THE DESIGN, TESTING, AND MANUFACTURING OF A PIN FIN EXTRUSION HEATSINK

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A Senior Project submitted
in partial fulfillment
of the requirements for the degree of
Bachelor of Science in Manufacturing Engineering

California Polytechnic State University

San Luis Obispo

Graded by:______________________ Date of Submission:__________________________

Checked by:_________________________ Approved by:____________________________

Contents

Abstract

My senior project focuses on the design, testing, and manufacturing of pin fin extrusion heat sinks that are you used to cool simple electronic applications across a multitude of markets. Without the modern day heat sink, electronics that we have become familiar with throughout our everyday lives will cease to exist. I will design these heat sinks using Solid Works 3D CAD. I will then test the heat sinks using ICEPAK CFD software, where I will model the heat sink against a 5 watt application, inside of a cabinet that models the chassis of a computer. After receiving these results, the drawing files were sent off to a Chinese Manufacturer by the name of Paramount Technology, located in Dong Guan, Guan Dong China. The heat sinks were received, retested to prove the validity of the ICEPAK results, and then marketed through the company website, www.heatscape.com. All products are available for purchase.

Introduction/Background

Project Overview

When electronic products (that are in use) are operating, an equivalent amount of power (Wattage) is necessary to operate the electronic products. The larger the operation, the more power is necessary to activate the product. More power means more complex (or in some cases larger) heatsinks are necessary to cool the electronic product. My project will deal in the design, testing, and manufacturing of heatsinks. The manufacturing material that will be pursued will be Aluminum, because it's light, effective in heat transfer, and cost effective.

Project Deliverables

Within this project, I will include everything that is necessary to go through designing, testing, and manufacturing of a heatsink. This includes the engineering drawing and 3D model (Solidworks 3D mechanical Design), ICEPAK (Computational Fluid Dynamics Software) results. I will also have the test rigs used for physical testing of soft tooled prototypes, and finally, the physical product itself. I will then design a brochure that markets all of the heatsinks thermal capabilities on PowerPoint. I will then take the file to either PolyPrints or FedEx Kinkos and get them printed out in a large sum. Finally, I will link with a local Heatsink company, and ask if I can start my product line on their website for sale. I will hopefully be able to split all proceeds with them 50/50. If time is allotted towards the end of the project, I will attempt to open up a second line of the other raw material, copper. Copper is a much more ductile metal, and it has very high thermal and electrical conductivity. Although, the performance comes at a heavier price, some buyers may overlook the dollar amount and focus strictly on performance capabilities.

Technical Approach

I will begin this project by designing a simple pin fin extrusion heatsink using Solidworks. I will then make the engineering drawings out of it with exact dimensions of the model. Then using ICEPAK, I will see if my product is thermally capable to cool a simple 5 watt computer chip, testing across various airflows. I will then contact a factory either in the United States or China, and have them build me a few soft tooled models. Take that soft tooled model and test it physically in a make shift test rig used to model the inside of a computer chassis. The computer chip that dissipates 5W power will be simulated using a TTV (Thermal Test Vehicle) attached to a power supply box, and temperature measurements are read using Thermal Couples. Finally, I will compare the results and begin to hard tool the heatsinks with the factory.

Industrial or Manufacturing Engineering Orientation

This project is manufacturing oriented with a mechanical engineering flare. The mechanical engineering side will involve the design, and testing portion of the entire project. Using the AutoCAD software as well as the CFD software falls under the category of Mechanical Engineering. This project is obviously manufacturing oriented, because I literally have to soft tool and hard tool heatsinks with a factory. This project is very closely related to “Tool Design” or really any pure manufacturing class I had to take at my time at Cal Poly. Since I am a Manufacturing Engineer, all manufacturing processes required to actually make the products

(Beginning with the raw material itself) will be perfectly correlated into any classes that I plan on (or have already) taken.

Figure 1. General Picture of a Simple Pin Fin Extrusion Heatsink

Literature Review: How a Heat Sink Works

The term heat sink isn't the first thing people think of when computers come to mind. However, it should be. This product is the sole reason modern, everyday computers, can run at the speeds that they do. To put the concept of a heatsink in simple terms, imagine you have just completed a very high impact exercise session. Afterwards, your body cools down with an ice cold glass of water. Equivalently, heat sinks cool down the processor of your computer after it has simultaneously run multiple programs at once. If you don't have a quality heat sink, your computer will eventually overheat, and completely meltdown your entire system, which would be a costly mistake (Mueller, Scott).

In order to actually appreciate what a heat sink is, one must understand how a heat sink works. Again, to put it simply, a heat sink is any object that disperses heat away from another object. Computers are the most common end product that a heat sink goes into; however, they can also be found in many cell phones, and even in huge refrigerators. Basically, a heat sink can be found in any object that requires a processor (micro-chip) to function. A heat sink in a computer is attached to the micro-chip using TIM (Thermal Interface Material), and it actually prevents the micro-chip from overheating. In new aged, more modern computers, a heat sink is arguably one of the most important components that go into it.

The same way a car radiator disperses heat away from your car's engine, a heat sink will draw heat away from your computer's CPU (Central Processing Unit). A heat sink is essentially one big (or small) thermal conductor that over time will carry heat away from the CPU and disperse it into the heat sink's fins, attached to the heat sink's base (Dagan, Barry). The fins provide additional surface area for the heat to travel, allowing the heat to dissipate through the rest of the computer, additionally cooling both the CPU and heat sink simultaneously. However, considering the car's radiator again, the radiator would pose no purpose without the necessity of airflow. A heat sink, as well, requires airflow. This is why cars as well as computers have fans built in.

Before computers became the processing powerhouses they are today (1980s to 1990s), heat sinks were usually only necessary in large super computers where the processor heat became an issue. Fast forward two decades, and you have the speed processor we have today. Heat sinks became absolutely essentially in every single computer, because without it, every computer saw a shelf life of just over 1 month. A cooling mechanism is always necessary when a processor is involved.

Thermal Conductivity

There is three ways that heat can be transferred: conduction, convection and radiation. In this project, we are talking about the interaction between two solid objects (the heat sink and the CPU); conduction will be our main focus. When two objects with differing core temperatures come into contact with one another, conduction occurs. The contact point between the two objects (whether is a surface or a point) is the focus of conduction. The faster moving molecules of the hotter object collide into the slower moving molecules of the cooler object (Steinbrecher, Tillmann). When this occurs, the molecules of the hotter object will transfer energy to the slower molecules of the cooler object, which obviously, will heat up the cooler object. This process is called “Thermal Conductivity”, which is exactly how a heat sink transfers heat away from the CPU in the computer.

Usually metals are the materials that have the highest conductivity (at an affordable cost). That is why all heat sinks are usually made of metals. Each metal has a different level of thermal conductivity. The greater the thermal conductivity of the metal, the more proficient it is at removing heat away from the CPU.

Aluminum is one of the most common metals used to make heat sinks. The thermal conductivity of Aluminum is a 235 Watts per Kelvin per meter (235 W/mK). The number 235 is the thermal conduction number, and it refers to the materials ability to conduct heat. The higher the thermal conductivity of the metal, the more heat the metal can conduct. The beauty of Aluminum is that it is fairly cheap to produce and it is incredibly lightweight. The weight is a huge factor, because when the attachment of the heatsink to the CPU happens, the weight of the heat sink puts stress on the motherboard, which the motherboard is generally designed to accept. So the aluminum is a nice because it adds very little stress and weight to the motherboard.

One of the best materials that are used for heat sinks is copper. Coppers thermal conductivity is nearly double that of Aluminum at 400 W/mK. However, copper is much heavier (a density of 8920 kg/m^3) than aluminum (a density of 2700 kg/m^3), and much more expensive too (86 cents per pound for aluminum versus $3.42 per pound for copper) (www.ibrtses.com) (http://www.infomine.com). However, for much larger systems like data storage facilities for large companies, or the network servers that go into satellites in space, copper is frequently used, because the cost of failure far outweighs the cost of copper. In addition the widespread amount of heat dissipated will allow the servers and operating systems to work at much faster rates.

There is still one question left to ask though, where does all of this heat go once it has been conducted away from the processor and through to the heat sink? The fans move the air across the heat sink and out the other end of the computer, like an exhaust pipe. Many computers these days actually have an extra fan that is designed directly above the heat sink, to actually assist the heat sink further in properly cooling the CPU. When you see heat sinks with this additional fan, they are called “active heat sinks”, while the ones with only one fan is called “passive heat sinks” (Maydanik, Yury F). Case fans are the most commonly used fans in the world (as well as in systems), because it draws the cool air from outside of the computer and blows that through the inside of the chassis, grabbing and pushing the hot air out the rear of the system.

The Future of Heat Sink Materials

When one thinks of a computer, the heat sink is arguably the last thing that comes to mind. However, like computers, heat sinks are always advancing along with the processing power of computers. Companies spend million on research and development to find lighter, more conductive materials to make heat sinks out of; the more conductive, the more efficient. The usual misconception of heat sinks is that they need to be made out of one material only. Some heat sinks are actually a bonded mixture of copper and aluminum. Most of the heatsink design is aluminum, since it is the more lightweight material. Generally, the aluminum is surrounded by copper, since copper is more thermally conductive. In theory, this is a great idea, but if the bond between the copper and aluminum is not sufficiently tight, the mixture can actually make the heat sink perform very poorly. These quality issues seem to be the case in most inexpensive, poorly made heat sinks.

“In October 2008, the firm Applied Nanotech announced that the future of heat sinks is an isotropic material called **CarbAl.** CarbAl is made up of 20 percent aluminum and 80 percent of two different carbon-derived materials with excellent thermal conductivity. Applied Nanotech was excited about the material because it has a thermal conductivity of 425 W/mK (higher than both aluminum and copper) and has a density similar to aluminum. Basically, CarbAl is more conductive than copper and weighs the same as aluminum, making it the best of both worlds” (Norley, Julian).

Natural Graphite composites are another quickly growing material in the field of heat sink manufacturing. It may not be as thermally conductive as copper, but it is incredibly close at 370 W/mK. However, the advantage lies in the weight of the graphite, completely rendering aluminum inefficient since its 70% of the overall weight.

No matter what material you end up with on your heat sink, there is a very simple rule of thumb when it comes to choosing your heat sink (talked about more in-depth in the next section), the cheaper heat sinks, will end up costing you much more in the future. For example, in the market, you will find many heatsinks that come accompanied by a fan (these are called fan sinks). The cheaper fan sinks come with a sleeve bearing adjusted on the fan. These sleeve bearings will break down in a very short period of time, essentially rendering the heat sink useless, leading to an overall system meltdown. The more expensive fan sinks are made using ball bearings, which last much longer then the sleeve bearings and are overall cheaper in the long run.

Design/Methods/Results

The initial design of the heatsink was modeled after the generic heatsinks offered from major suppliers across the world (Aavid Tech, Cooler Master, etc.). It is a square base, pin fin extruded heatsink, with vary base sizes, as well as fin sizes.

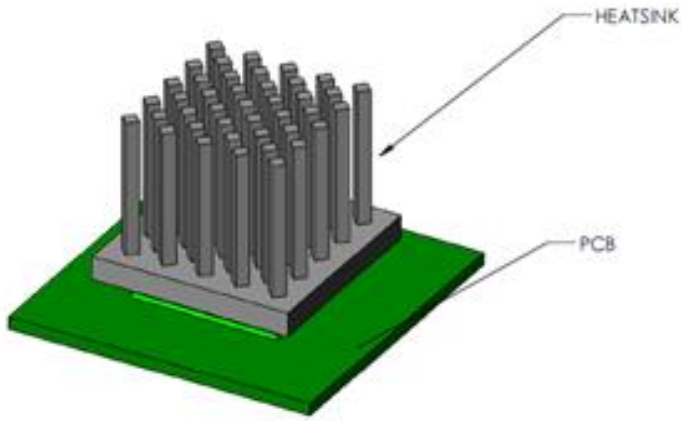


Figure 2. SolidWorks Model of Example Pin Fin Heatsink

The heatsink also underwent a secondary process, cross cutting, in order to give the heatsink the pin-fin like design, as seen in Figure 2. The design of the pin fins allows the heatsink to be oriented in any direction when sitting on the computer chip, increasing customer satisfaction.

After the design was completed on SolidWorks, the engineering drawings were created with the proper dimensioning, and sent off to Paramount Tech for quoting.

Concurrently, the thermal analysis on the heatsink was being conducted using ICEPAK CFD software. The heatsink was placed in a cabinet that modeled a generic computer chassis, and sat on a computer chip that dissipated 5 watts of power. A fan was placed in the cabinet, and ran at various airflows, and the data was recorded. Imaging of the heatsink can show the effects of airflow against power, like in Figure 3.

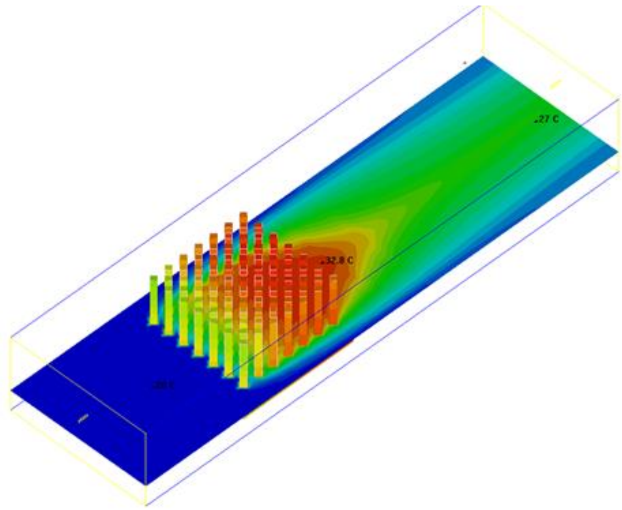


Figure 3. Example Rendered Image of Thermal Imaging for Heatsink

The heatsink prototype was received and tested in a physical test chamber modeled after the design in ICEPAK. TTV's were used to generate 5 watts of power to the base of the heatsink, and a wind tunnel was used to model the airflow differences. The data matched within 5% of ICEPAK results.

Once images and results were rendered, they were compiled in a brochure (Appendix E), and given to the company IT specialist to integrate into the website, and make available for purchase.

Tooling orders were placed for each heatsink with Paramount Tech at the Tooling Cost shown in appendix D.

Conclusion

This project solves the issue of multi sourcing for Heatscape Inc. with future projects with their customers. Previously Heatscape was the place OEMs and CMs would stop by for a custom design solution. They would then take care of their other weaker watt applications with much larger companies that purely specialized in off the shelf standard solutions (like the project that I have done now). Heatscape now offers solutions across the Mother Board for any application across any power consumption.

