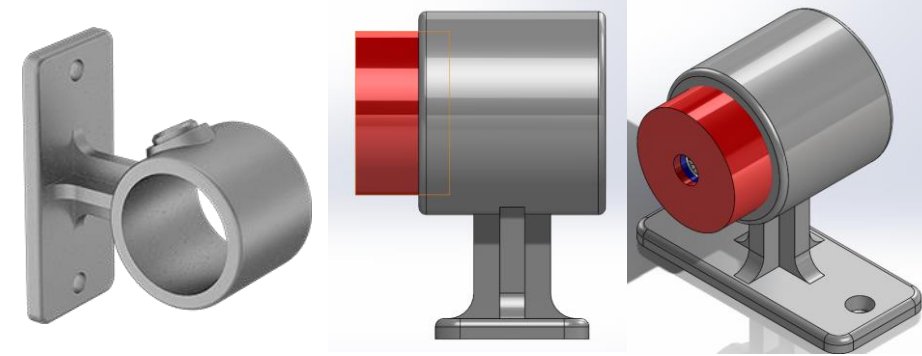
Cons: Expensive, difficulty to wire system



Non-conventional

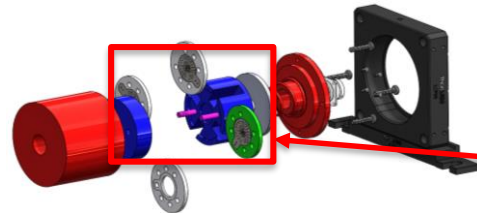
Pros: 360 degree rotation, dynamic movements

Cons: Very expensive, sophisticated vacuum compatibility



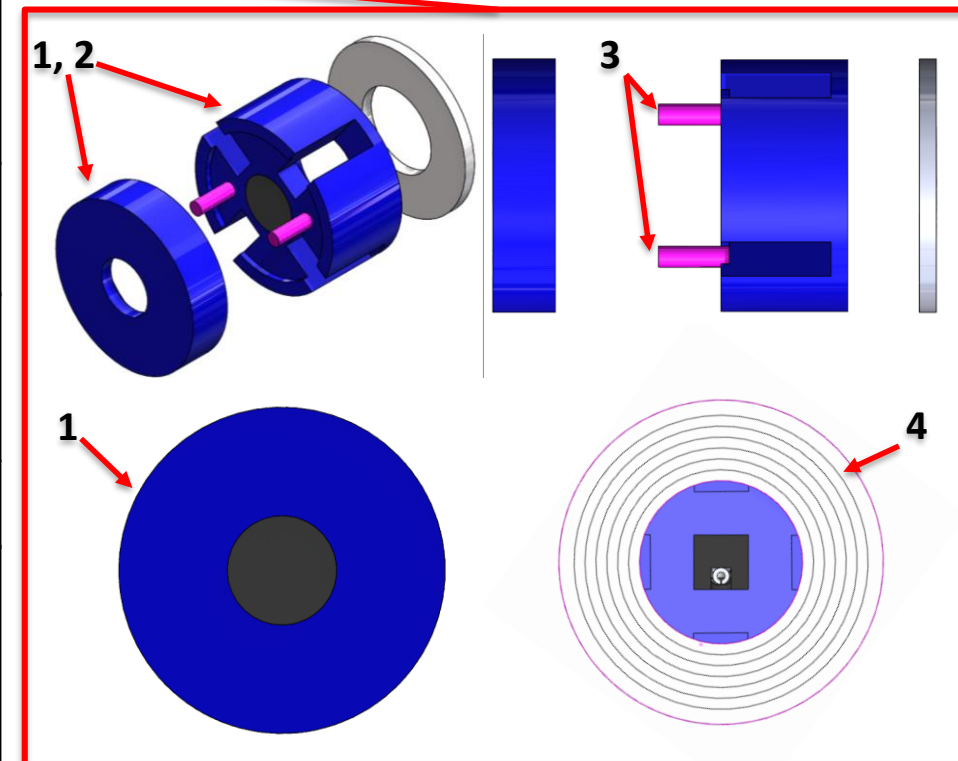
Our selection provides a combination of **robustness** and **adjustability/flexibility**. By sizing for optical components, we have many options available and the user can select various configuration based off parameter interest

CDR Model: Mechanical Design (2/2)



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Part Parameter	Dimensions L x W [in x in] or stated	Approx. Weight [lbs]	Material	Procurement
1. Internal Sleeve ¹	1.5 x 0.37 with x2 Ø 0.125 ↓ THRU ALL	0.03	Macor	Custom Fab
2. Internal Housing ¹	1.5 x 0.75 with Ø 0.5 ↓ 0.10, Ø 0.025 ↓ THRU ALL	0.06	Macor	Custom Fab
3. Pin ¹ (x2)	Ø 0.125 x 0.52	-	Ceramic	Custom Fab
4. Spring washer disk ¹	Overall: 1.5 x 0.10 Ø 0.3 THRU ALL, Ø 0.5 ↓ 0.10, Ø 0.6 ↓ 0.10, Ø 0.7 ↓ 0.10, Ø 0.8 ↓ 0.10	0.01	Aluminum	Custom Fab



****Procurement:**
CF – Custom Fabrication¹
TL – Thor Labs²

CDR Model: Mechanical Design (2/2)



