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Indianapolis

Richard G. Lugar Center for Renewable Energy
Purveyors of
Space Solar Power

Overcoming the GEO WPT Show-Stopper

presented by

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to the Judges of the
International Space Solar Power Student Competition
International Astronautical Conference 2019

Introduction

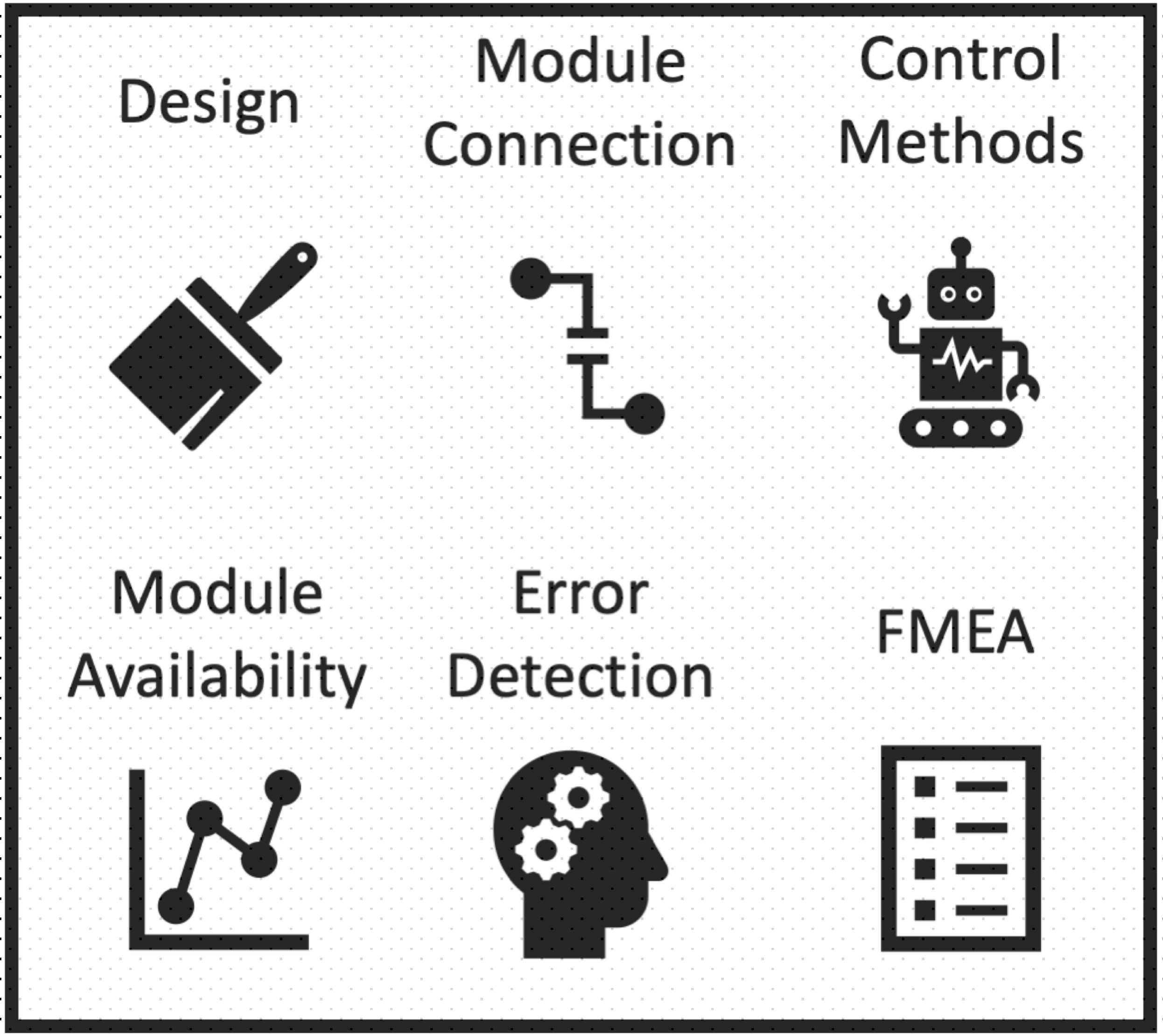
Areas of Focus:

1. Spacetenna Design – modular tile/sandwich
2. Spacetenna Maintenance (detect/repair faults)
3. Spacetenna Flatness (needed for pencil beam)

Primary Goal:

- Side Lobe Levels below **-82 dB**
- Needed for Comms:
  - Bluetooth
  - IEEE 802.11
  - IEEE 802.15.4
  - First responder radios

per McSpadden, IEEE Wireless Power Transfer Conference 2015

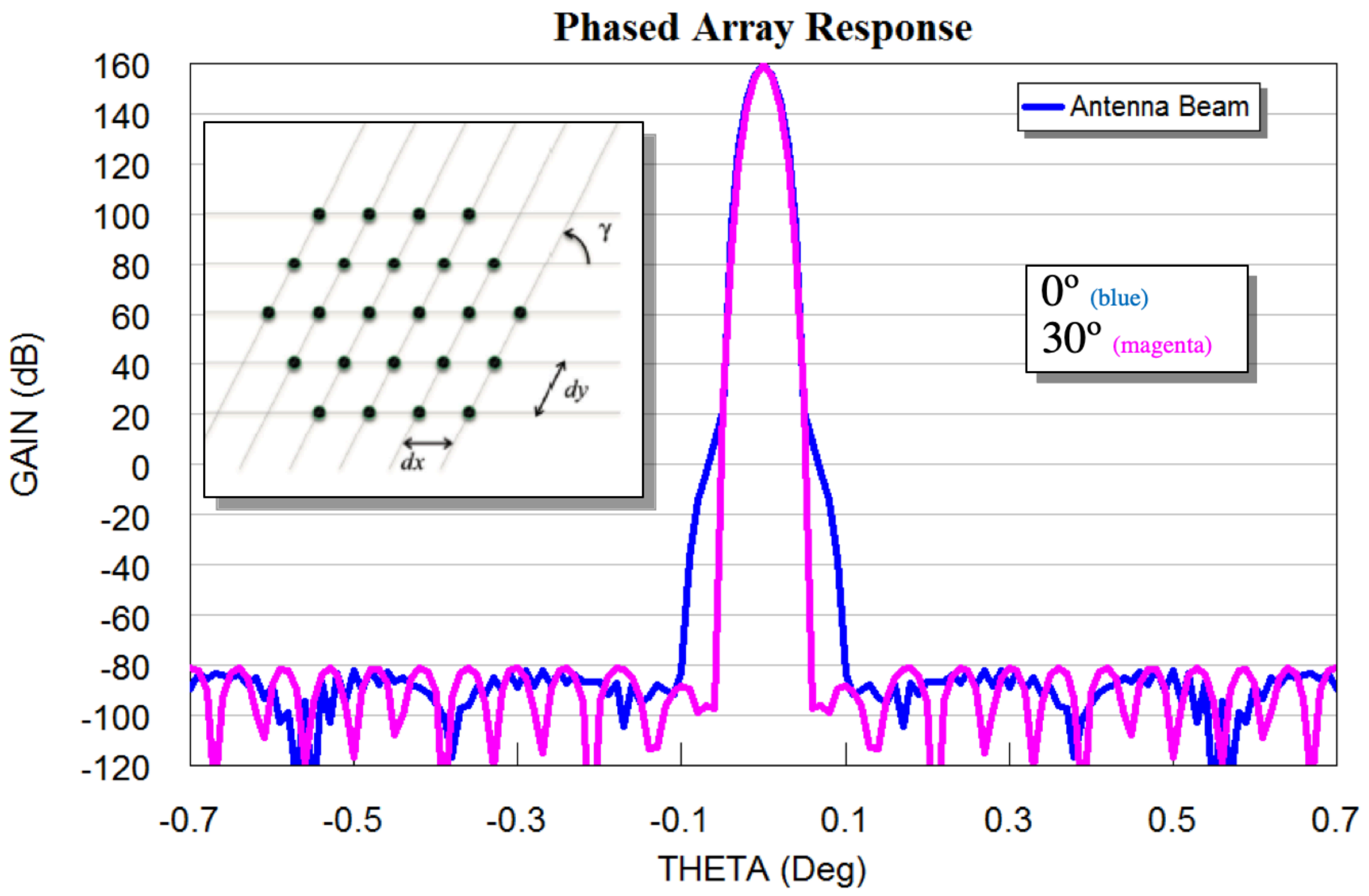

Design
Module Connection
Control Methods
Module Availability
Error Detection
FMEA

SLL Breakthrough

Hexagonal perimeter

Symmetry every 60º

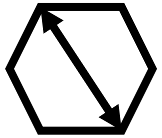
Many Components



Schubert, P., “SIDELOBE REDUCTION FOR GEO TO EARTH WIRELESS POWER TRANSFER”, paper **IAC-16.C3.2.3**, International Astronautical Conference 2016. Guadalajara, MX.