I sought out a complete A-Z project that works in product development, and product life cycle design. At the completion of this project, I finished:

1) A complete mechanical design of 22 different heat sinks on Solidworks 3D CAD Software
2) Completed a detailed engineering drawing for all 22 heat sinks on Solidworks 3D CAD Software
3) Thermal Analysis on all 22 heat sinks using ICEPAK 3D CFD Software
4) Contacted Chinese manufacturers via email and telephone to set up quotations for tooling and prototyping
5) Placed an order for a 35x35x20 (mm) heatsink for a prototype
6) Tested the received prototype via physical test rig and compared results to that of ICEPAK analysis
7) Statistically modeled all of the results onto an excel spreadsheet
8) Designed a standard product line brochure that features all of the heat sinks offered with their corresponding results from their thermal testing
9) Launched the product line online, and is now available for purchase

This project has also taught me many things that I can truly use in any career path that I decide to take. A few of them are:

1) How to budget time efficiently, and more importantly… concurrently
    a. Mixture of design/testing/manufacturing

   b. Timing when it comes to contact with manufacturers

2) How to be more patient
   a. Learning how to spend my downtime (while waiting for response from China) on productive tasks

3) How to take short cuts effectively, but accurately
   a. Thinking multiple steps ahead of your current position and strategize a proper attack plan on getting there quickly
   b. Doing an excellent job the first time around on the task

4) Using all available resources
   a. Not relying solely on your own ability to get tasks done
   b. Team morale is heavily underrated