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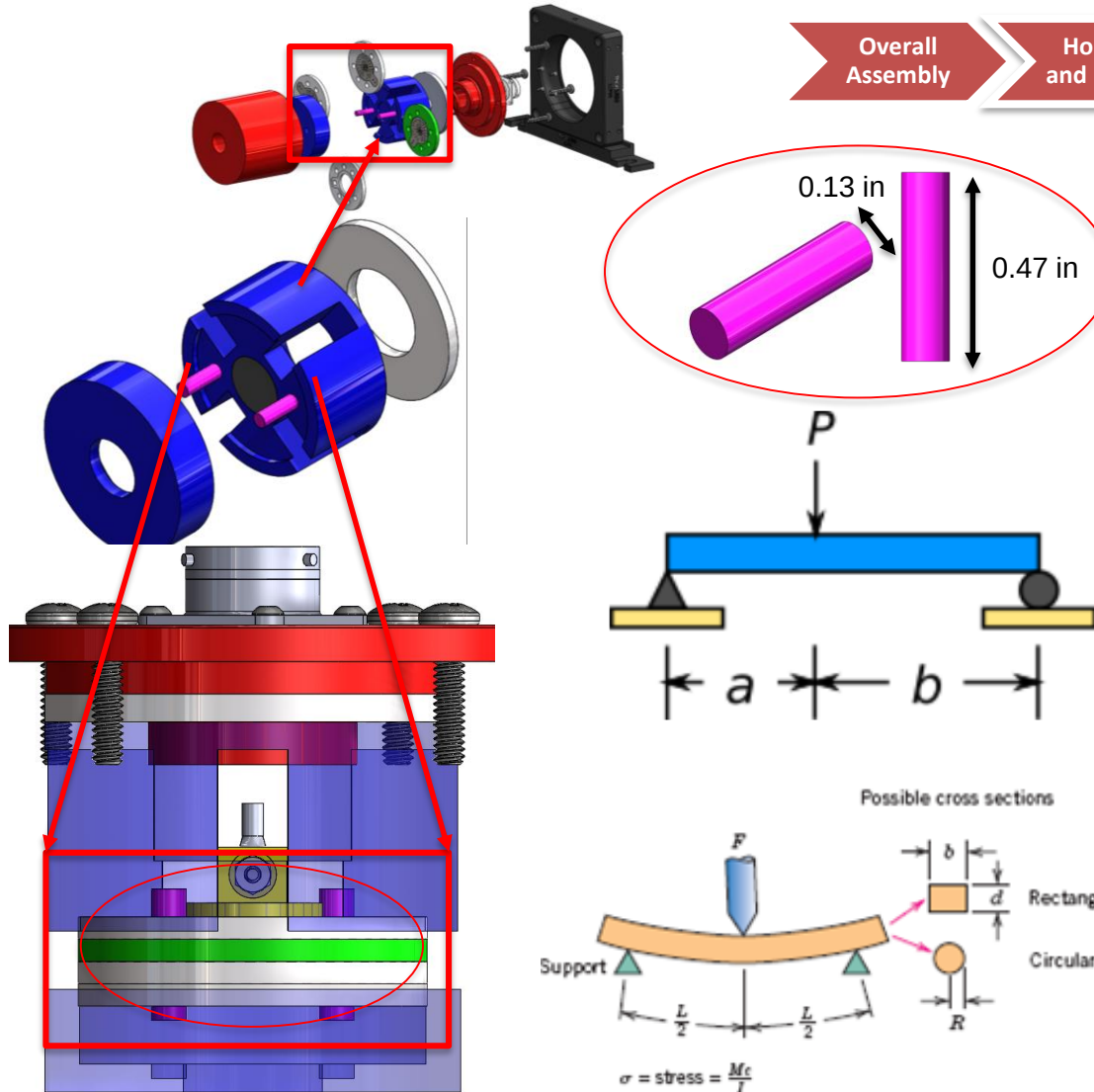
PDR Model

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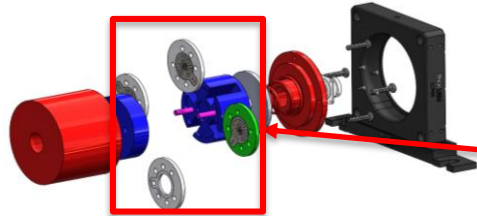
Key Take Aways



Material	Dim (in)	Force (lbf)	Flexural Strength (psi)	Deflection (in/mm)	Bending Stress (psi)
Macor	0.13	0.75	13,600	0.0004/ 0.01	1,390.89
Macor	0.13	3	13,600	0.0001/ 0.003	5,563.54
Macor	0.14	3	13,600	0.0001/ 0.003	4,454.48
Macor	0.14	4	13,600	0.0002/ 0.005	5,939.31
Macor	0.15	5	13,600	0.0002/ 0.005	7,424.14
Macor	0.15	12	13,600	0.0003/ 0.008	14,486.6

Pin displays minimal deflection and allowable bending stress at maximum force conditions

CDR Model: Electromechanical Design (1/3)

