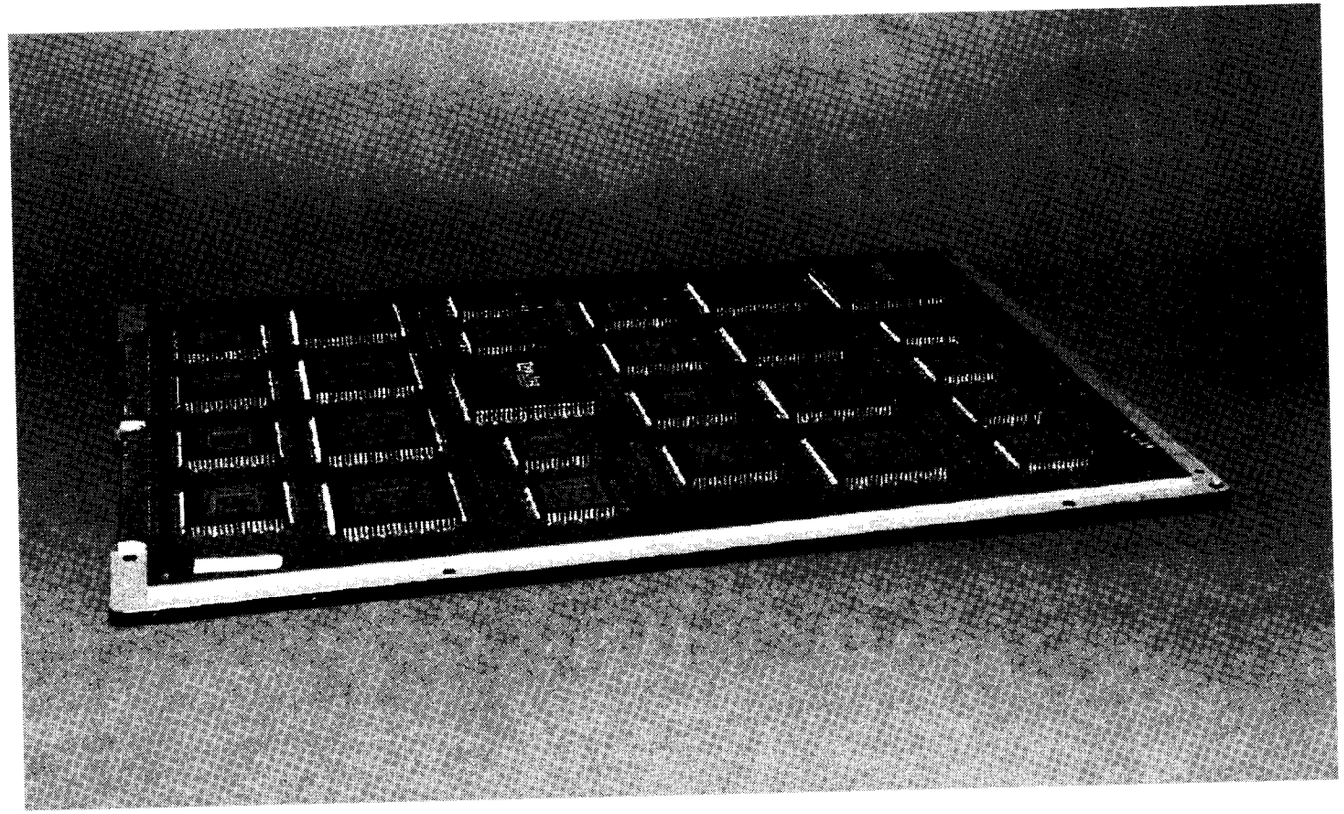


Figure 1. Prototype PWB assembly with composite heat sink.

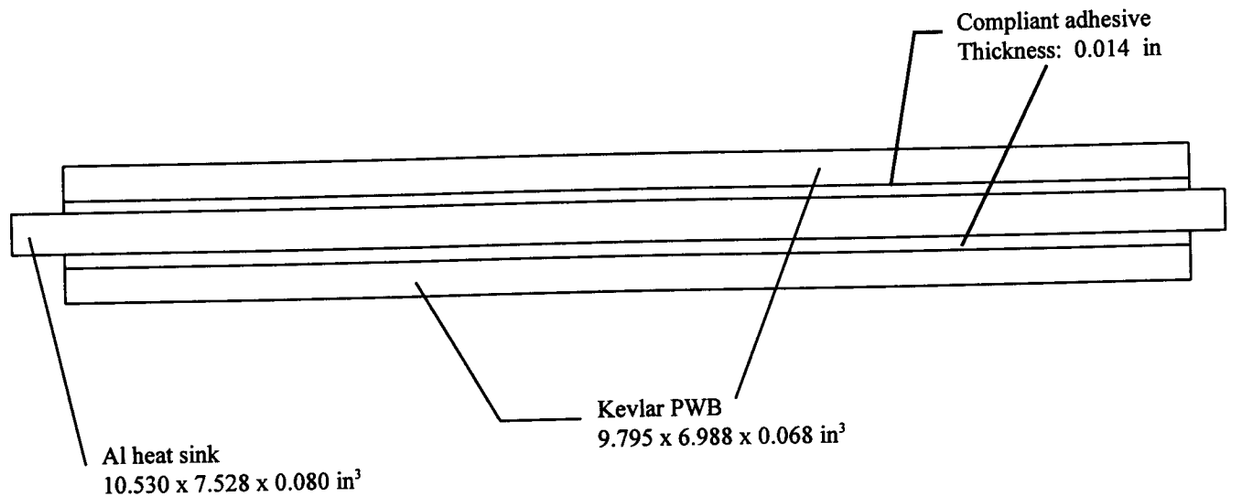


Figure 2. Side-view of the baseline PWB assembly with Al heat sink (not to scale).

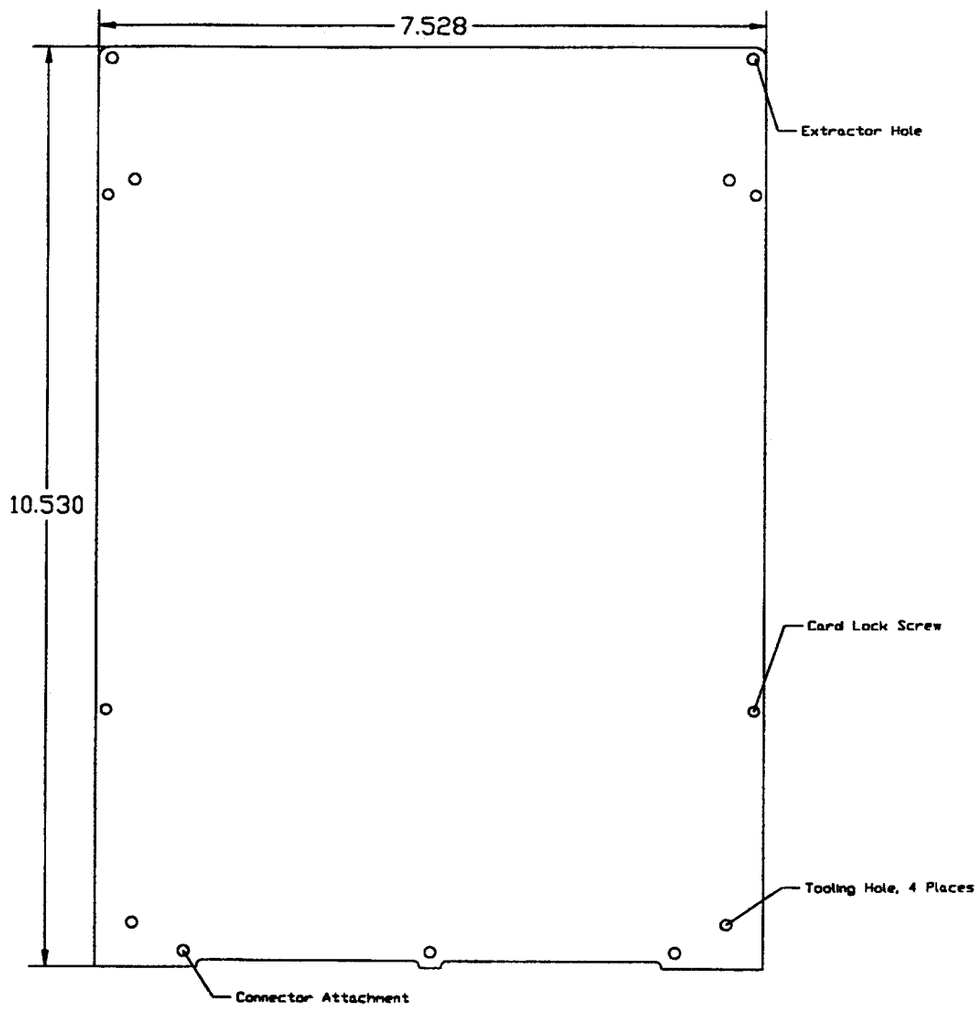


Figure 3. Heat sink outline.