Appendixes

Appendix A: Drawing files for all heatsinks

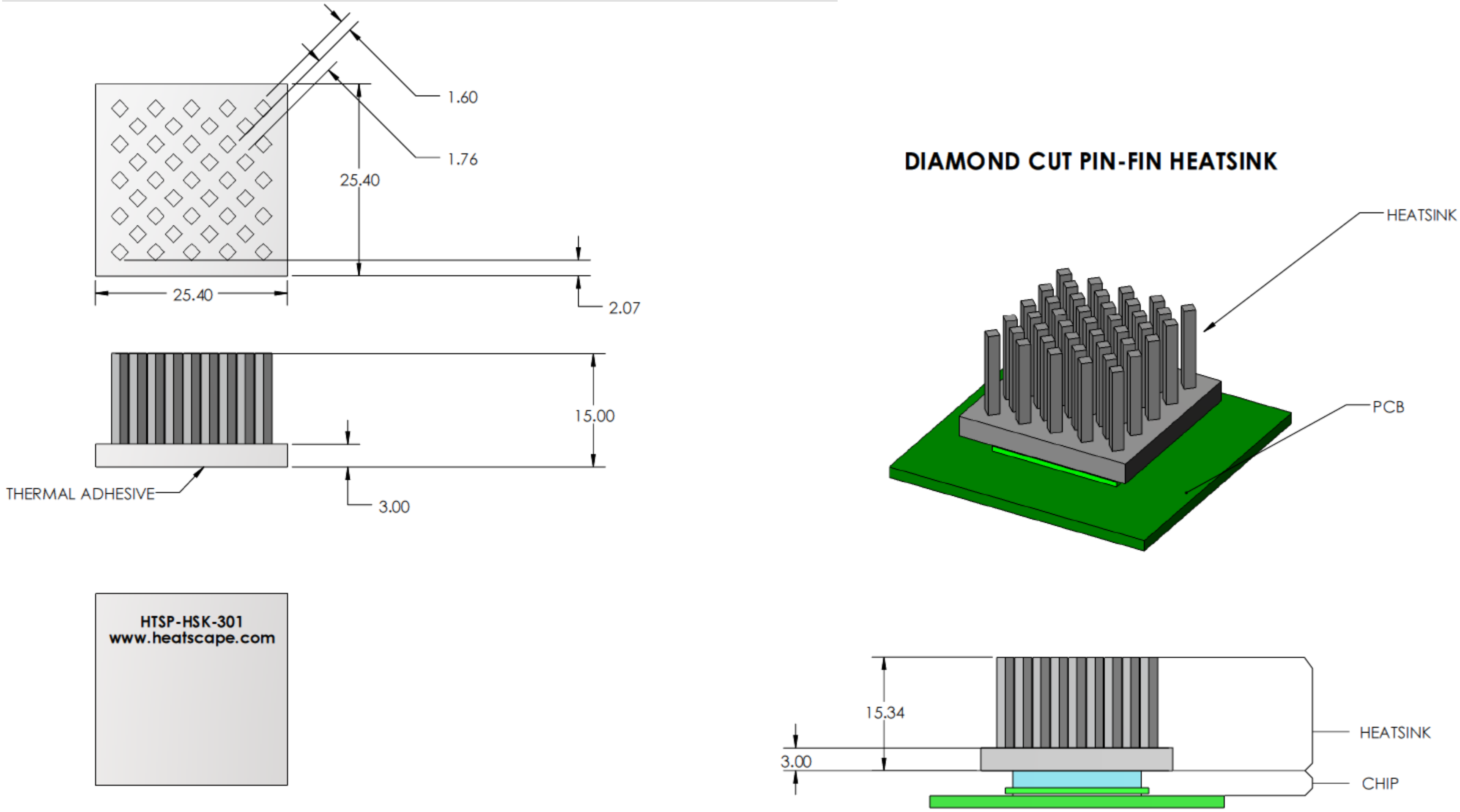


Figure 4. HTSP-HSK-301 25.4mmx25.4mmx15mm

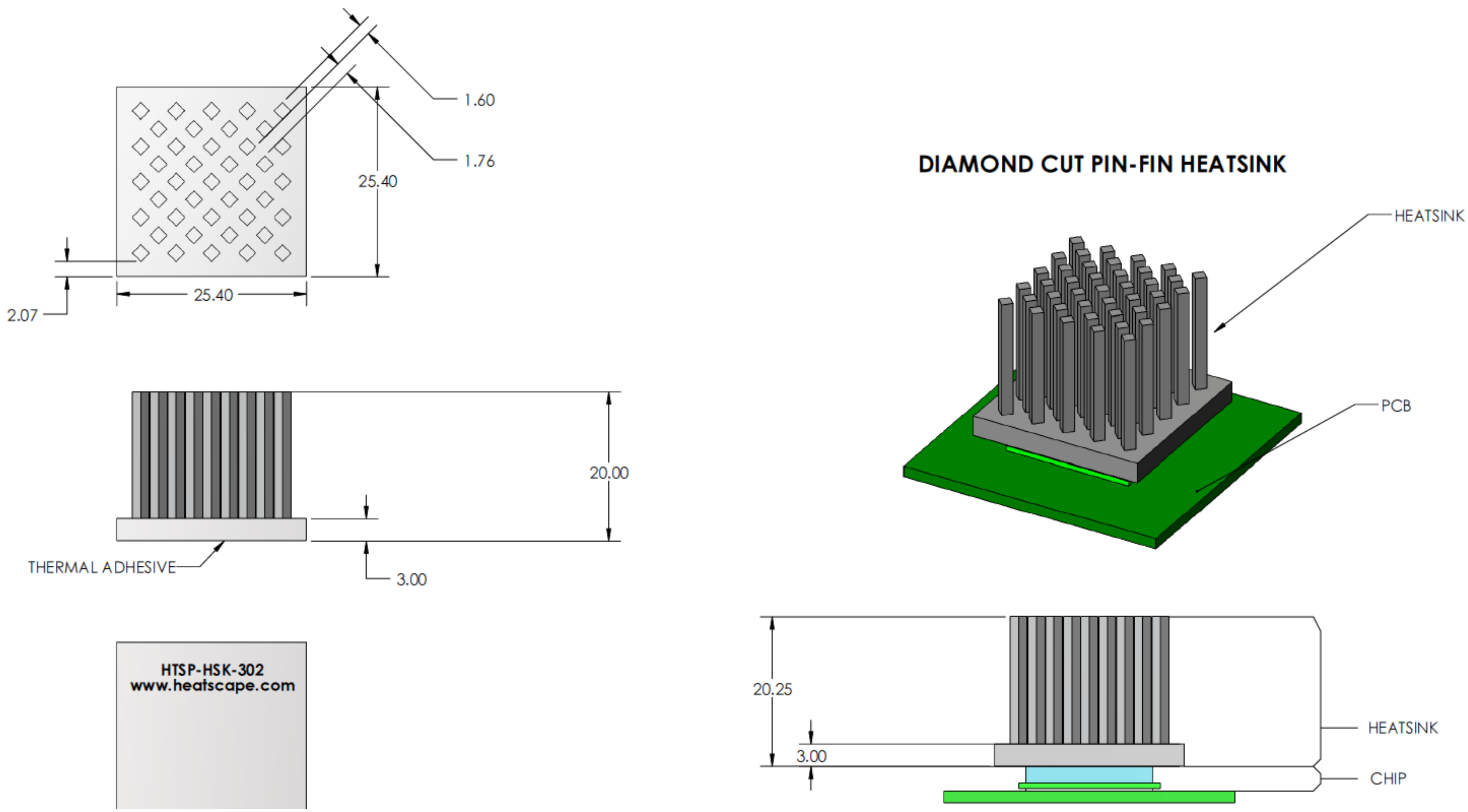


Figure 5. HTSP-HSK-302 25.4mmx25.4mmx20mm

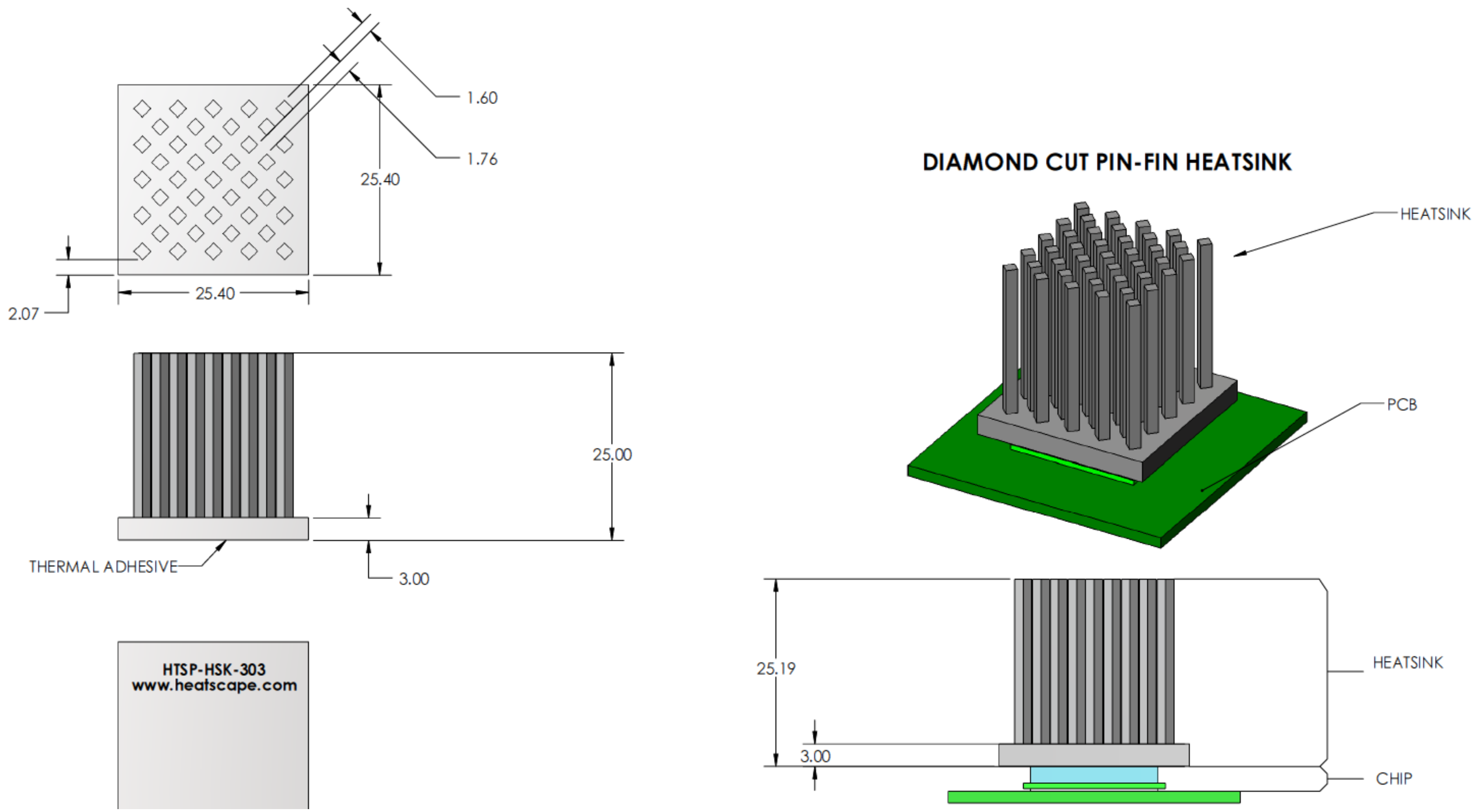


Figure 6. HTSP-HSK-303 25.4mmx25.4mmx25mm

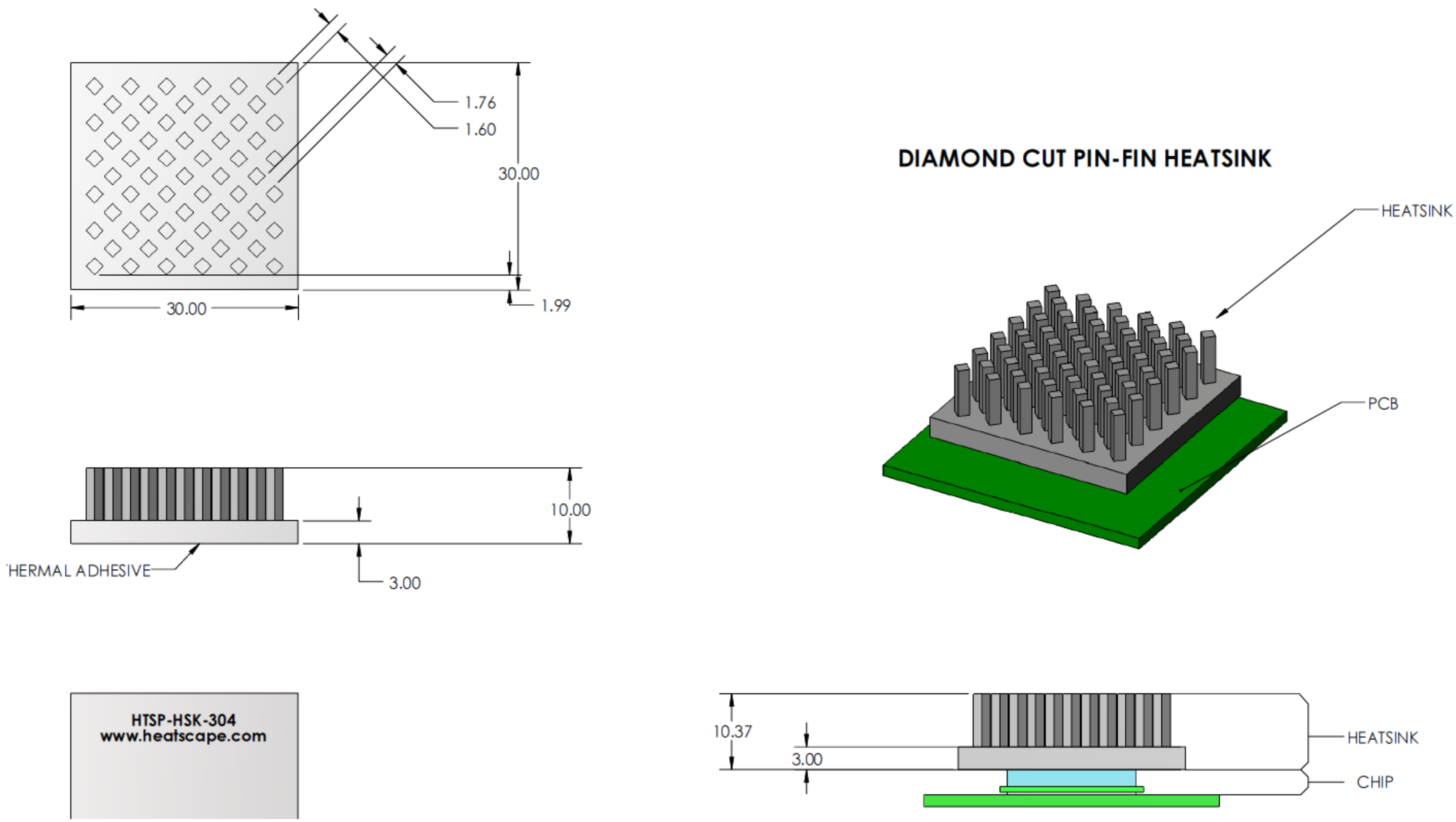


Figure 7. HTSP-HSK-304 30mmx30mmx10mm

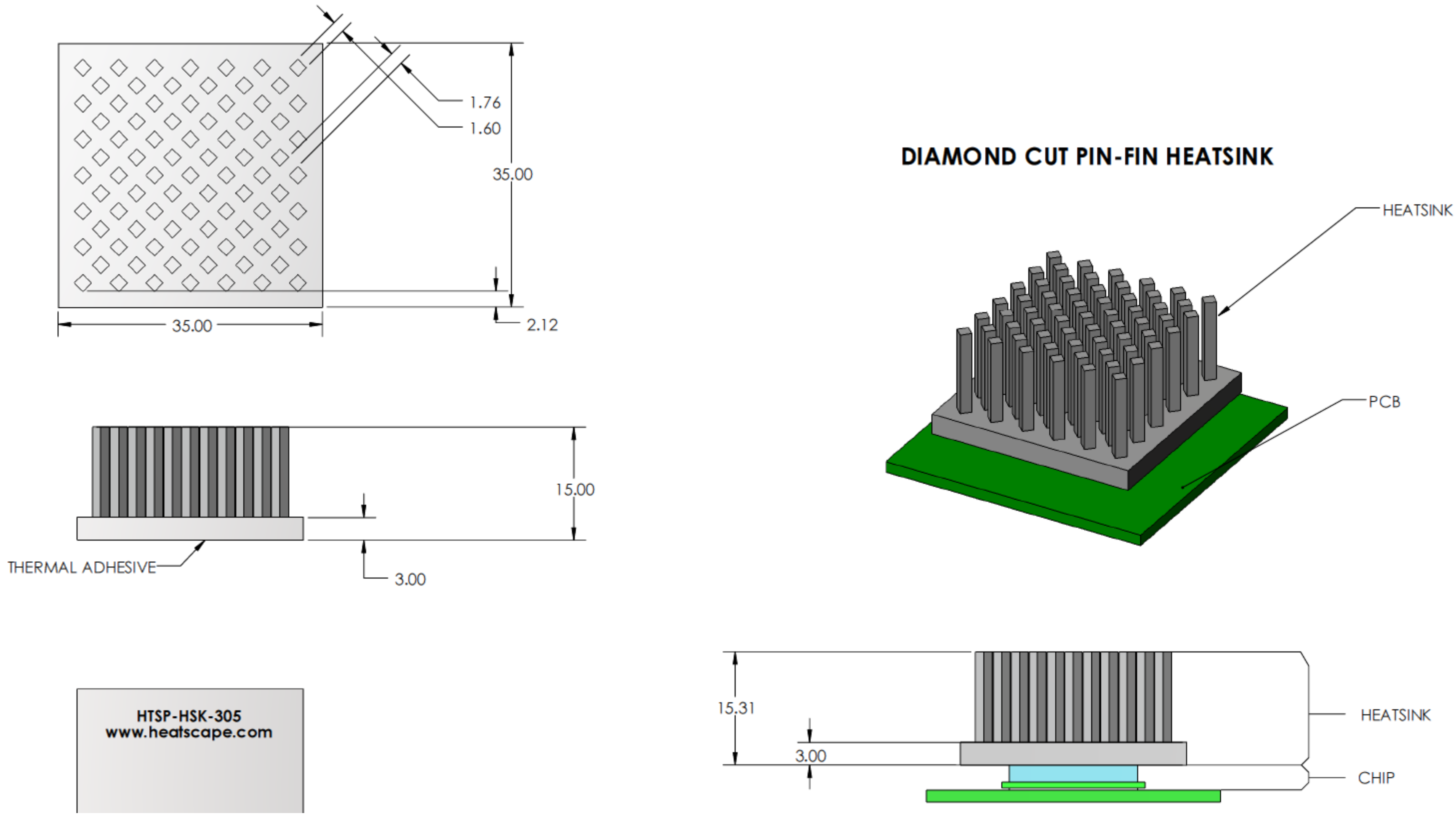