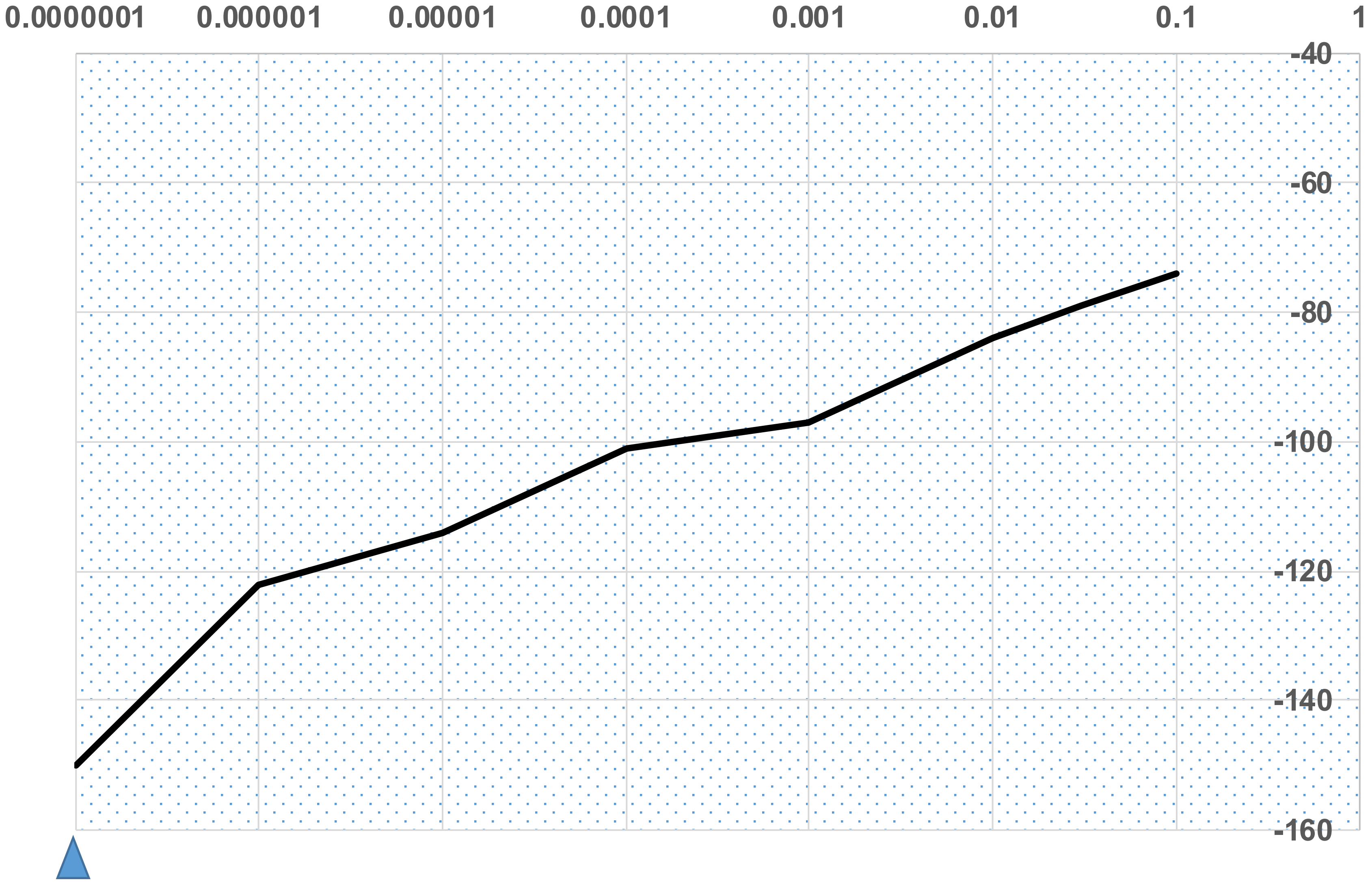
Side Lobe Level vs Element Error Fraction