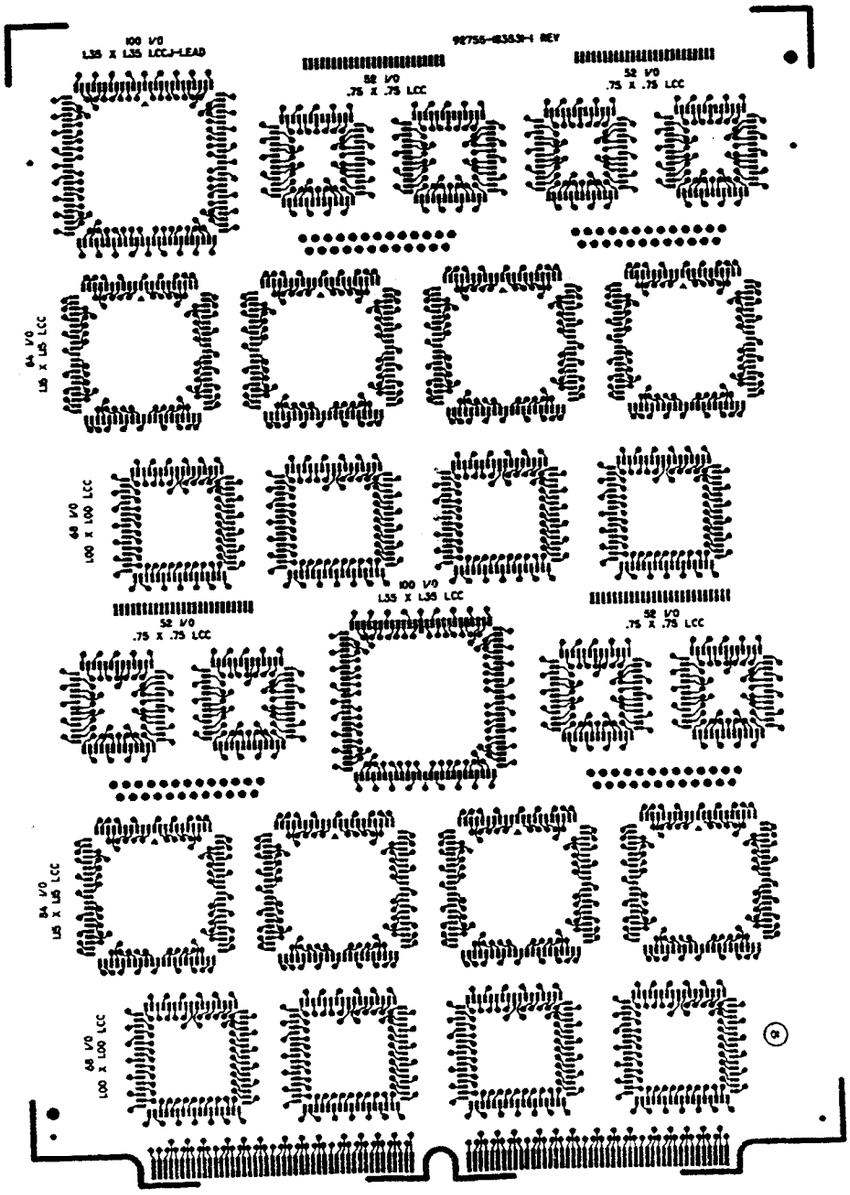


Figure 4. PWB layout.

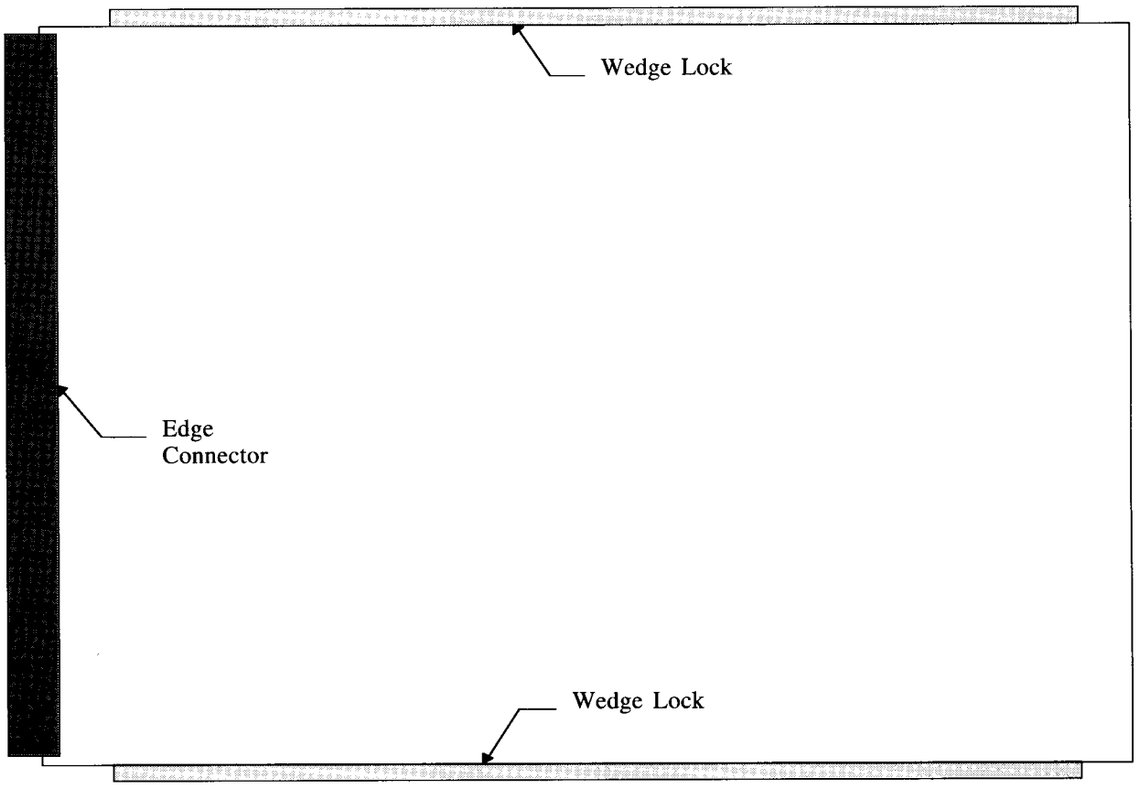


Figure 5. Edge supports for the PWB assembly (not to scale).

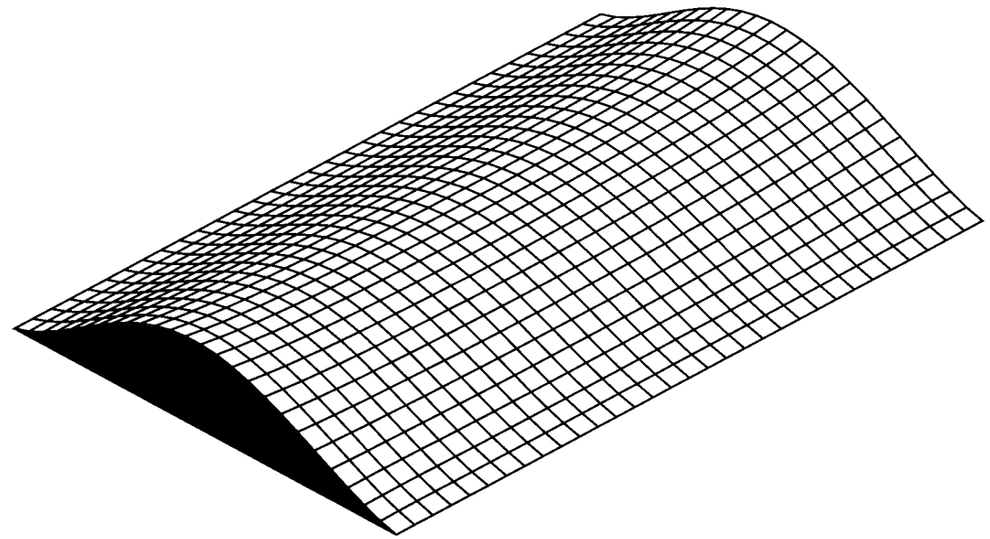


Figure 6. First mode for Al plate.

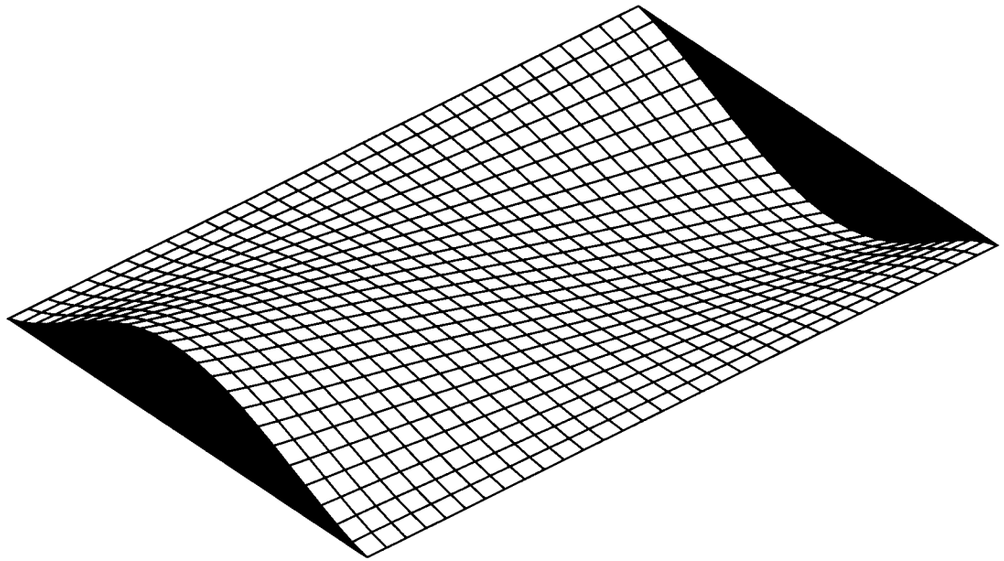


Figure 7. Second mode for Al plate.