Figure 8. HTSP-HSK-305 30mmx30mmx15mm

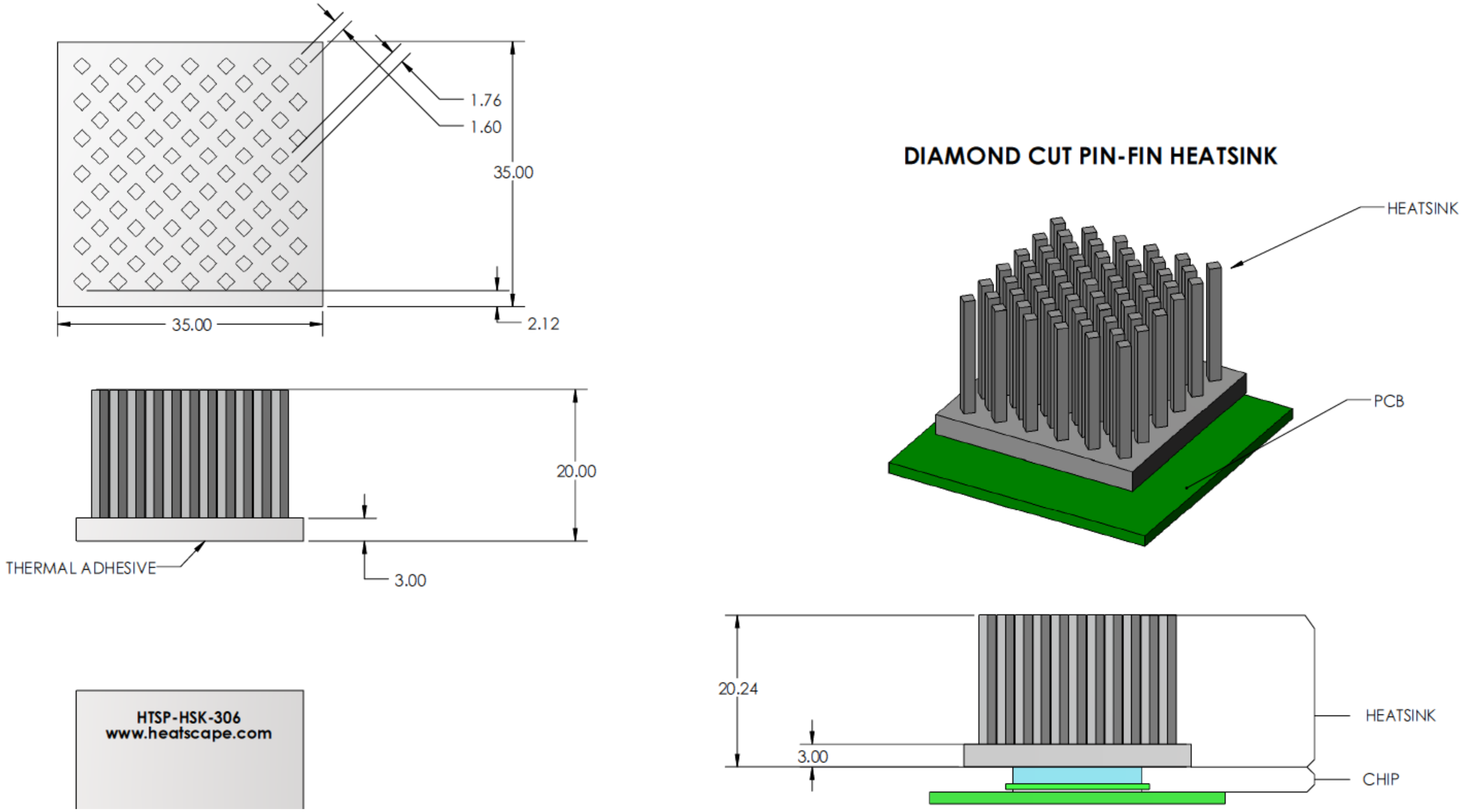


Figure 9. HTSP-HSK-306 30mmx30mmx20mm

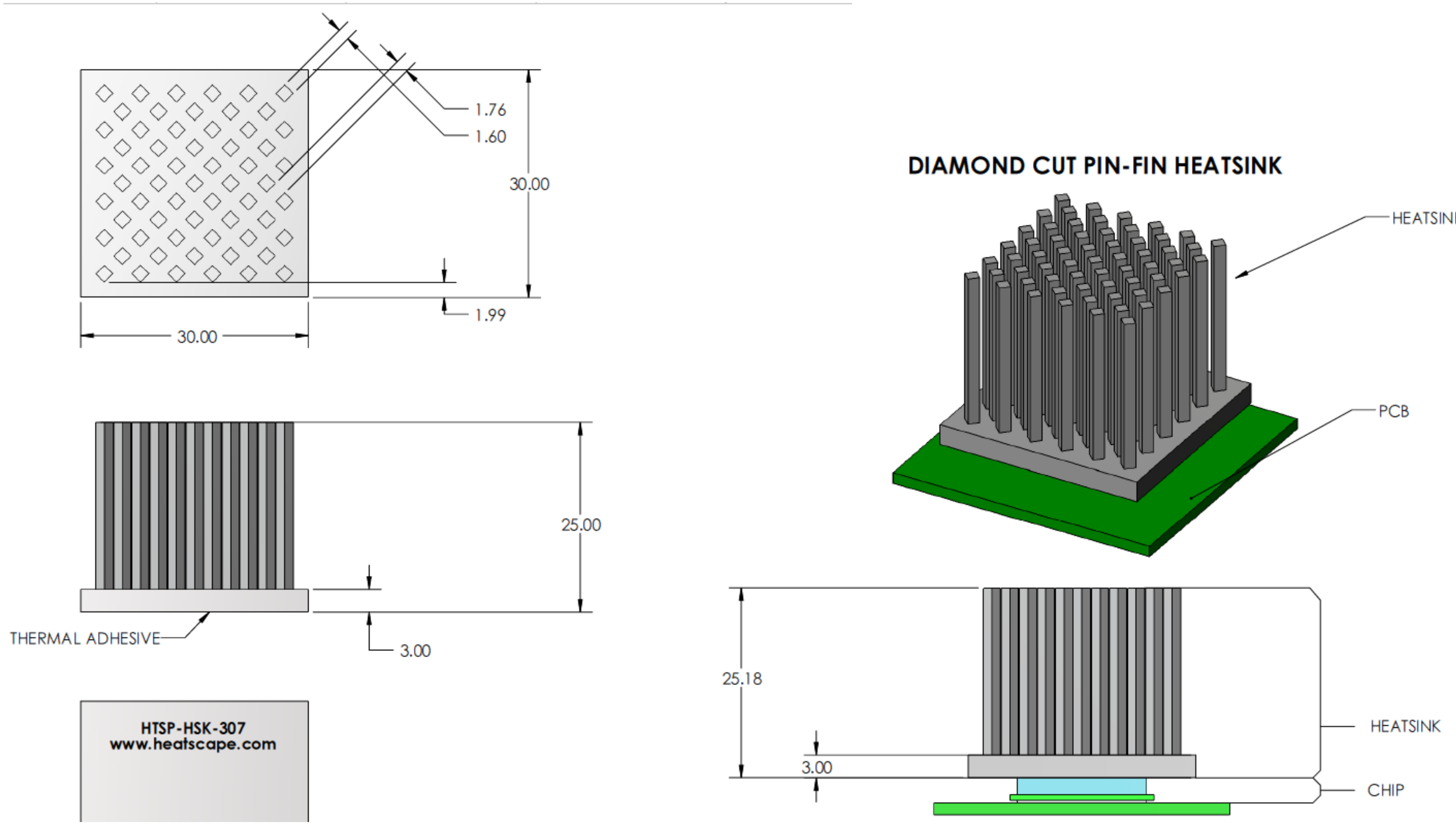


Figure 10. HTSP-HSK-307 30mmx30mmx25mm

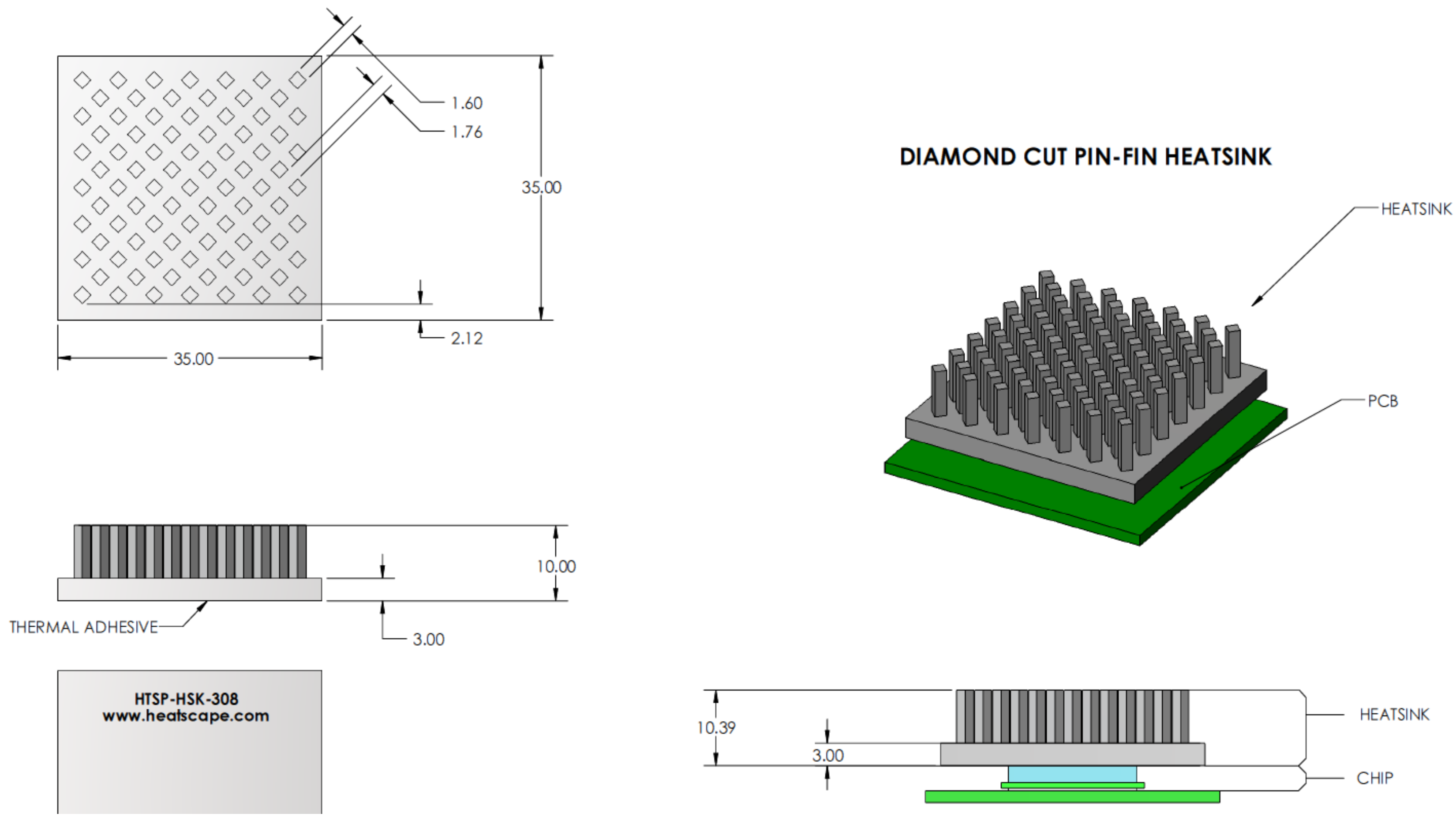


Figure 11. HTSP-HSK-308 35mmx35mmx10mm

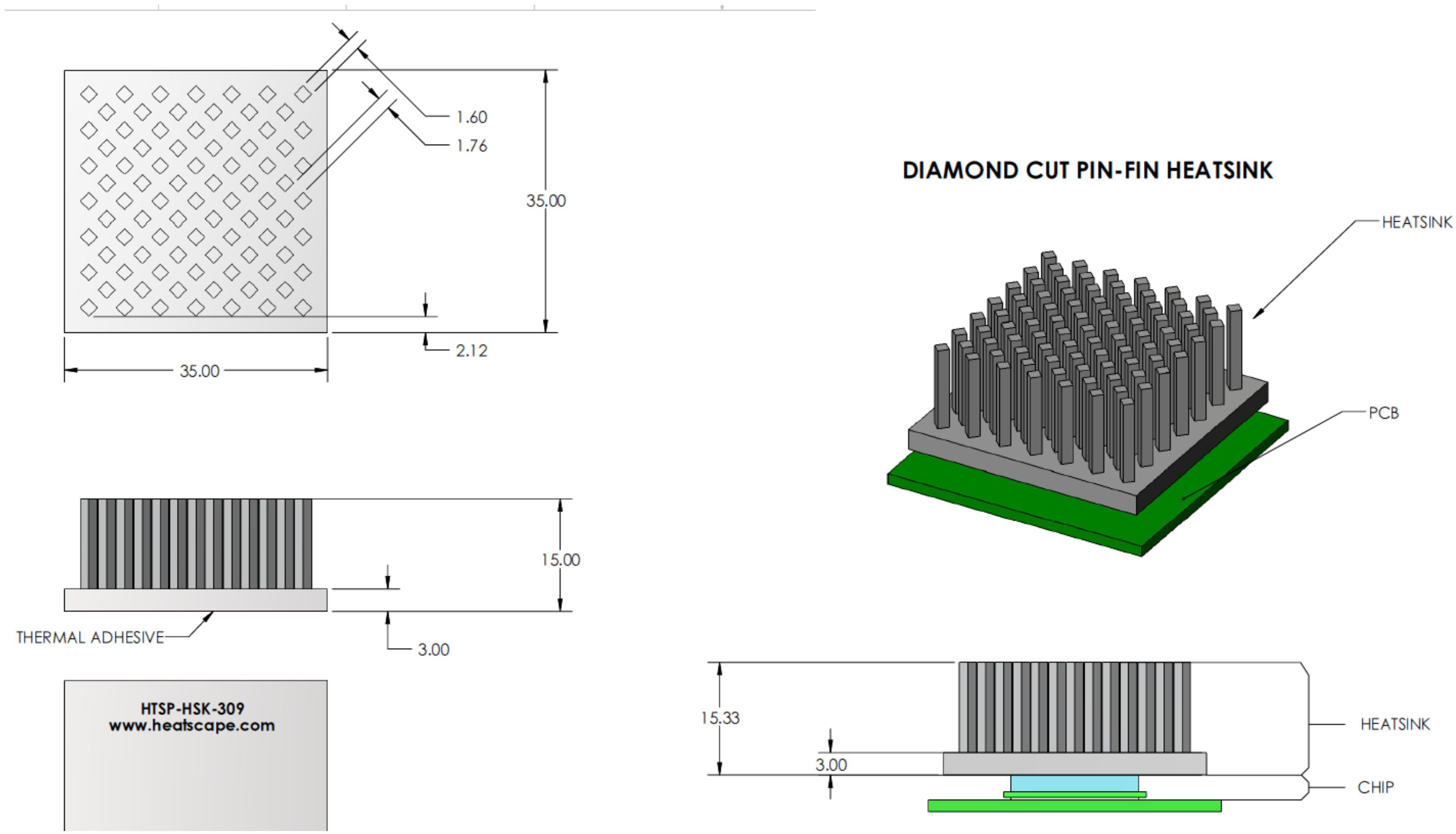


Figure 12. HTSP-HSK-309 35mmx35mmx15mm

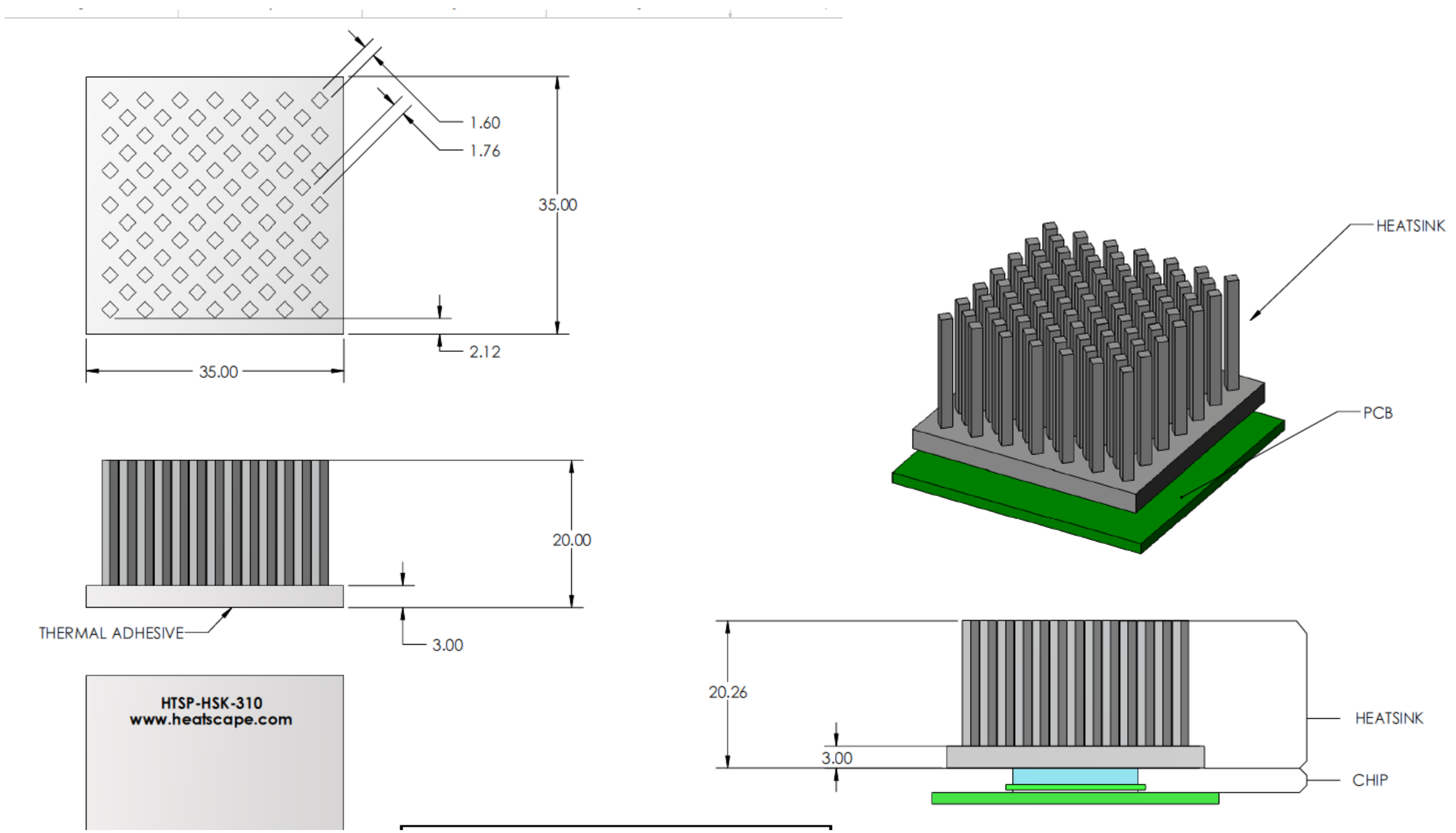