950m diameter spacetenna



Randomized failures

AWS VSS Tool

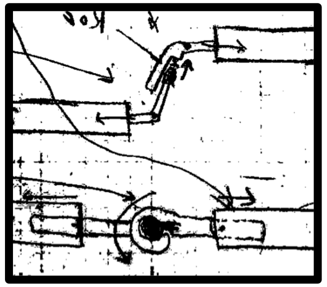


** All errors at this level or lower are -240 dB*

Module Connection

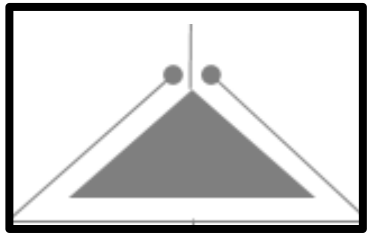
Railroad Coupling

Mechanical hand

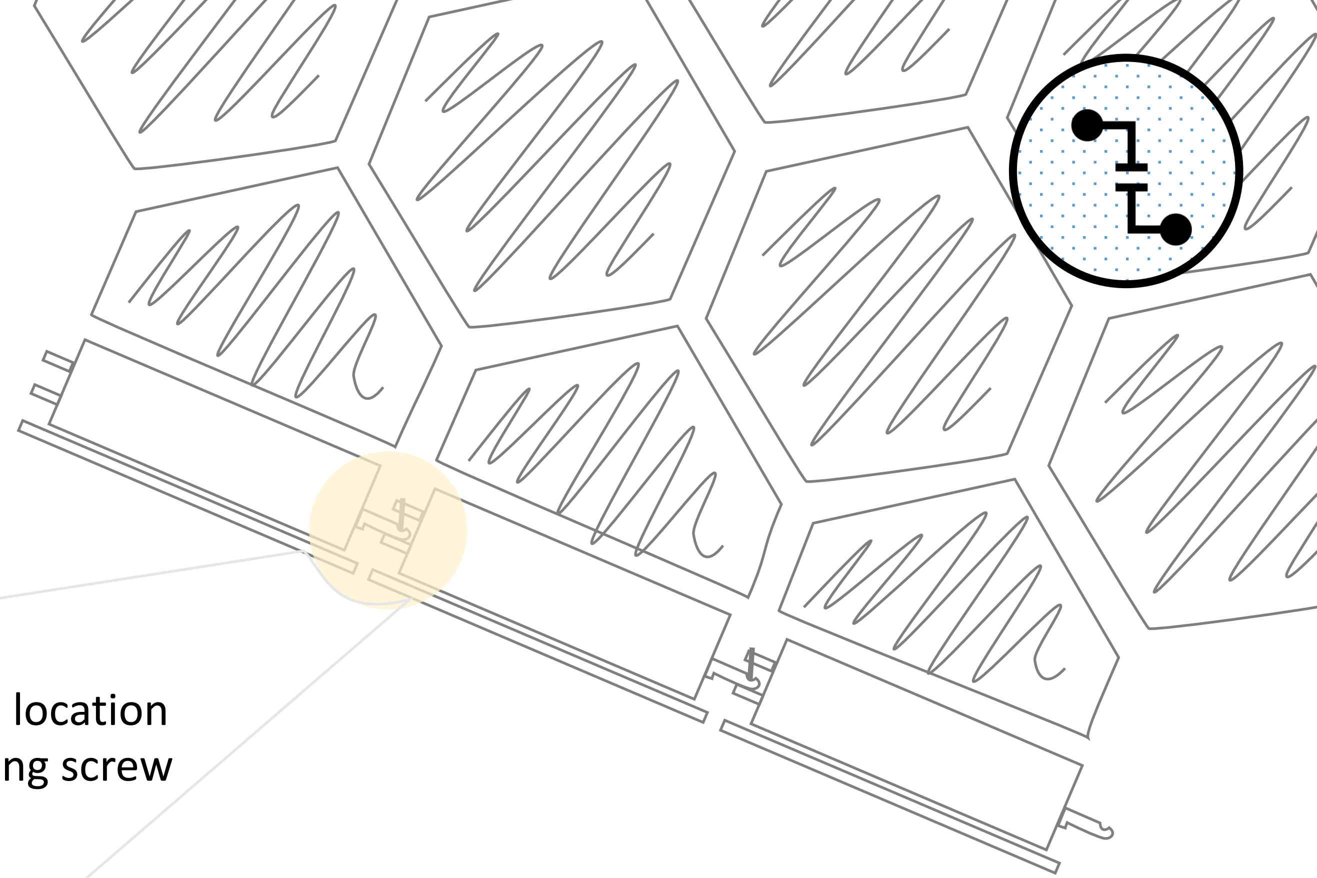


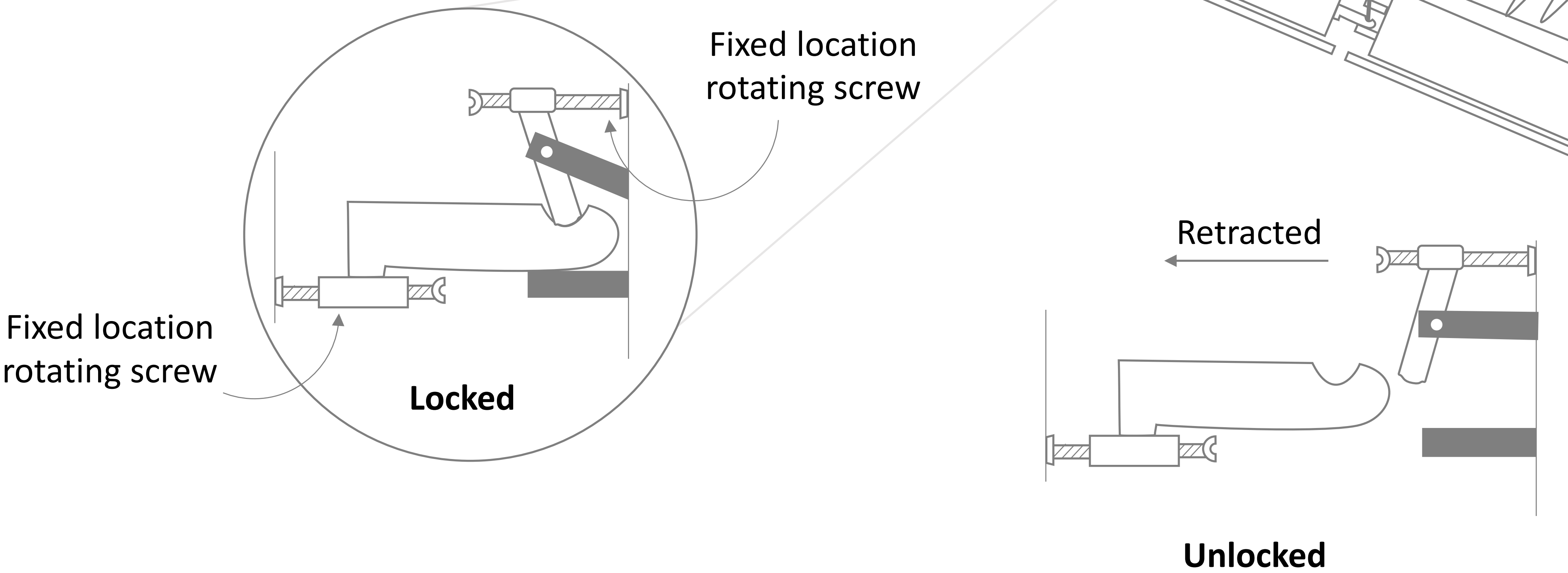
Flying tab

Binder clip

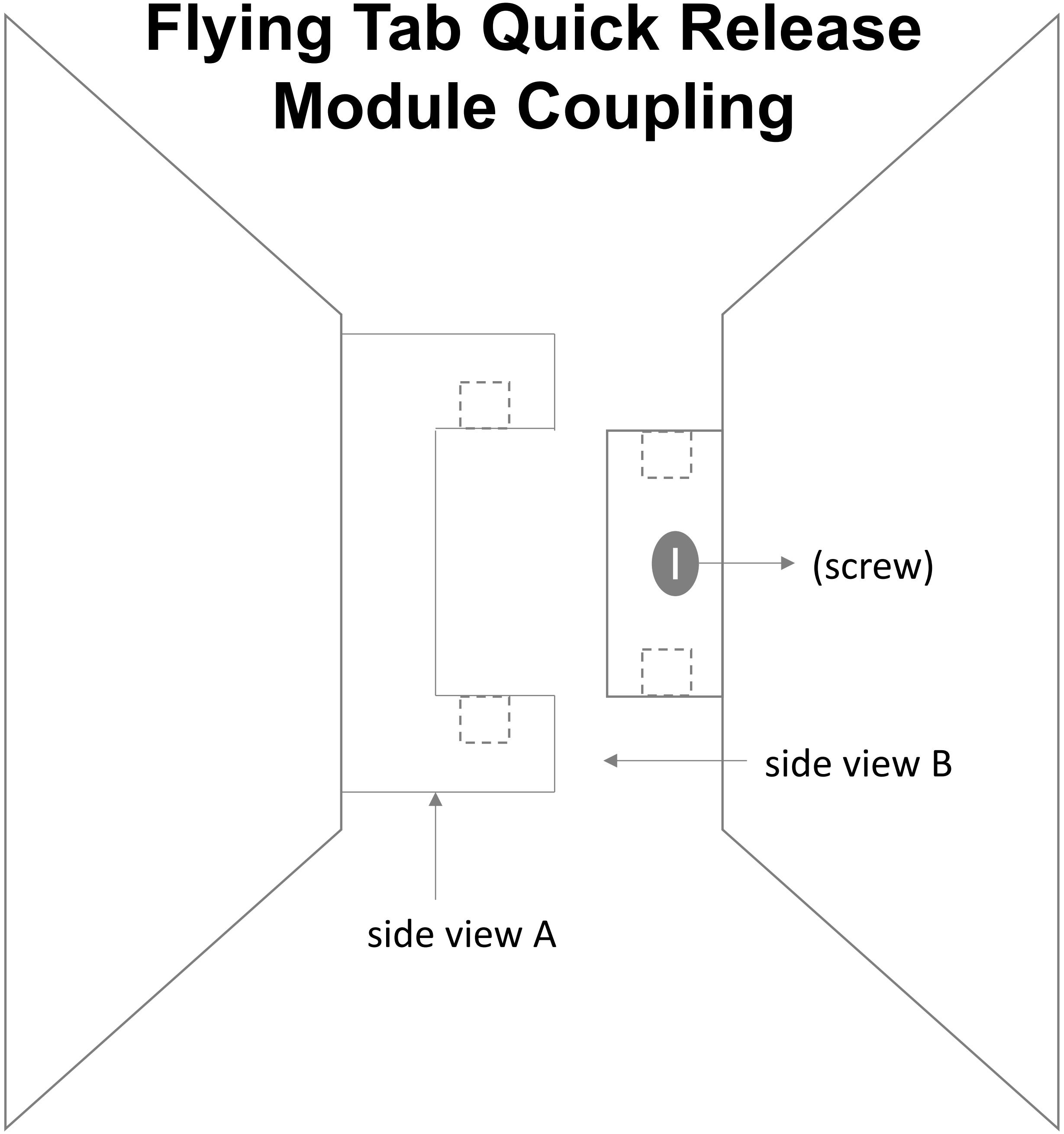


Railroad Inspired Coupling Design



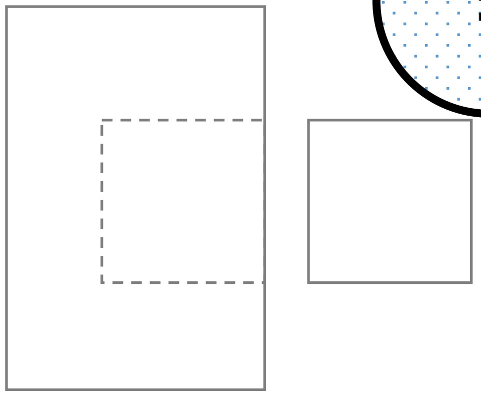