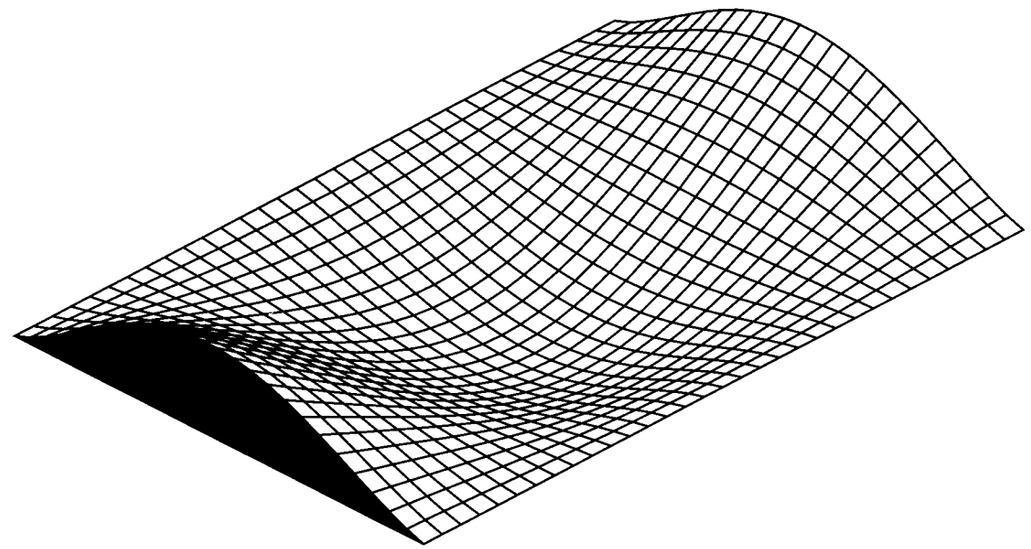


Figure 8. Third mode for Al plate.

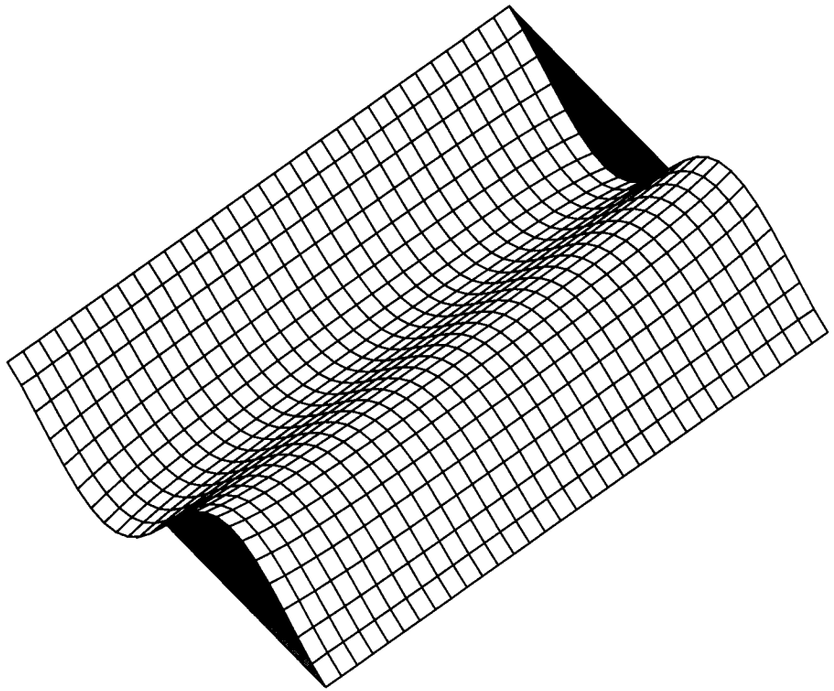


Figure 9. Fourth mode for Al plate.

Stacking Sequence $[(0\pm60)_2]_s$			
Layer	Angle	Ply Thickness (in)	
1	N/A	.002	Al
2	N/A	.003	Adhesive
3	0	.005	Ply 1
4	60	.005	Ply 2
5	-60	.005	Ply 3
6	0	.005	Ply 4
7	60	.005	Ply 5
8	-60	.005	Ply 6
9	-60	.005	Ply 7
10	60	.005	Ply 8
11	0	.005	Ply 9
12	-60	.005	Ply 10
13	60	.005	Ply 11
14	0	.005	Ply 12
15	N/A	.003	Adhesive
16	N/A	.002	Al

Figure 10. Stacking sequence for the composite heat sink.

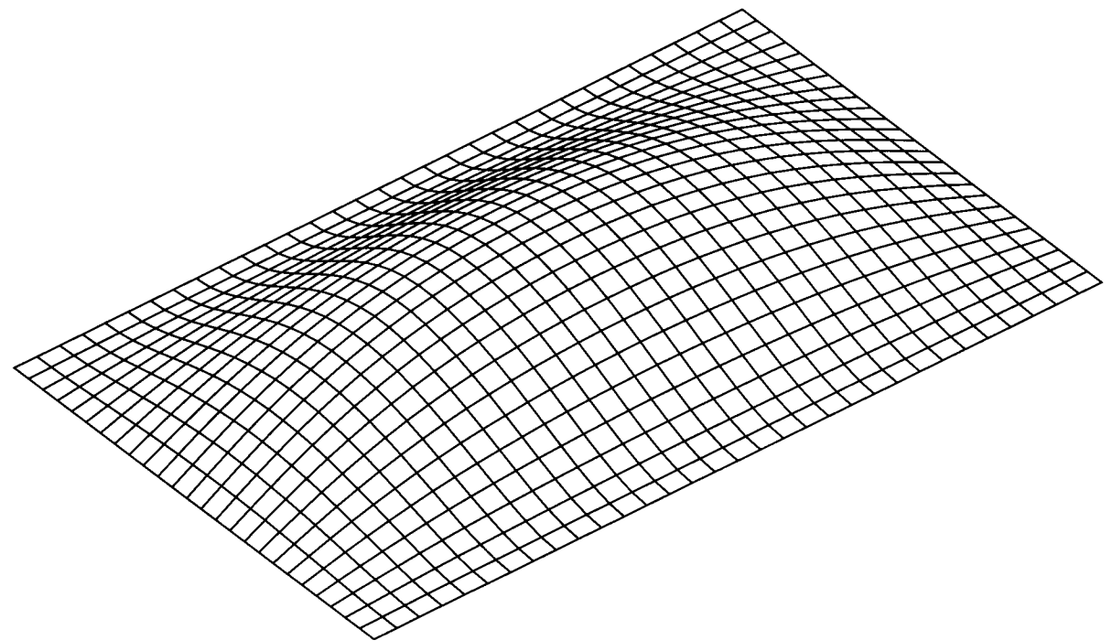


Figure 11. Plate displacement under a uniform load.

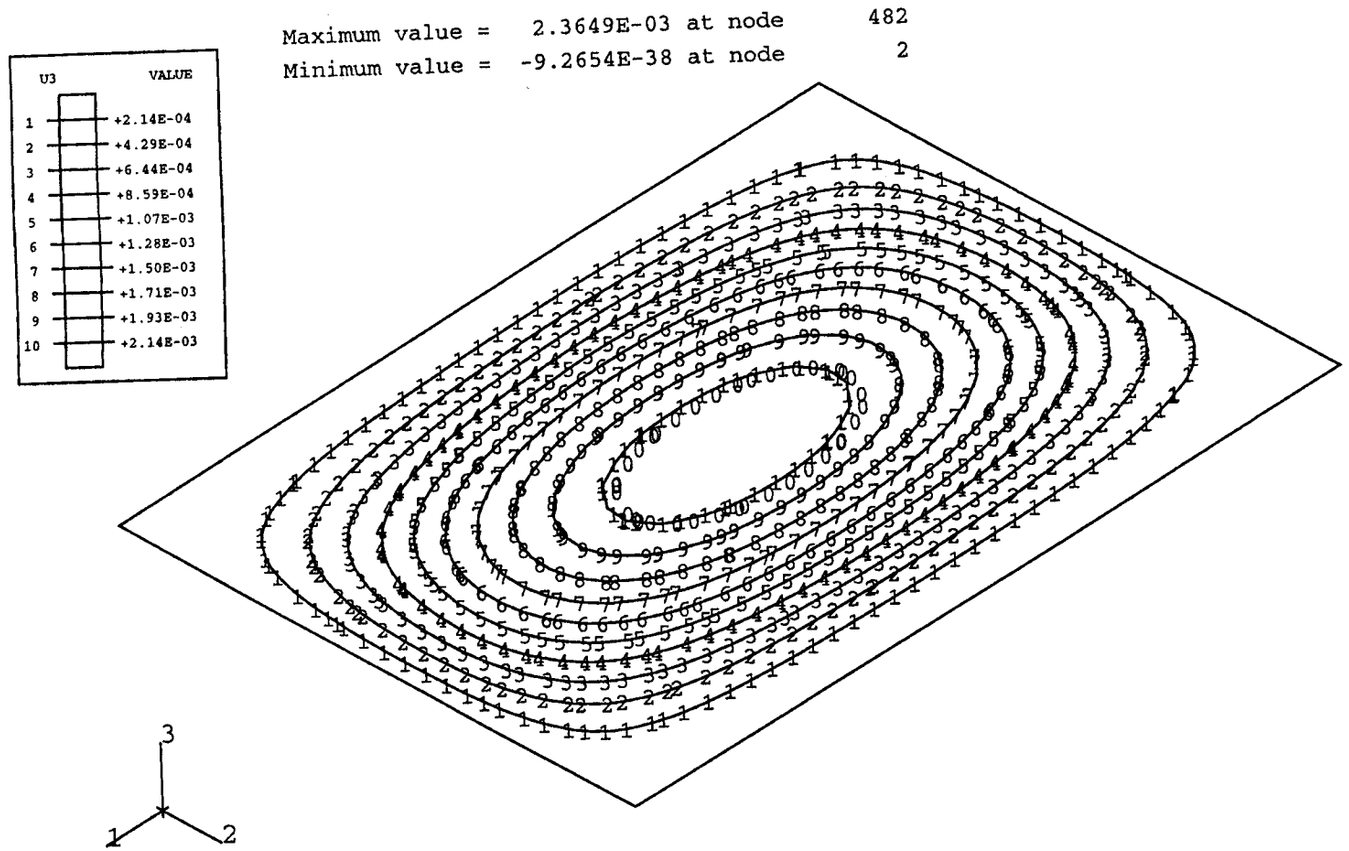
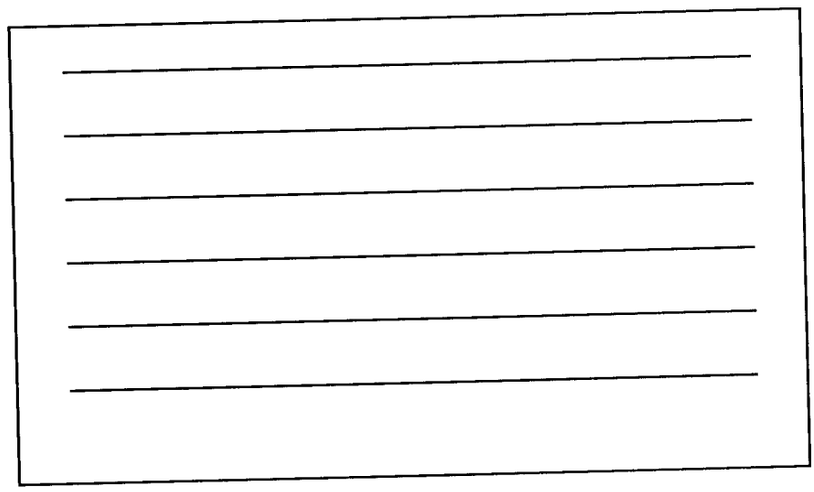