Figure 13. HTSP-HSK-310 35mmx35mmx20mm

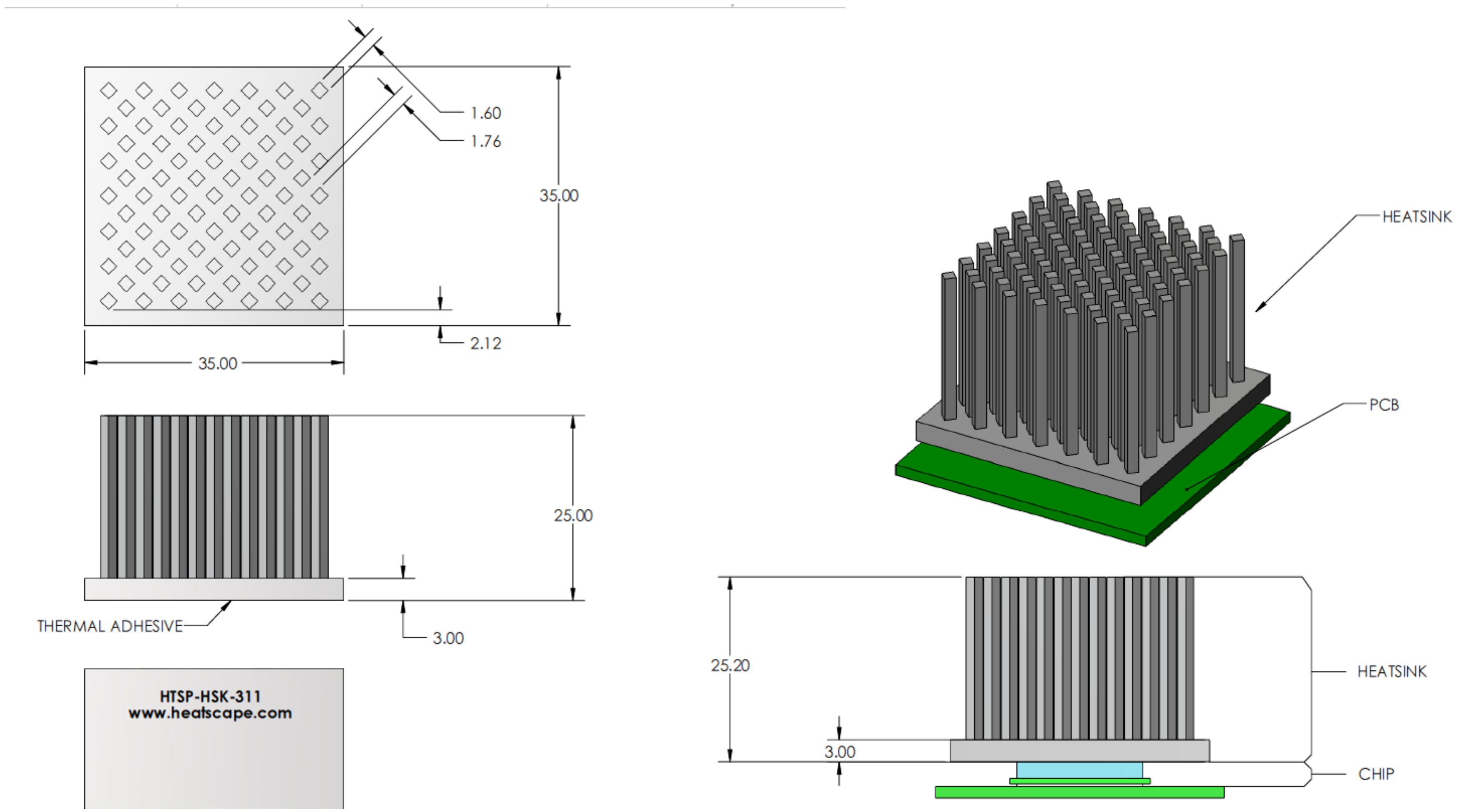


Figure 14. HTSP-HSK-311 35mmx35mmx25mm

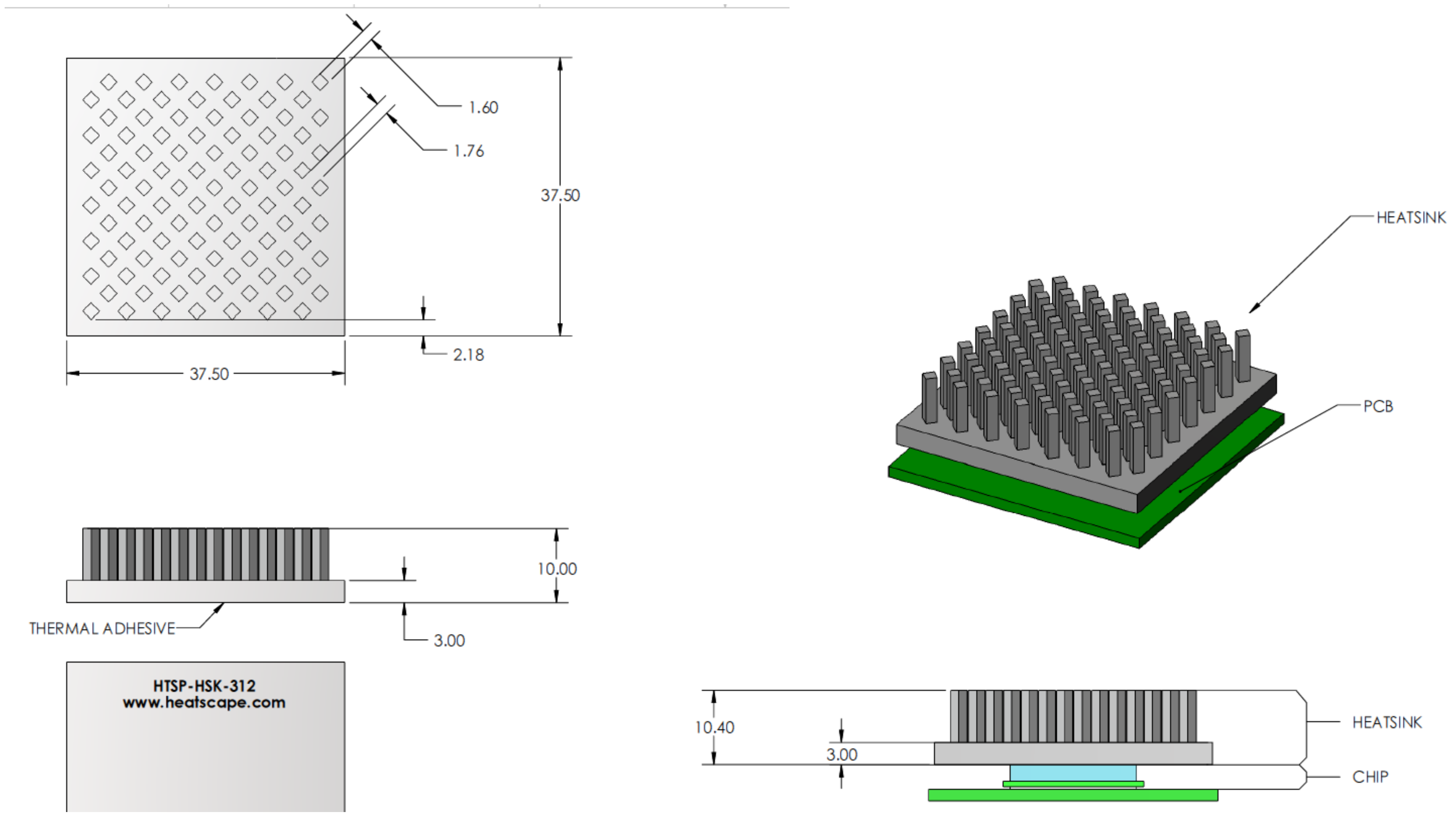
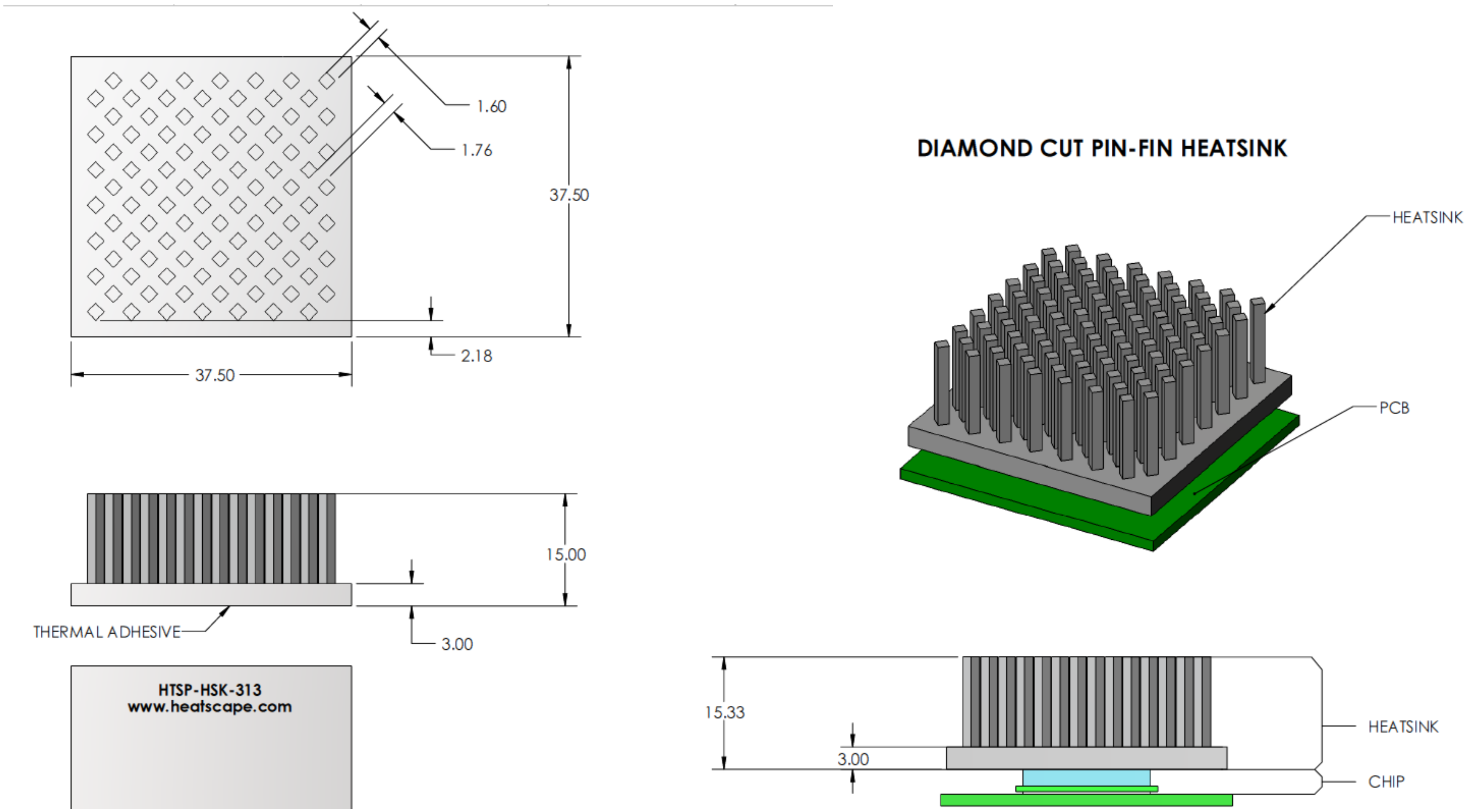


Figure 15. HTSP-HSK-312 37.5mmx37.5mmx10mm



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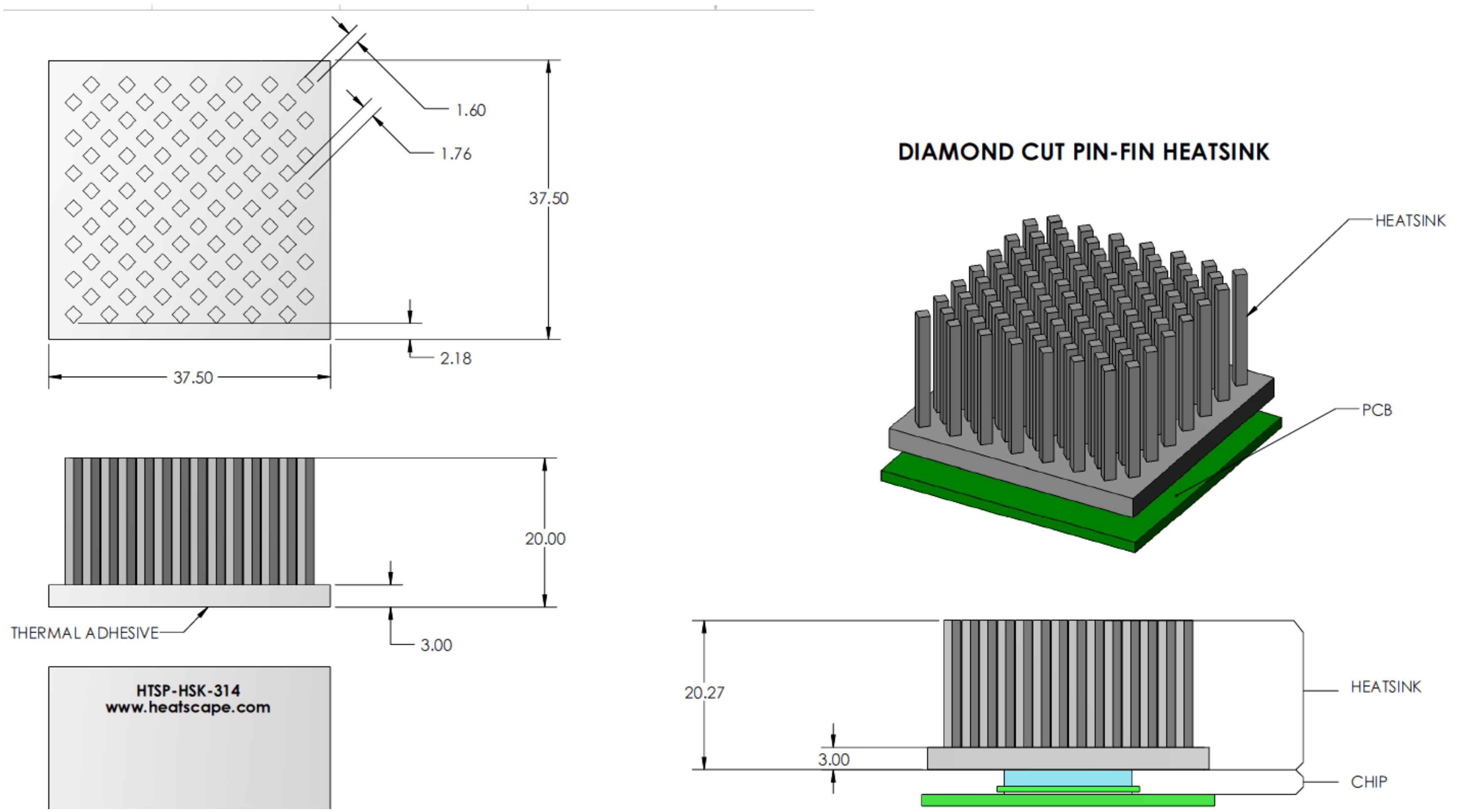

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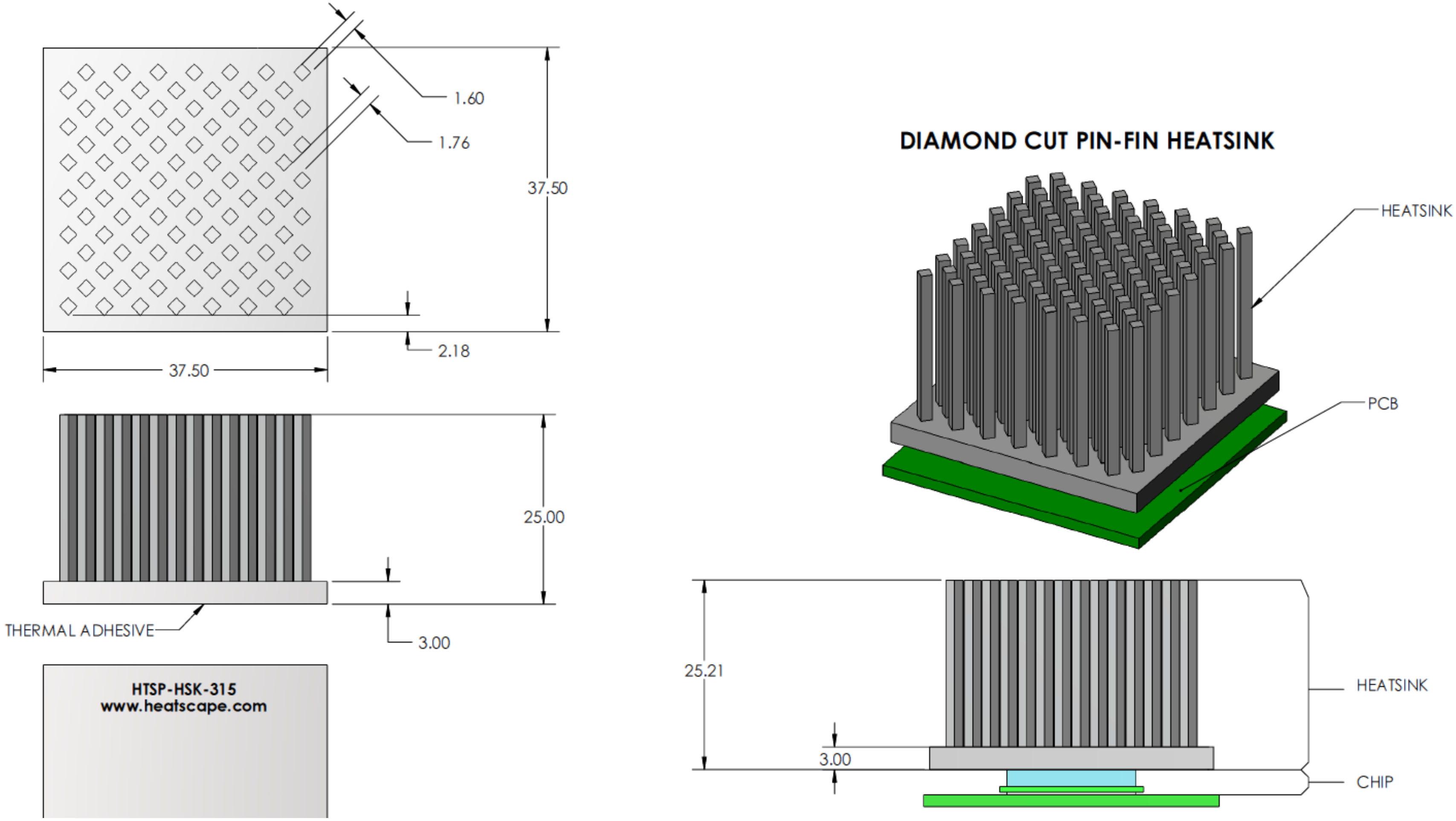