Flying Tab Quick Release Module Coupling

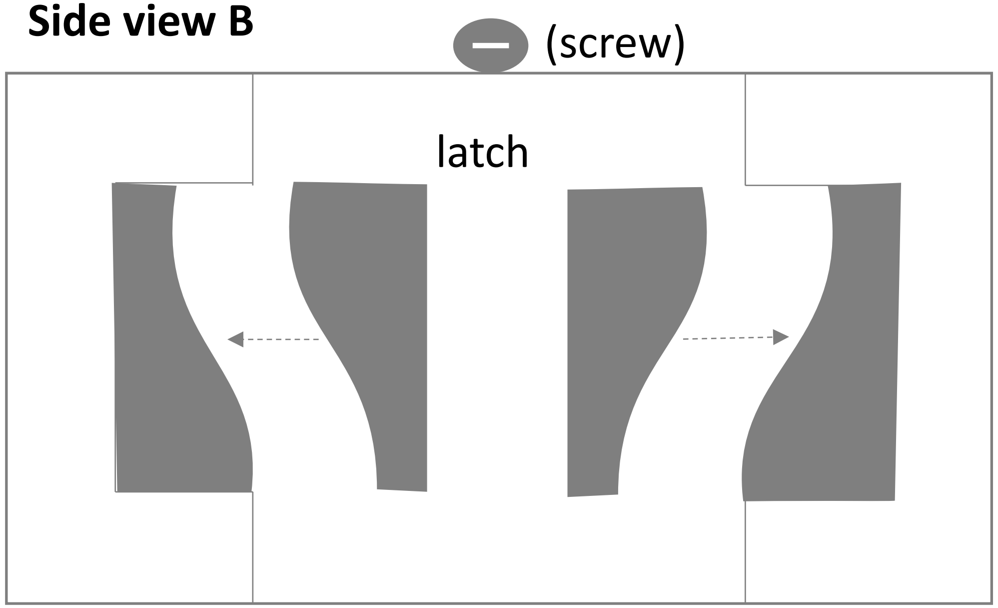


Lock System

Side view A

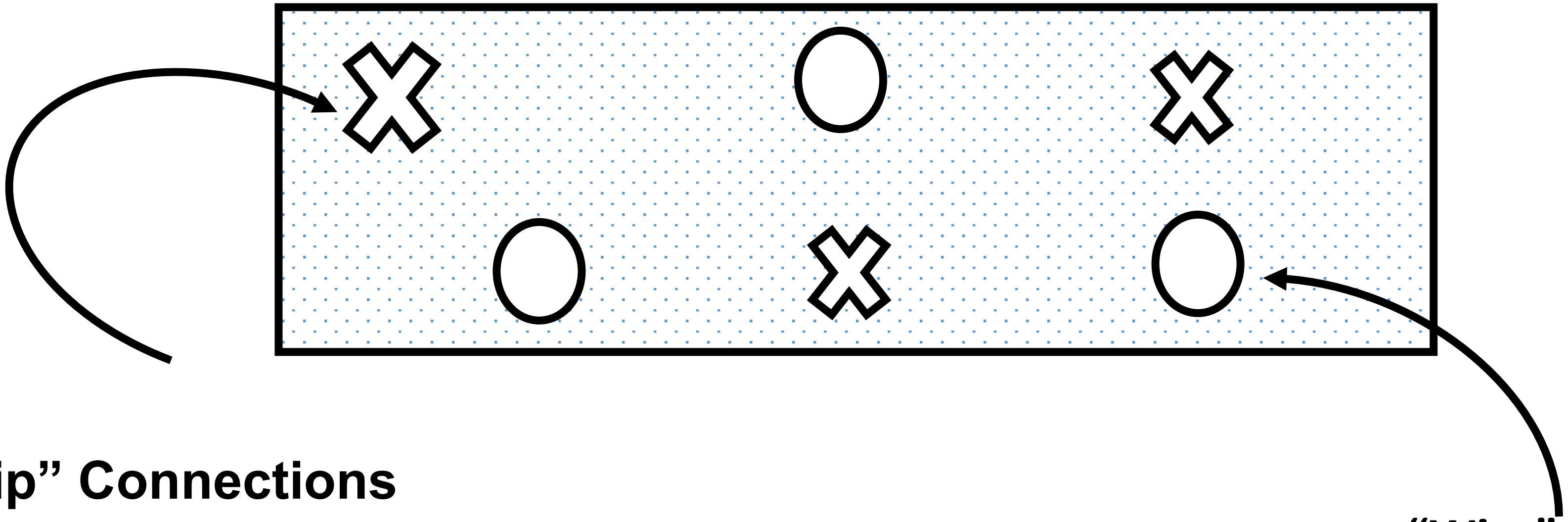


Side view B

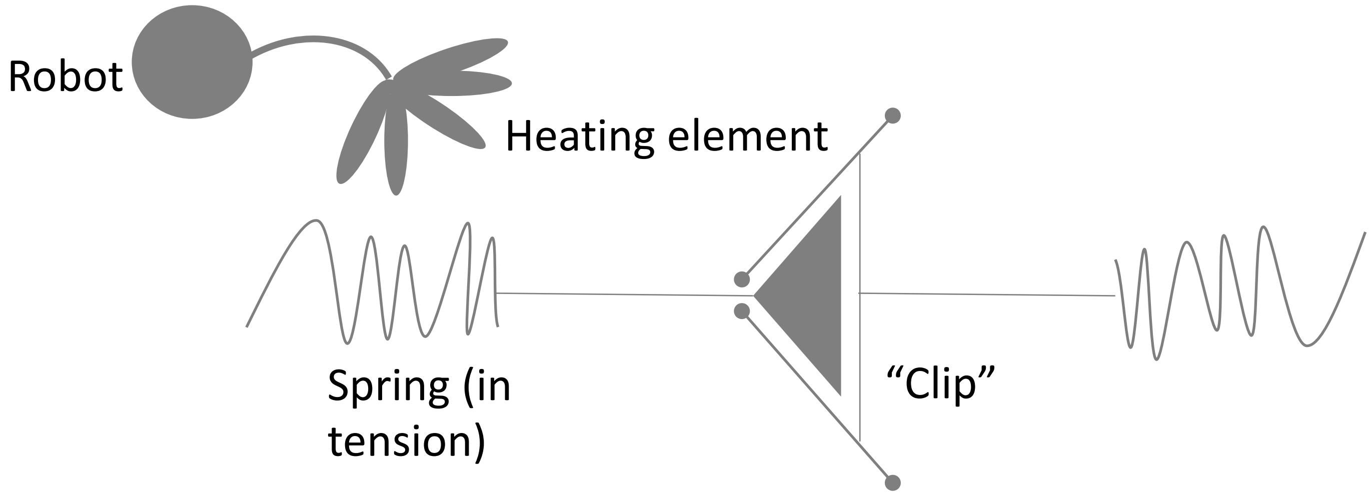


Binder Clip Inspired Coupling

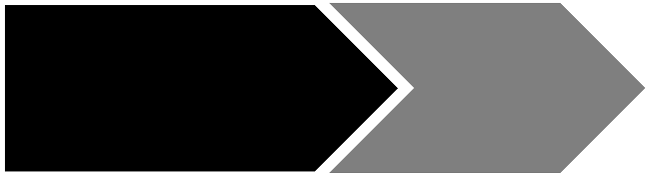
Cross section of hexagon side



“Clip” Connections

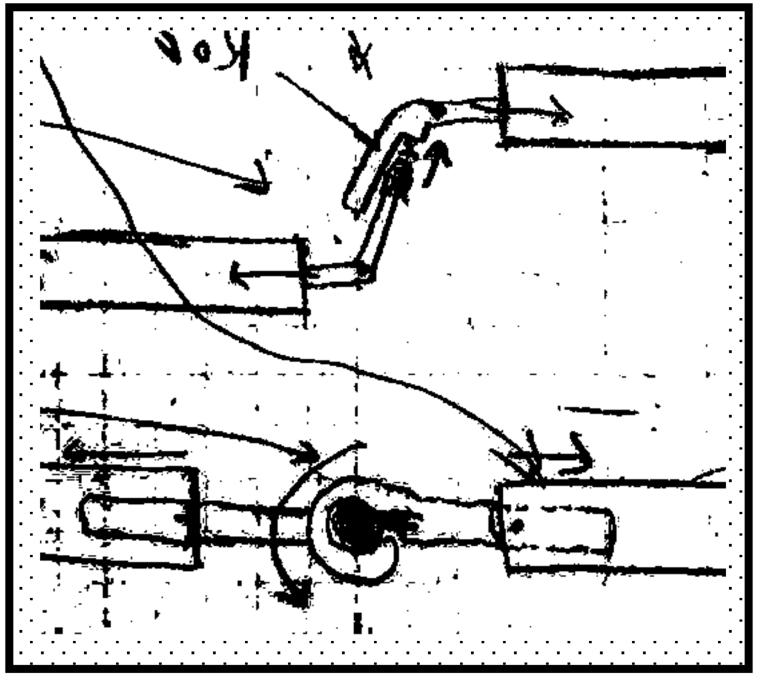


“Wire” Connections



In compression

Mechanical hand inspired coupling