Figure 12. Composite heat sink deflection under a uniform load.

[0°] fiber orientation:



[90°] fiber orientation:

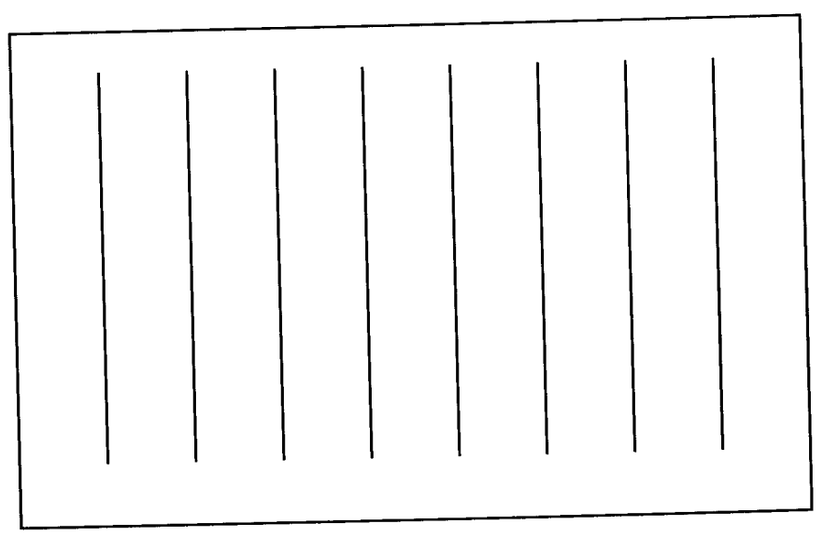
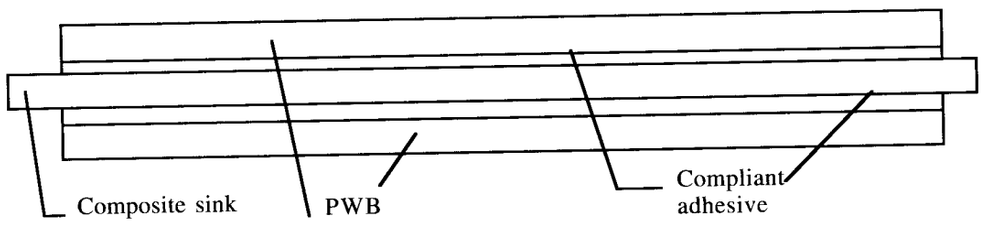


Figure 13. Switching fiber orientation for altering stiffness (not to scale).

(a)



(b)

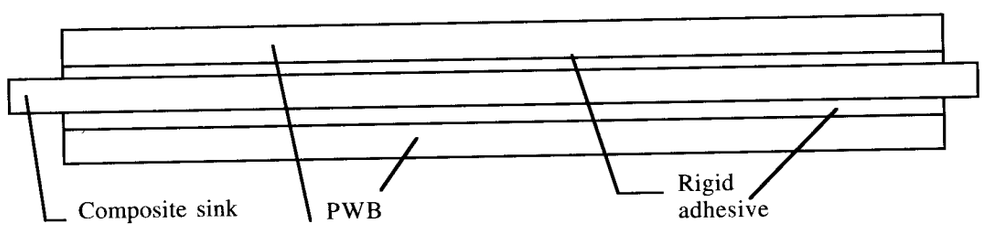


Figure 14a and b. PWB assemblies using different adhesives for heat sink attachment (not to scale).

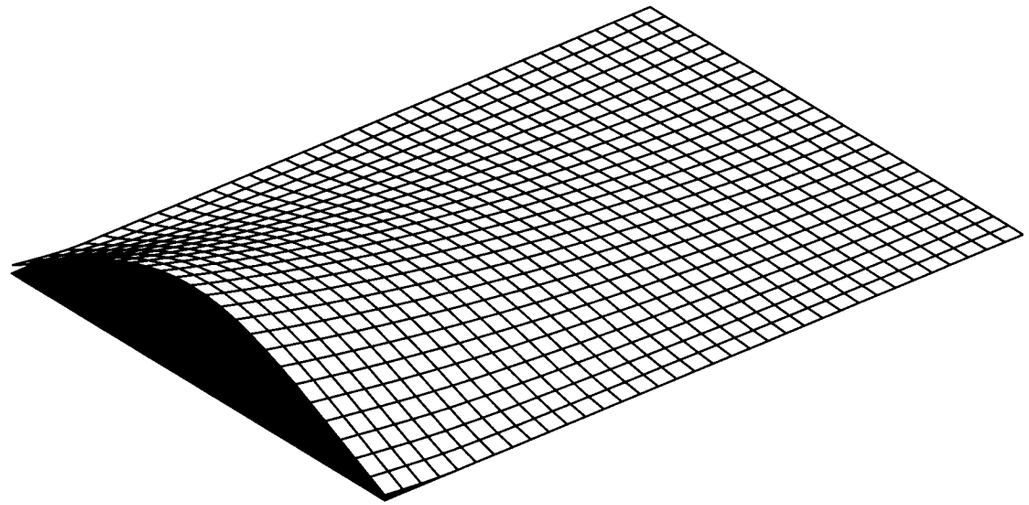


Figure 15. First mode for PWB assembly with composite heat sink.

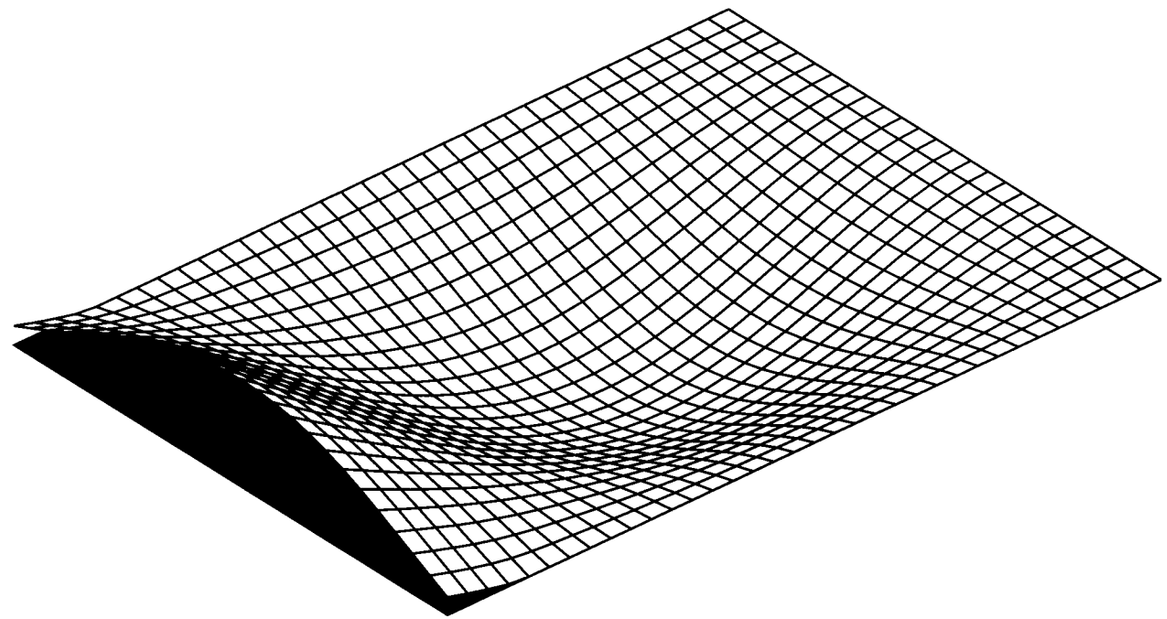


Figure 16. Second mode for PWB assembly with composite heat sink.