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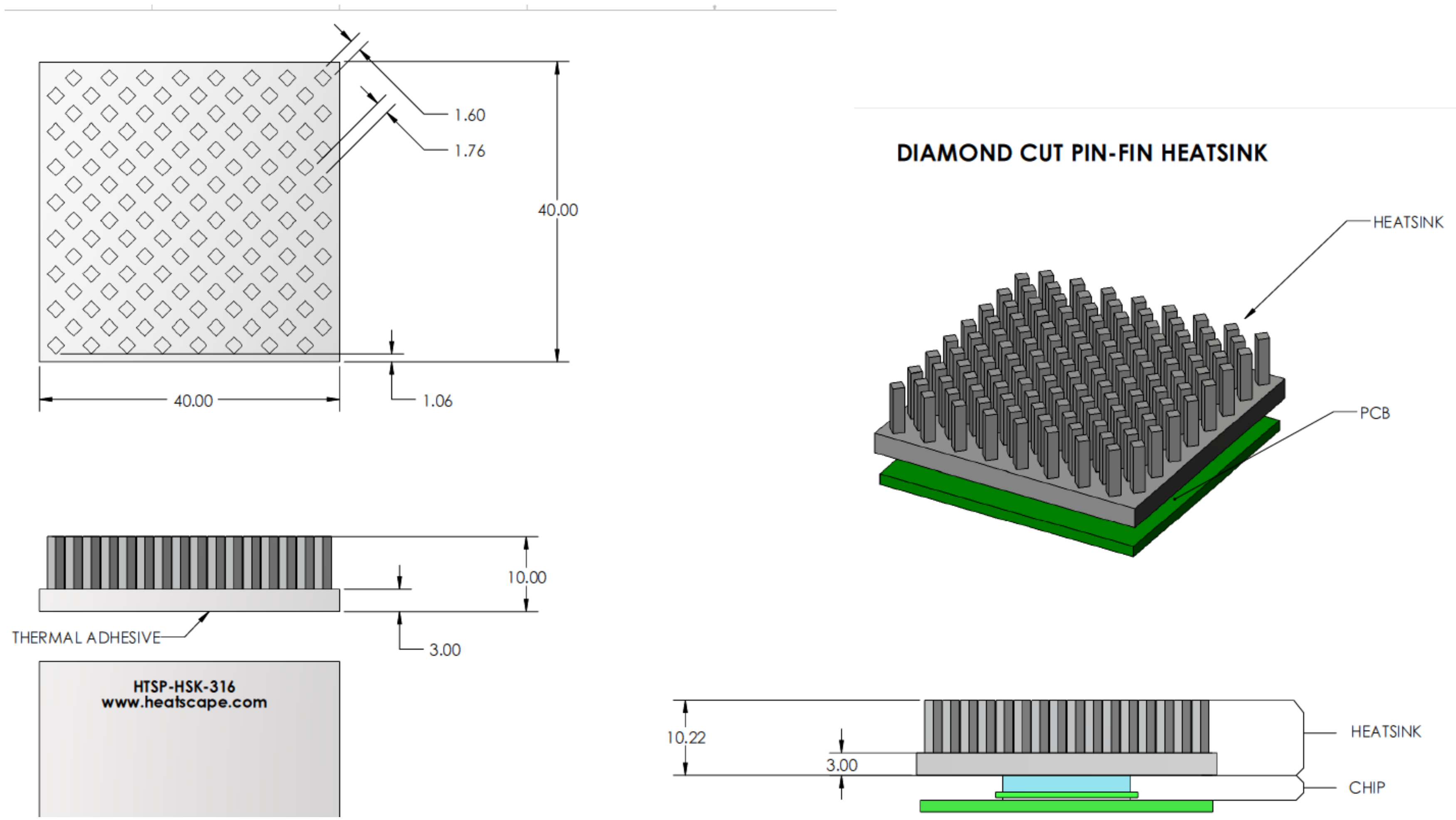
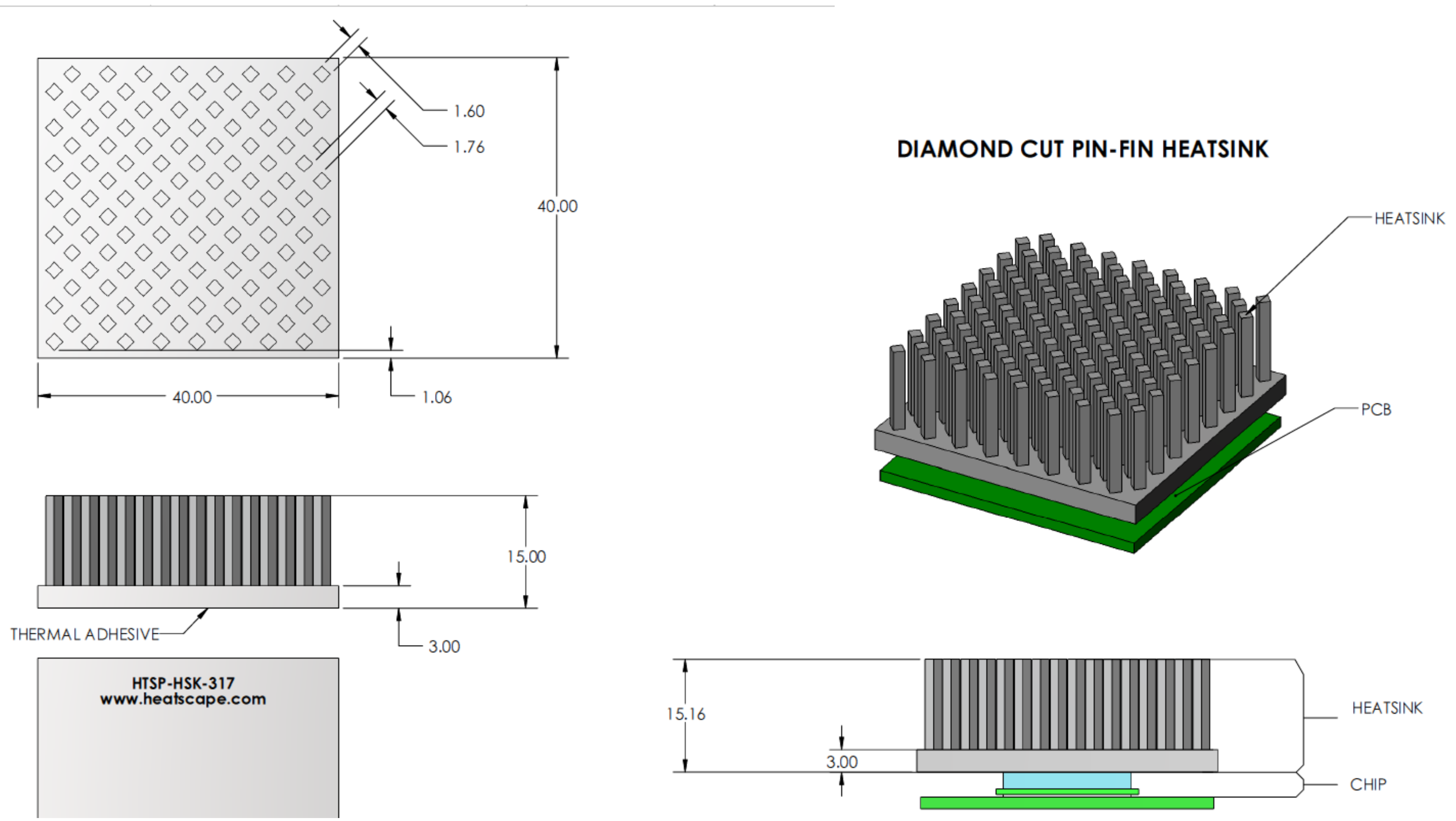


Figure 19. HTSP-HSK-316 40mmx40mmx10mm



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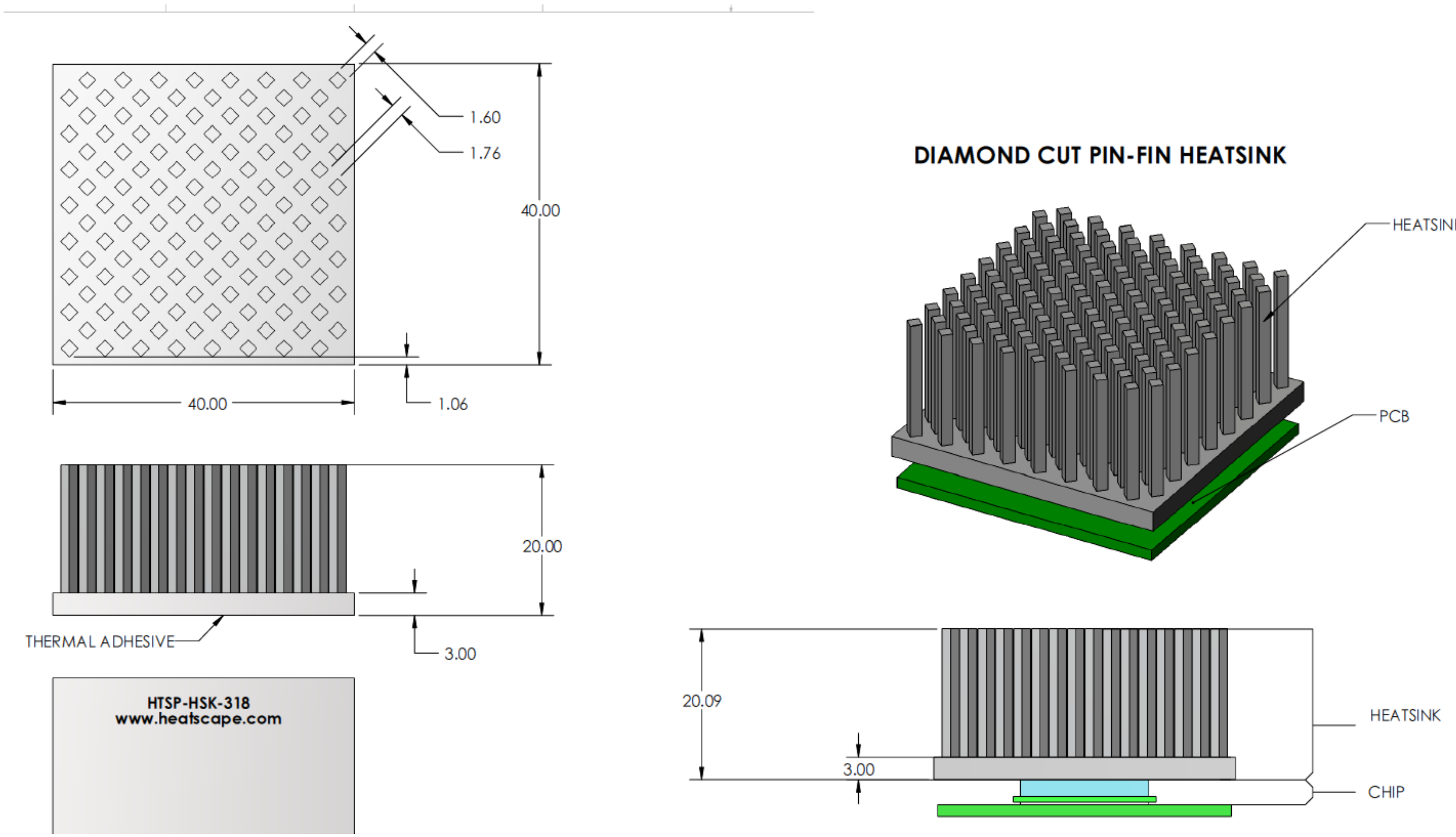

