Pretension Modal Analysis of Nvidia Jetson Nano

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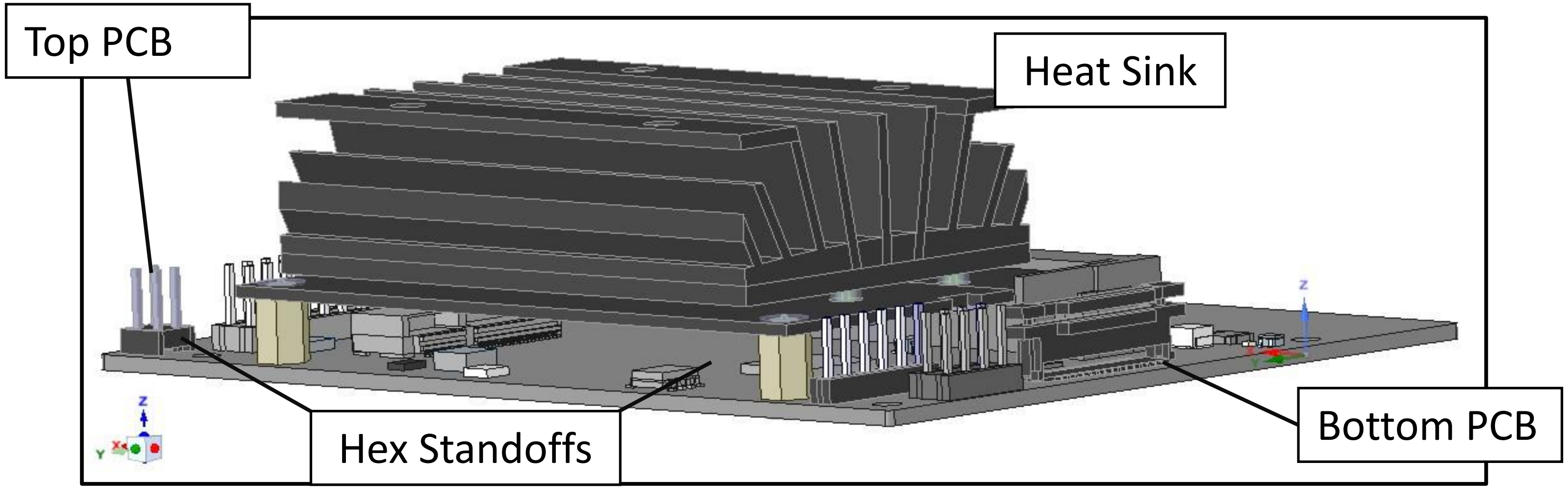
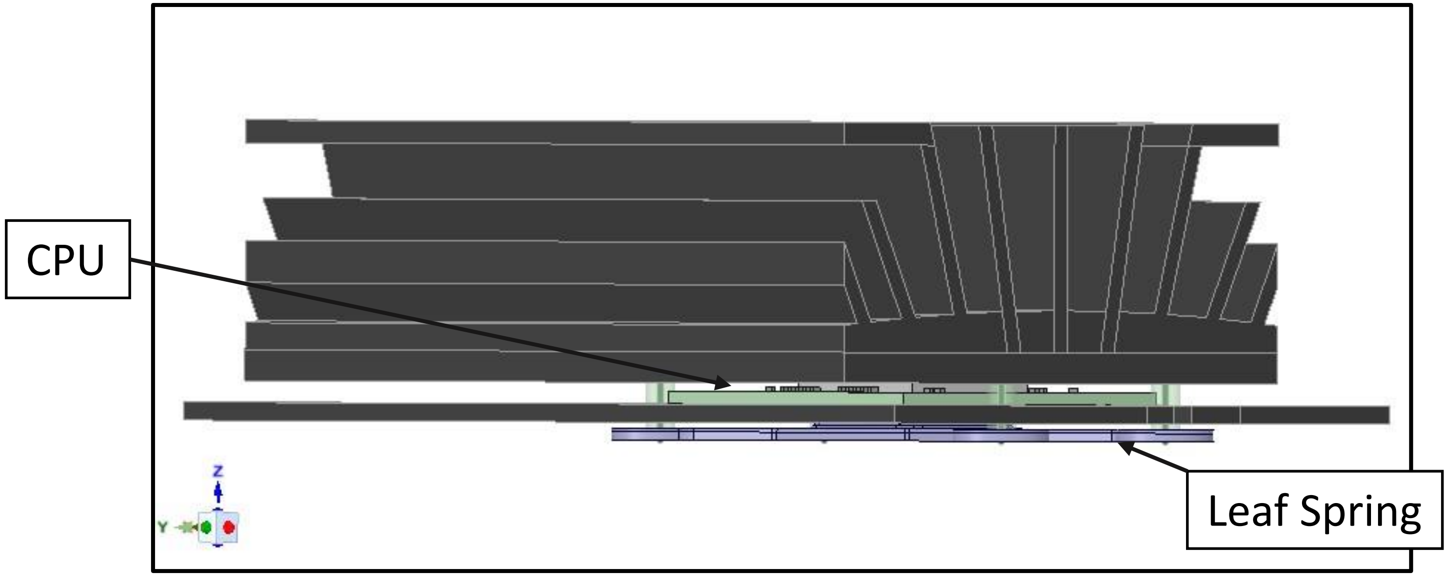
SCOPE

- To perform a sequential FEAa nalysis on NVIDIA Jetson Nano PCB Assembly.
- A Bolt pretension Nonlinear static analysis of the NVIDIA Jetson Nano PCB Board assembly is performed. Focus will be to monitor the contact pressure between the CPU unit & Heat Sink surface (not to exceed 50Psi).
- Based on pretension results, perform a modal analysis to calculate the natural frequencies of the assembly. And define a frequency range for the PCB assembly and major components.
- The FEA is performed for different boundary conditions i.e. 2 different fixed locations.
- The parts that are analyzed are the heat sink, CPU and leaf spring assembly, connections between hex standoff screws and the PCBs.

- Model Assumptions:
  - All small ICs, transistors, resistors etc. are suppressed due to small mass.
  - Screws are replaced by beam elements.

GEOMETRY





Material Properties

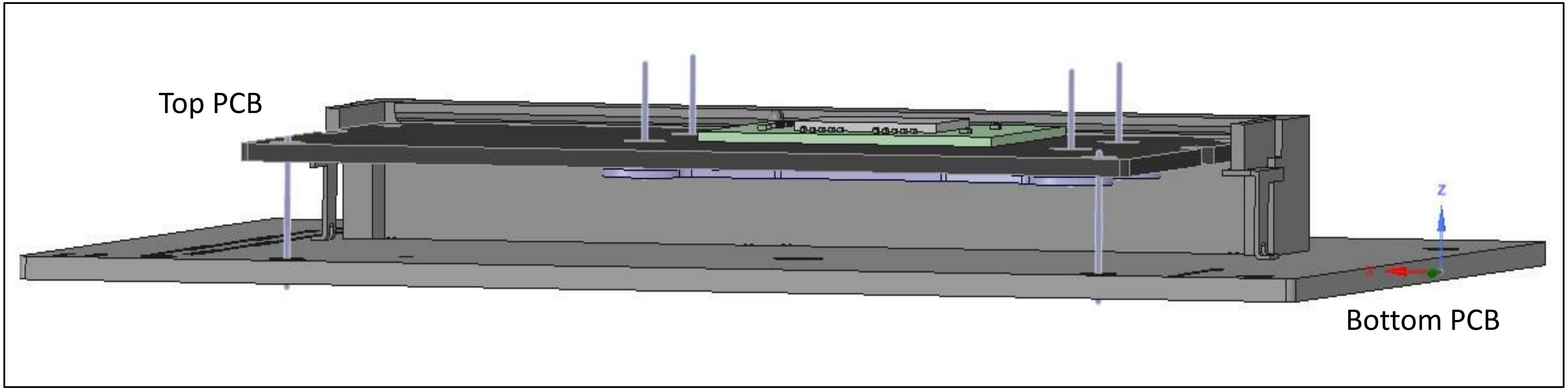
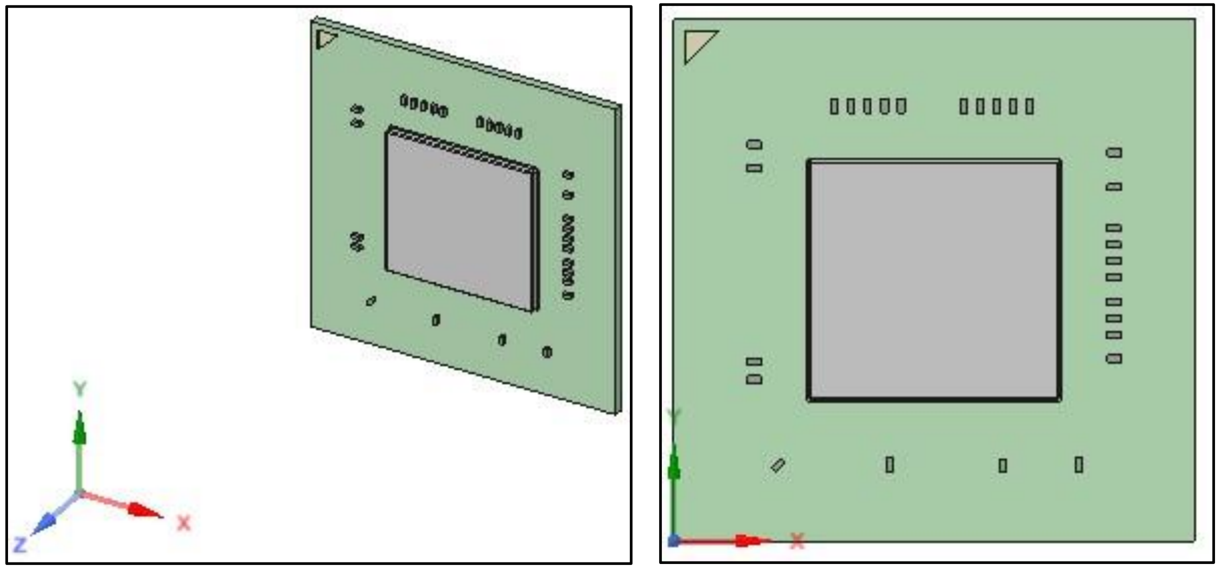


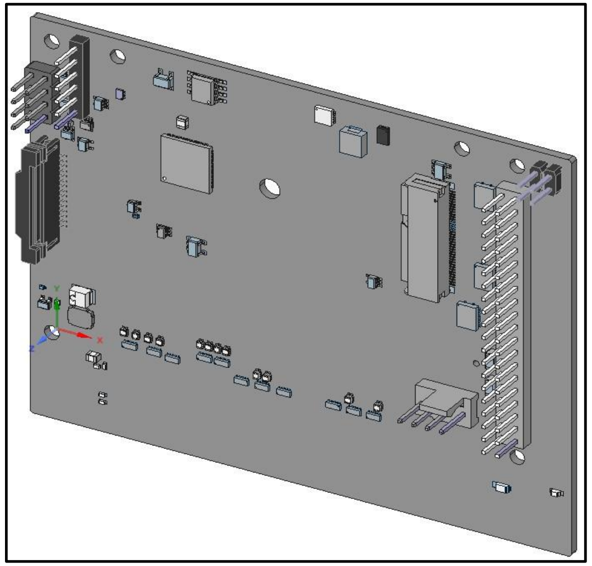
Table. Material Properties for PCB – Material used : FR-4

Component Name	Material Used	E in N/mm2	G in N/mm2	Poisson's Ratio
PCB Board (Linear Orthotropic Material)	FR4	Ex = 21994 Ey = 21994 Ez = 997.4	Gxy = 10000 Gyz = 5000 Gxz = 5000	PRXY = 0.11 PRYZ = 0.28 PRXZ = 0.28

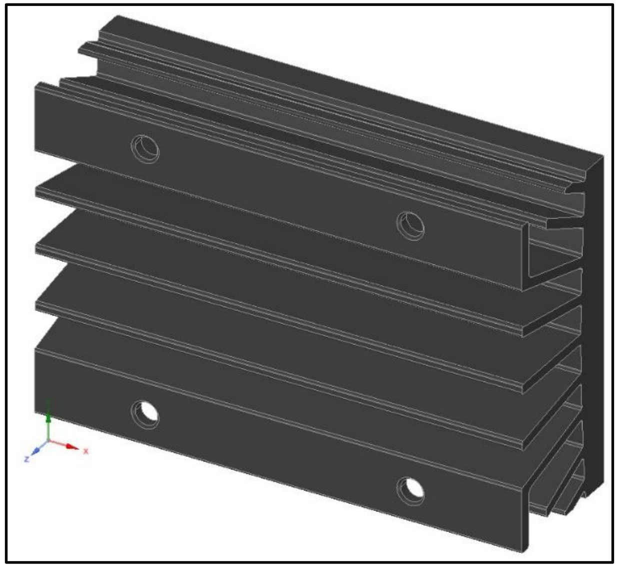
Material Properties



CPU - Cortex-A57



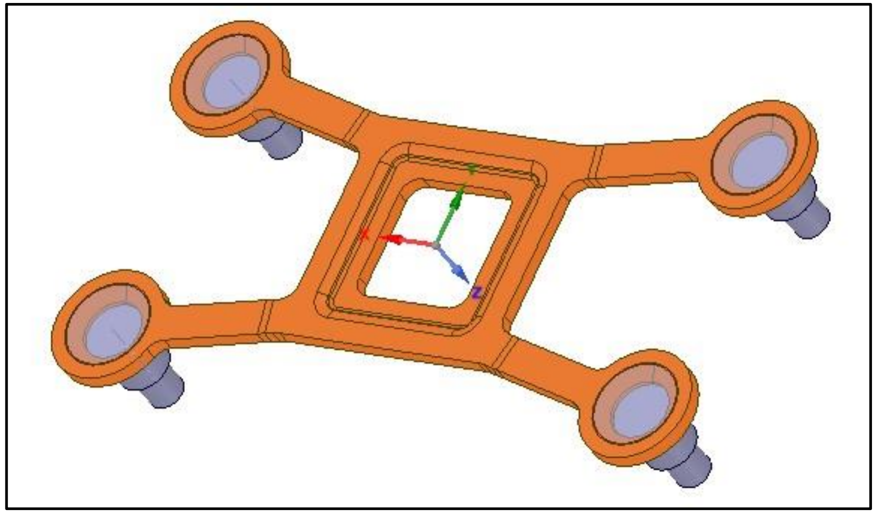
GPU – NVIDIA Tegra-X1



Heat Sink

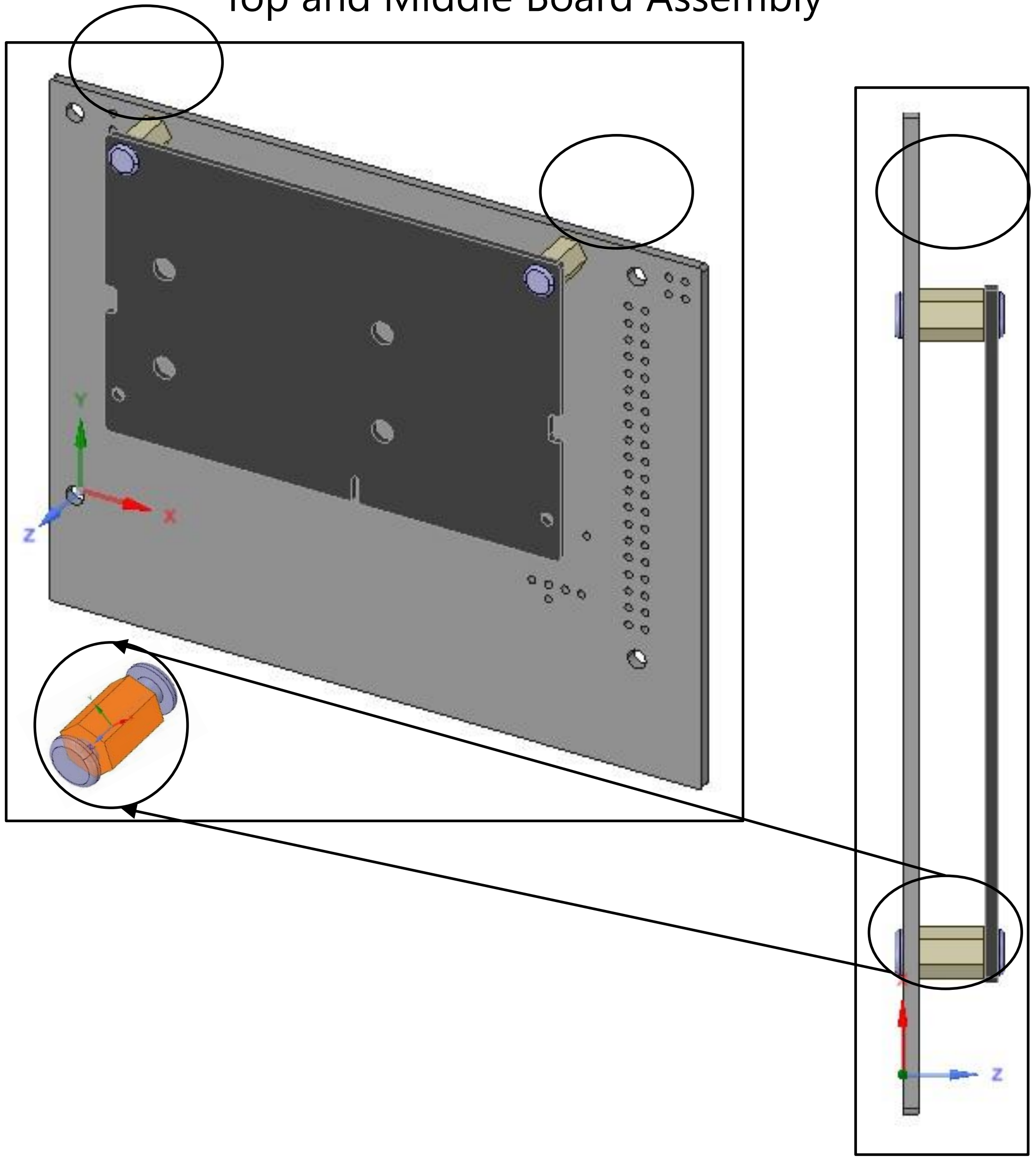
<table>
<tr><th colspan="4">Heat Sink</th></tr>
<tr><td>Fin Space</td><td colspan="3">3.00mm</td></tr>
<tr><td>Dimensions</td><td colspan="3">61mm x 40mm x 16mm/2.40″ x 1.57″ x 0.63″</td></tr>
<tr><td>Weight</td><td colspan="3">34g</td></tr>
<tr><td>Mountain Fasteners</td><td colspan="3">M3.0X0.5, Ultra Low Profile 6.0mm long, Alloy Steel</td></tr>
<tr><td rowspan="2">Material</td><td colspan="3">Aluminium Alloy 6061</td></tr>
<tr><td>Density = 2.7 g/cc</td><td>Youngs Modulus = 68900 MPa</td><td>Poissons Ratio = 0.33</td></tr>
</table>