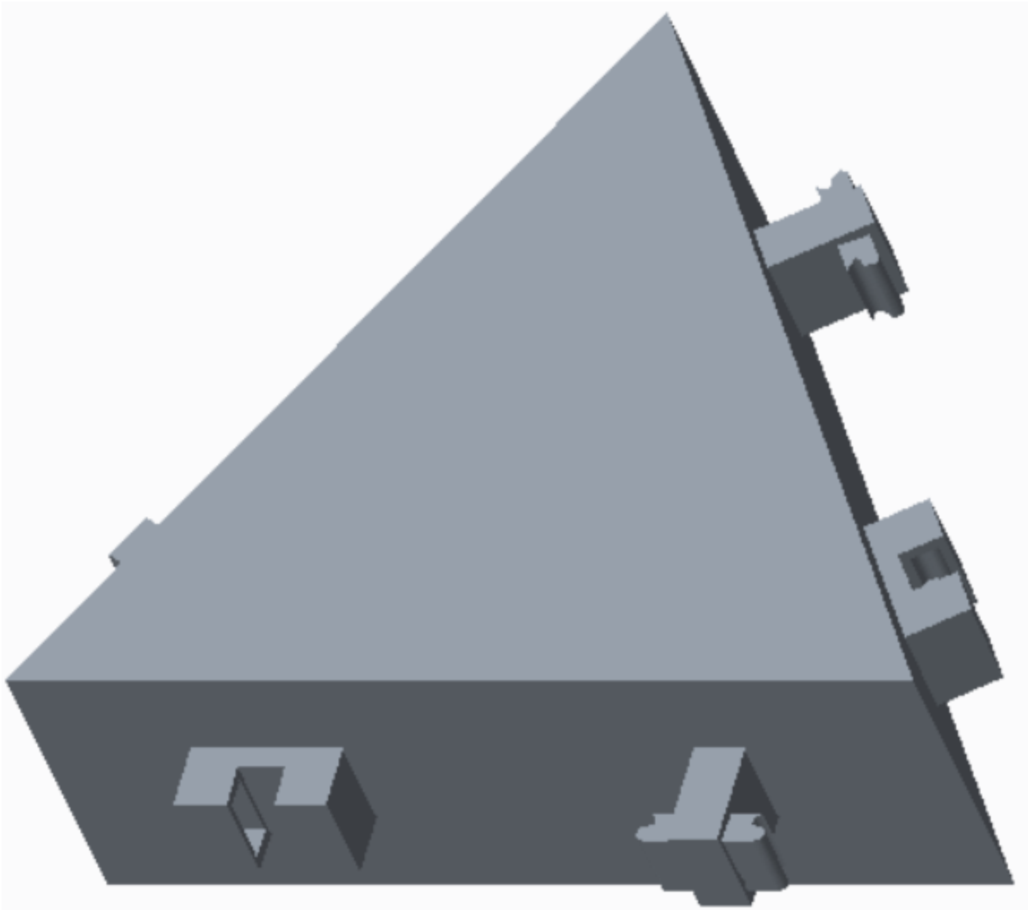
Side view of two sandwich modules connecting

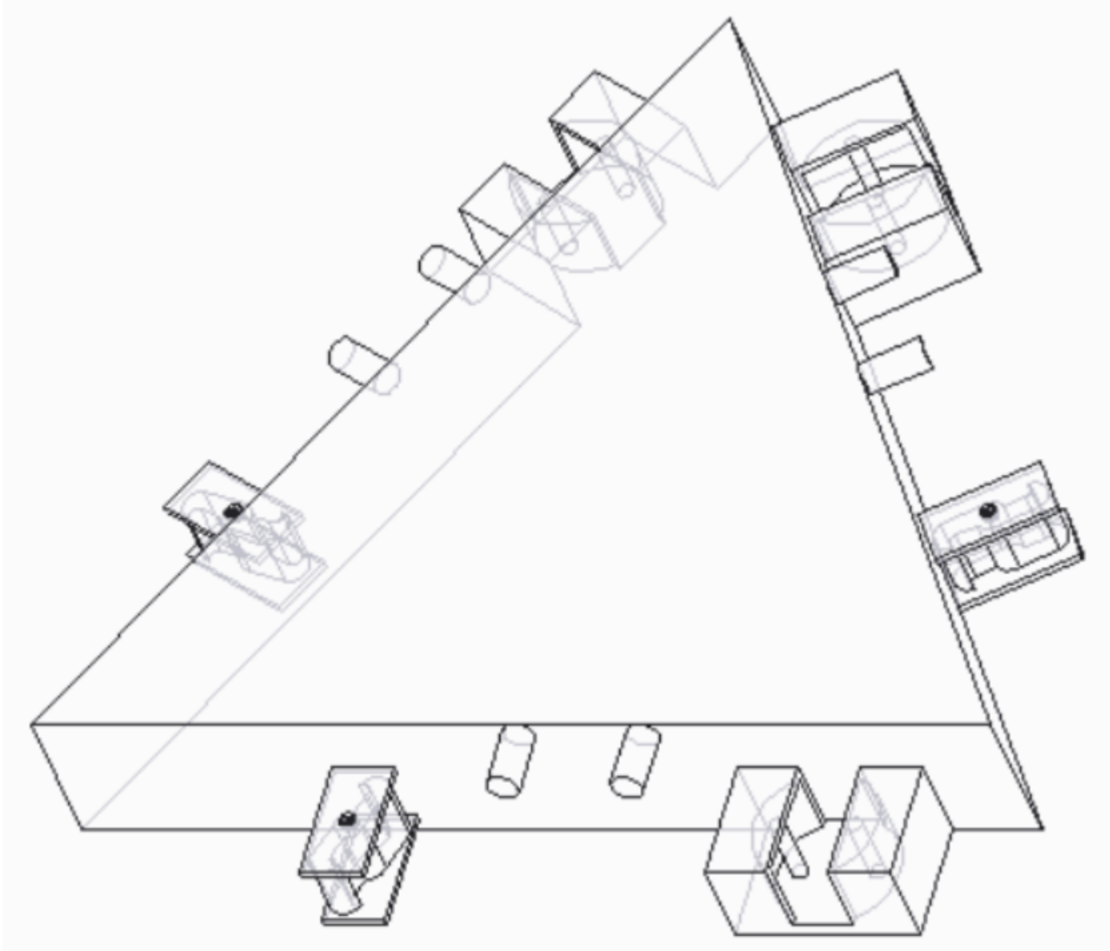
Mechanical analogy

Connection Analysis Chart

	Registration	Connection speed	Stability in all axes	Electrical Connection	Robot simplicity	Mechanism simplicity	Rubbing metal	Brittle metal	Total Score
Railroad Coupling	3	1	9	1	1	3	1	9	142
Mechanical Hand	3	9	3	1	9	1	9	3	180
Flying Tab	3	3	9	9	3	3	1	3	184
Binder Clip	3	1	9	9	1	9	9	1	184
Weight	9	9	9	3	3	3	1	1	