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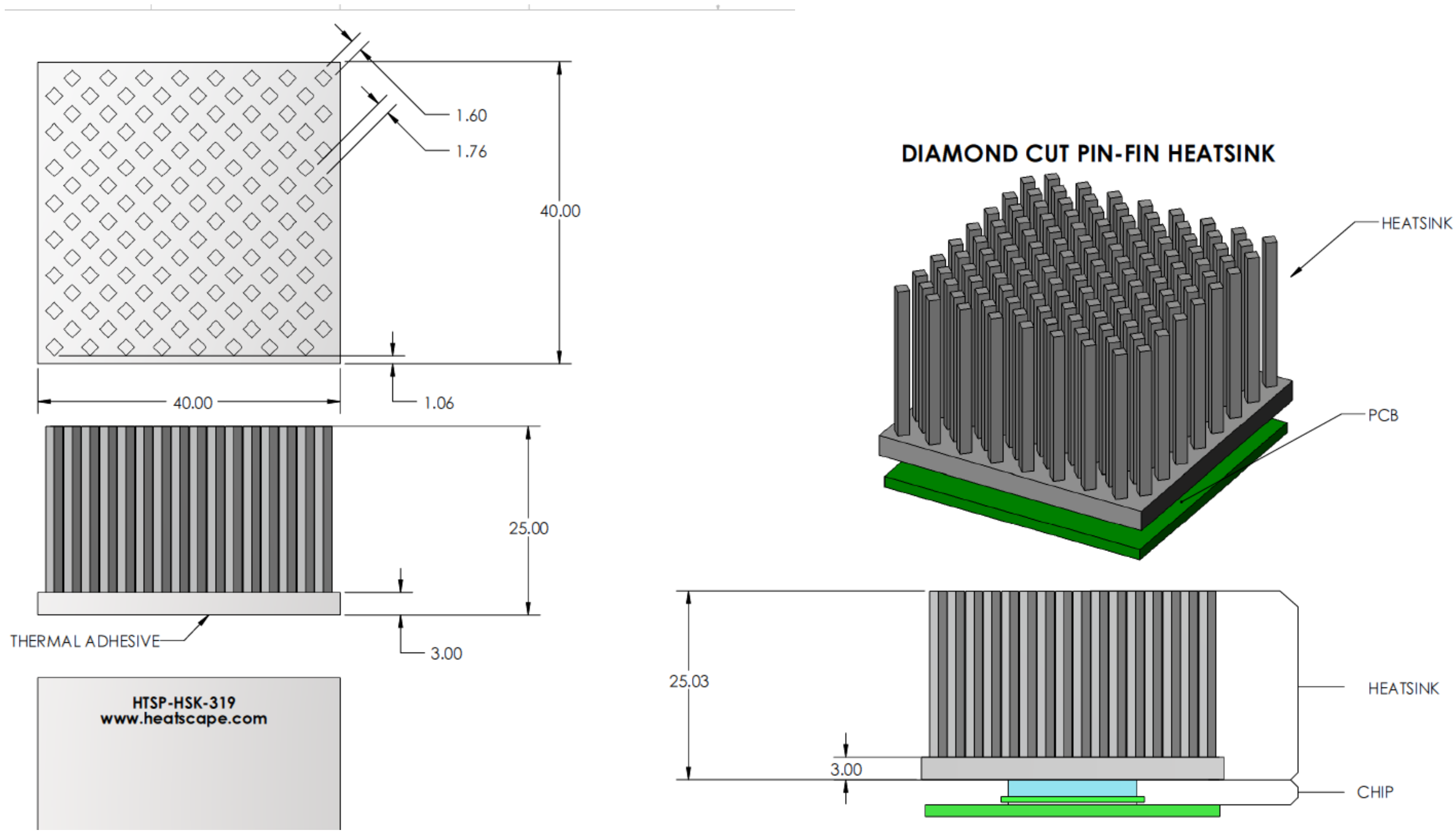

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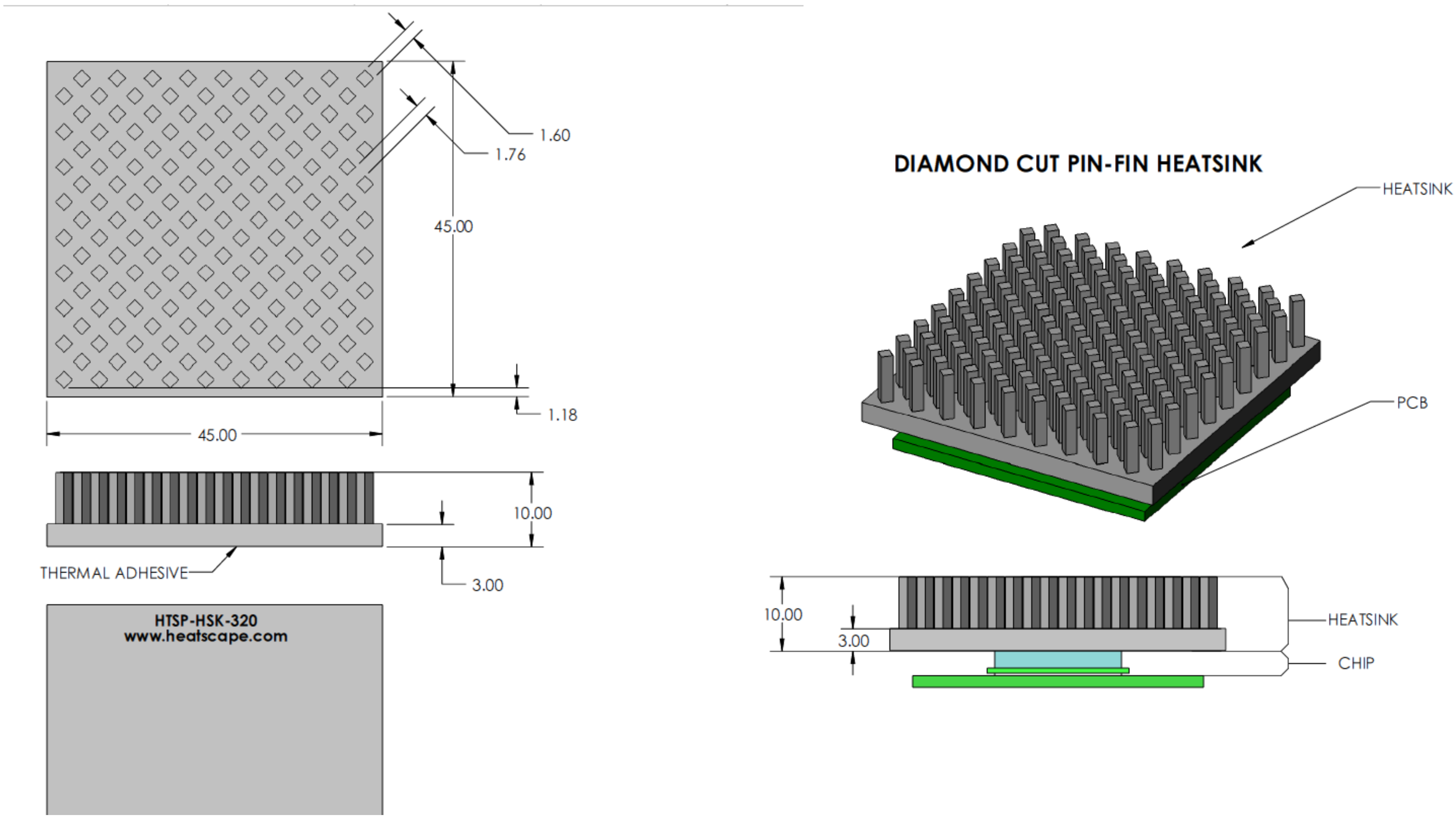
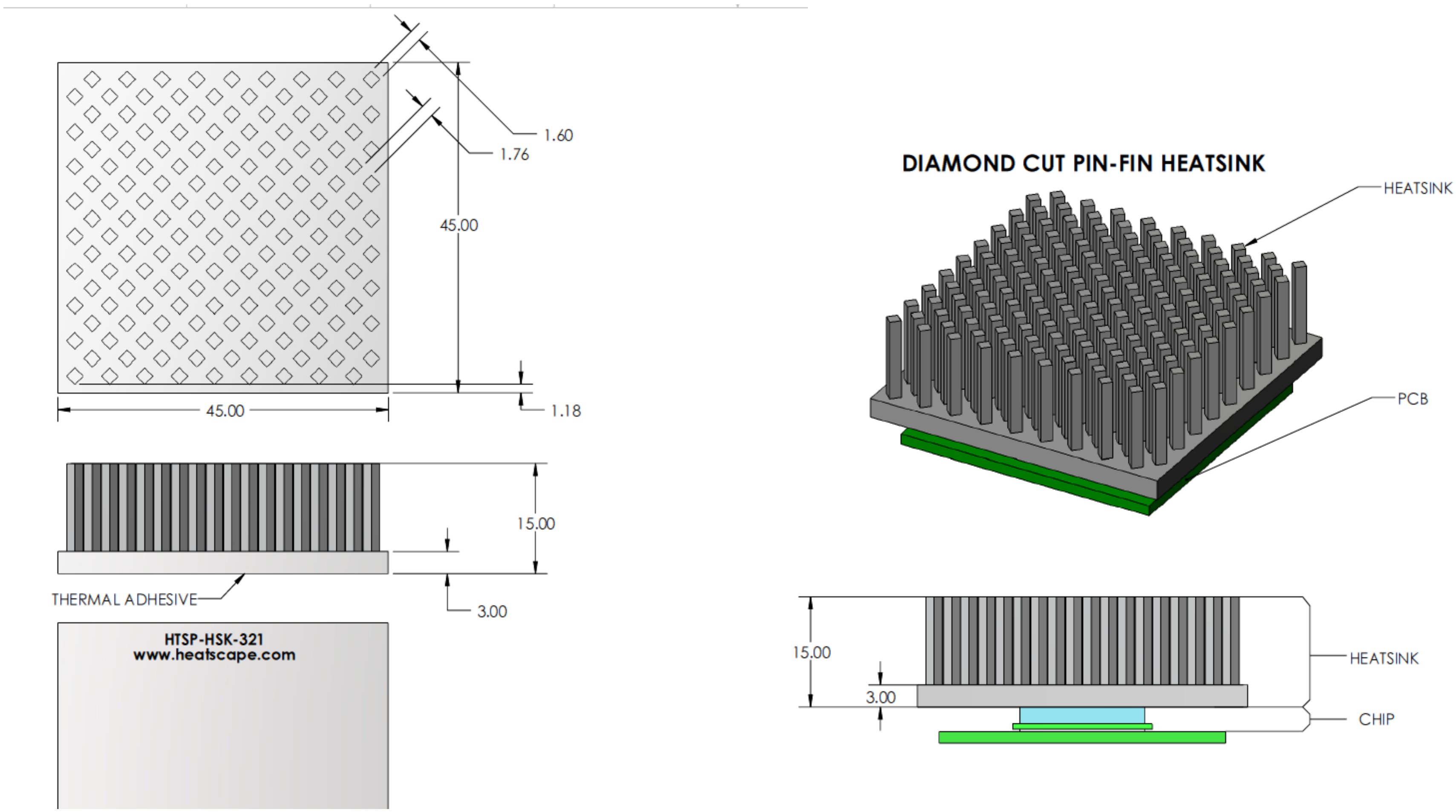


Figure 23. HTSP-HSK-320 45mmx45mmx10mm



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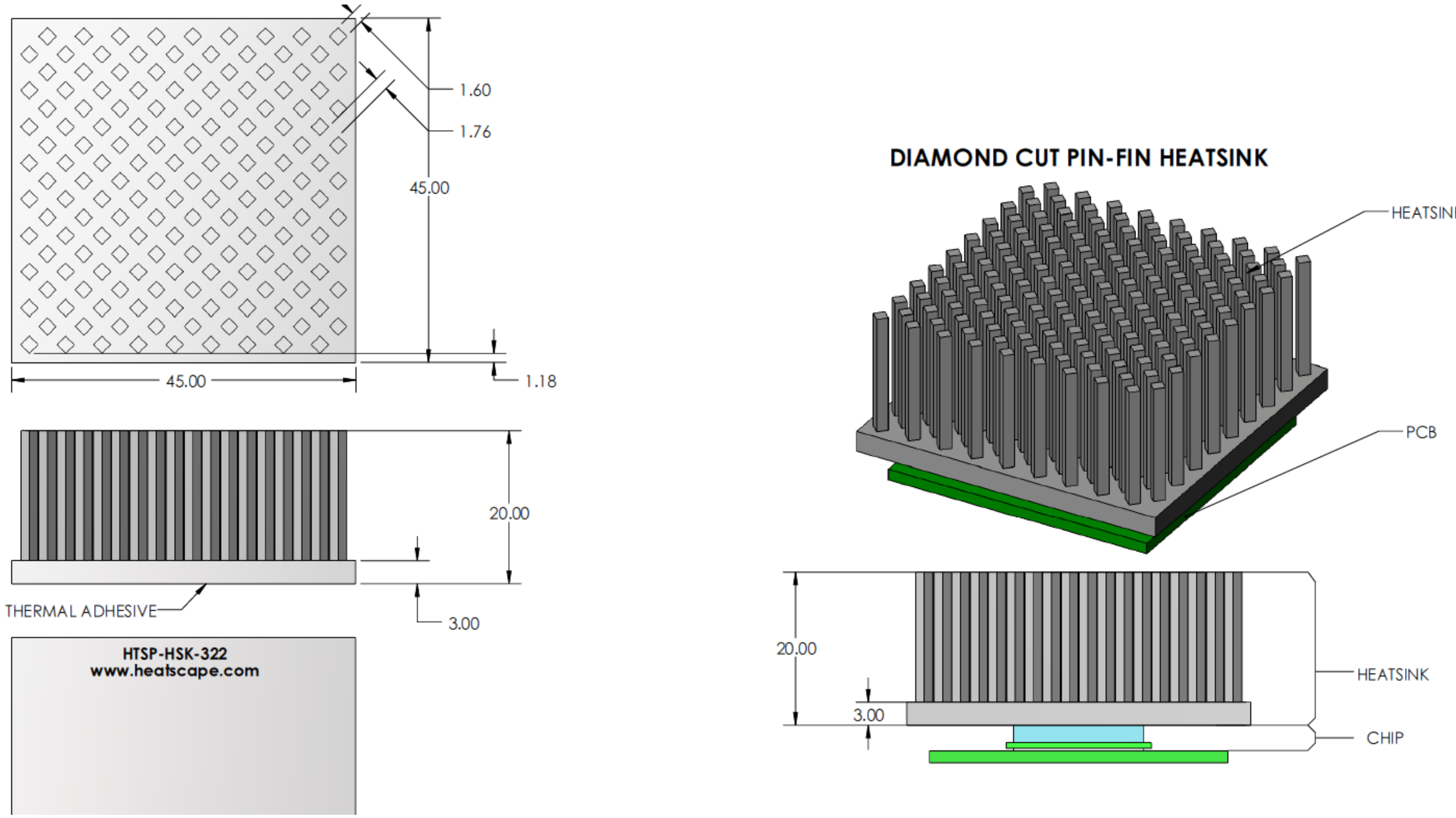