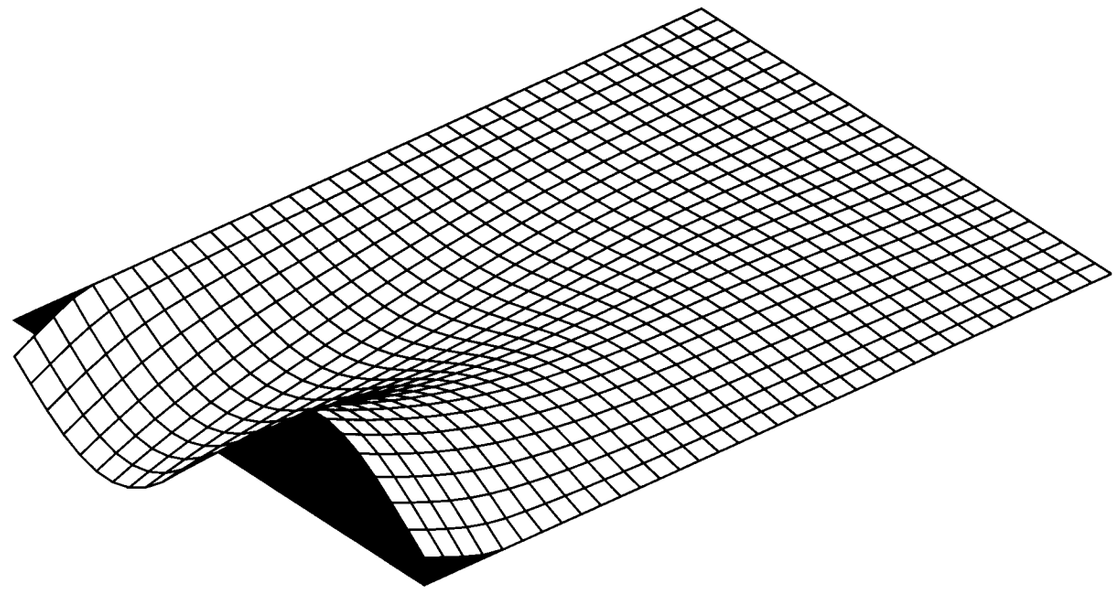


Figure 17. Third mode for PWB assembly with composite heat sink.

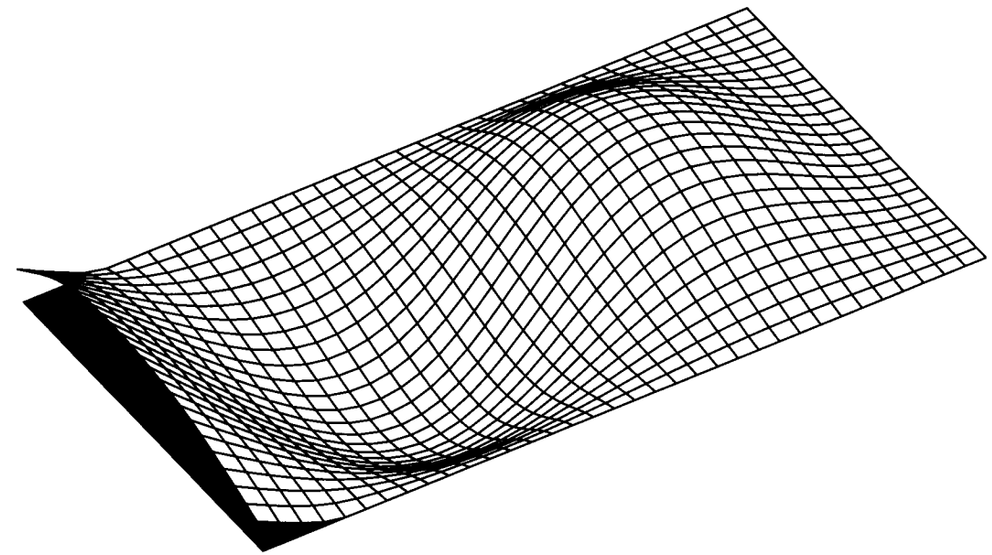


Figure 18. Fourth mode for PWB assembly with composite heat sink.

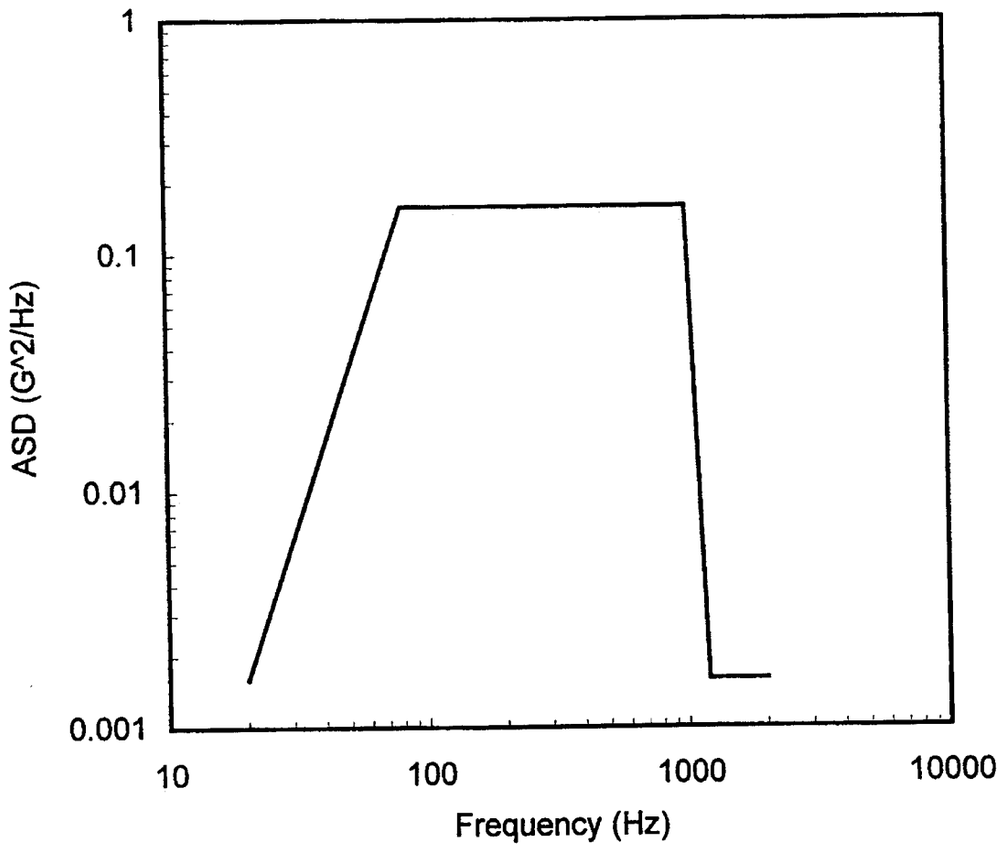


Figure 19. ASD for random vibration analysis.

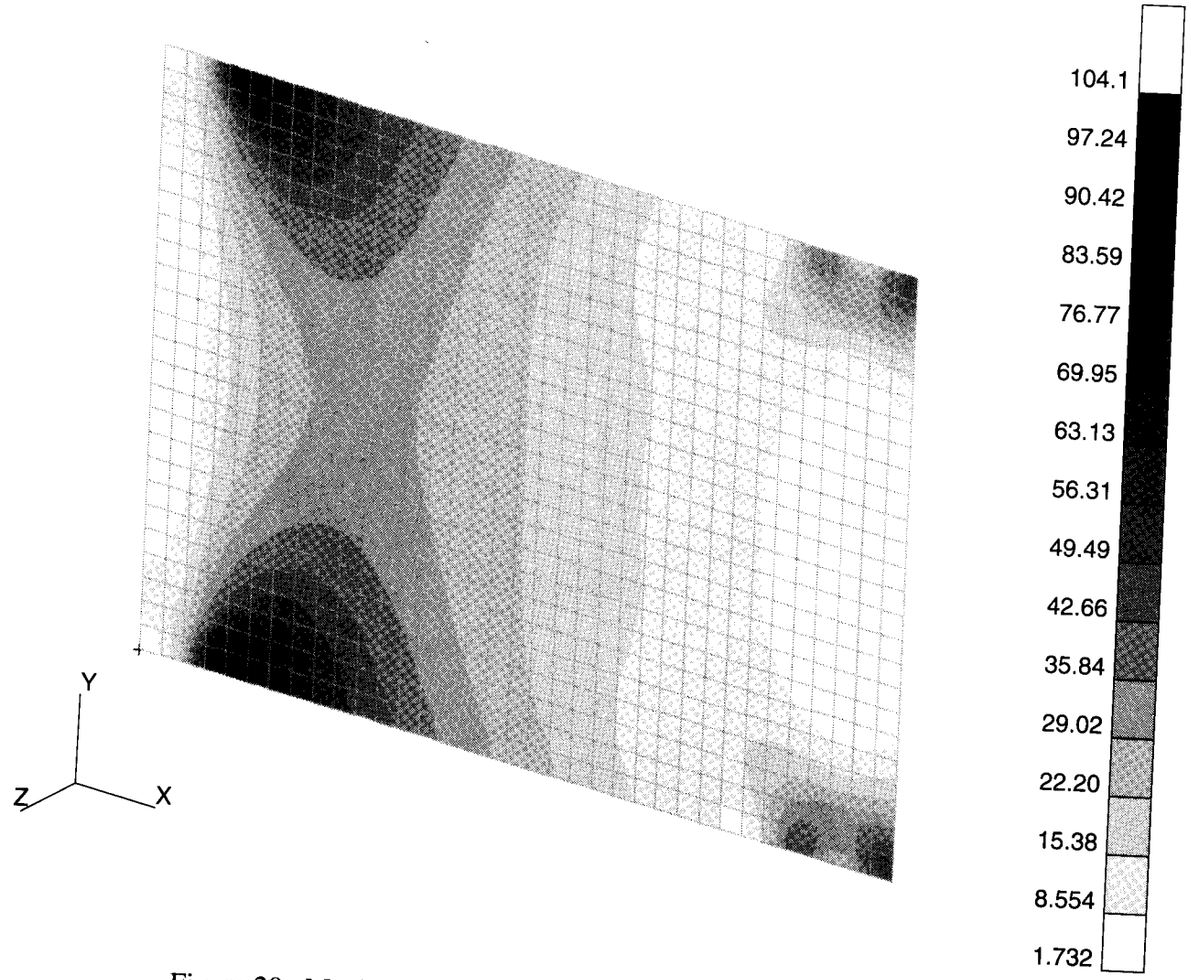


Figure 20. Maximum shear stress in the rigid adhesive layer.