Material Properties



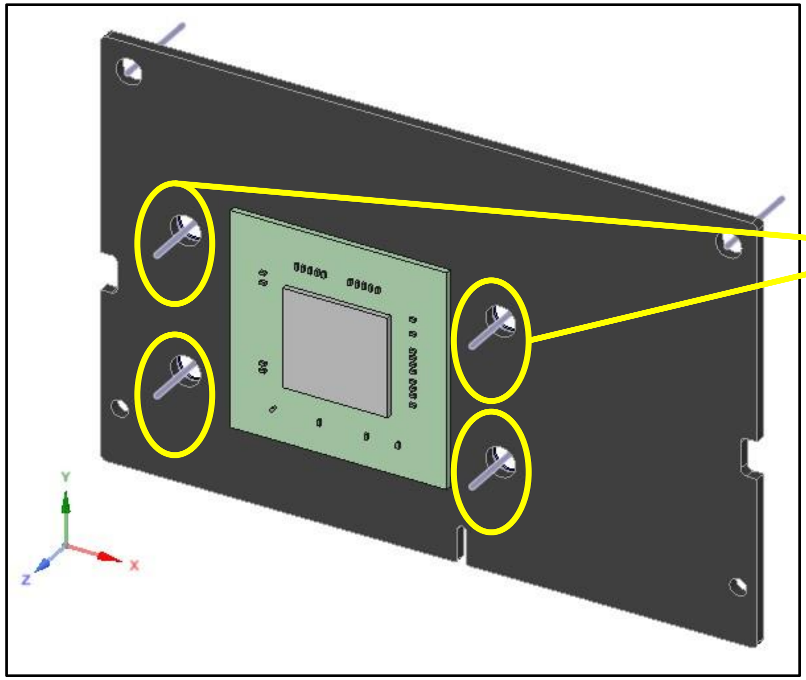
Leaf Spring with 4 screws

Top and Middle Board Assembly

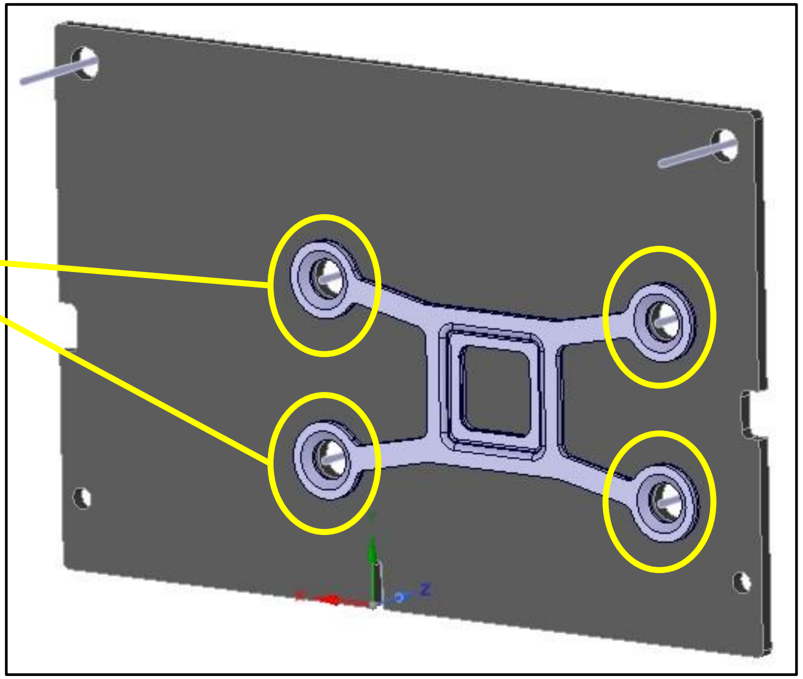


Component Name	Material Used	E in N/mm2	Poisson's Ratio
Screws, Leaf Spring & Hex Standoffs	AISI 12L 14	2.00E+05	0.3
CPU, IC, SODIMM, Connectors	Silicon chip material	1100	0.25

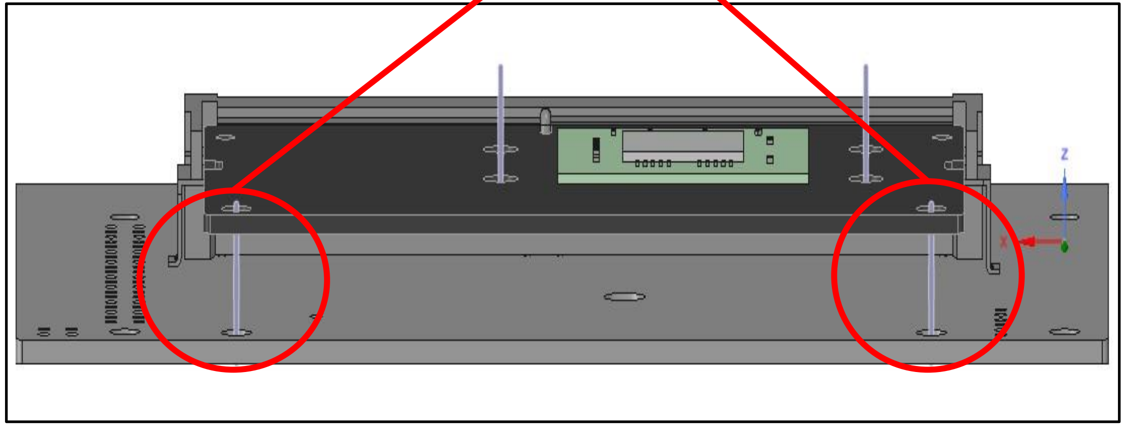
Beam Connections



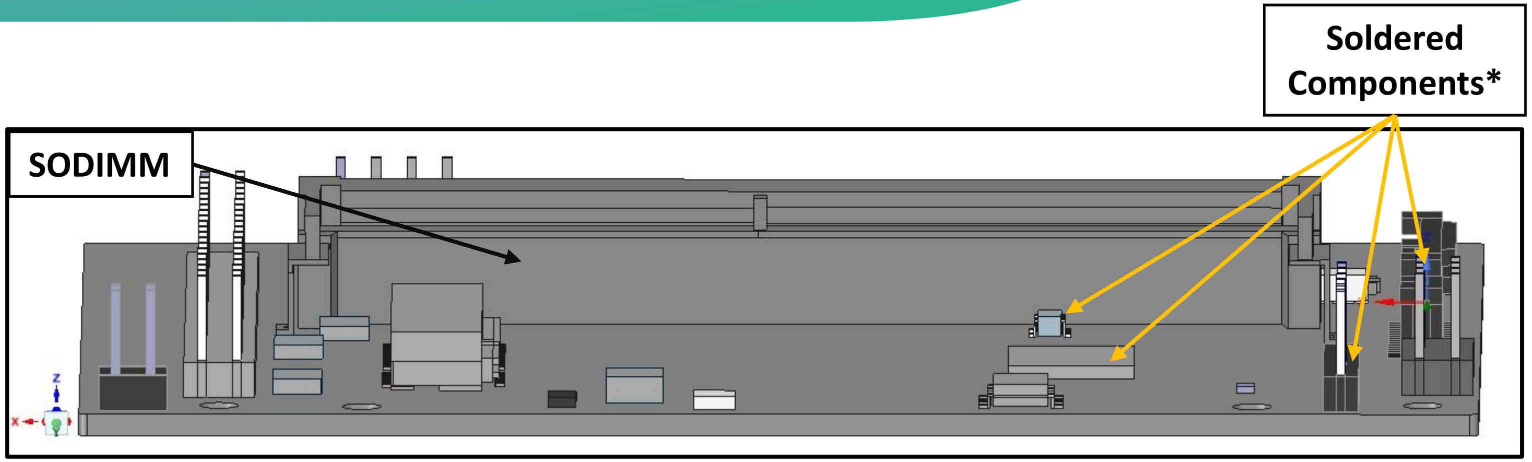
Beam elements connecting Heat Sink + Leaf Spring + Top PCB

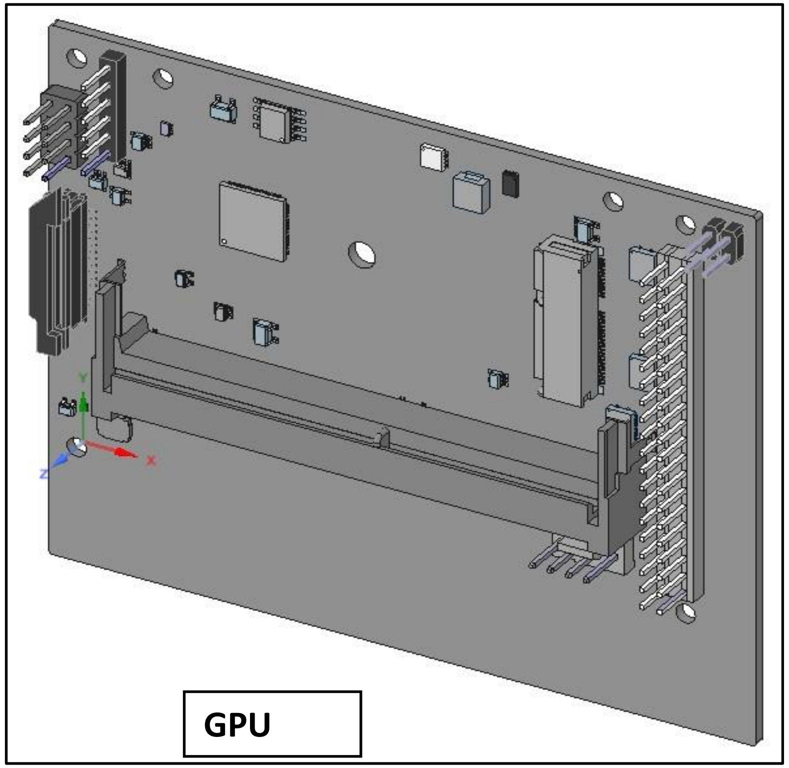


Beam elements connecting Top PCB to Bottom PCB



Contacts : BONDED

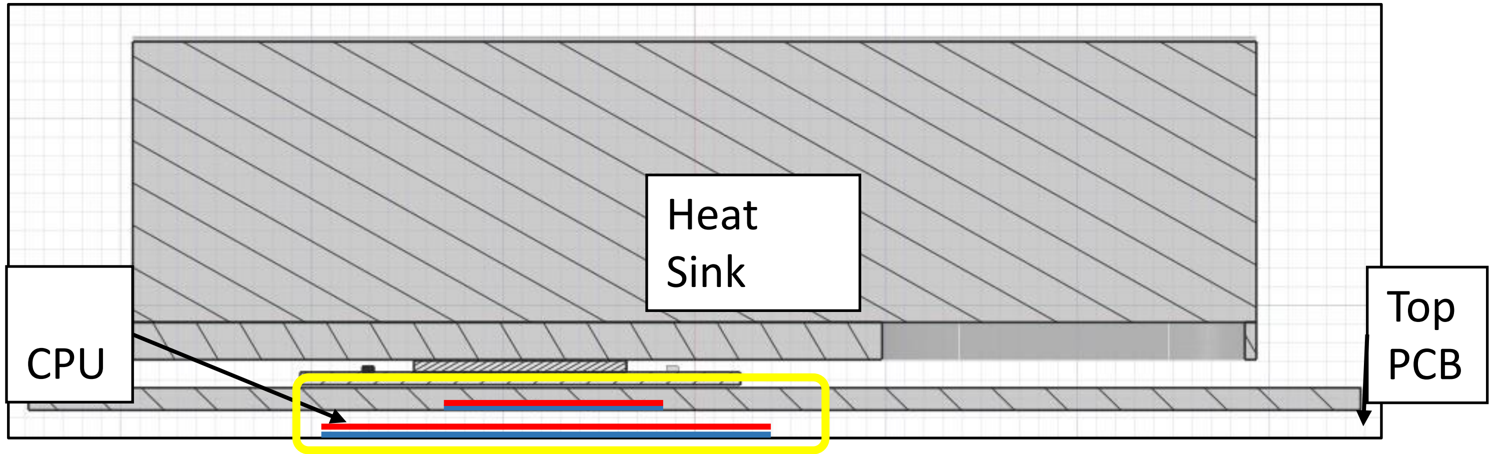


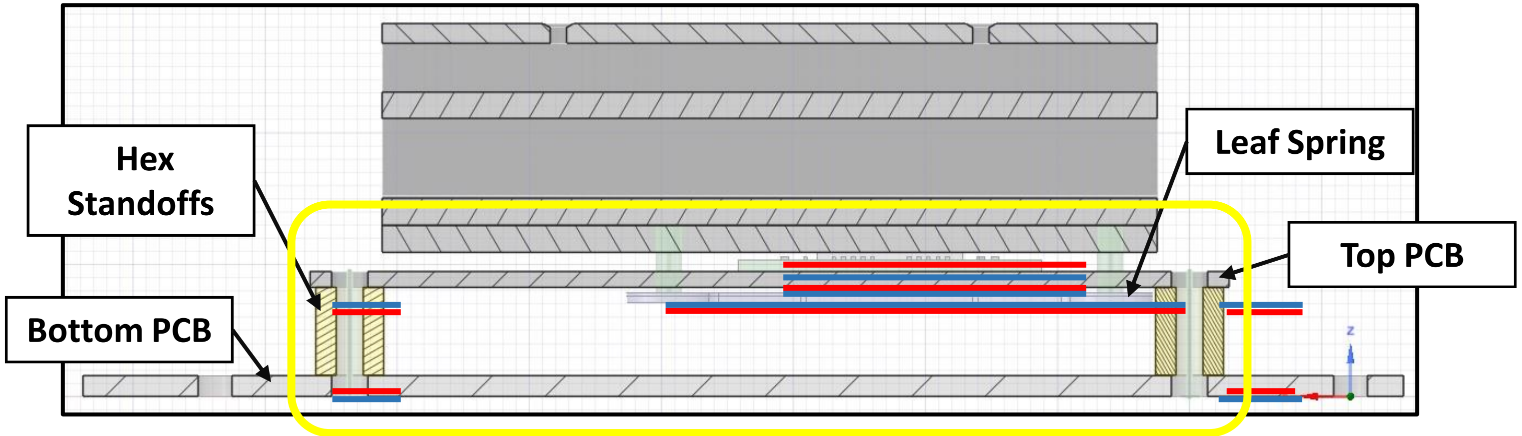


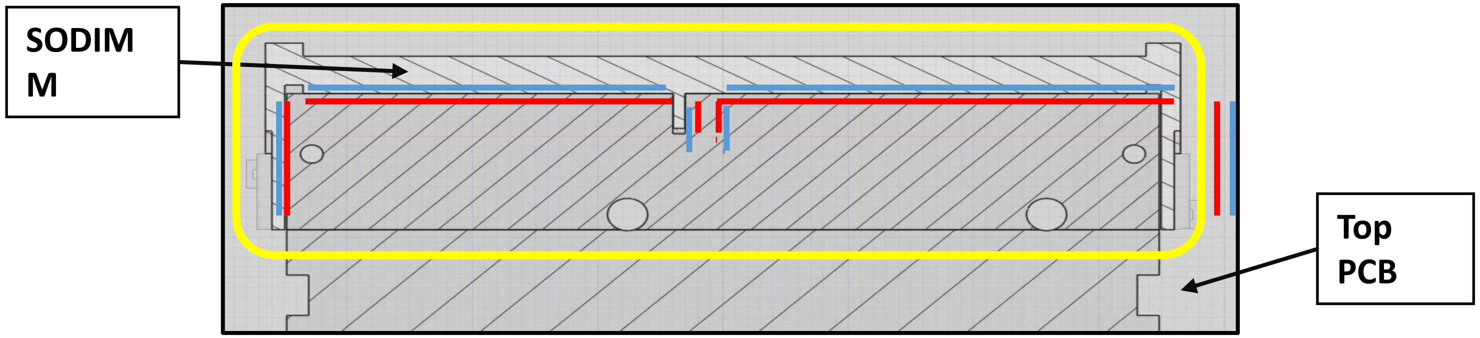
- ➢ Bonded Type Contacts between all chips and small components and GPU (Bottom PCB).
- ➢ Symmetric Behavior.