Final Module Design

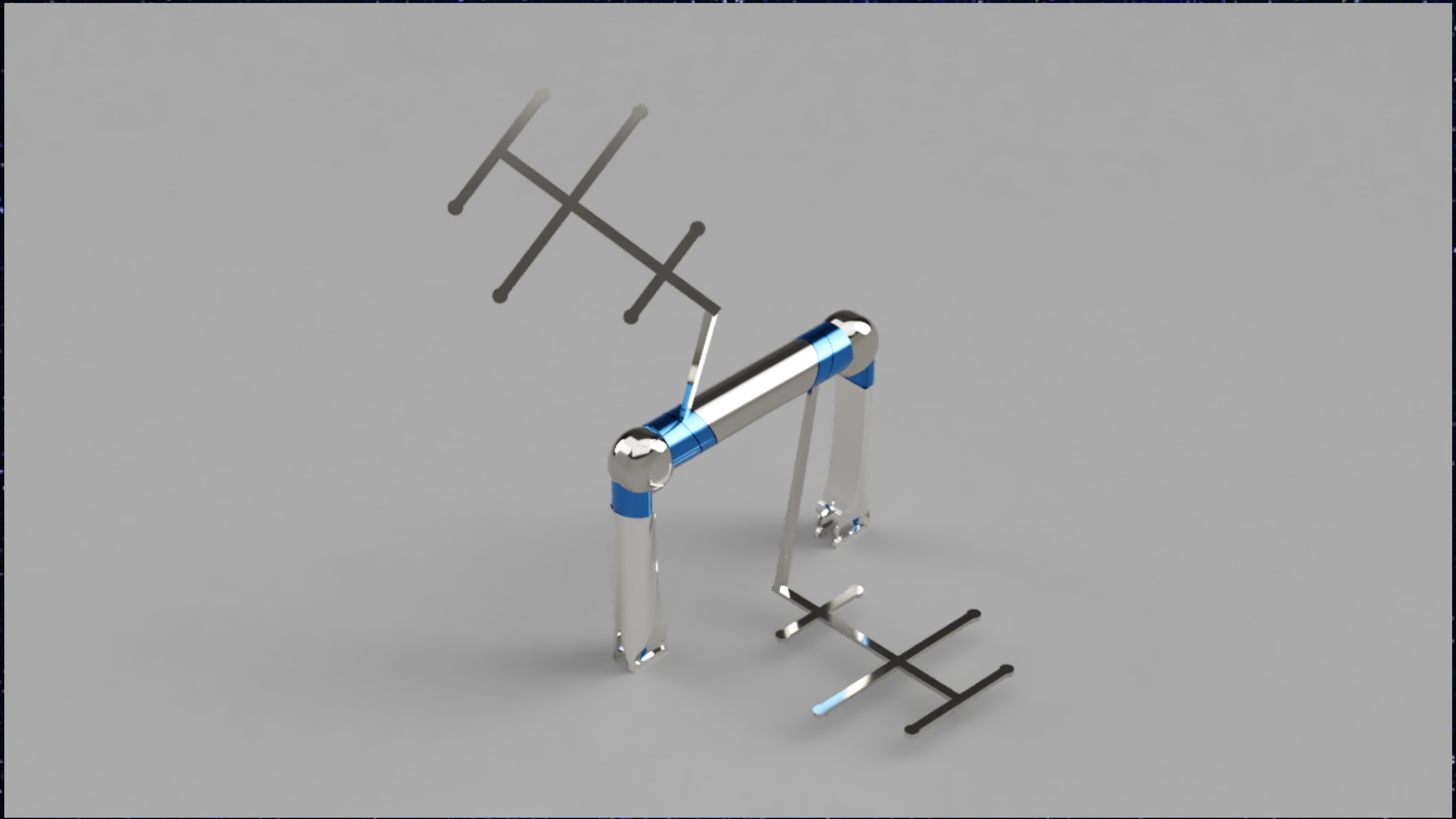




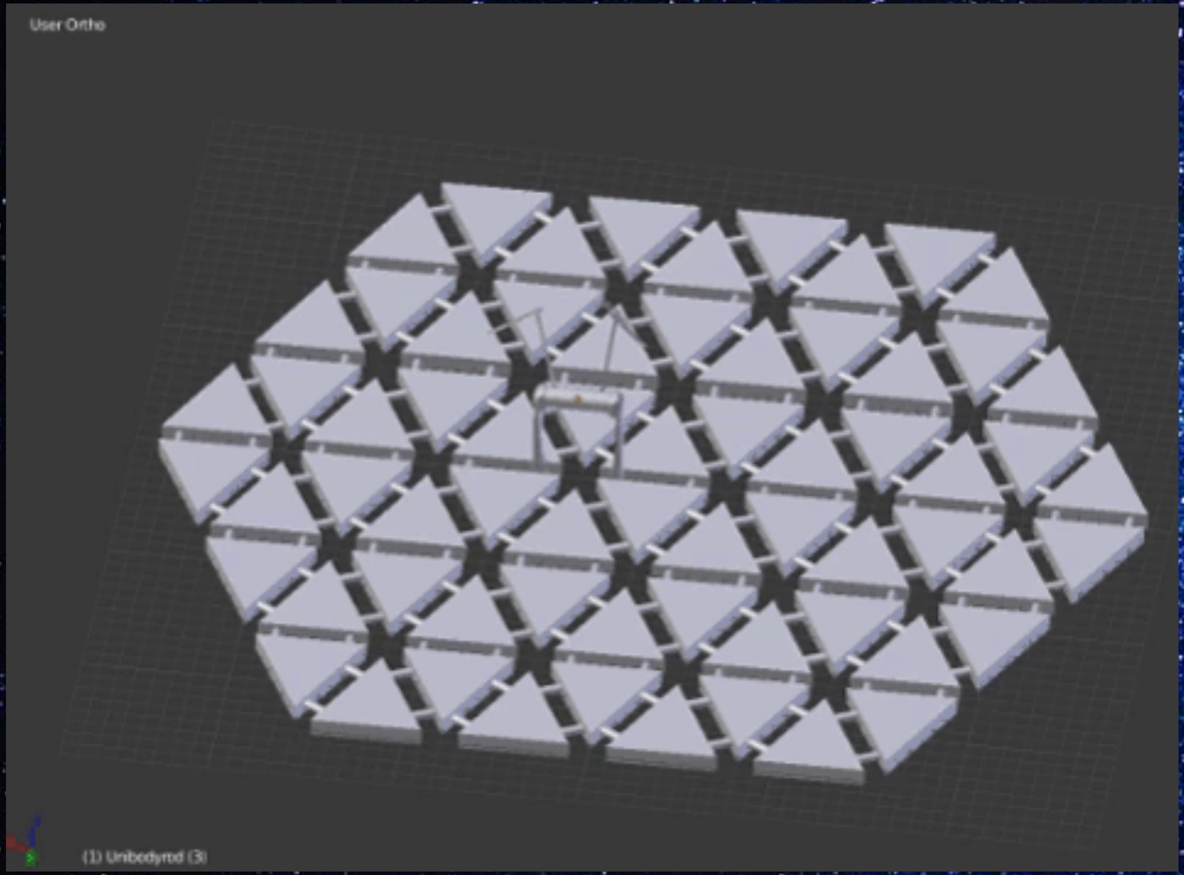
Error Detection

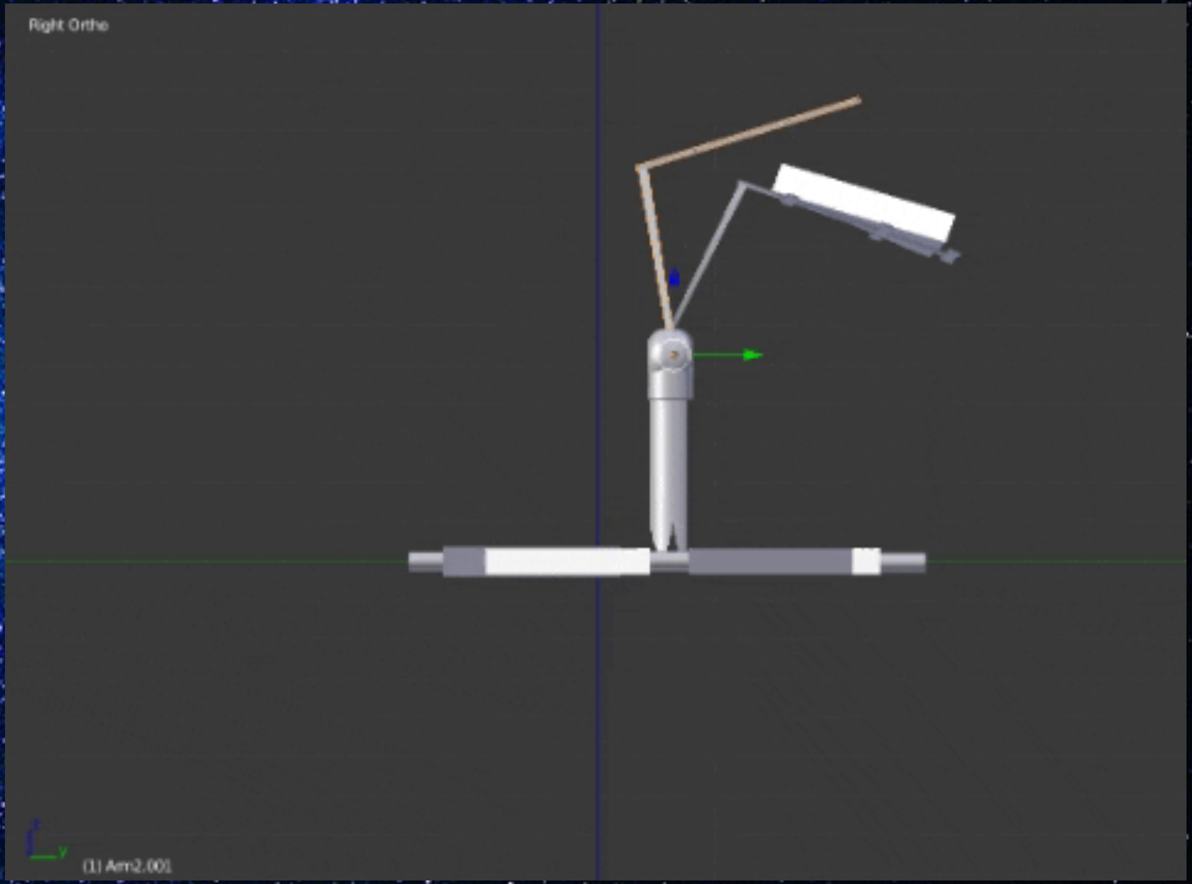
	Reliability	Non-invasiveness	Accuracy	Cost	Speed	Complexity	Total
Coordinate Method	3	9	3	6	3	3	165
Robots check modules	9	1	9	3	1	9	192
Peer to peer check	3	5	3	9	9	3	156
Reverse simulation based on rectenna patterns.	1	9	1	9	3	1	136
Weights	9	9	9	3	3	1	