Overall
AssemblyHousing
and MountInternal
Sleeve

Grids

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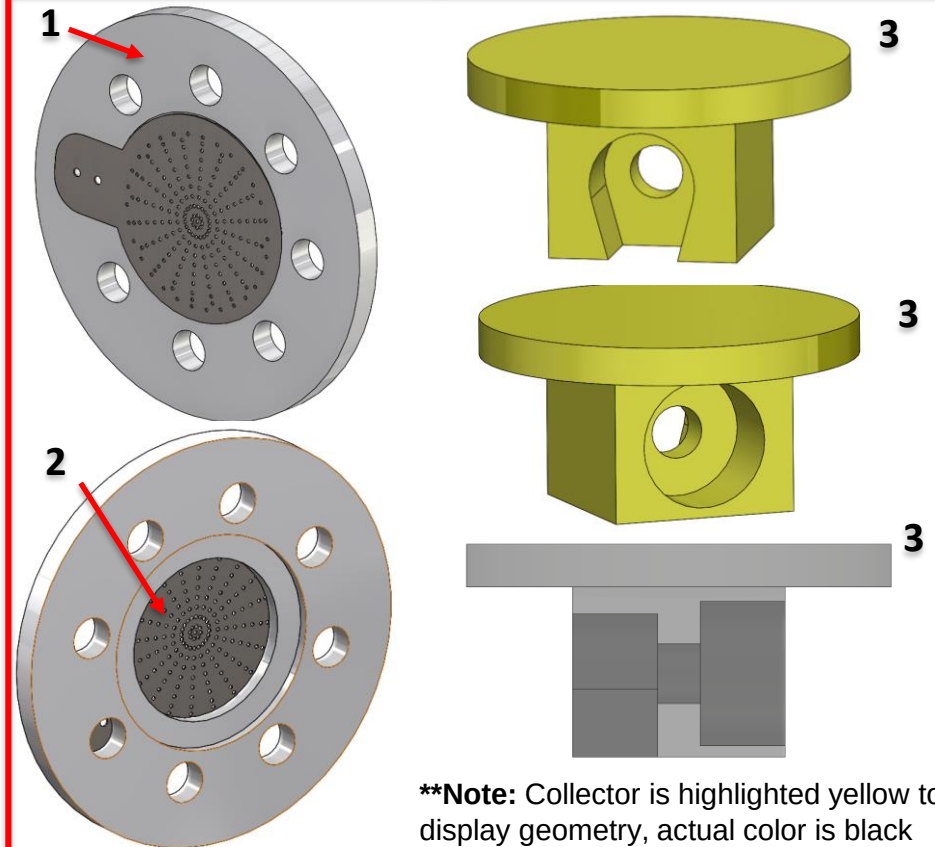
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Part Parameter	Dimensions L x W [in x in] or stated	Approx. Weight [lbs]	Material	Procurement
1. Washer Spacer (x4) ¹	Overall 1.25 x 0.08, $\varnothing 0.5 \downarrow 0.0005$, (x8) $\varnothing 0.125 \downarrow$ THRU ALL $\varnothing 0.66 \downarrow 0.03$	0.01	Macor	McMaster
2. Grid (x4) ¹	$\varnothing 0.5 \downarrow 0.0005$	0.02	SS	McMaster
3. Collector ¹	Overall 0.4 x 0.4 Houses 22 AWG wire	0.01	Graphite	McMaster

****Procurement:**CF – Custom Fabrication¹TL – Thor Labs²****Note:** Collector is highlighted yellow to display geometry, actual color is black

CDR Model: Electromechanical Design (2/3)



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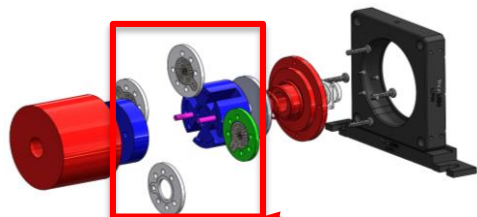
PDR Model