Standard Contacts

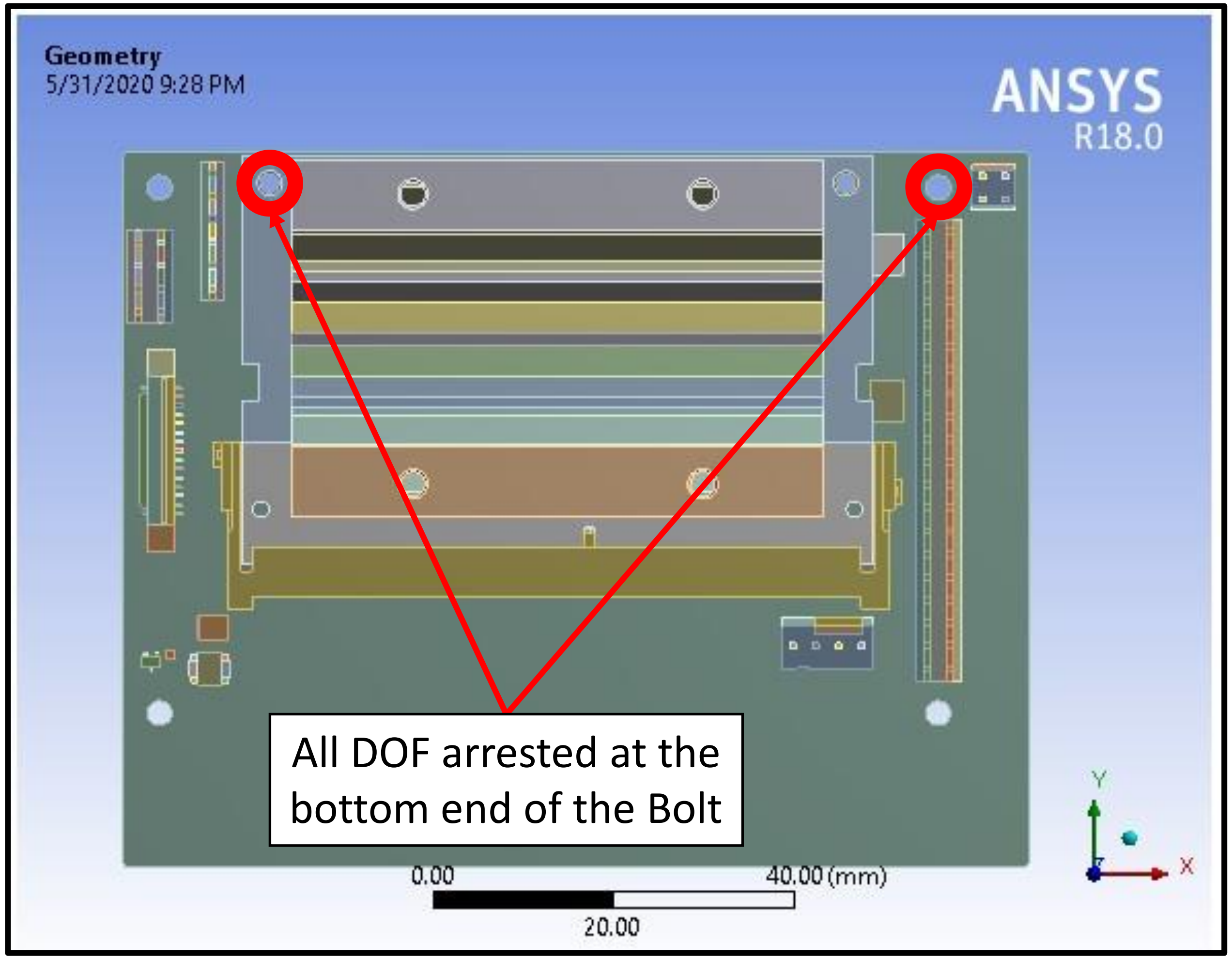
➢ Frictional contact ($\mu = 0.2$) between
  - Heat sink and Tegra X1 CPU
  - CPU and Top PCB.
  - Leaf Spring and Top PCB
  - Hex Standoffs and top and bottom PCBs.
  - SODIMM and Top PCB.

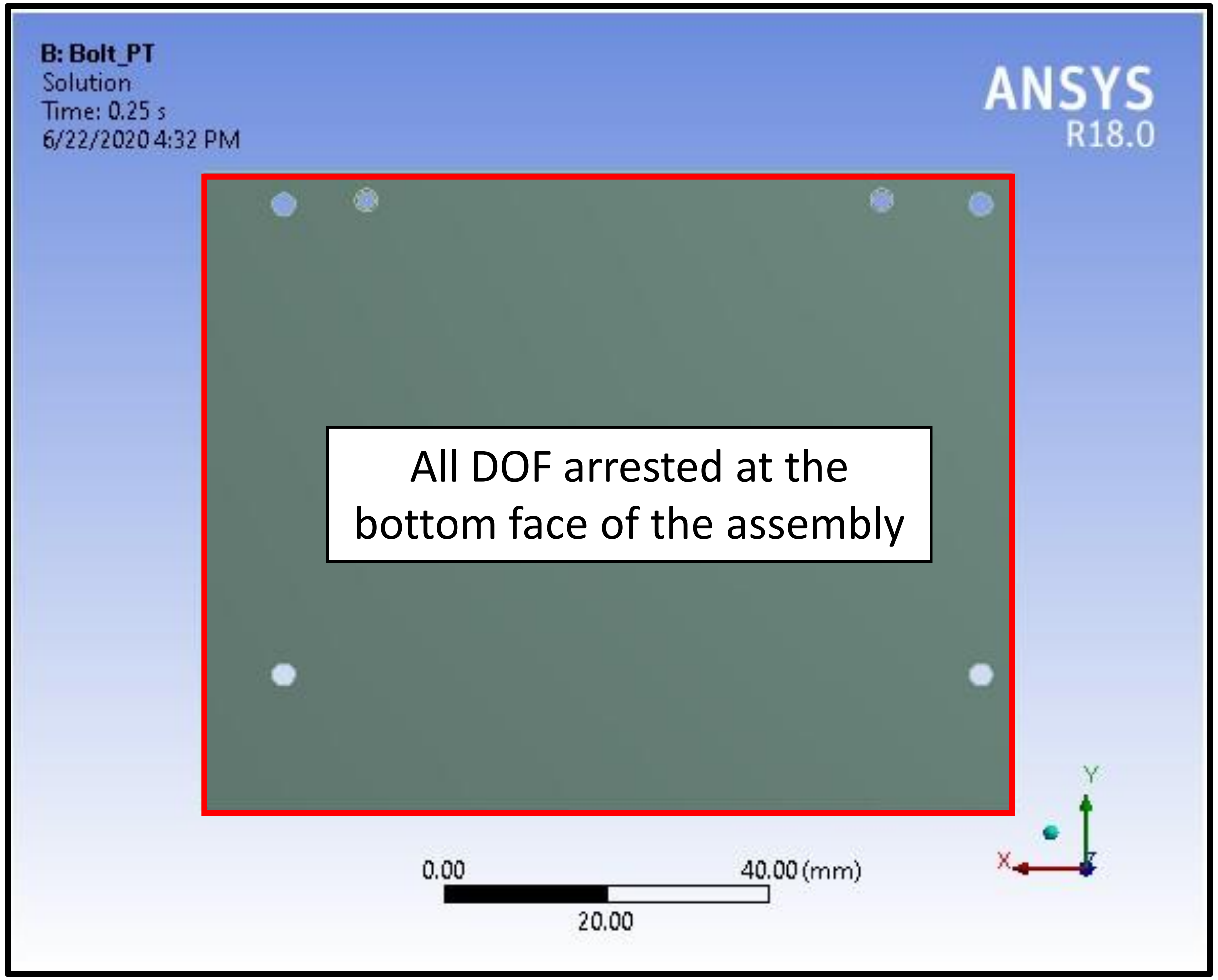




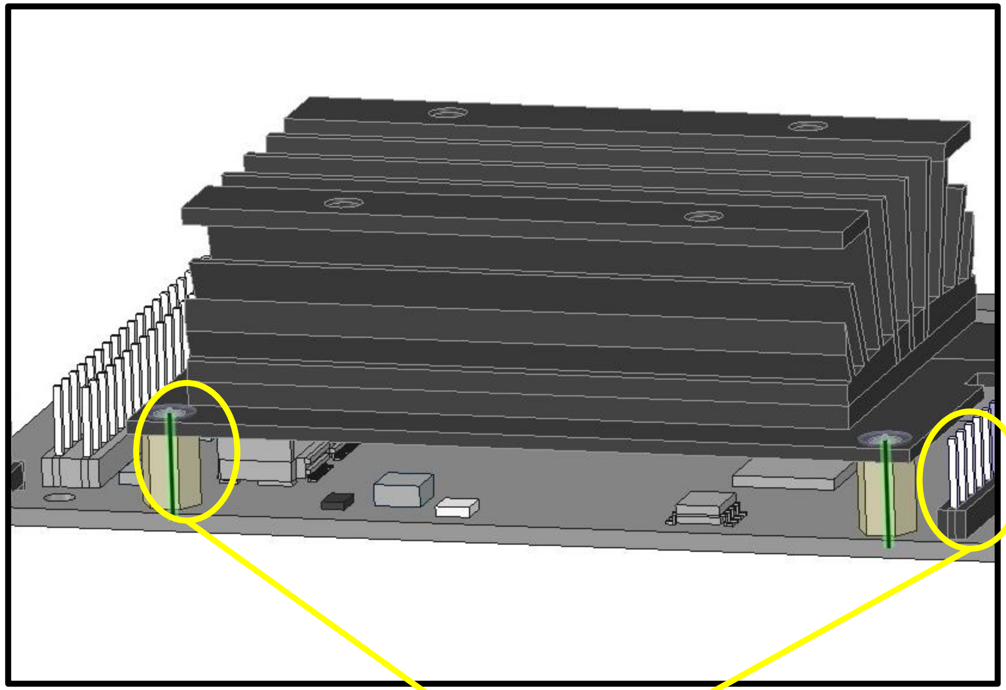


Boundary Condition

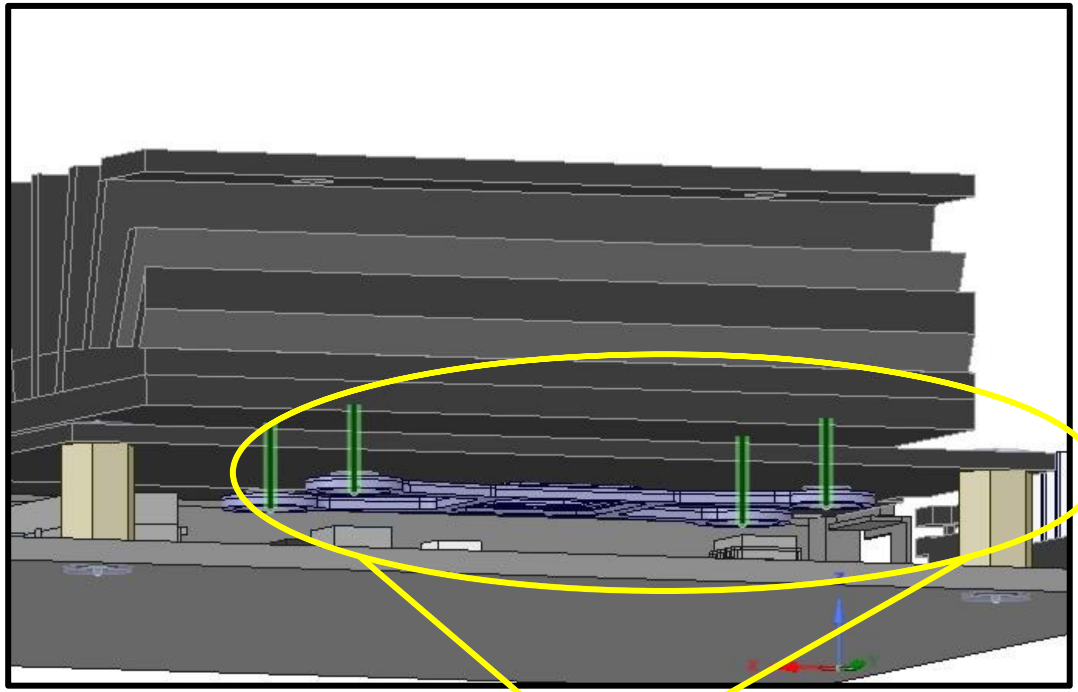




Loading Conditions



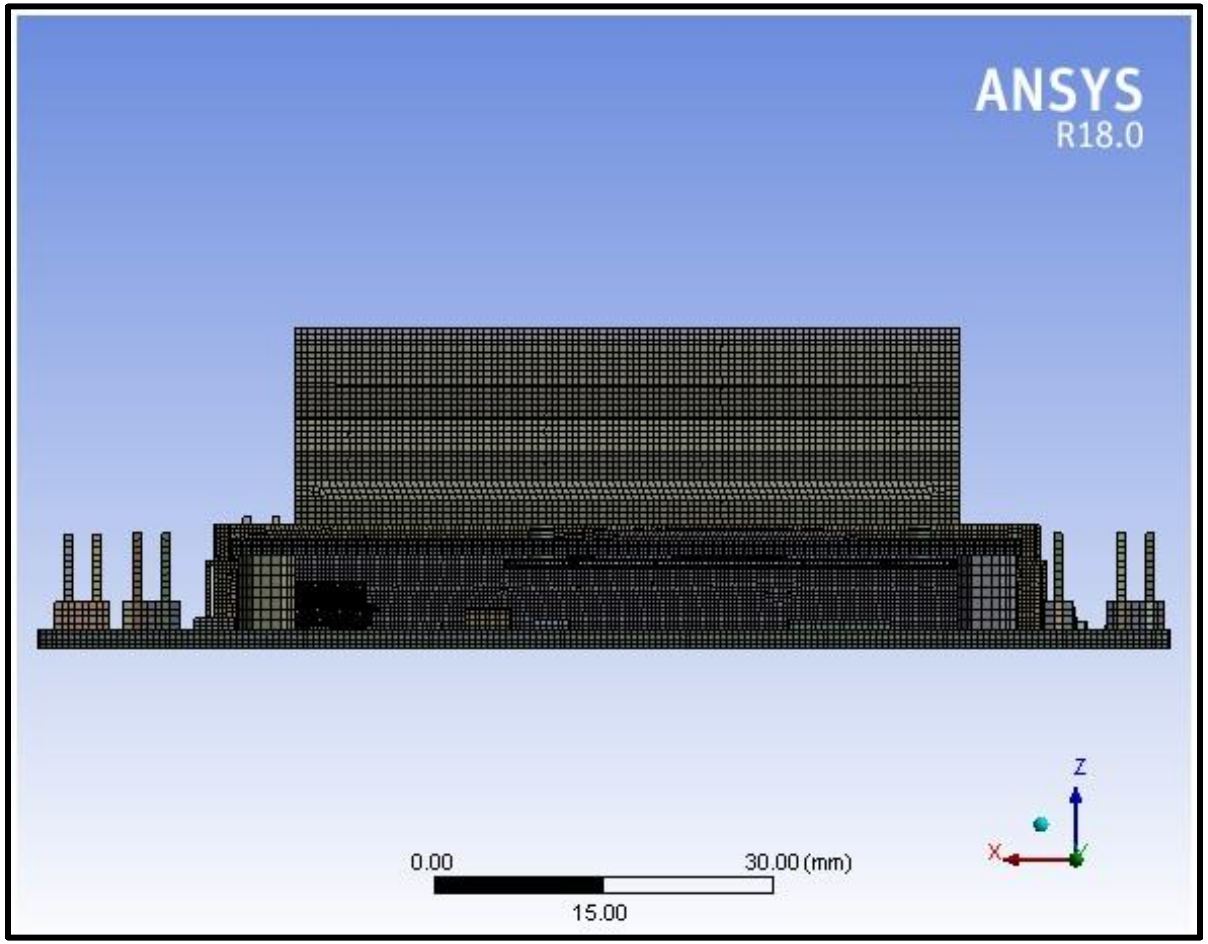
1KN Pretension for Top and Bottom PCB Assembly