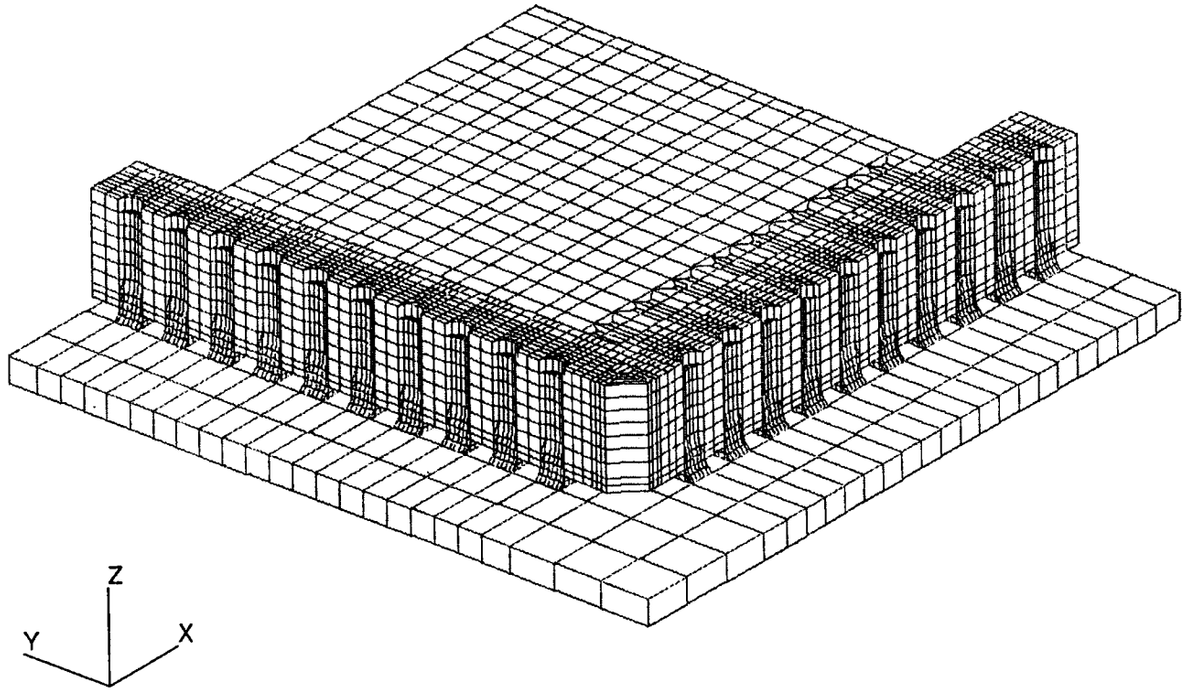


Figure 21. 1/4 FEA model for the largest LCC.

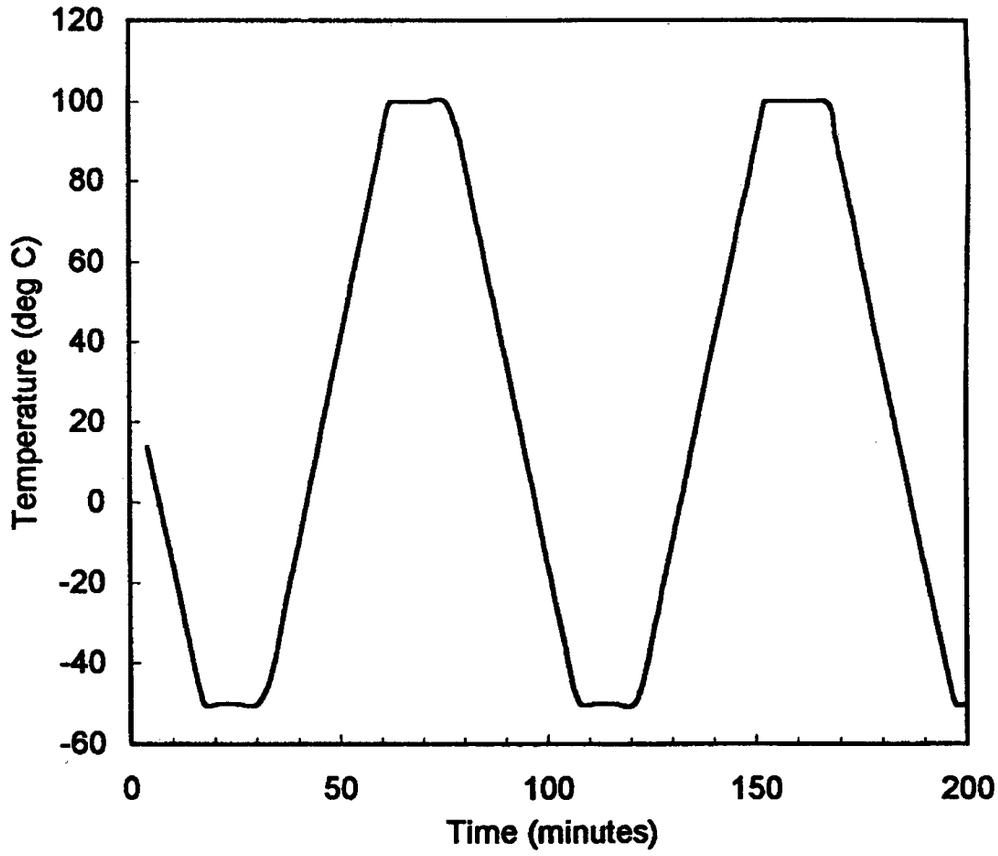


Figure 22. Temperature cycling profile.

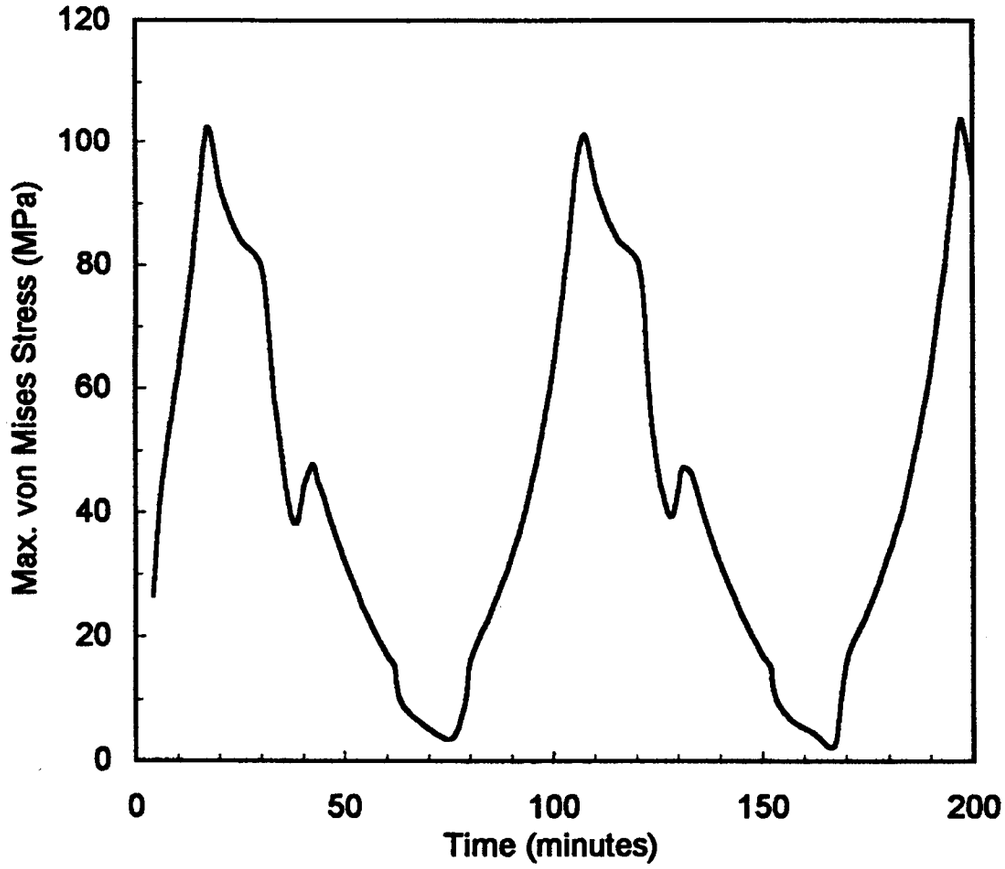


Figure 23. Maximum local von Mises stress in ther corner solder joint.