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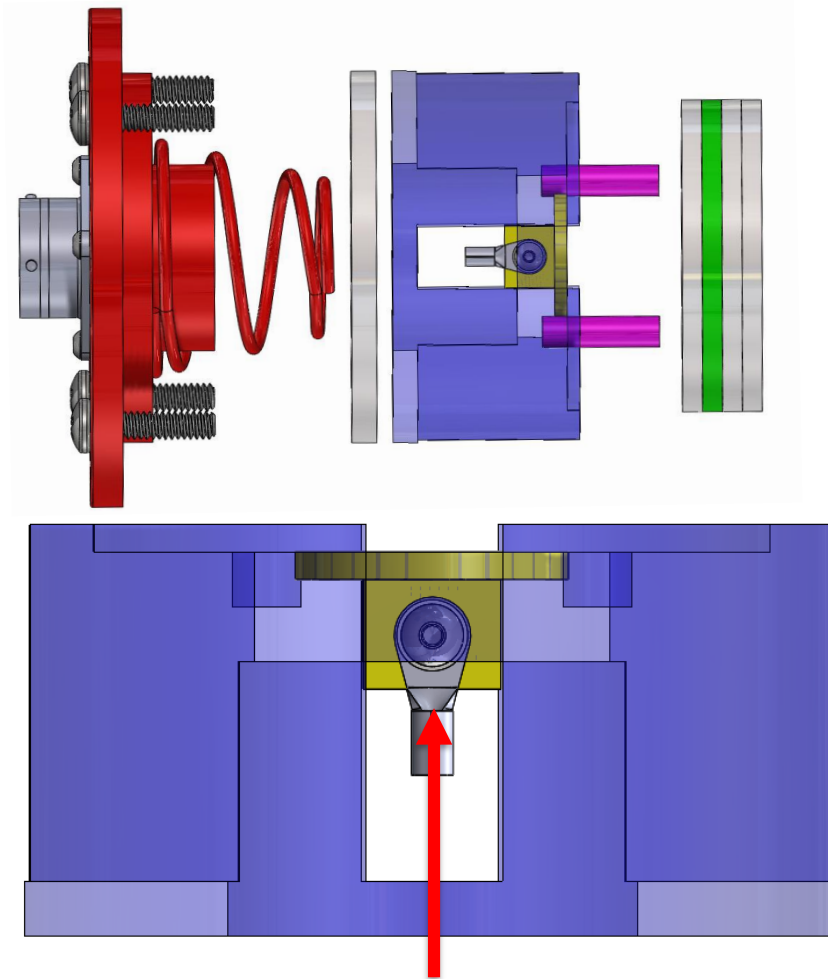
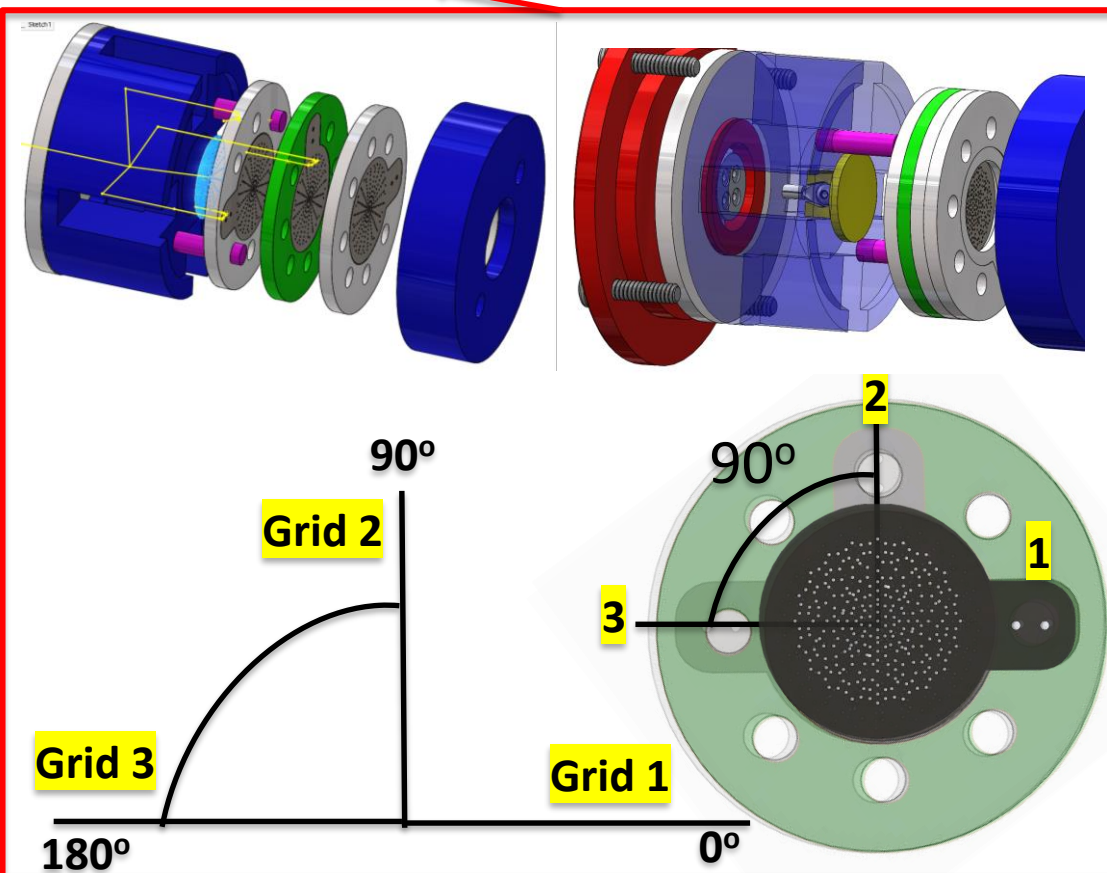
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