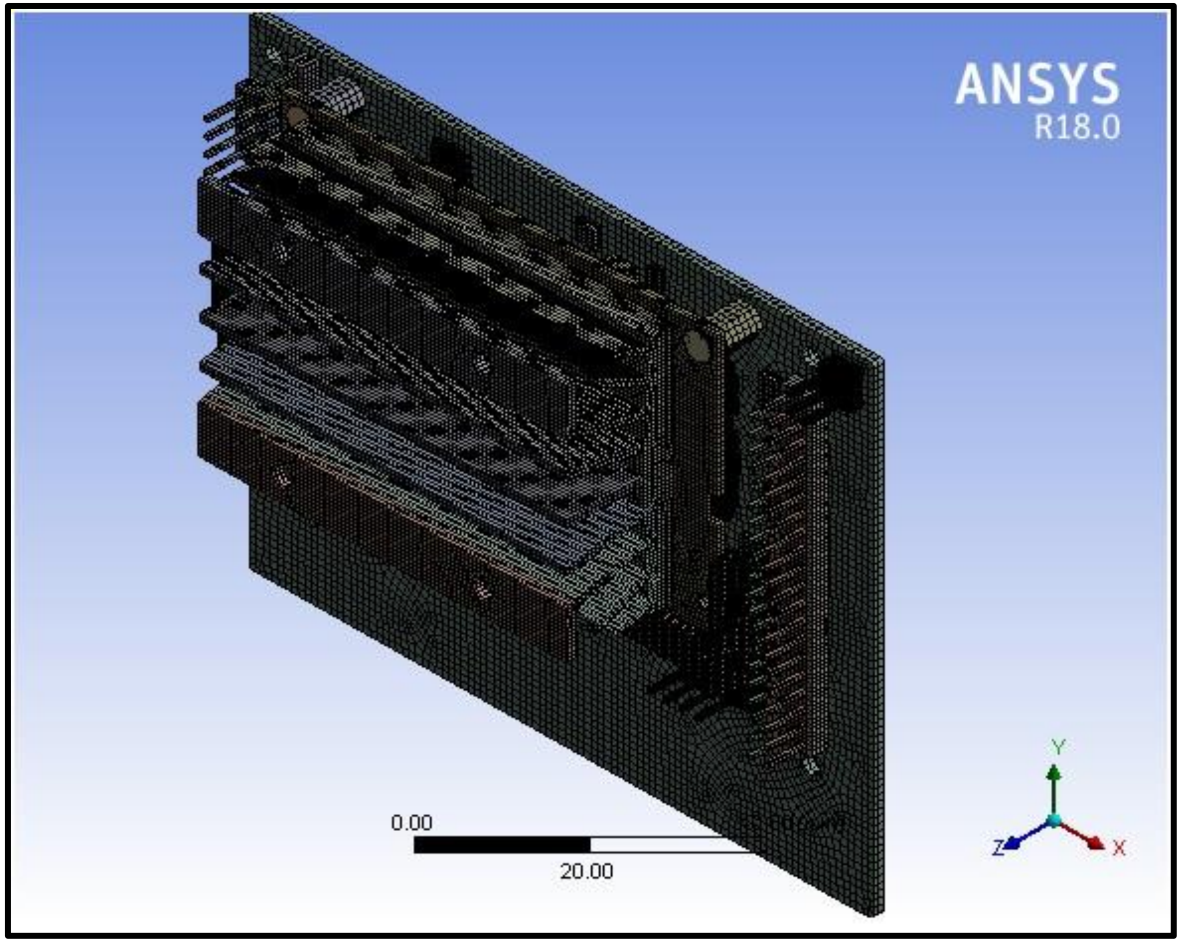


1.8 KN pretension load on Leaf spring-CPU-Heat sink Assembly

MESH

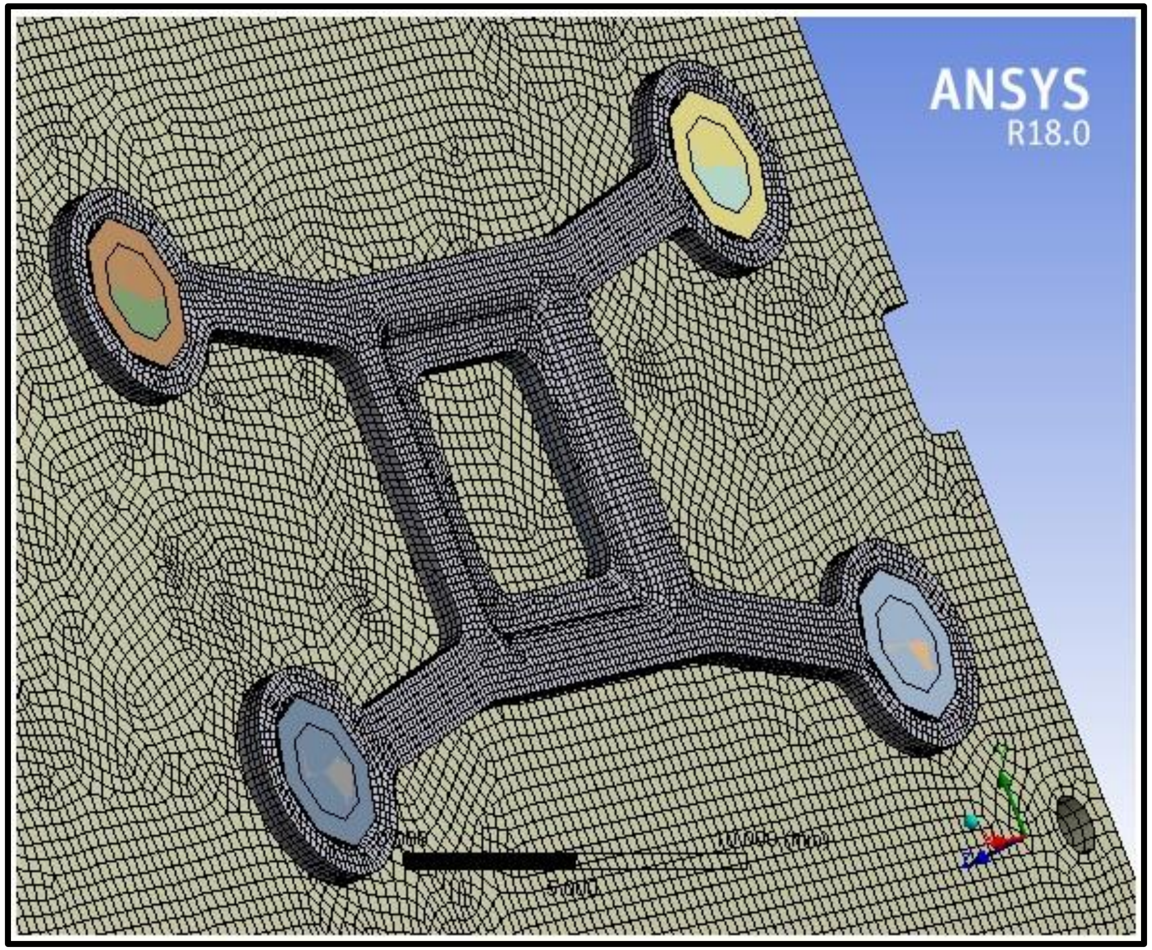
- Linear Hex mesh : Number of Nodes = 671078

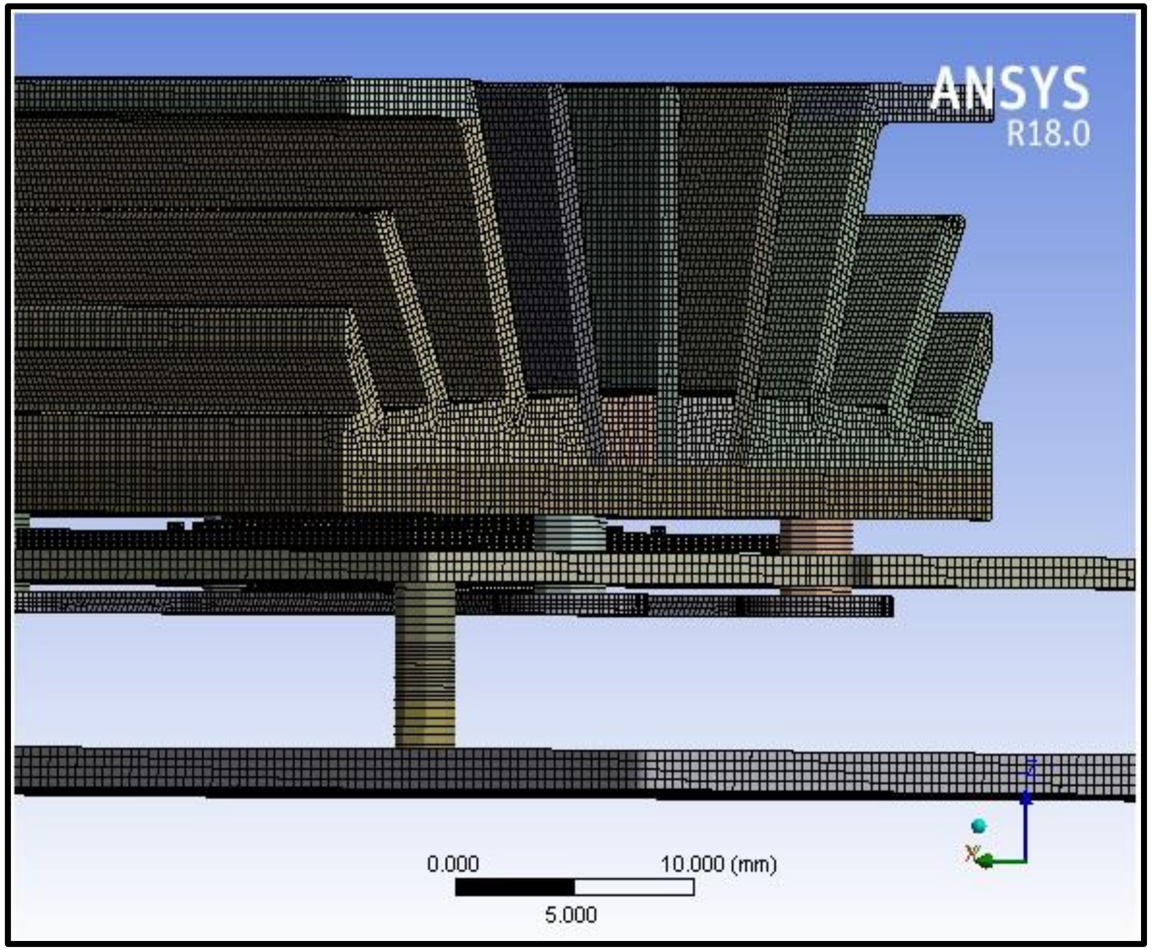




MESH

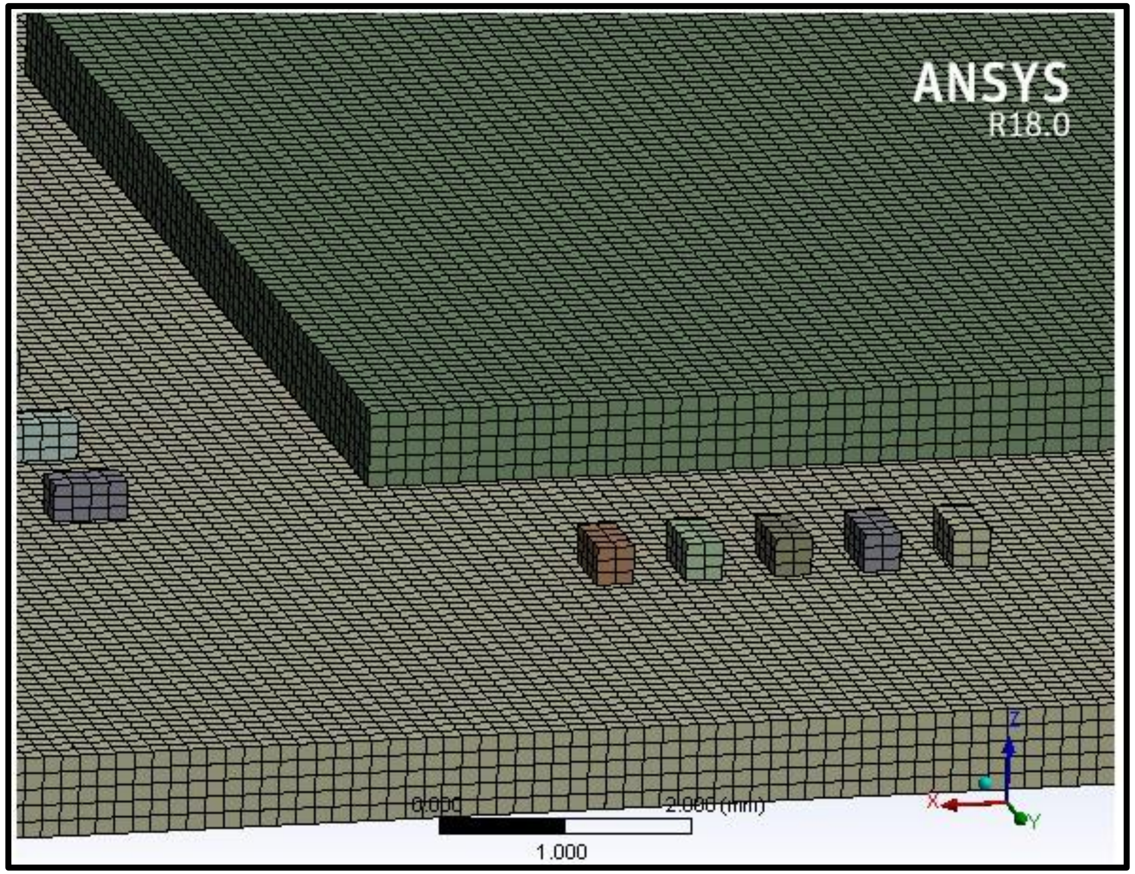
- Linear Hex mesh : Number of Nodes = 671078