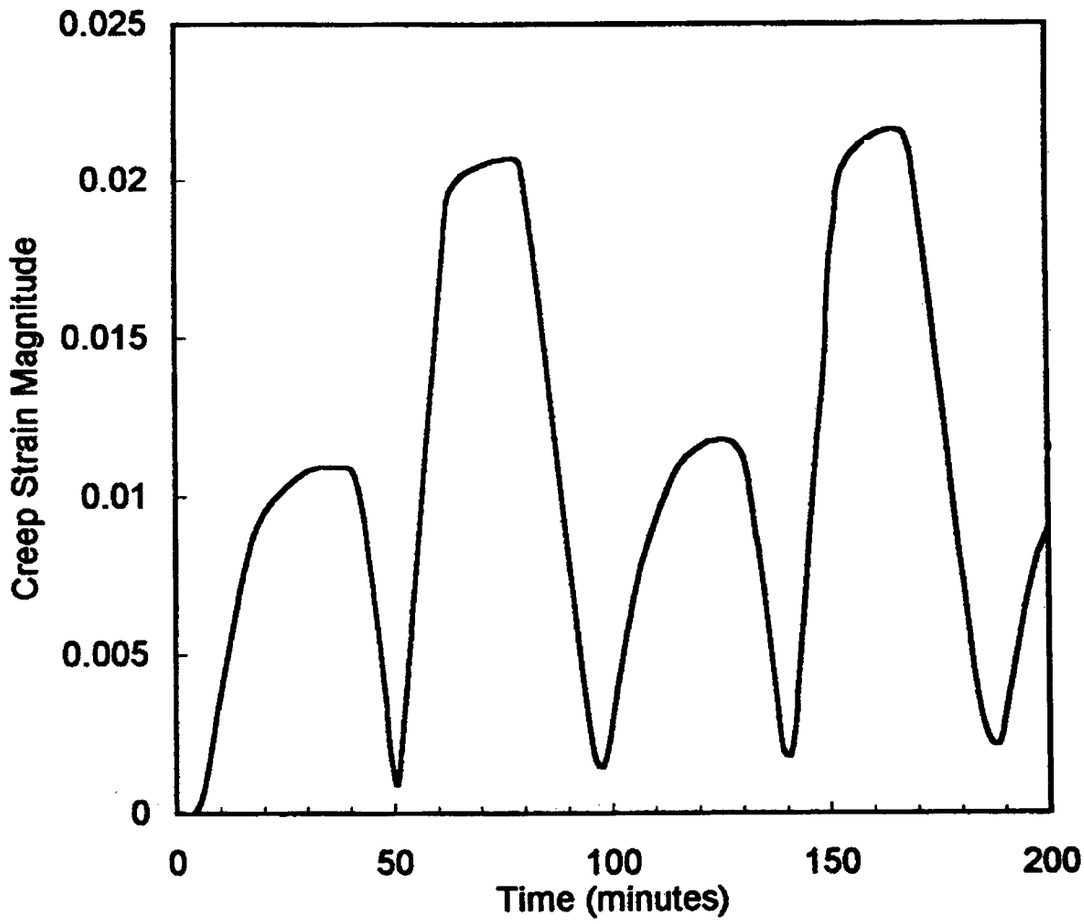


Figure 24. Creep strain magniture in the corner solder joint.

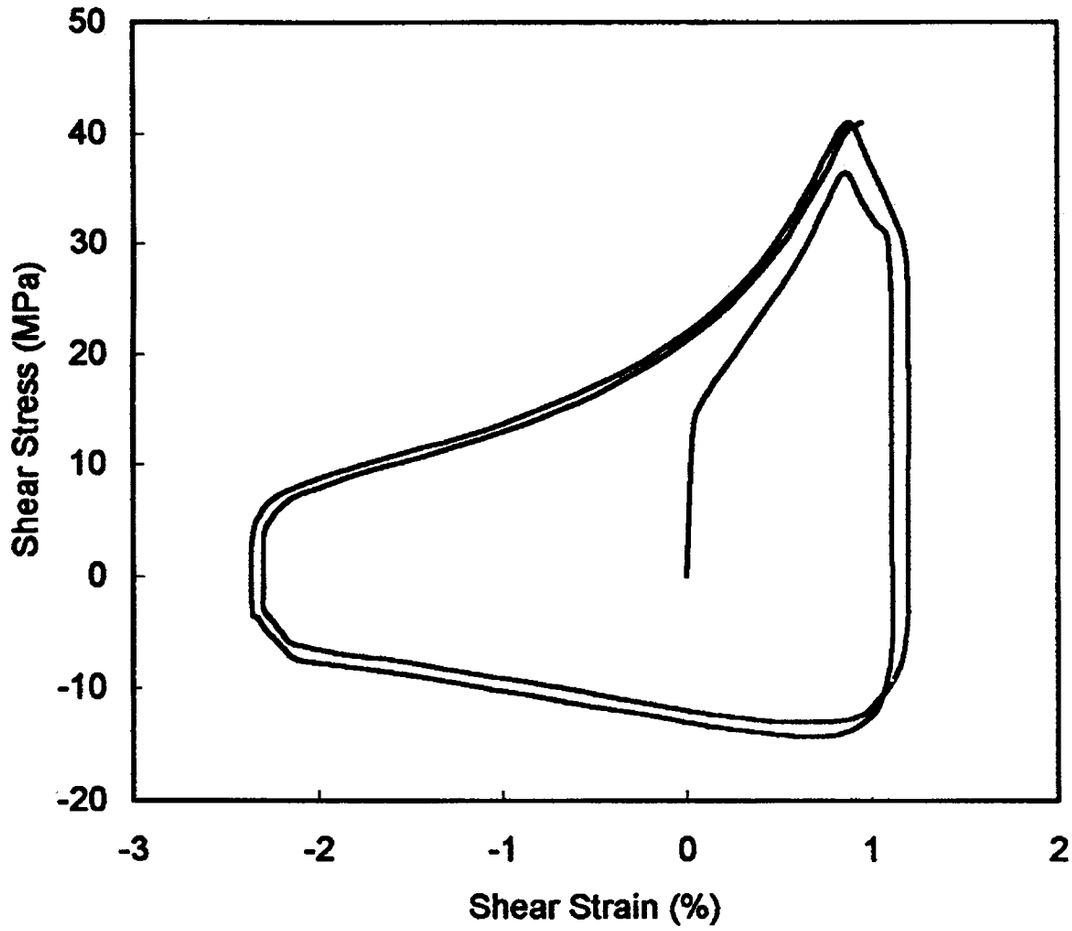


Figure 25. Hysteresis loop showing creep ratcheting phenomenon.

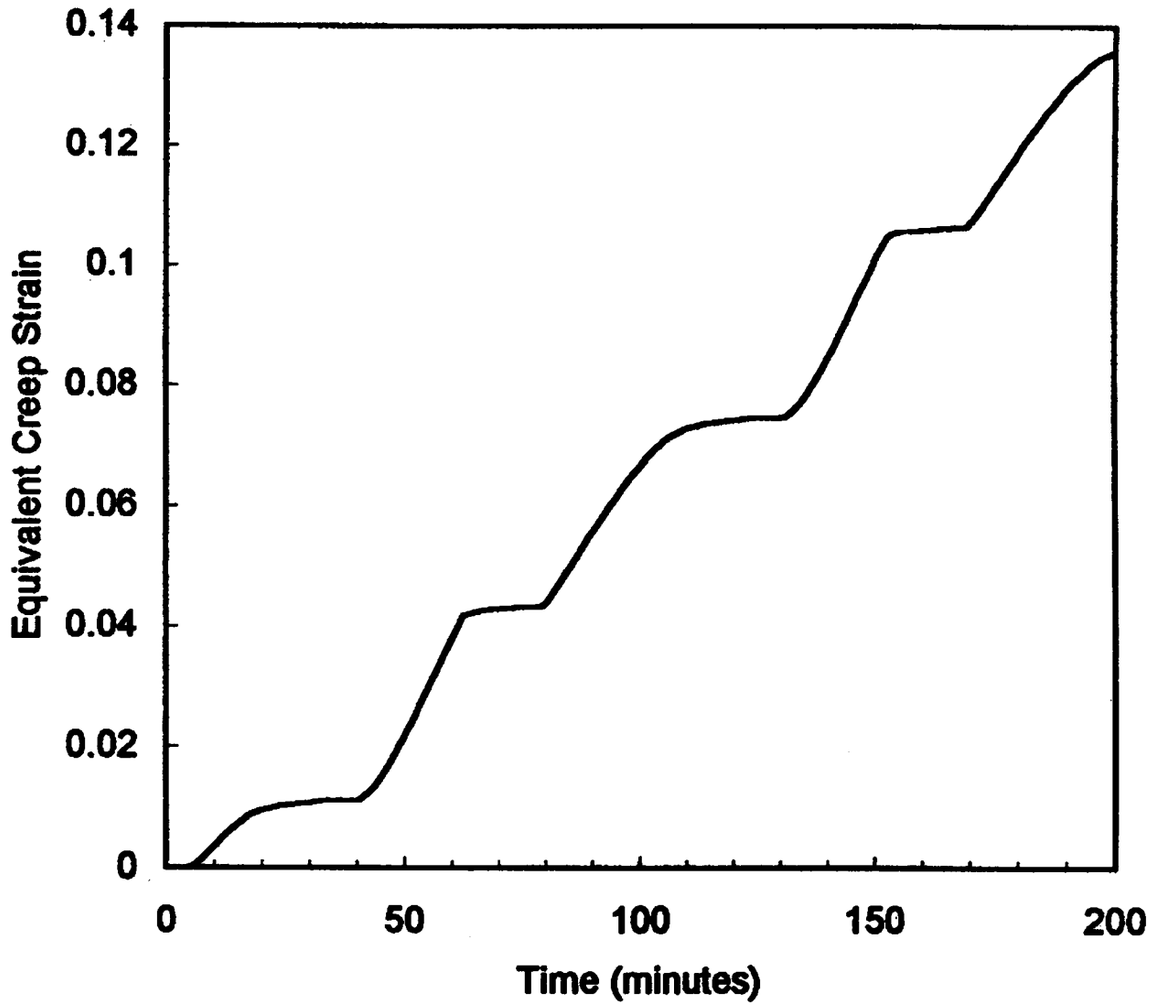


Figure 26. Equivalent creep strain in the corner solder joint.