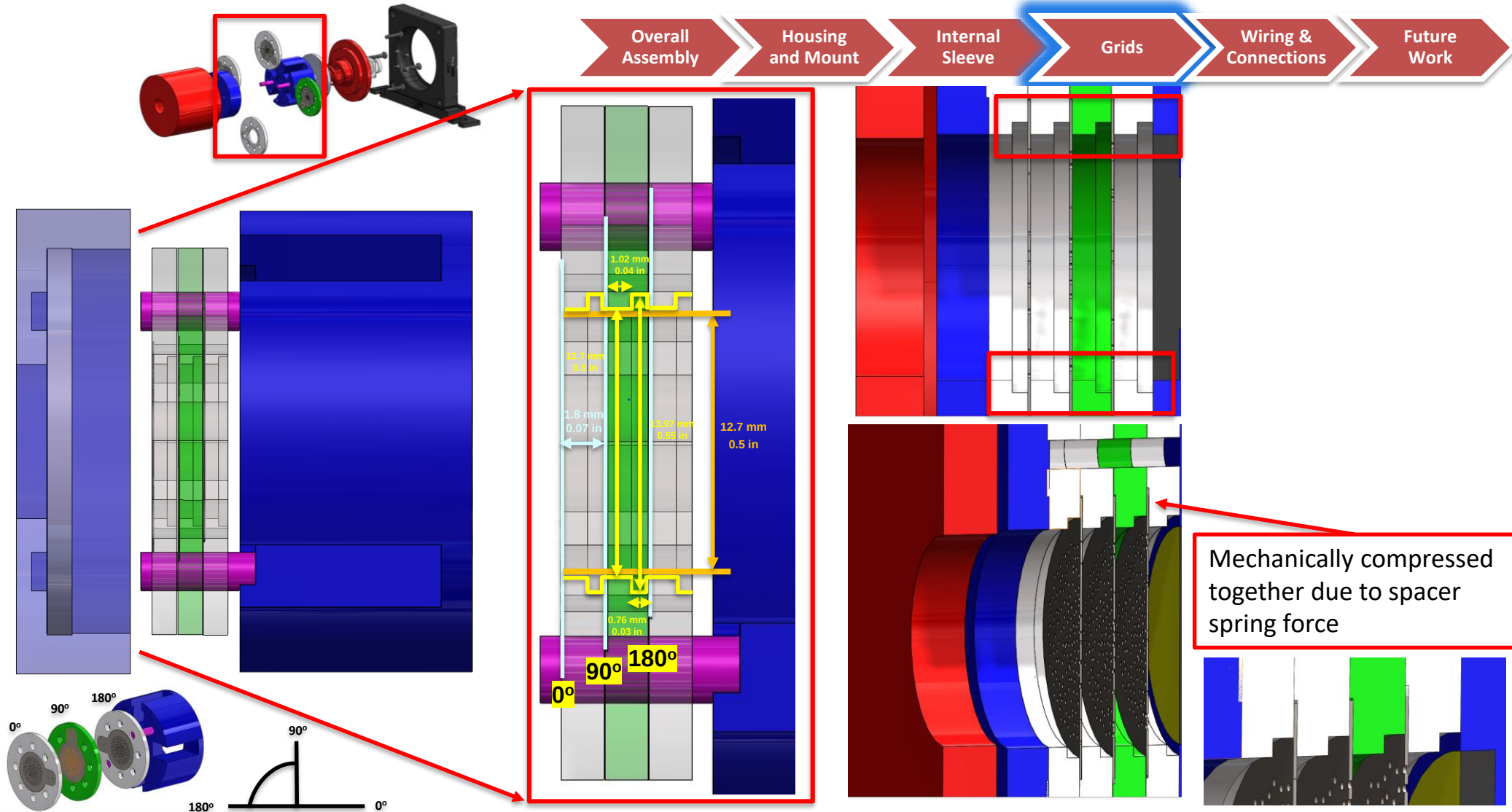
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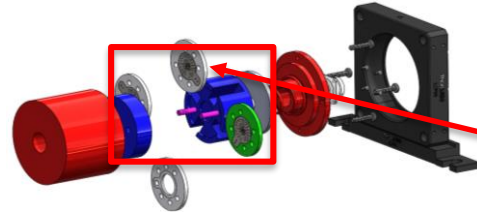
CDR Model: Electromechanical Design (3/3)