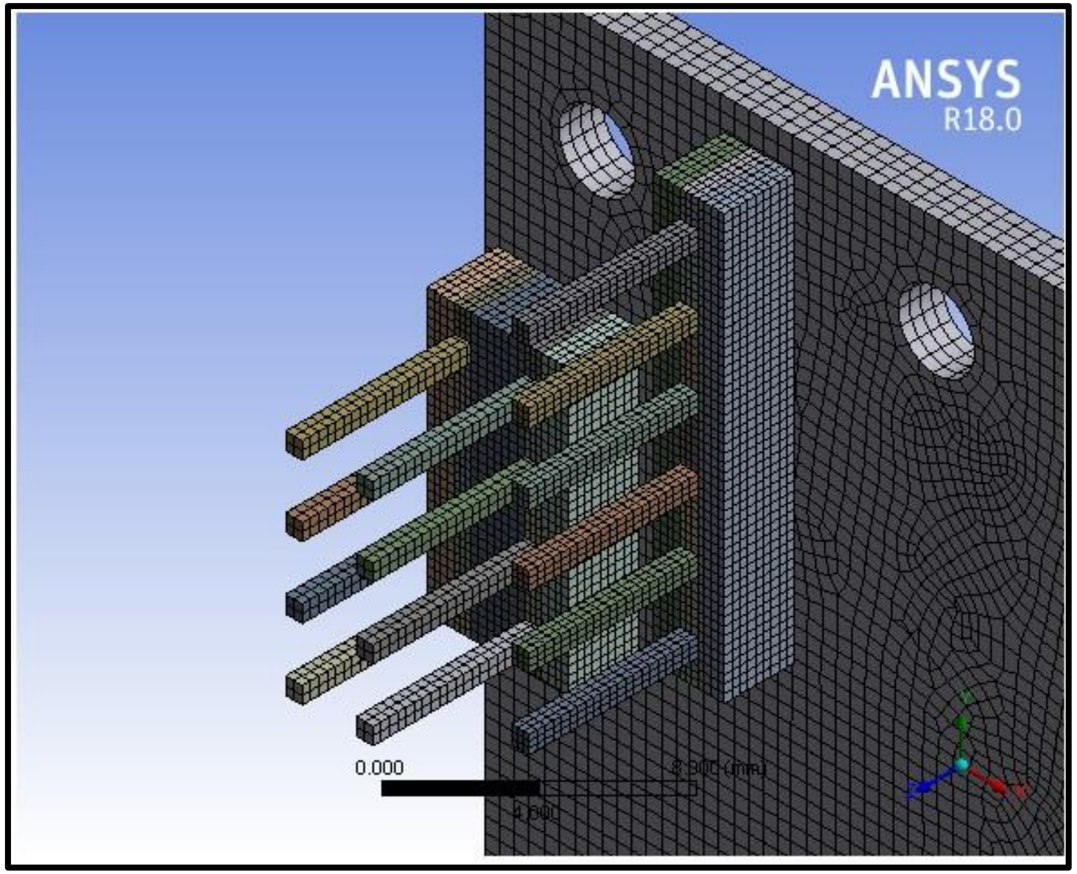




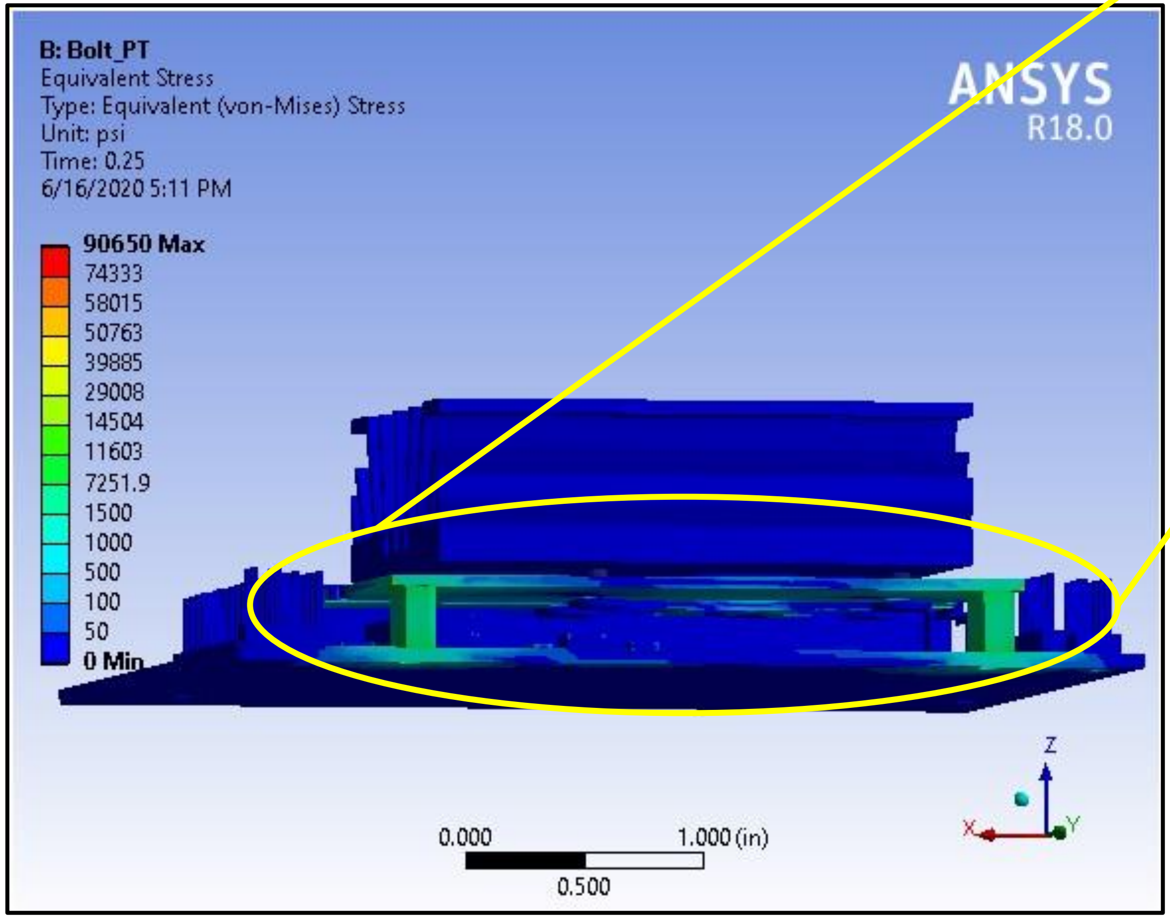
MESH

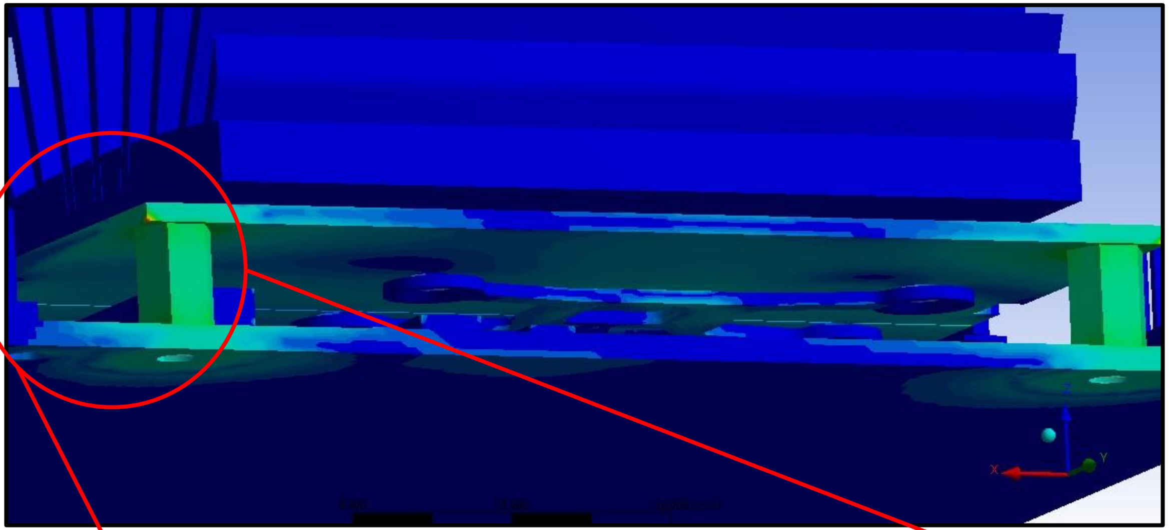
- Linear Hex mesh : Number of Nodes = 671078

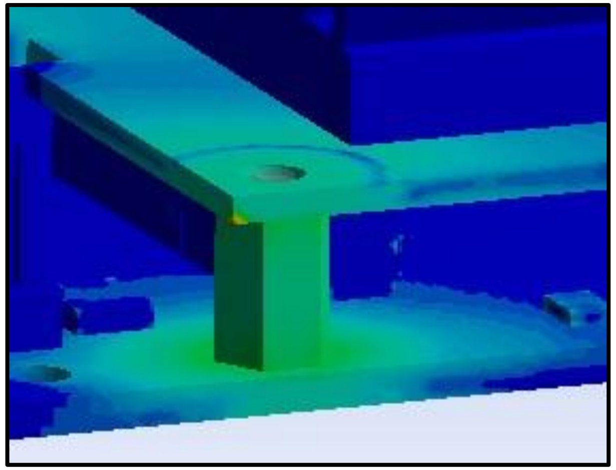




Equivalent Stress Plot : Overall

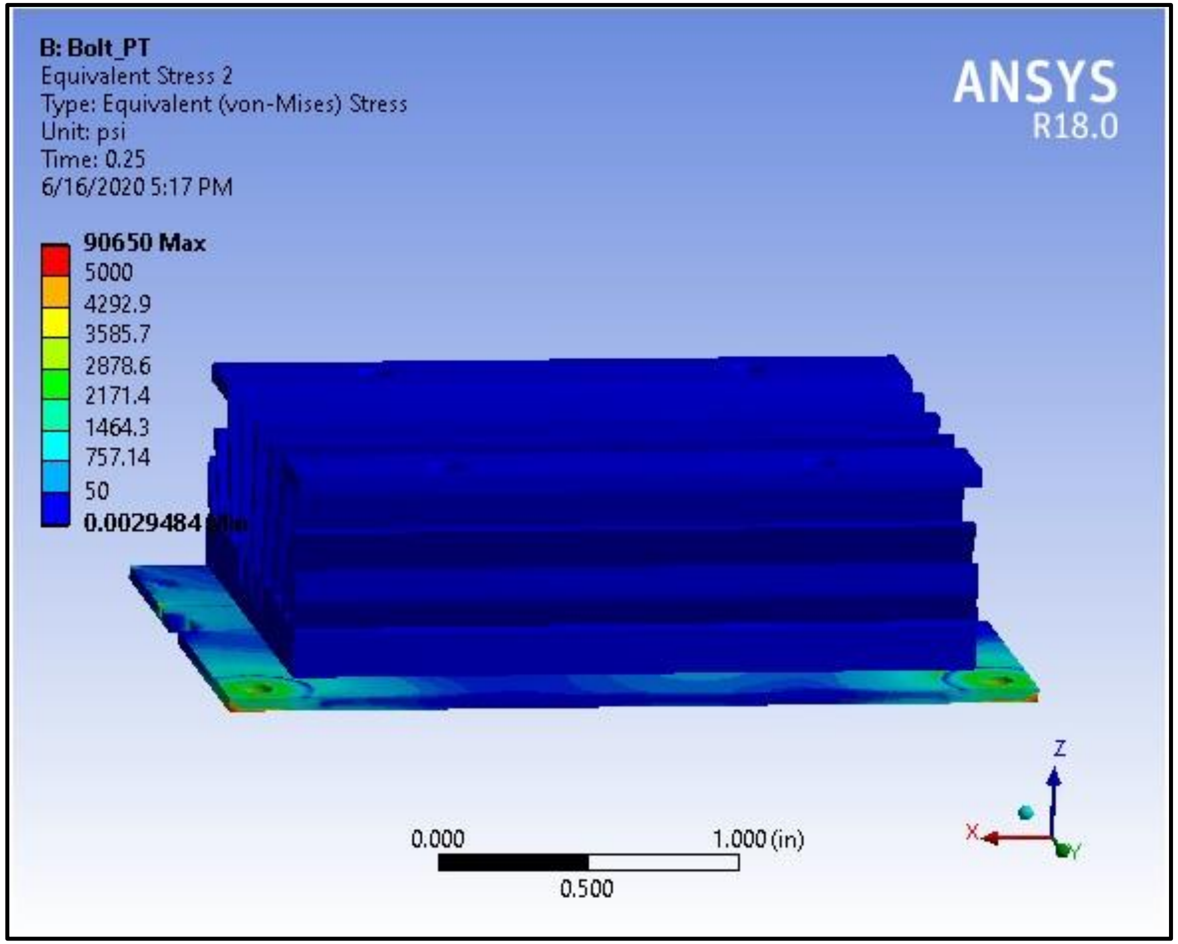


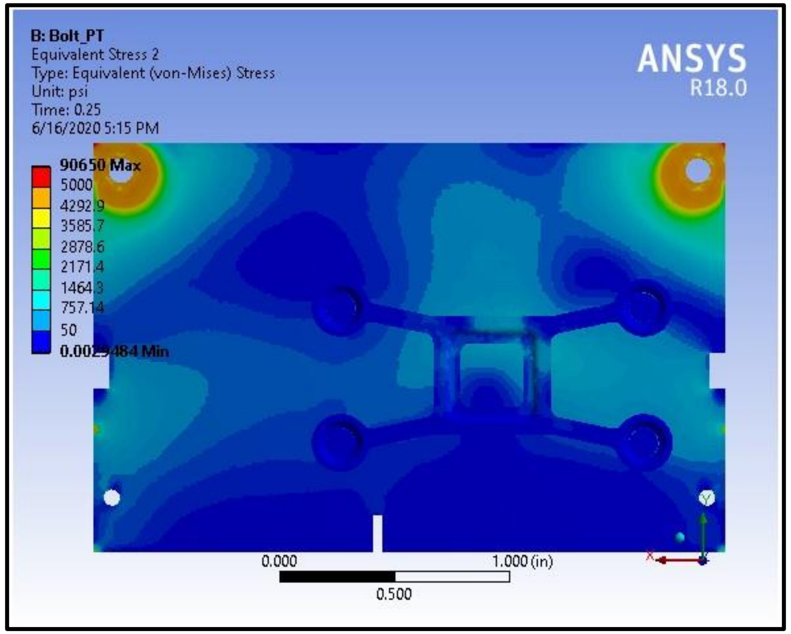




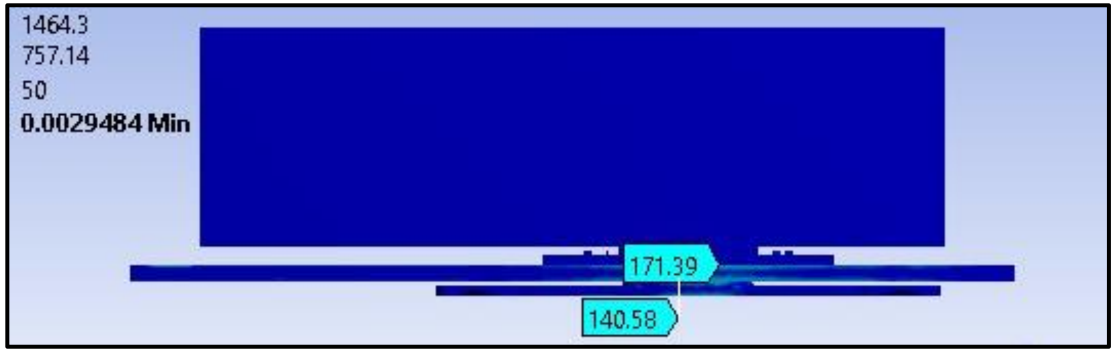
➢ Maximum stress of 625 MPa (90650 Psi) induced on the top PCB area near hex standoffs.