Repair Robot



Repair Robot

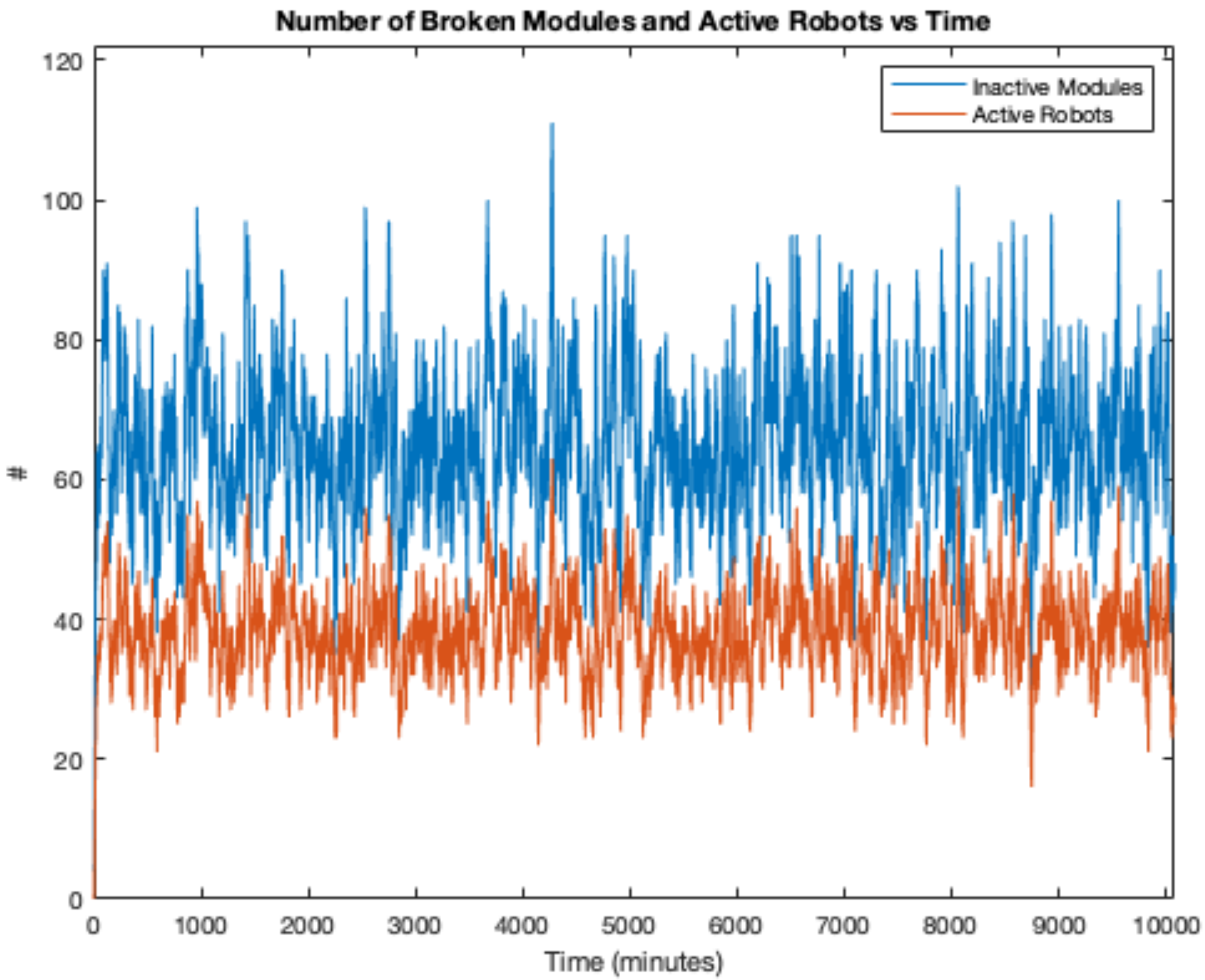




Module Availability

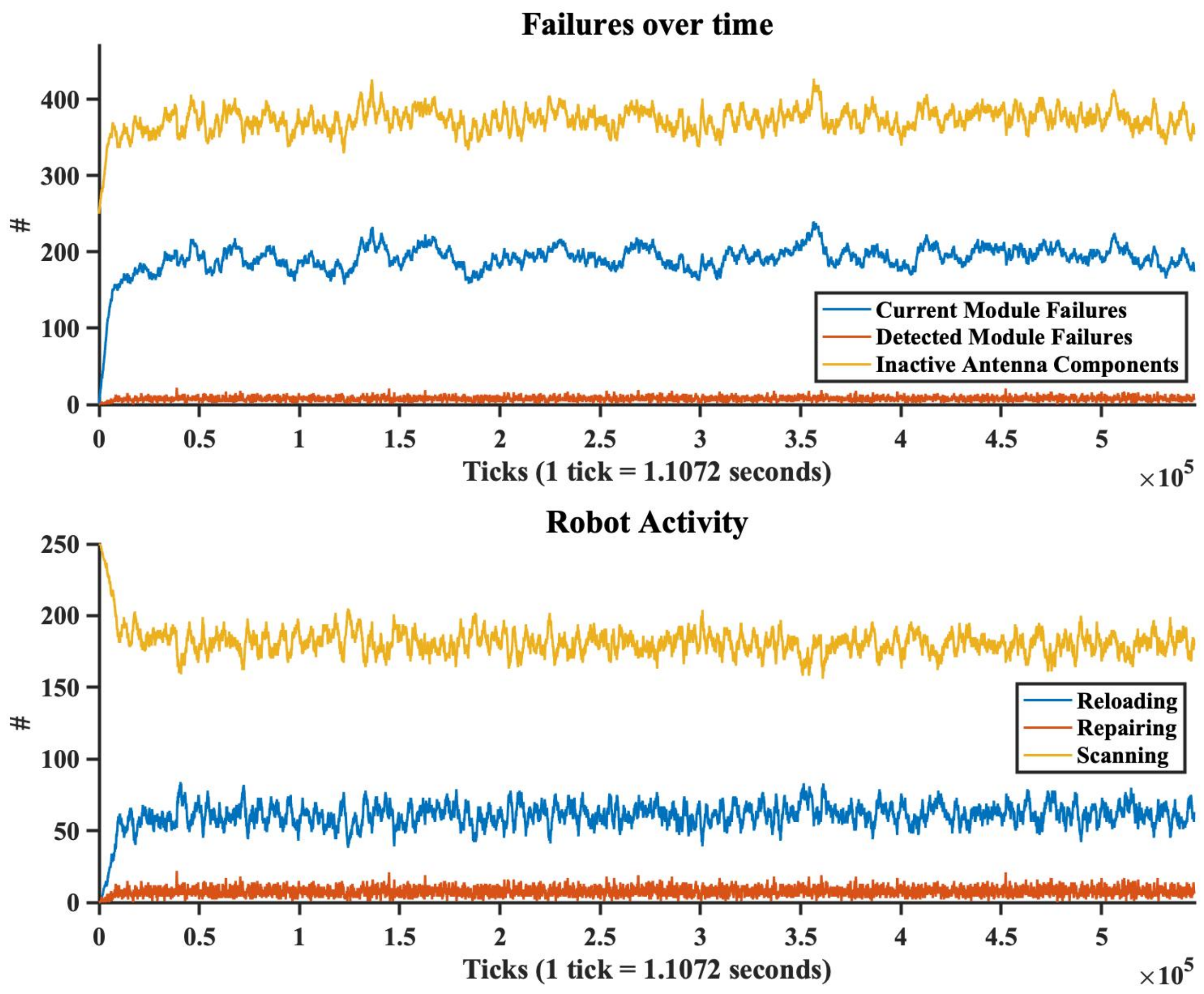
```
hour = 60;
day = 24*60;
week = 7 * day;
month = day * 30;
year = day * 365;

time = 0;
failureRateMinute = ...
    failureRateDay / (1440);

robotQueue = [];
totalCurrentFailures = 0;
failureHistory = [];
unaddressedFailures = 0;
robotHistory = [];

% Robot info in robotqueue:
% traveldist, distleft, repTimel

f = waitbar(0, "Simulating...");

 timeSpan = week;

 robotSpeed = robotSpeed * 60;

while(time < timeSpan) % Every
    waitbar(time/timeSpan);

    queueSize = size(robotQueue);
    queueSize = queueSize(1);
```

```
i = 1;

% Updating status of the bots

while i < queueSize
    % Update current distance left to travel
    distLeft = robotQueue(i, 2);
```