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CDR Model: Electrical Design (1/3)

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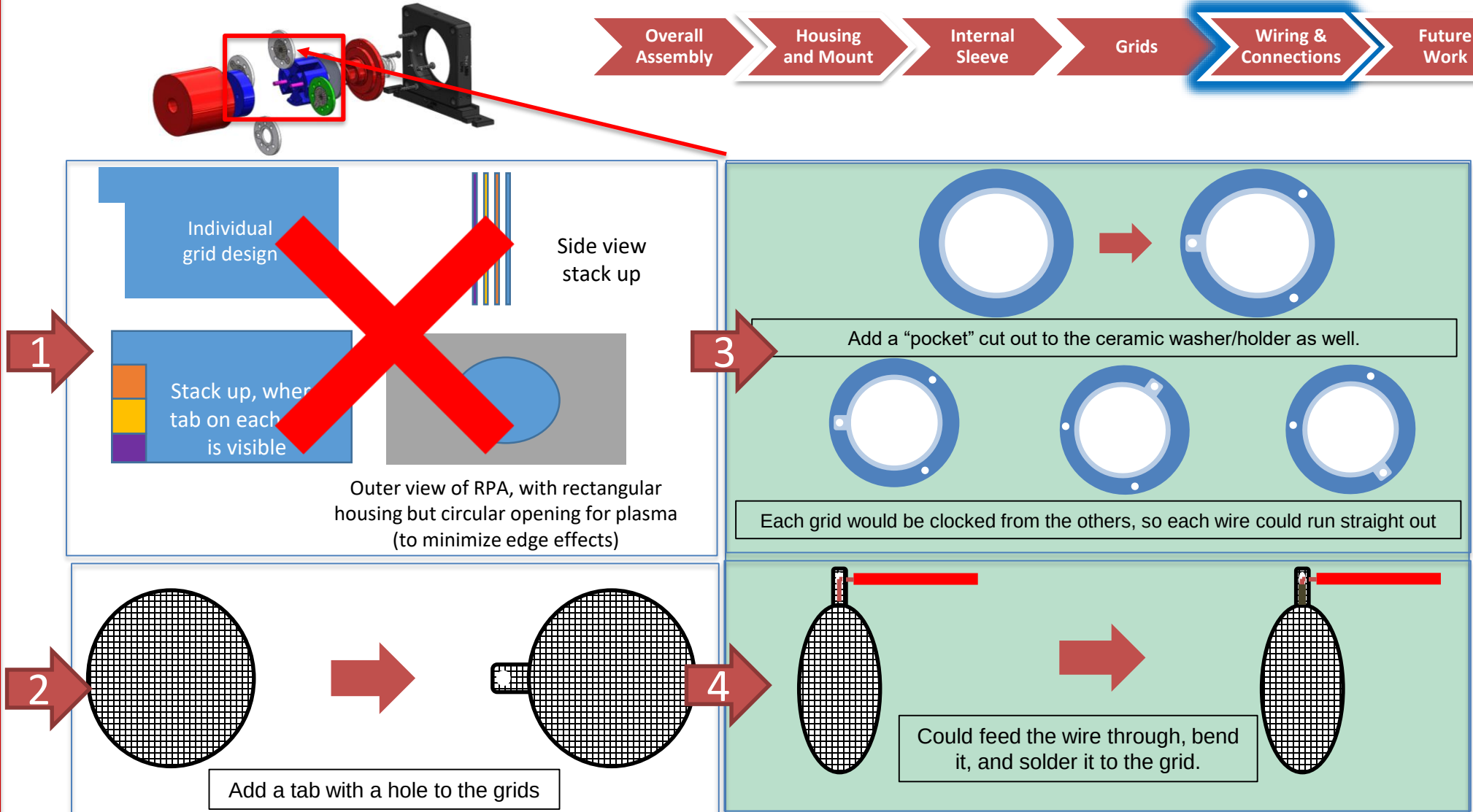
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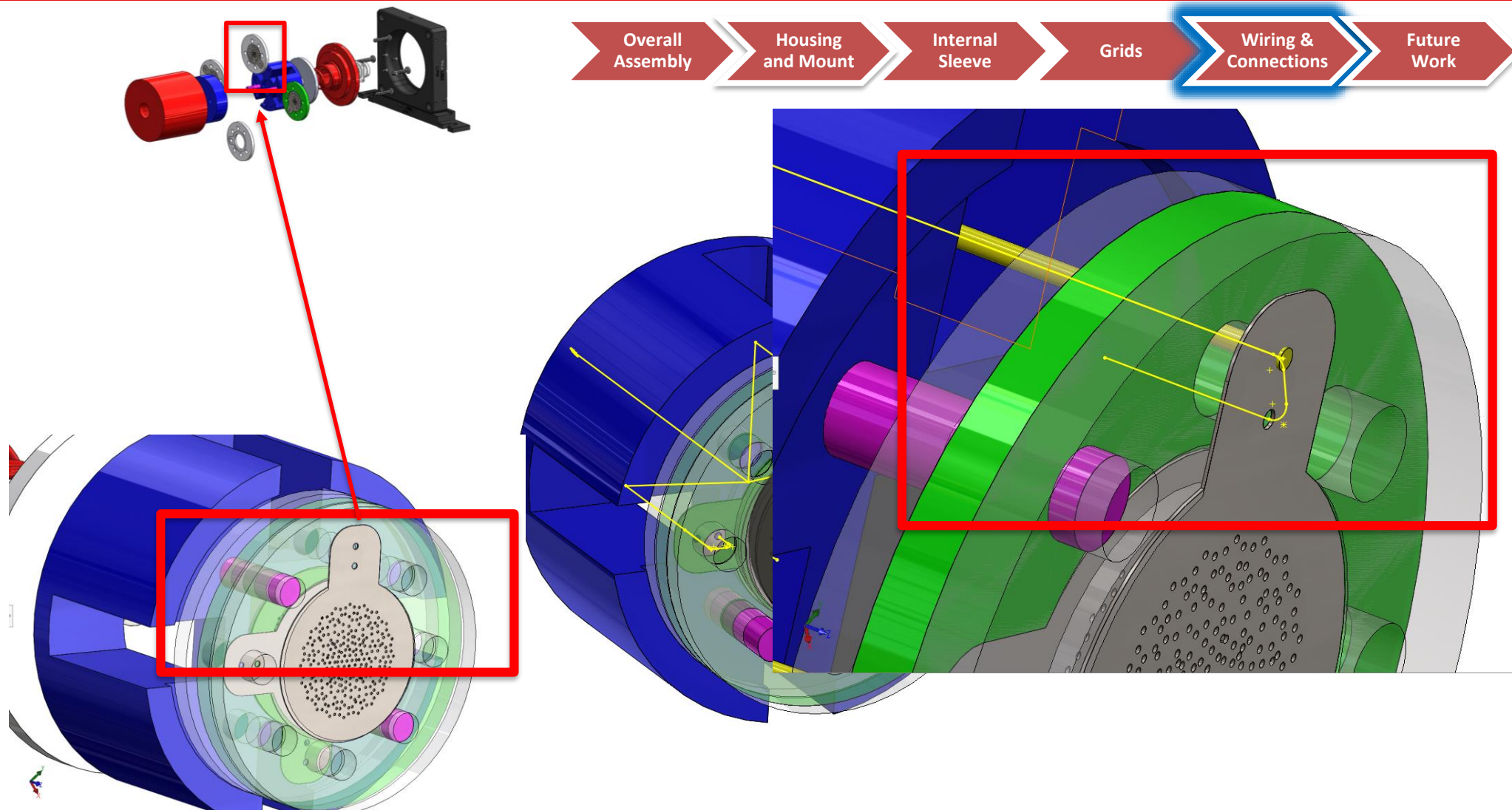
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CDR Model: Electrical Design (2/3)