Equivalent Stress Plot : CPU, Heat-sink, Leaf spring assembly





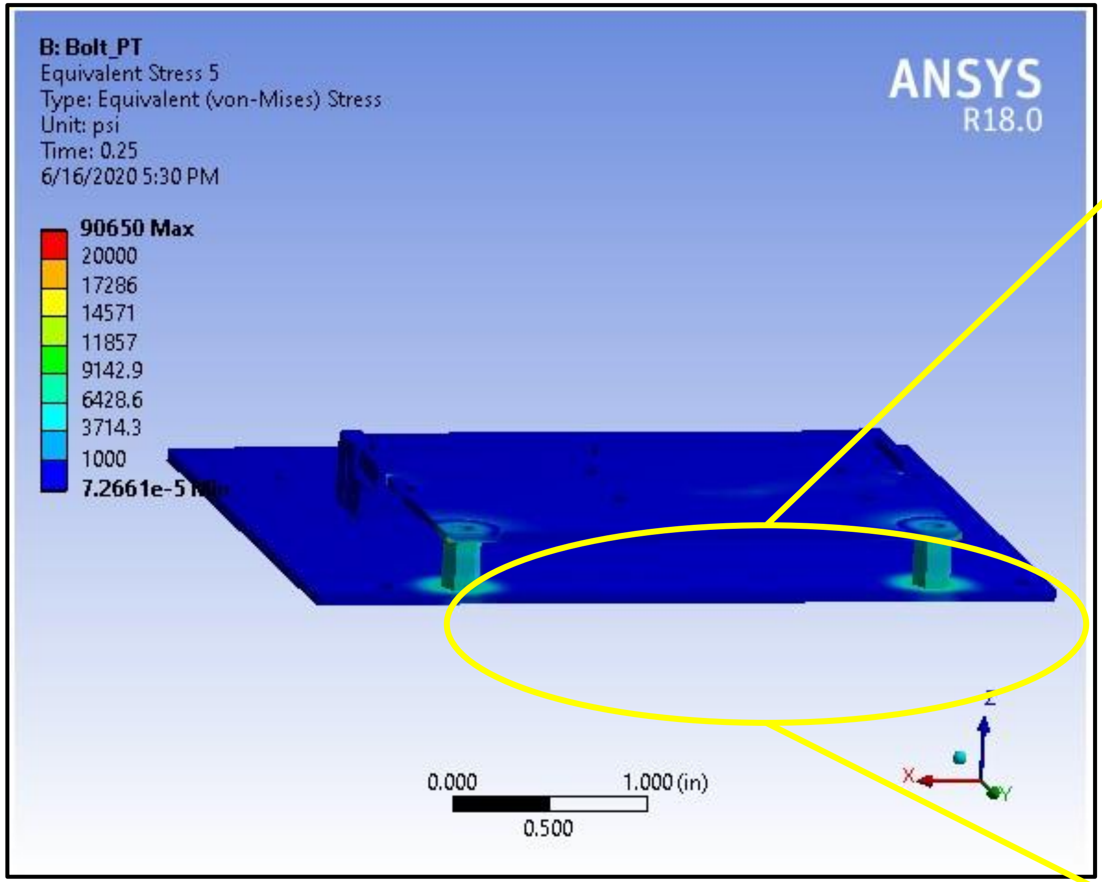
Bottom View

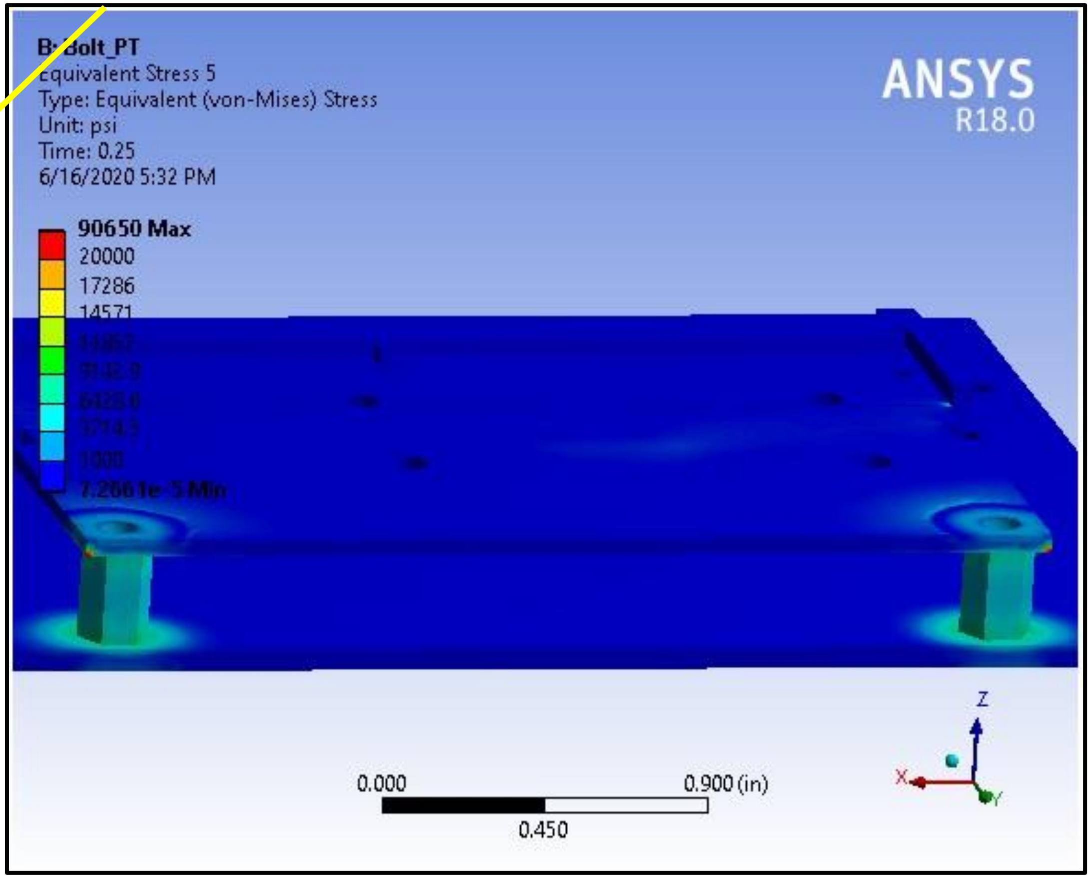


Cross Sectional view

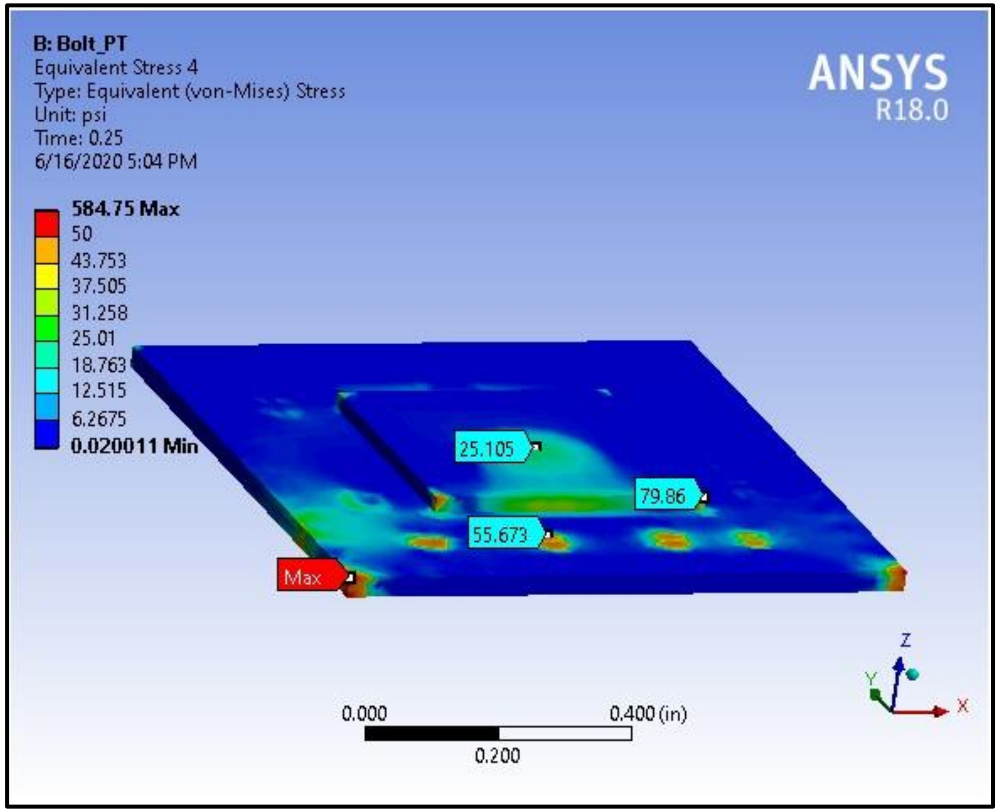
➢ High Stresses are concentrated near the hex standoffs around the top PCB.

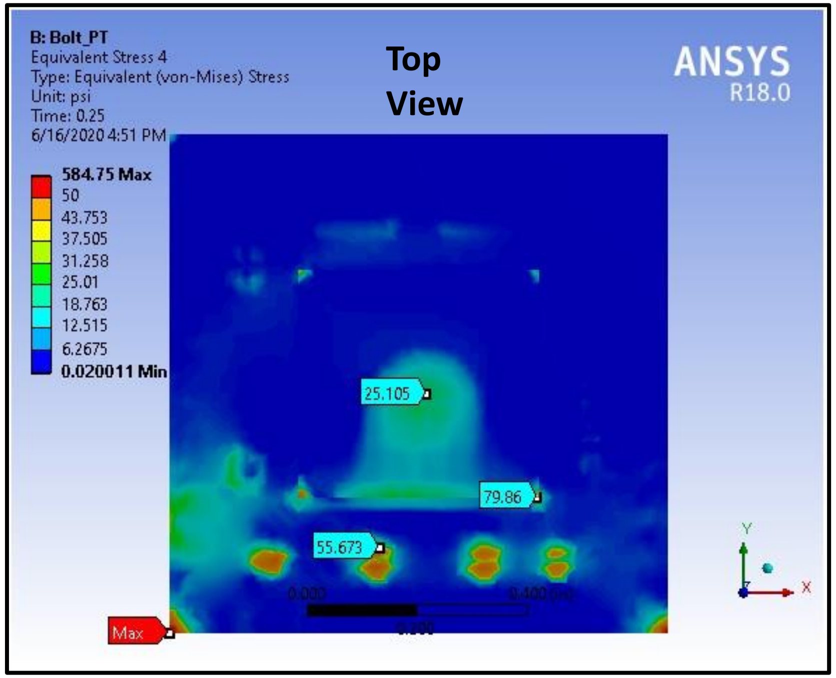
Equivalent Stress Plot : Bottom and Top PCB assembly

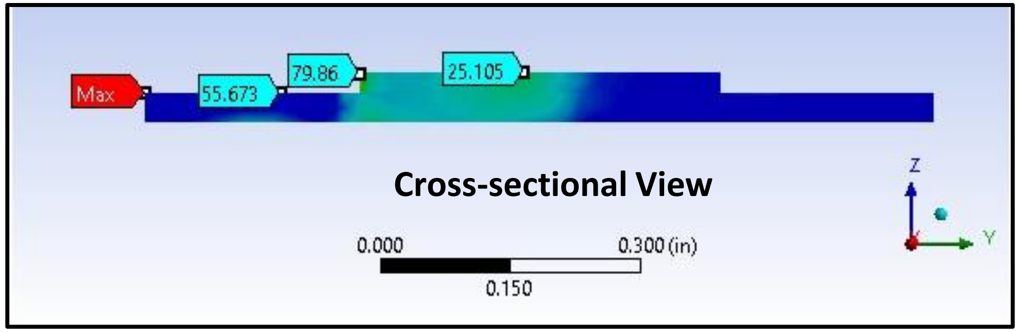




Equivalent Stress Plot : CPU



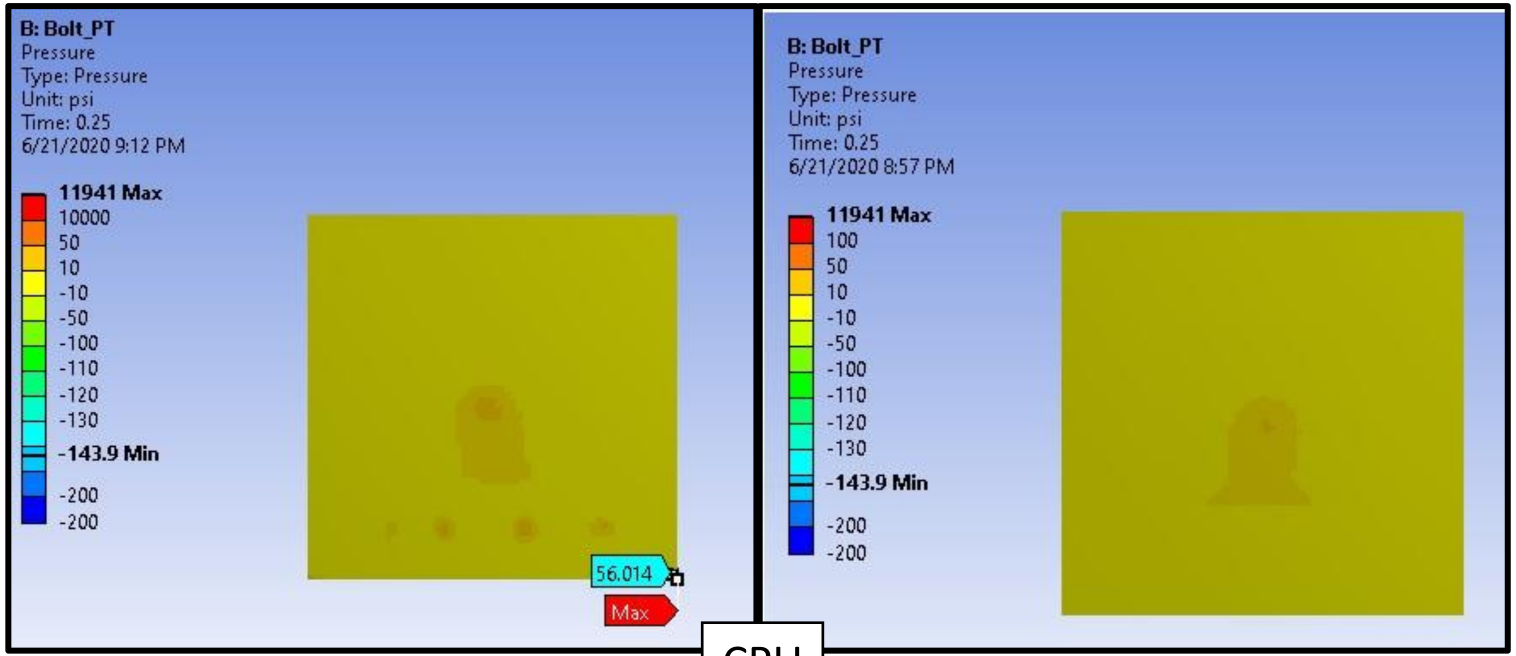




- Stress results at pretension load of 450 N (101.2 lbf) applied to the bolts.
- Maximum stress of 4.032 MPa (584.75 Psi) induced around the corners of the CPU due to non-uniform stress transfer from pretension to the CPU-Heatsink Contact.

CONTACT STRESSES

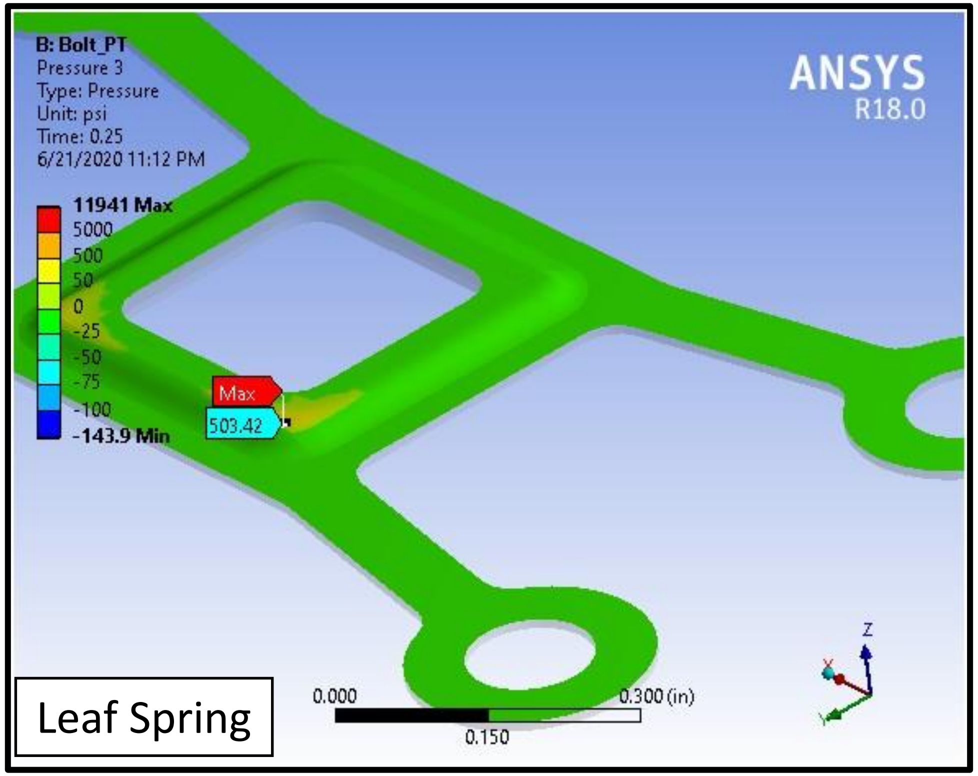
- Contact stresses shown are calculated near the maximum stress region calculated by ANSYS to approximate the weak springs effect.
- Maximum stress of 56.014 Psi (3.86E5 Pa) induced around the corners of the CPU.
- Contact stresses on leaf spring are not symmetrical due to non-uniform stress transfer from pretension to the CPU-Heatsink Contact.



CPU

Top View

Bottom View

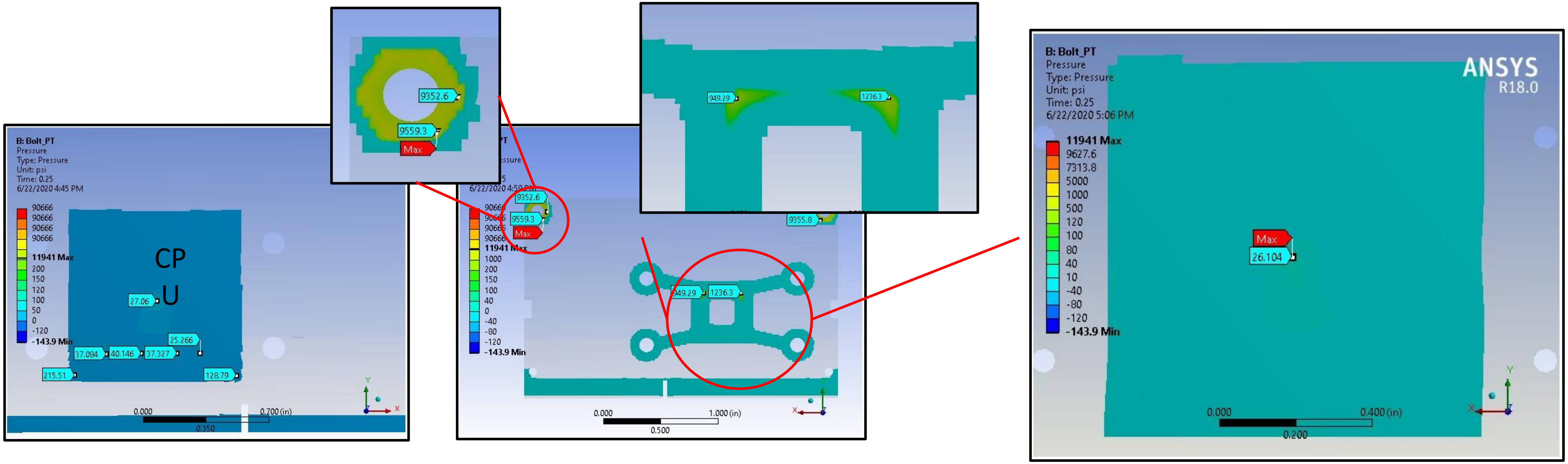


Leaf Spring

AES

CONTACT STRESSES

- Contact stresses on top PCB show stresses ranging from 129 to 216 psi around the corners where the CPU is located.
- In the middle region of the CPU to Top PCB contact, the stresses are around 27 to 41 psi range.
- Bottom face of the top PCB is showing stresses from leaf spring contact from 950 to 1236.3 psi around the rounded corners due to unsymmetrical load transfer from bolt pretension.
- Contact stresses due to Heat sink on the top PCB shows 26.104 psi stresses around the middle part where the Heat sink is in contact with the CPU.