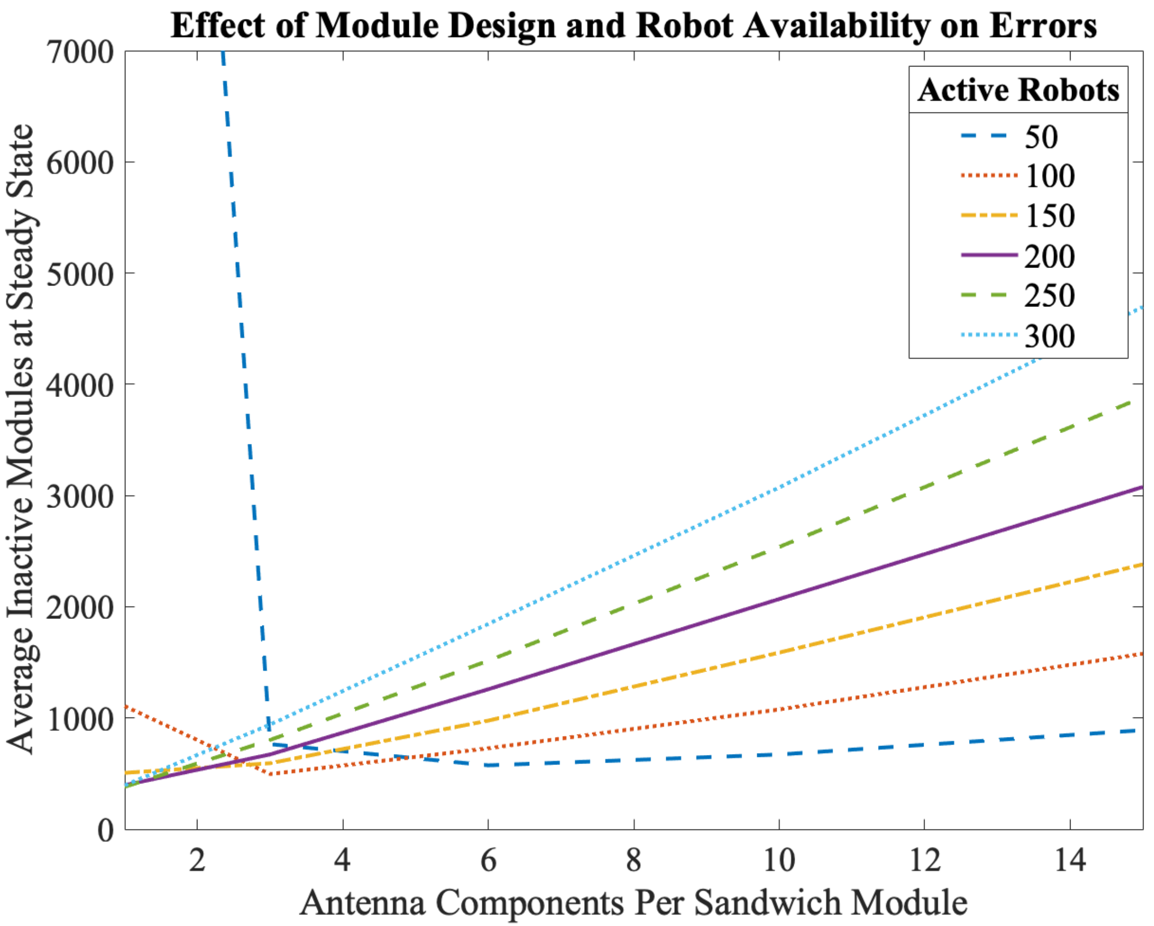



```
        totalCurrentFailures = totalCurrentFailures - 1;
    end
```

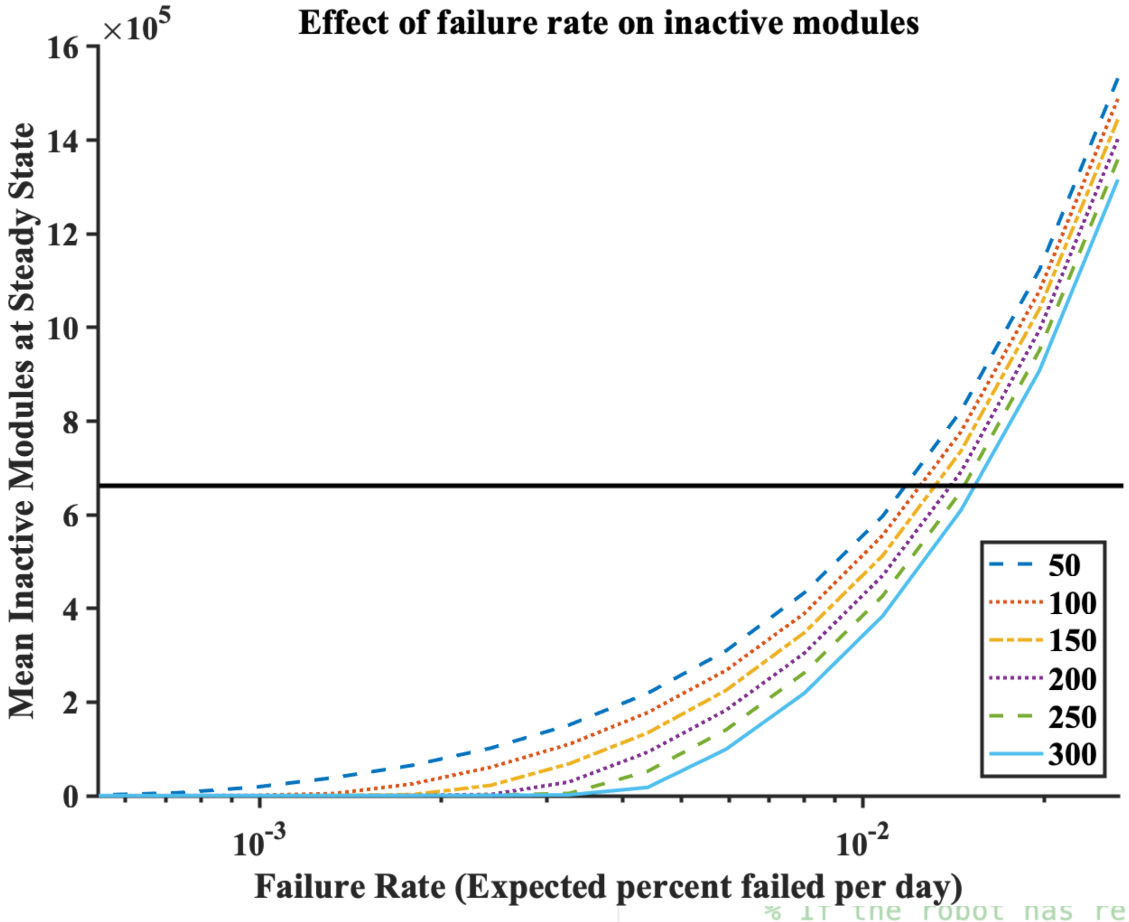
Module Availability



Module Design and Robot availability



Failure Rate and Module Availability



FMEA: Failure Modes and Effect Analysis

- FMEA for identifying failues in a design
  - Systematic
  - Formal
  - Step-by-step.

- Murphy’s Law

FMEA

Process Step/Input	Potential Failure Mode	Potential Failure Effects	Potential Causes	Action Recommended	SEVERITY (1 - 10)	OCCURRENCE (1 - 10)	DETECTION (1 - 10)	RPN
Pilot beam	Loss of Signal	Beam direction off	Loss of power, sabotage, broken parts, interference	Shut off beam	10	4	1	40
Phase	Phase decoherence	High sidelobe levels (SLL)	Loss of flatness	Shut off beam /or spin the spacetenna	7	5	1	35
Acts of Nature	Solar Flare	Wipe out electronics	coronal mass ejection	Shut off beam, use rad-hard electronics	9	3	1	27
Module	Module comes loosed	Debris field	Micrometeorite	Debris avoidance manoeuvre	3	3	2	18
			Failed coupling	Debris avoidance manoeuvre	3	3	2	18
Acts of War	Large-scale damage	Loss of beam coherence	Missile	Shut off beam	9	2	1	18
Solar Panel	Connection is loose	Decrease energy captured by the panel	Collision of space debris	Debris avoidance manoeuvre	2	[illegible]	2	16
DC to RF converter	device might burned out	Decrease in efficiency	Manufacturing defect	Replace module	2	4	2	16
Phase Electronics	Phase shifter broken	Beam decoherence	Manufacturing defect	Replace module, insist on improved quality	2	4	2	16
	Temperature is too high	Decrease in efficiency	Concentration level is too high	addition of radiator area to the PV panel	2	3	2	12
Antenna	Multipactor which might damage antenna	Decrease in efficiency	exponential electron multiplication	Replace module, improve design, operate at lower power	2	2	2	8

Power Control Methods

Centralized	Distributed
Less equipment on each individual sandwich model, leading to fewer components.	More equipment on each individual sandwich module, leading to higher component count.
Higher control over control software, allowing for adjustments and updates.	Phase control is more sophisticated and individualized to each module.
Increased wiring connecting each sandwich module, allowing for connection-based failures and increased connection complexity.	Fewer wired connections between neighboring sandwich modules, reducing connection-based failures.
Increased potential for delayed controls with large array structure.	Completely localized control, reducing errors due to communication delay.
Increased communication between modules, allowing for a connection-based error detection system.	Higher difficulty communicating with neighboring modules, requiring more complex RF communication.

Results

Areas of Focus:

1. Control (Centralized or Decentralized)
2. Error Detection Method
3. Error Repair Method
4. Minimization of Askew Angles Between Adjacent Sandwich Modules

Goal:

- Side Lobe Levels (SLL) less than **-82 dB**
- Avoid “desense” of nearby comms
- Lean, automated operation