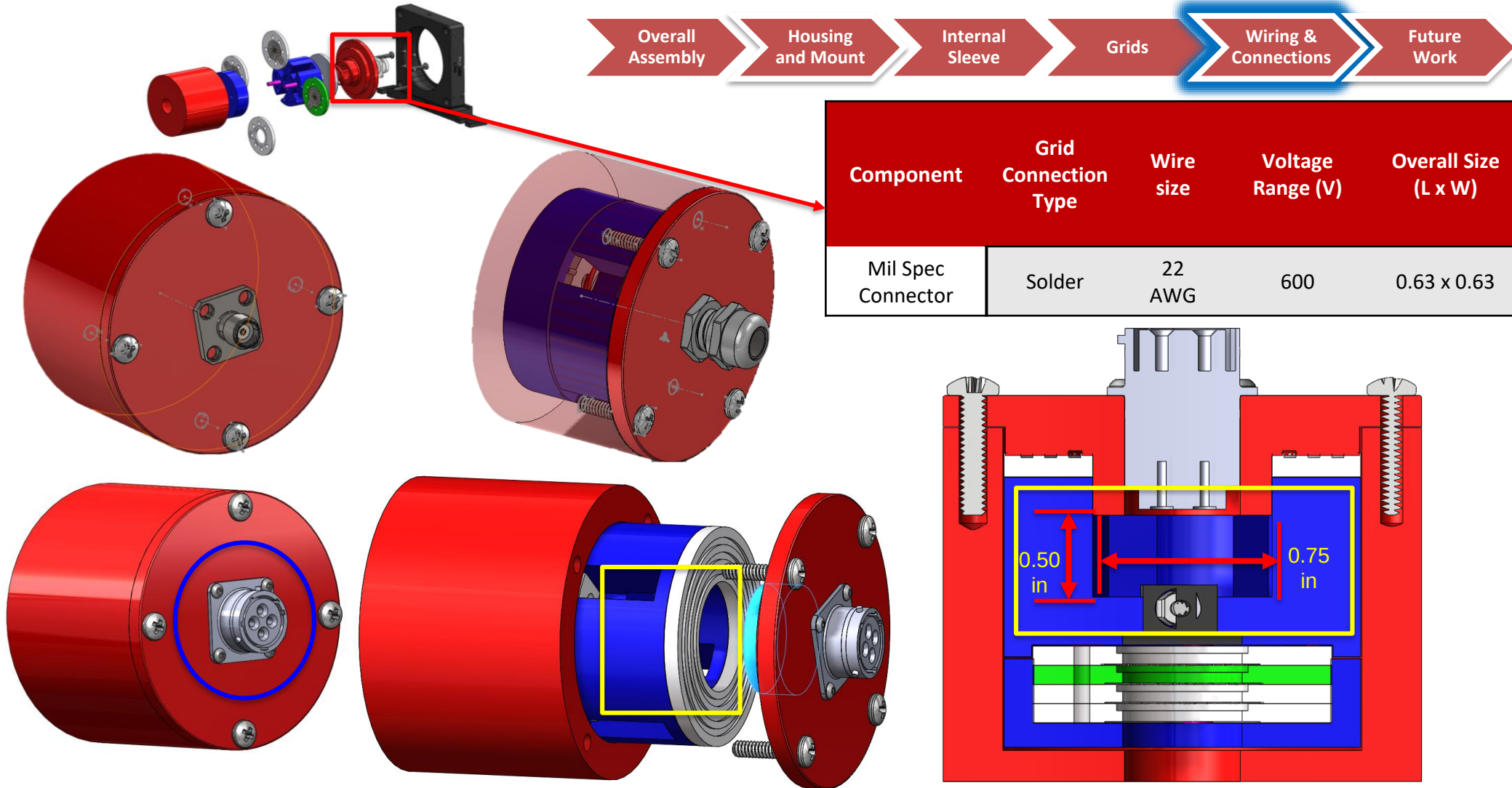
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CDR Model: Electrical Design (3/3)



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Meeting Design Goal



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Small size/reduce size (input visual
and show percentage)