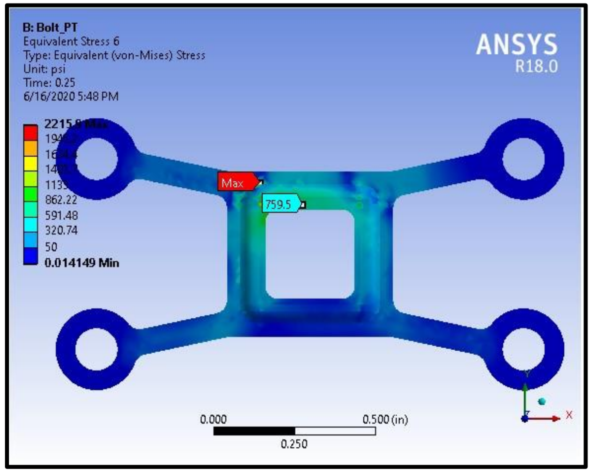
Top View

Top PCB

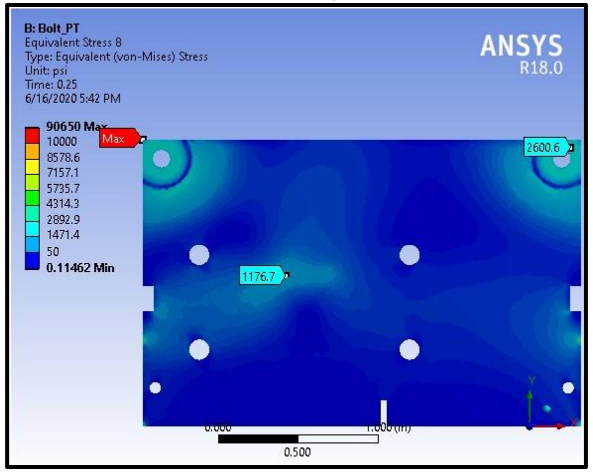
Bottom View

Equivalent Stress Plot : Leaf Spring, PCB Boards

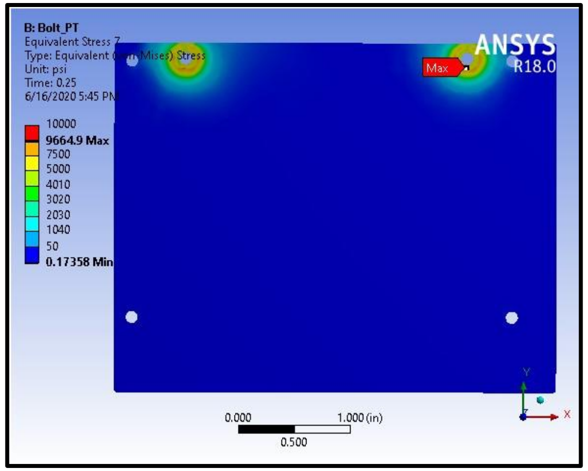
Top View



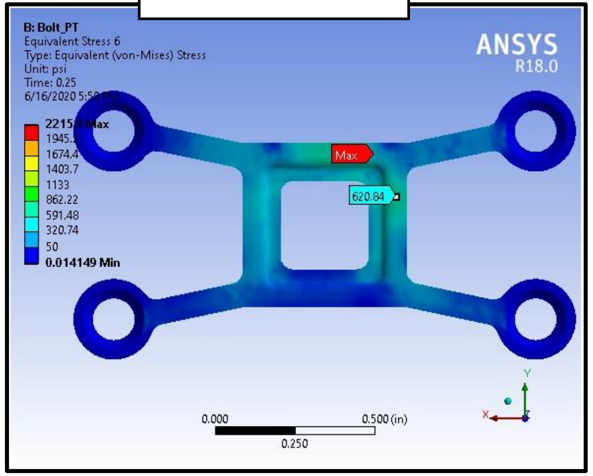
Top View



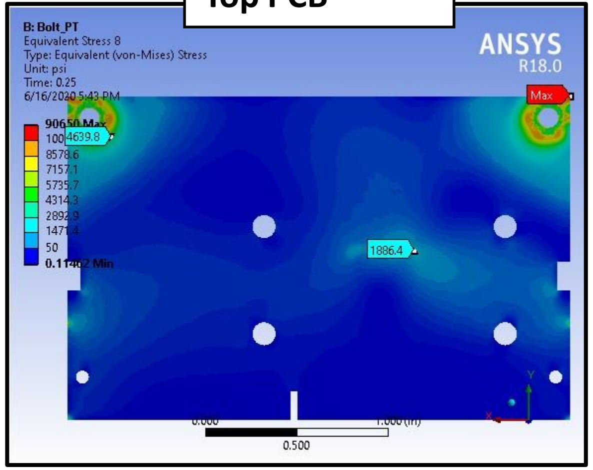
Top View



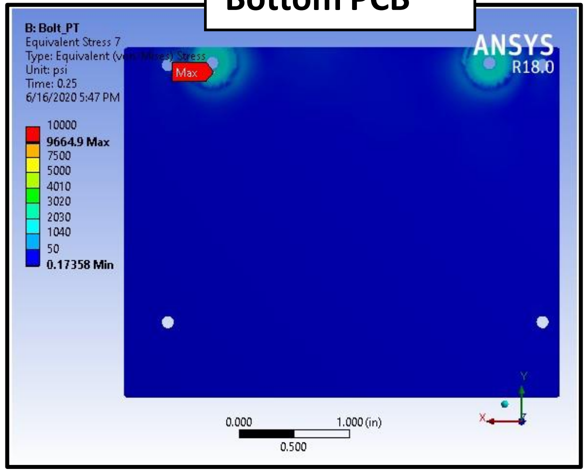
LEAF SPRING



Top PCB



Bottom PCB



Bottom View

Bottom View

Bottom View

Maximum Von-Mises Stress Table

- Maximum von-mises stress values are taken around the ANSYS generated maximum values to avoid weak springs and stress singularity effects.

- The table below shows a max von-mises stress comparison to the yield strength of respective materials.

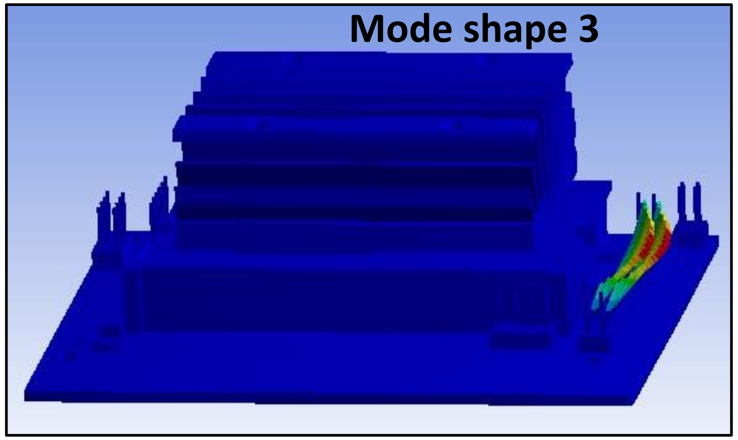
- Stresses are calculated for a preload value of 450N (101.164 lbf).

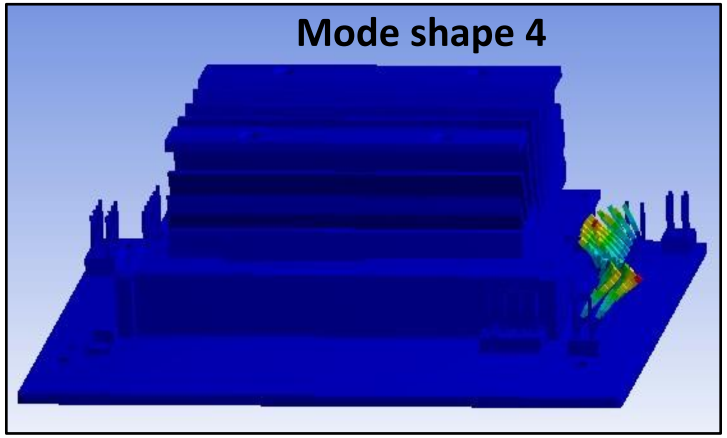
Table. Max von-mises stresses in major components

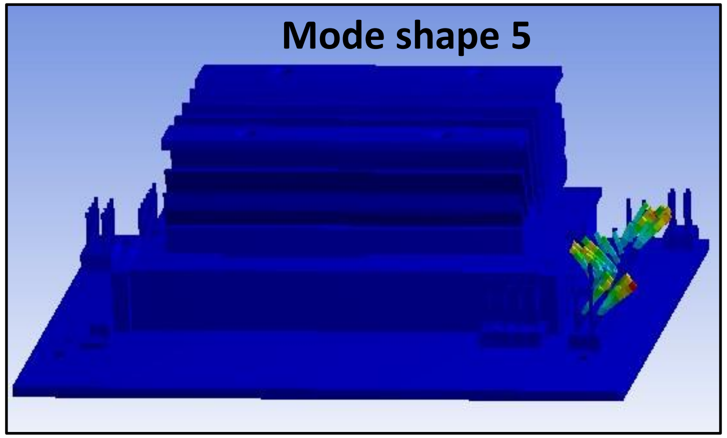
Component	Material	Max. Von-Mises Stress (Psi)	Yield Strength (Psi)
Leaf Spring	AISI 12L14	2215.9	60200
Heat Sink	Aluminum Alloy 6061	360.17	35000
Top PCB	FR-4	20070	55000
Bottom PCB	FR-5	9664.9	55000
CPU	Silicon Chip Material	188.31	
Hex Standoffs	AISI 12L14	11159	60200

PRESTRESSED MODAL ANALYSIS

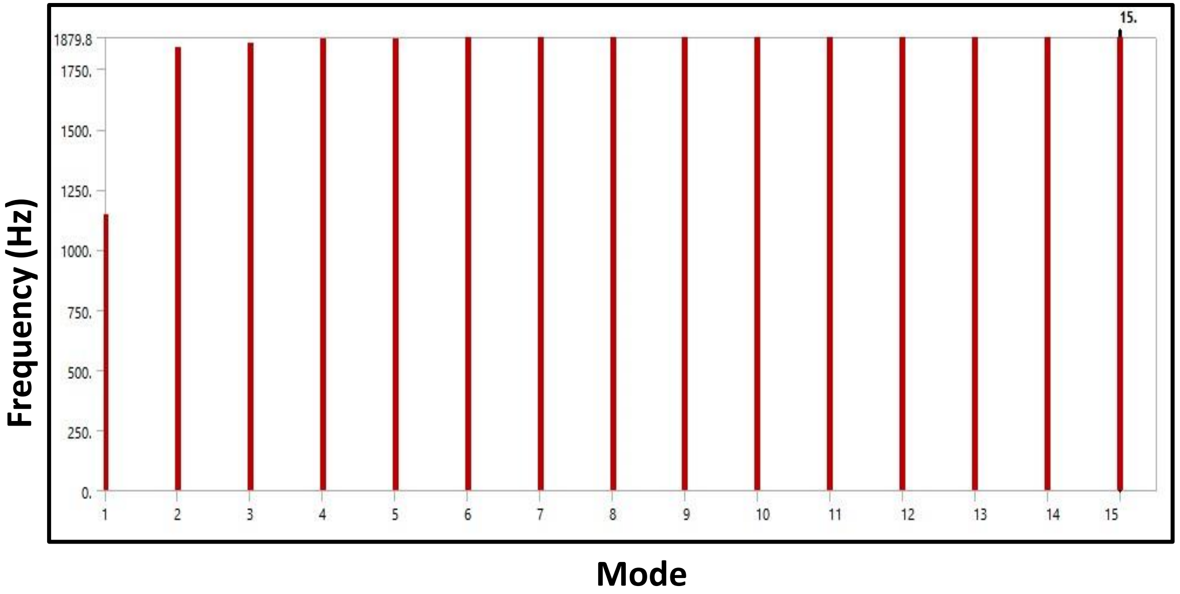
Natural Frequencies w/o Pins





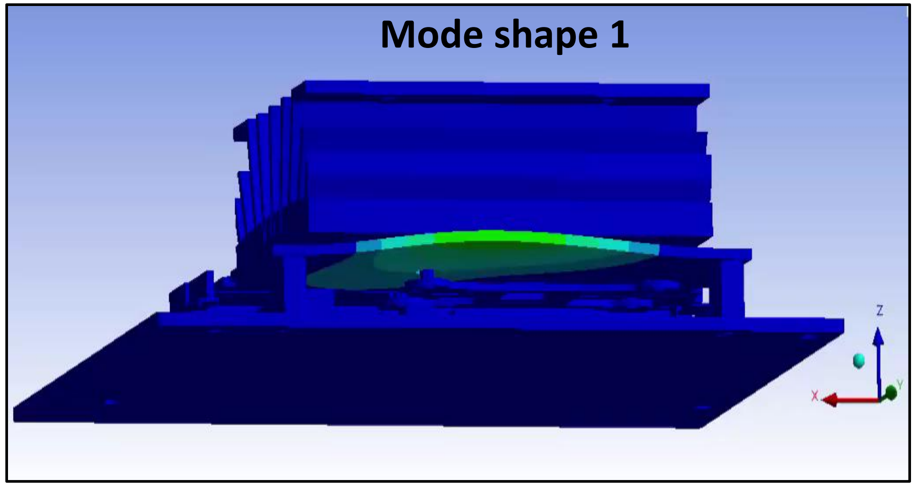


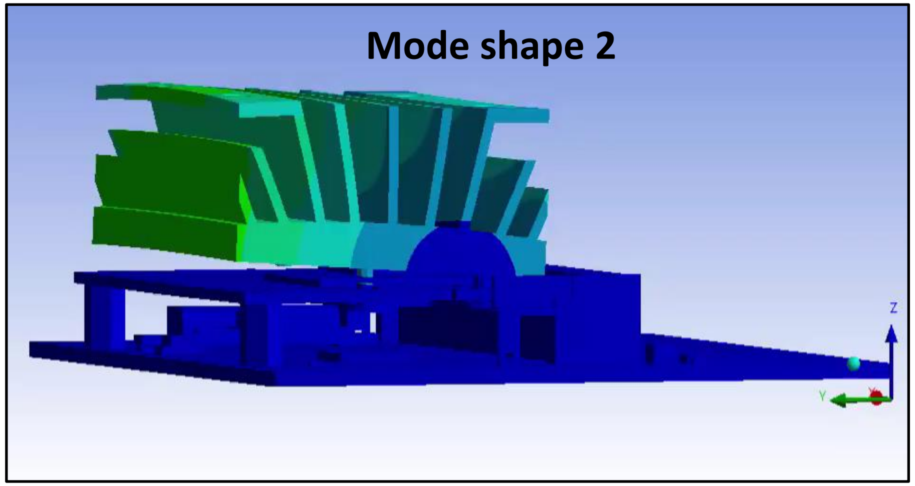
- All mode shapes and natural frequencies for the assembly with pin headers were calculated around the pins.
- The slender pins show the maximum deformation and the natural frequencies calculated are majorly on the pins.



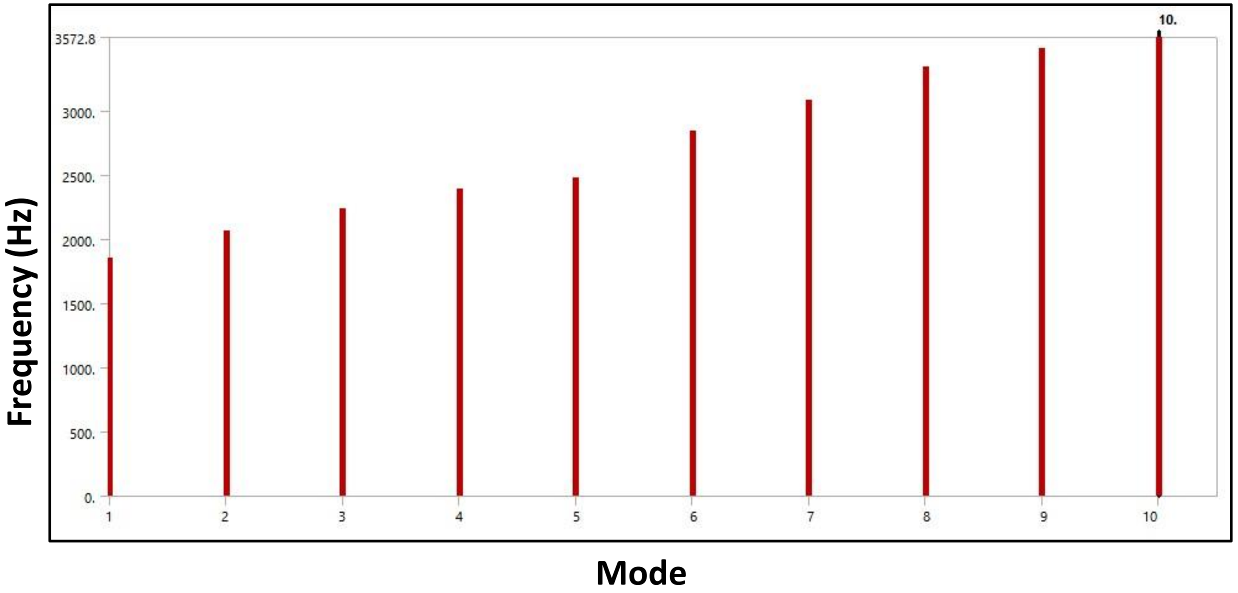
Mode	Frequency (Hz)
1	1145.3
2	1837.4
3	1856.3
4	1872.9
5	1876.3
6	1877.7
7	1878.5
8	1878.8
9	1879.4
10	1879.5

Natural Frequencies w/o Pins



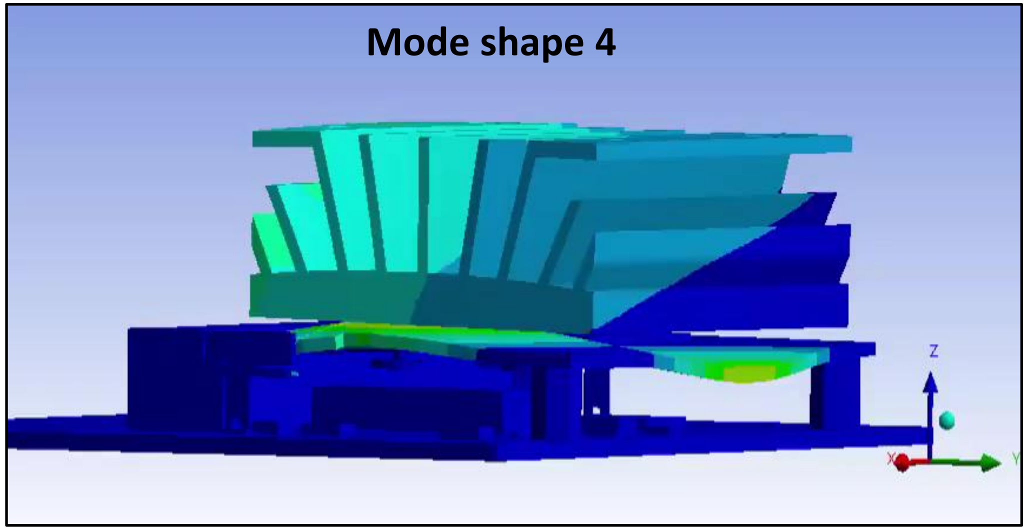


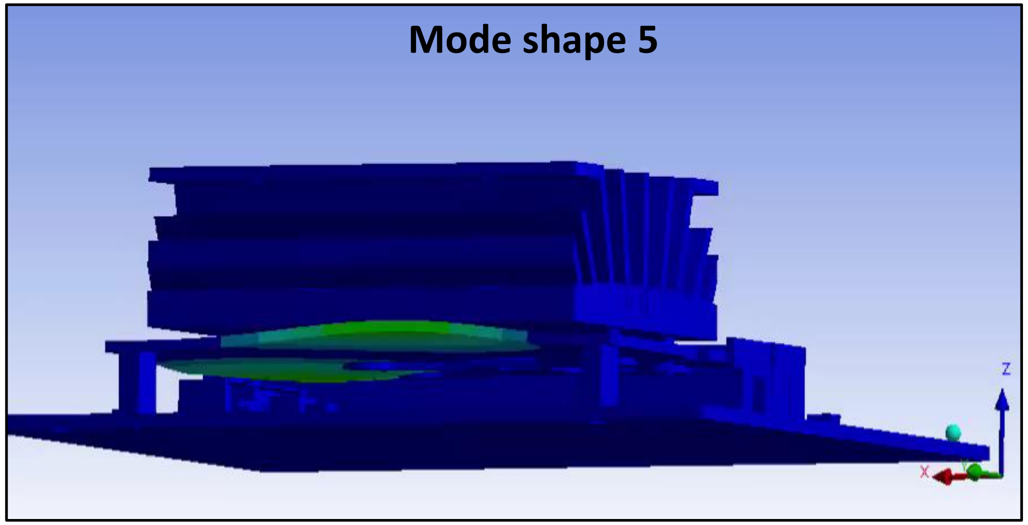
- All mode shapes and natural frequencies were recalculated by suppressing the components with pins.
- Mode shape 1 (1854.1Hz) shows the deformation of top PCB in Z direction.
- Mode shape 2 (2065.9Hz) shows the heat sink rotating about X axis.