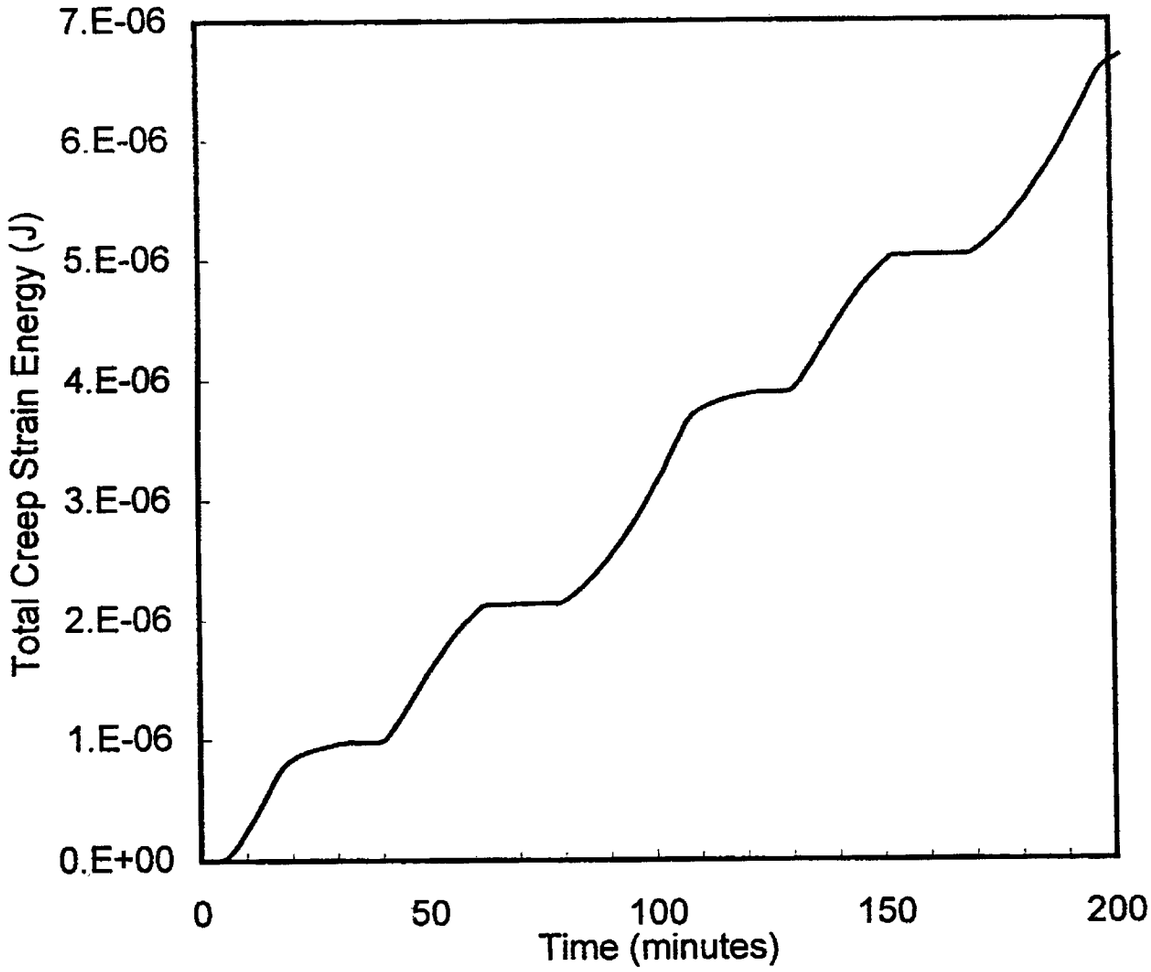


Figure 27. Total creep strain energy in the corner solder joint.

Appendix 1. Weight Reduction Comparison

Table A1

	Composite Heat Sink	Aluminum Heat Sink
Al Skin Volume (in^3)	10.53×7.528×0.004	N/A
Adhesive Volume (in^3)	10.53×7.528×0.006	N/A
Sink Core Volume (in^3)	10.53×7.528×0.060	10.53×7.528×0.080
Total Weight (lb)	0.335	0.621
Weight Reduction	46%	-

Appendix 2. Matrices of Lamina for $[(0\pm60)_2]_s$ Stacking Sequence

(1) Stress-strain relation (Msi):

$$\begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \gamma_{12} \end{Bmatrix} = \begin{pmatrix} S_{11} & S_{12} & 0 \\ S_{21} & S_{22} & 0 \\ 0 & 0 & S_{66} \end{pmatrix} \begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \tau_{12} \end{Bmatrix} = \begin{pmatrix} \frac{1}{E_{11}} & -\frac{\nu_{12}}{E_{11}} & 0 \\ -\frac{\nu_{21}}{E_{22}} & \frac{1}{E_{22}} & 0 \\ 0 & 0 & \frac{1}{G_{12}} \end{pmatrix} \begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \tau_{12} \end{Bmatrix}$$

$$= \begin{pmatrix} 0.014 & -0.0047 & 0 \\ -0.0047 & 1.43 & 0 \\ 0 & 0 & 1.35 \end{pmatrix} \begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \tau_{12} \end{Bmatrix} \qquad \text{(A2-1)}$$

(2) Lamina stiffness matrix (Msi):

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \tau_{12} \end{Bmatrix} = \begin{pmatrix} Q_{11} & Q_{12} & 0 \\ Q_{21} & Q_{22} & 0 \\ 0 & 0 & 2Q_{66} \end{pmatrix} \begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \gamma_{12}/2 \end{Bmatrix} = \begin{pmatrix} \frac{E_{11}}{1-\upsilon_{12}\nu_{21}} & \frac{\nu_{12}E_{22}}{1-\nu_{12}\nu_{21}} & 0 \\ \frac{\nu_{12}E_{22}}{1-\nu_{12}\nu_{21}} & \frac{E_{22}}{1-\nu_{12}\nu_{21}} & 0 \\ 0 & 0 & 2G_{12} \end{pmatrix} \begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \gamma_{12}/2 \end{Bmatrix}$$

$$= \begin{pmatrix} 68.31 & 0.22 & 0 \\ 0.22 & 0.70 & 0 \\ 0 & 0 & 1.48 \end{pmatrix} \begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \gamma_{12}/2 \end{Bmatrix} \qquad \text{(A2-2)}$$

(3) Transformed lamina stiffness matrix for +60° ply (Msi):

The following transformation relations are used:

$$
\begin{aligned}
Q_{11}^T &= Q_{11}\cos^4\theta + Q_{22}\sin^4\theta + 2(Q_{12}+2Q_{66})\sin^2\theta\cos^2\theta \\
Q_{12}^T &= (Q_{11}+Q_{22}-4Q_{66})\sin^2\theta\cos^2\theta + Q_{12}(\sin^4\theta+\cos^4\theta) \\
Q_{22}^T &= Q_{11}\sin^4\theta + Q_{22}\cos^4\theta + 2(Q_{12}+2Q_{66})\sin^2\theta\cos^2\theta \\
Q_{16}^T &= (Q_{11}-Q_{12}-2Q_{66})\cos^3\theta\sin\theta - (Q_{22}-Q_{12}-2Q_{66})\sin^3\theta\cos\theta \\
Q_{26}^T &= (Q_{11}-Q_{12}-2Q_{66})\cos\theta\sin^3\theta - (Q_{22}-Q_{12}-2Q_{66})\sin\theta\cos^3\theta \\
Q_{66}^T &= (Q_{11}+Q_{22}-2Q_{12}-2Q_{66})\sin^2\theta\cos^2\theta + Q_{66}(\sin^4\theta+\cos^4\theta)
\end{aligned}
\tag{A2-3}
$$

$$
[Q]_{+60} = \begin{pmatrix} 5.3 & 12.52 & 7.53 \\ 12.52 & 39.10 & 21.73 \\ 7.53 & 21.73 & 13.03 \end{pmatrix}
$$

(4) Transformed lamina stiffness matrix for -60° ply (Msi):

$$
[Q]_{-60} = \begin{pmatrix} 5.3 & 12.52 & -7.53 \\ 12.52 & 39.10 & -21.73 \\ -7.53 & -21.73 & 13.03 \end{pmatrix}
$$

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13. ABSTRACT *(Maximum 200 words)*

In order to reduce the overall weight in spaceborne electronic systems, a conventional metallic heat sink typically used for double-sided printed wiring boards was suggested to be replaced by light-weight and high-strength laminated composite materials. Through technology validation assurance (TVA) approach, it has been successfully demonstrated that using laminated composite heat sink can not only reduce the weight of the heat sink by nearly 50%, but also significantly lower the internal thermally-induced stresses that are largely responsible for potential delamination under cyclic temperature variations. With composite heat sink, both thermal and dynamic performance of the double-sided printed wiring board (PWB) exceeds that of its counterpart with metallic heat sink. Also included in this work is the original contribution to the understanding of creep behavior of the worst-case leadless chip carrier (LCC) surface mount solder joint. This was identified as the interconnection most susceptible to thermal fatigue damage in the PWB assembly.

14. SUBJECT TERMS
PWB; Wedge lock; Natural frequency; Laminated composite; Thermal stress; Random vibration; Creep; Fatigue; Creep strain.

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