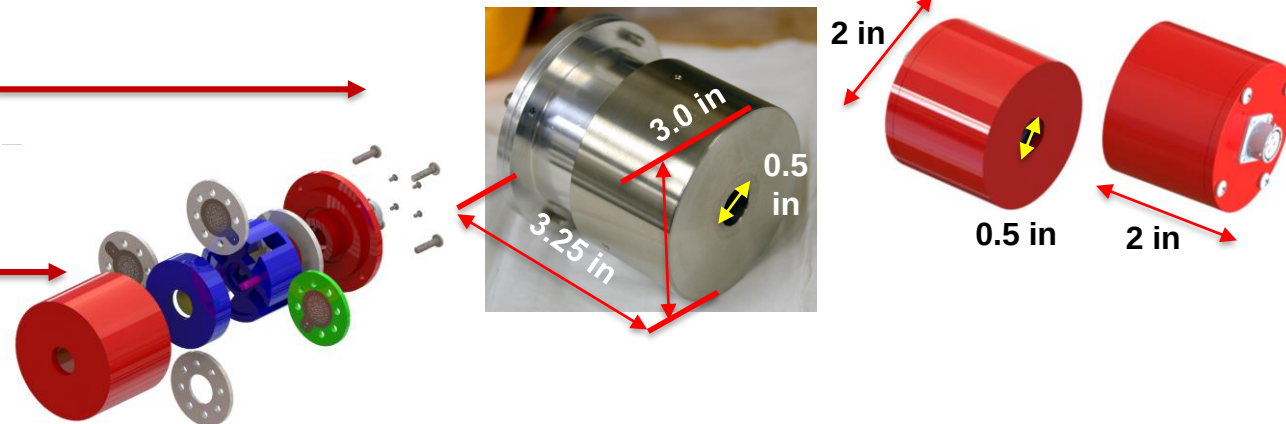
Easy to assemble/manufacture

No exotic or expensive materials

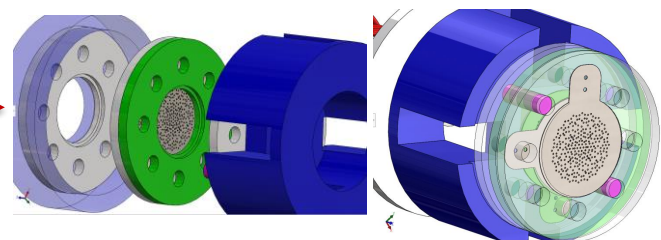
Capable of operating in cathode
plasma

Leverage AFRL design when possible

Apply lessons learned from plasma
diagnostics experience



Ready and available materials: SS,
Aluminum, Graphite, Macor etc.



Organizations from but not limited to:
NASA, JPL, AFRL, PPPL, NRL, NREL etc.

Detailed Design – Post CDR



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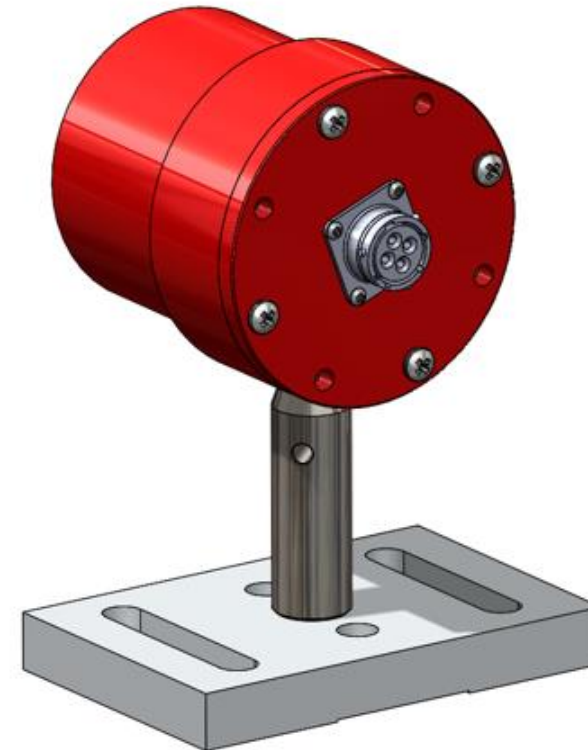
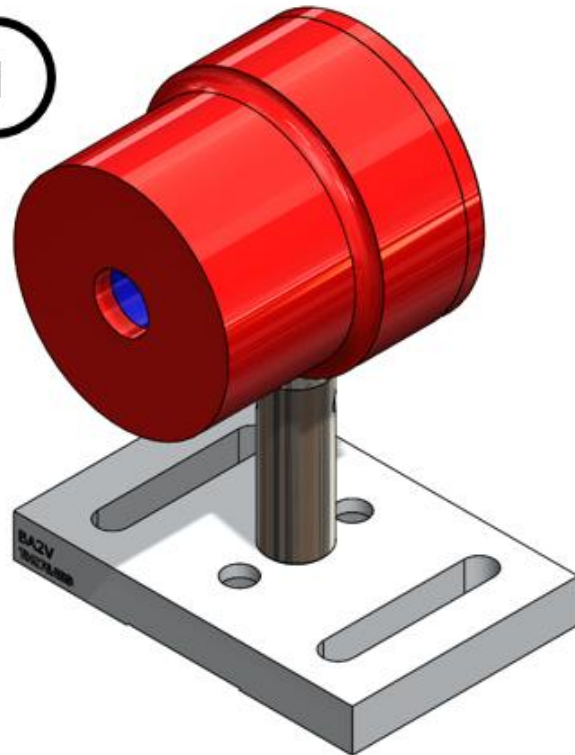
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1



Finalized Design as of
8/7/20:

Next several slides walks
through the assemble
process

Concluding Remarks



Success Criteria:

- ✓ ☒ Present motivation, goals, and requirements of RPA design activity
- ✓ ☒ Present technical design information
- ✓ ☒ Demonstrate design is at fidelity to move forward for detail design
- ✓ ☒ Demonstrate that recommended critical concept will meet project requirements

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Challenges](#)[Key Take Aways](#)

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