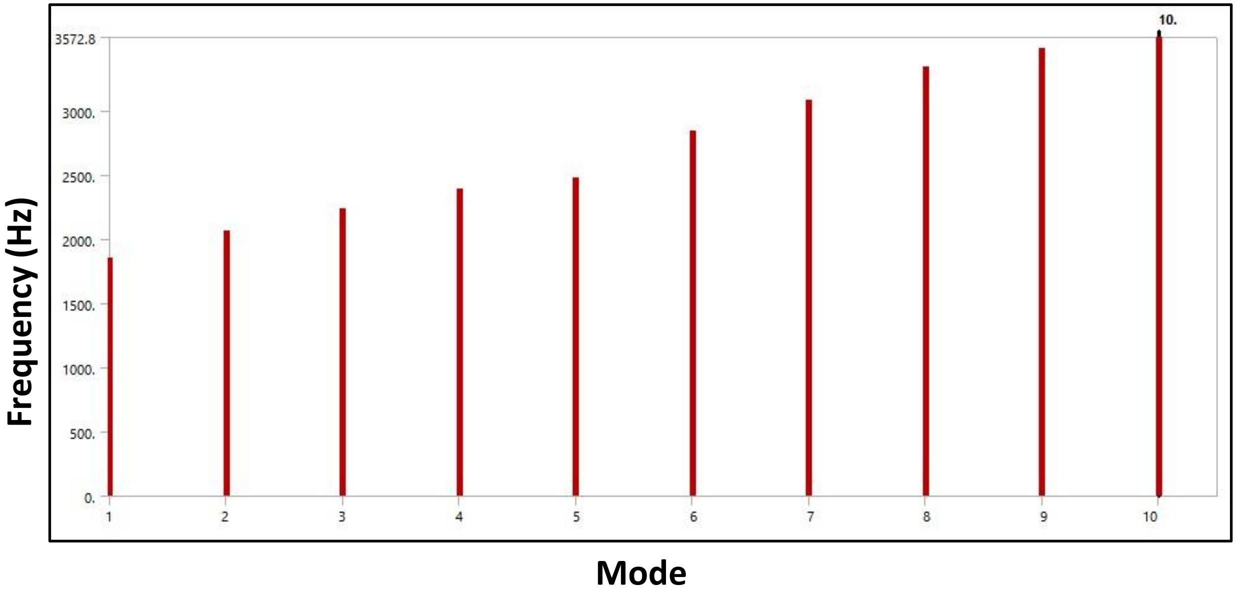
Mode	Frequency (Hz)
1	1854.1
2	2065.9
3	2235
4	2394.1
5	2480.7
6	2838.8
7	3083.6
8	3337.6
9	3484.8
10	3572.8

Natural Frequencies w/o Pins





- Mode shape 4 (2394.1Hz) & 5 (2480.7Hz) shows the top PCB deformation relative to the Heat sink displacing in Z axis along the Y-Z plane.
- Here we can observe how due to the pretension, the top PCB swings from front end (near Hex Standoffs) and left end (near SODIMM connector).



Mode	Frequency (Hz)
1	1854.1
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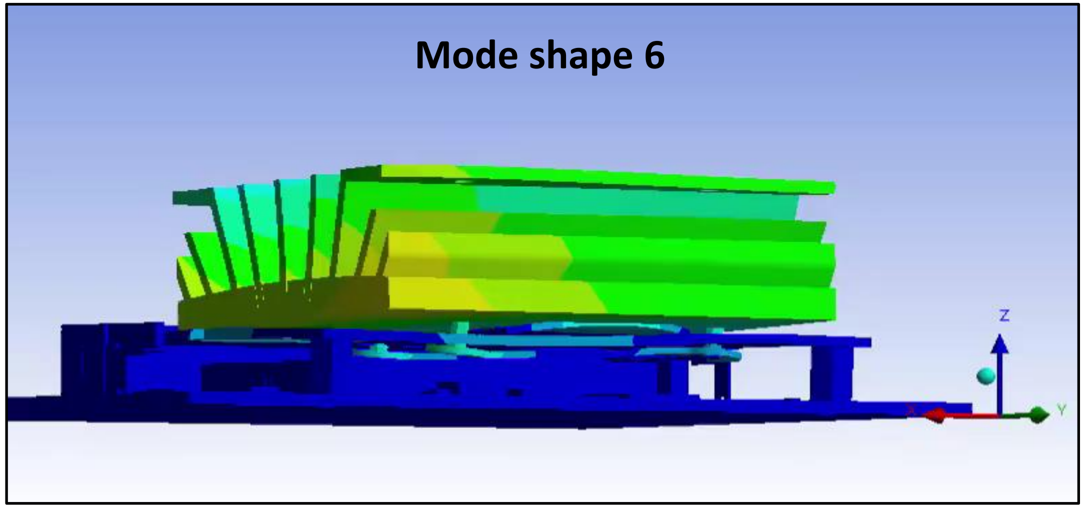
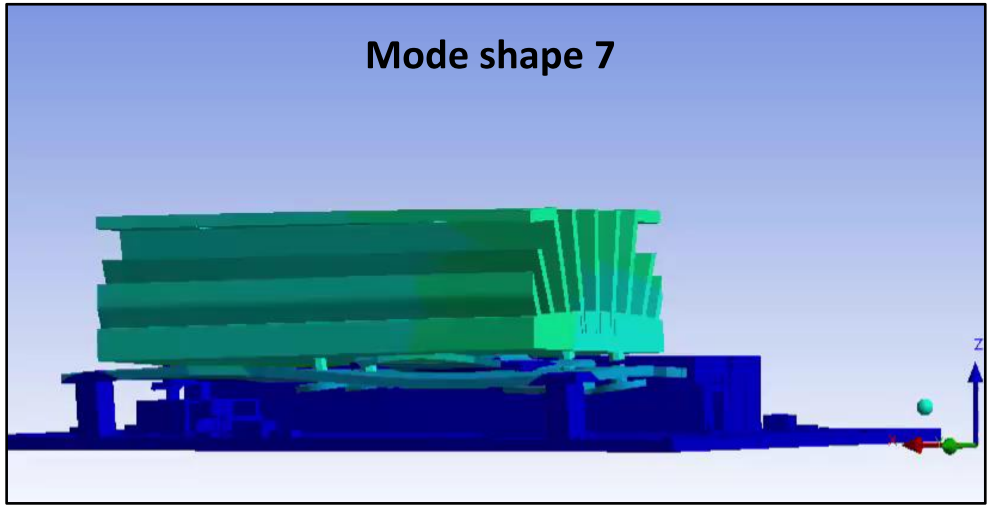
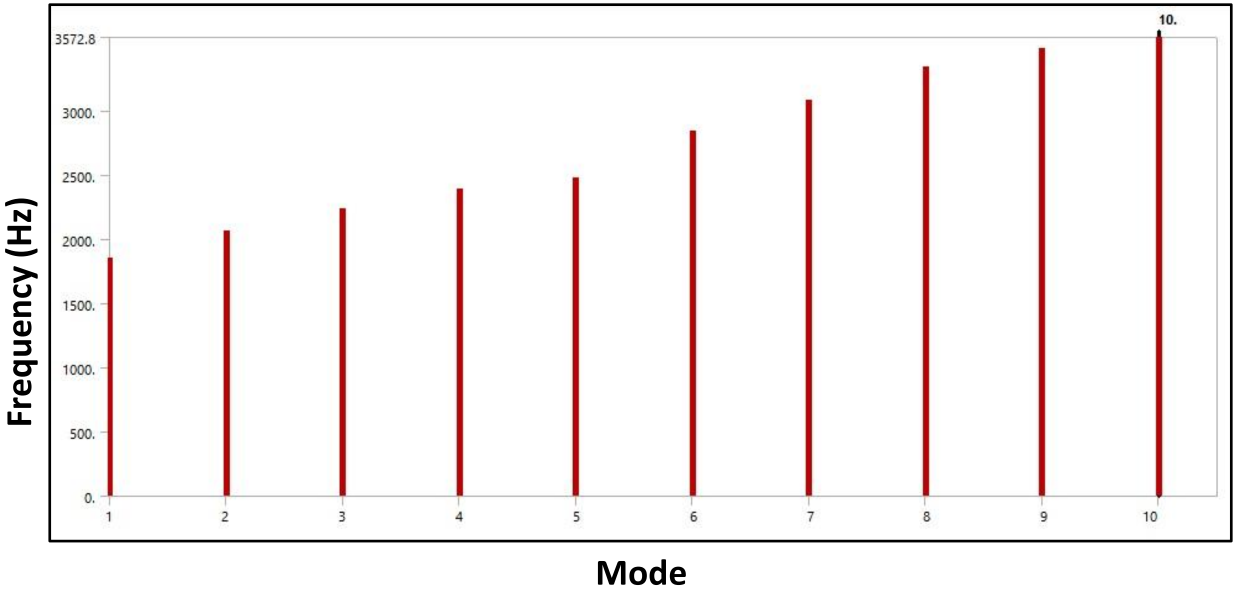
Natural Frequencies w/o Pins



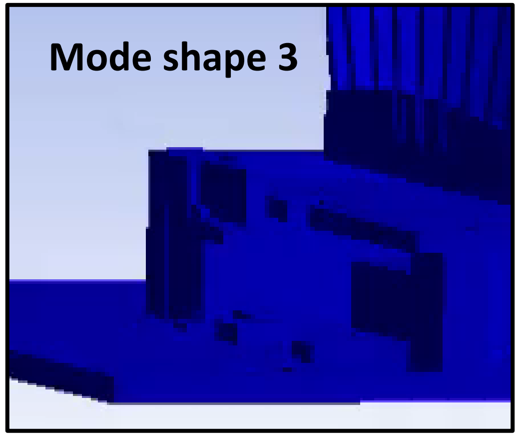


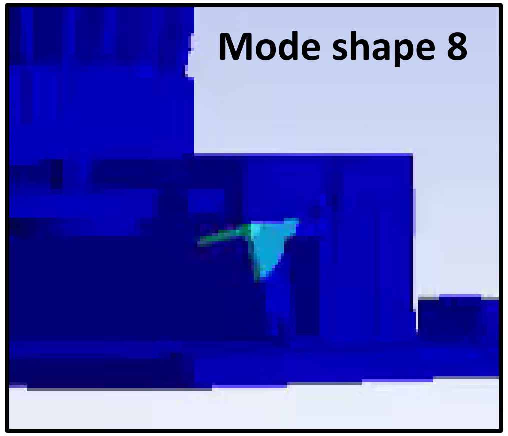
- Mode shape 6 (2838.8Hz) & 7 (3083.6Hz) show the natural frequency of Leaf Spring - Top PCB - CPU – Heat sink assembly.
- It is observed that for mode shape 6 the assembly is deforming along X axis in a rocking motion.
- Mode shape 7 show the same deformation patter in a diagonal axis along X-Y plane

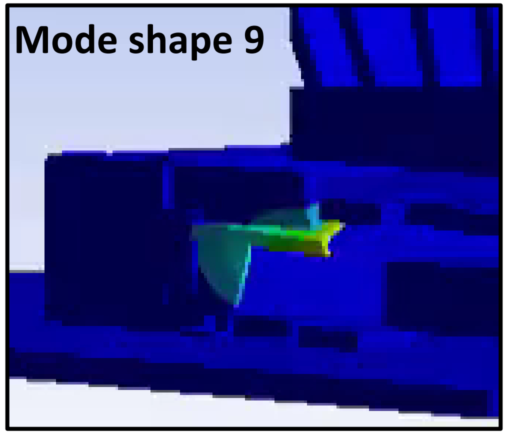


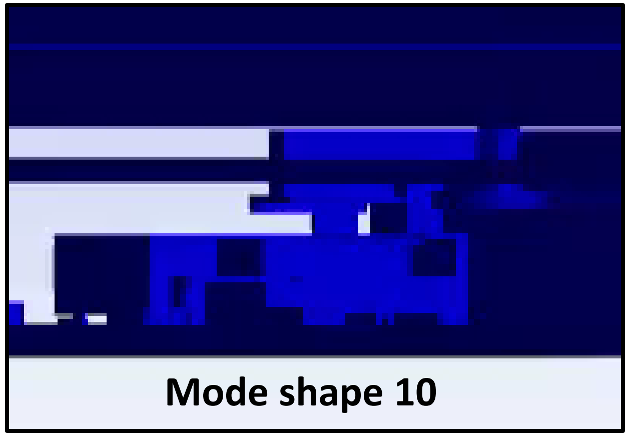
Mode	Frequency (Hz)
1	1854.1
2	2065.9
3	2235
4	2394.1
5	2480.7
6	2838.8
7	3083.6
8	3337.6
9	3484.8
10	3572.8

Natural Frequencies w/o Pins

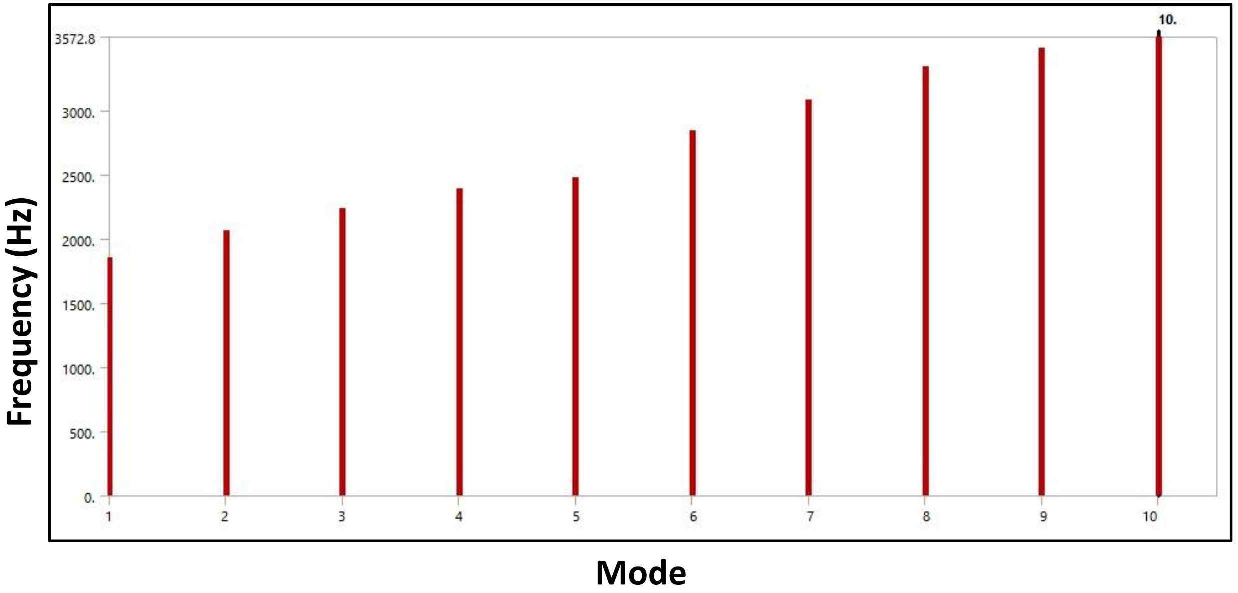








- Mode shape 3 (2235Hz), 8 (3337.6Hz) and 9 (3484.8Hz) represent deformation of the SODIMM clips on the sides.
- Mode shape 3 represents displacement in Z axis and mode shapes 8 & 9 show swinging type deformation along X axis.
- Mode shape 10 (3572.8Hz) show the M.2 slot deforming in Z axis.



Mode	Frequency (Hz)
1	1854.1
2	2065.9
3	2235
4	2394.1
5	2480.7
6	2838.8
7	3083.6
8	3337.6
9	3484.8
10	3572.8

CONCLUSION

- After performing a sequential FEA analysis on NVIDIA Jetson Nano PCB Assembly, von-mises and contact stresses were monitored around the critical areas and contact surfaces such as CPU, Heat sink, Leaf spring and PCBs.

- A preload value of 101.014 lbf was found to impart around 26.104 psi pressure on the CPU due to the preload.

- Pretension modal analysis was performed to get the natural frequencies of the Jetson Nano assembly under bolt preload.

CONTACT US

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THANK YOU