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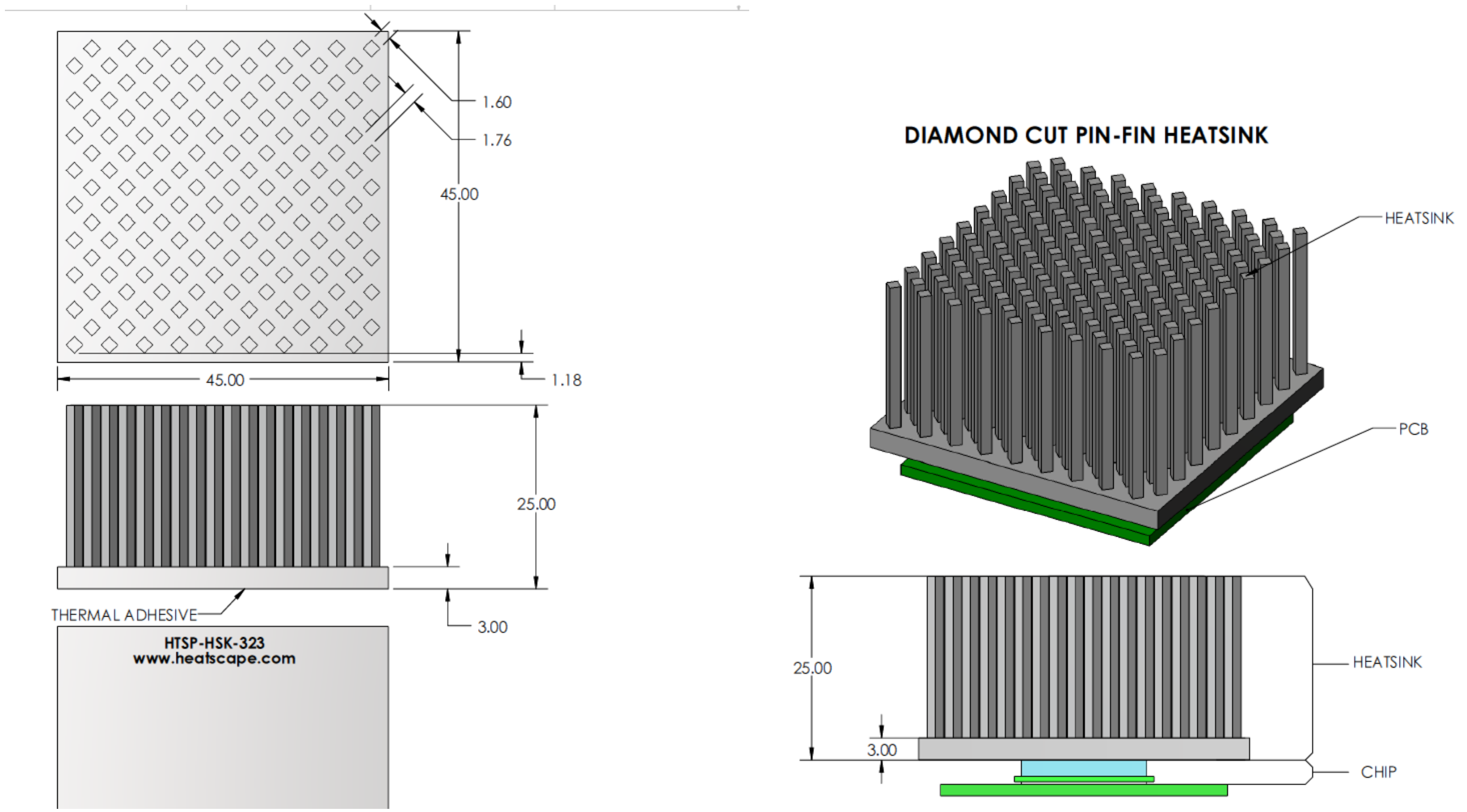

Figure 26. HTSP-HSK-325 45mmx45mmx25mm

Appendix B: Rendered Thermal Images of Heatsinks at 250 FPM Airflow

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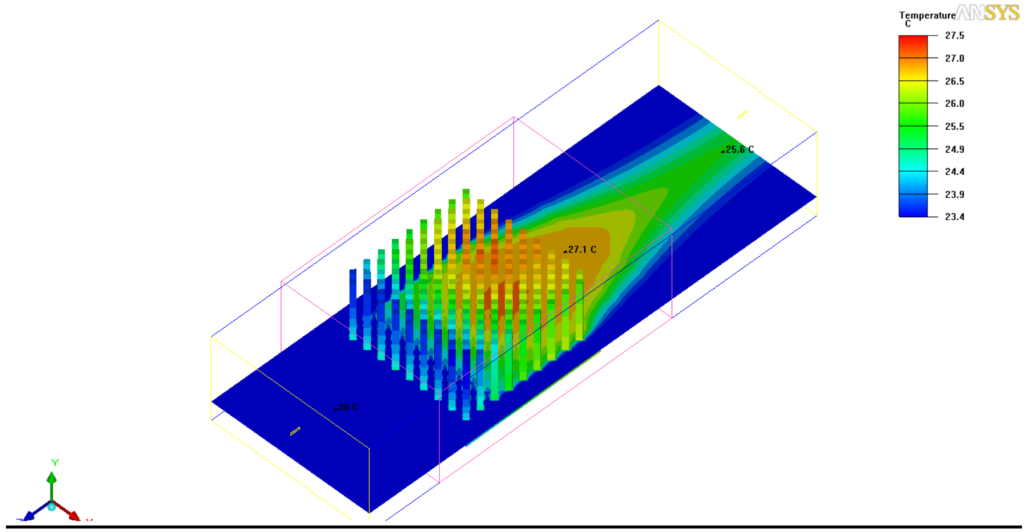

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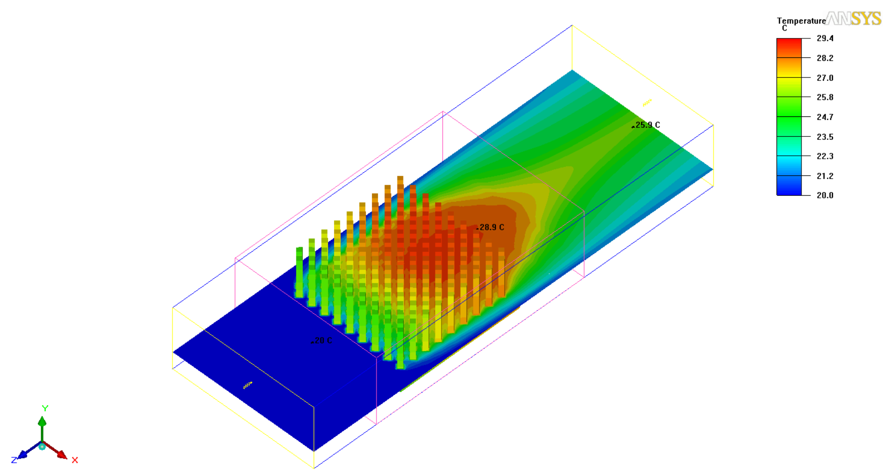

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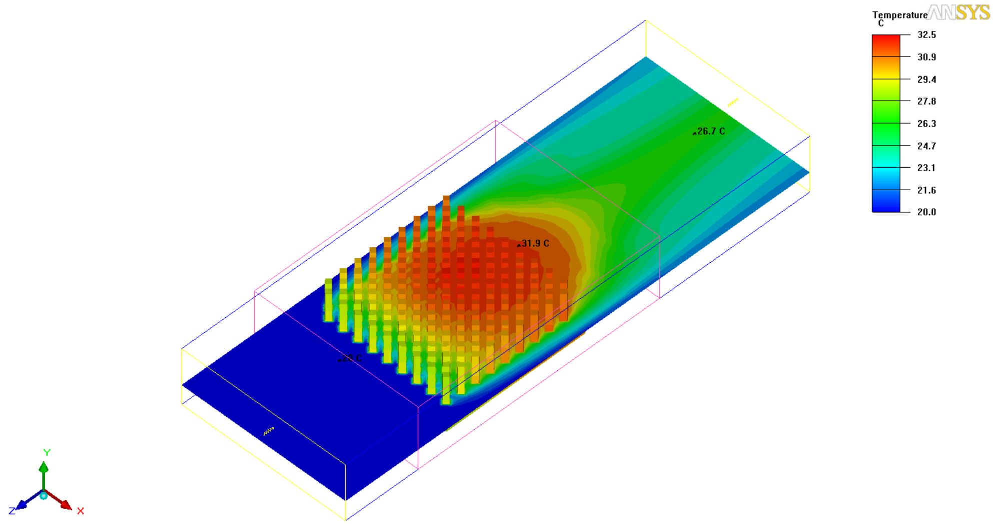

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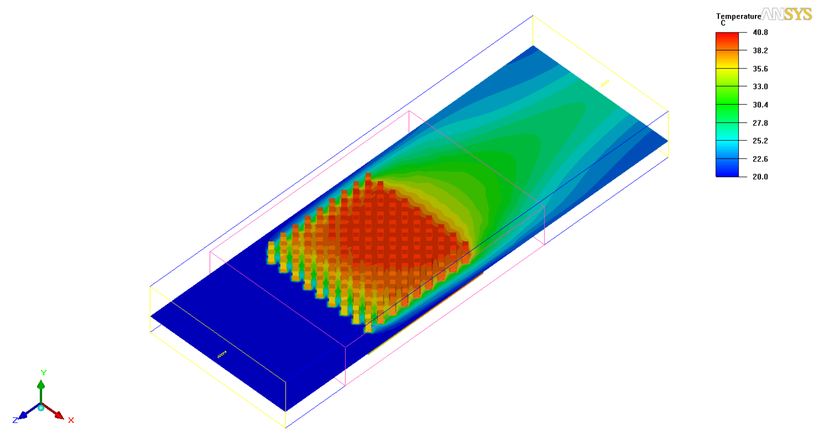

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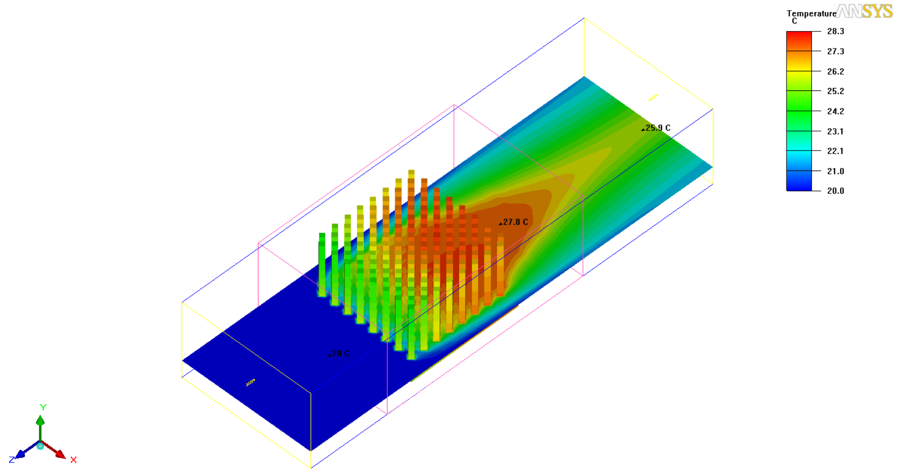
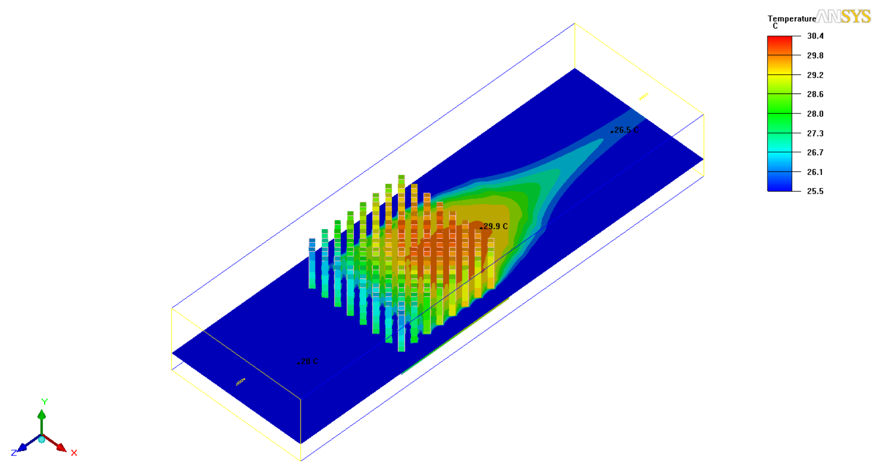


Figure 31. 40mmx40mmx25mm



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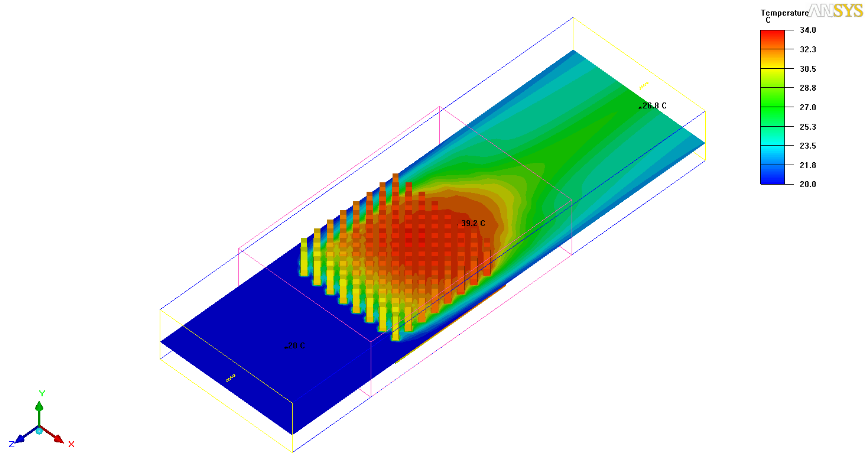

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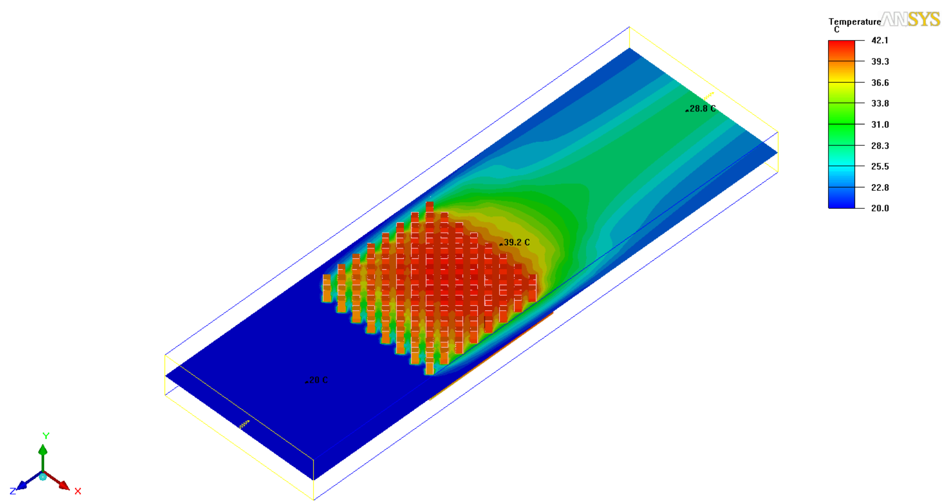


Figure 34. 40mmx40mmx10mm

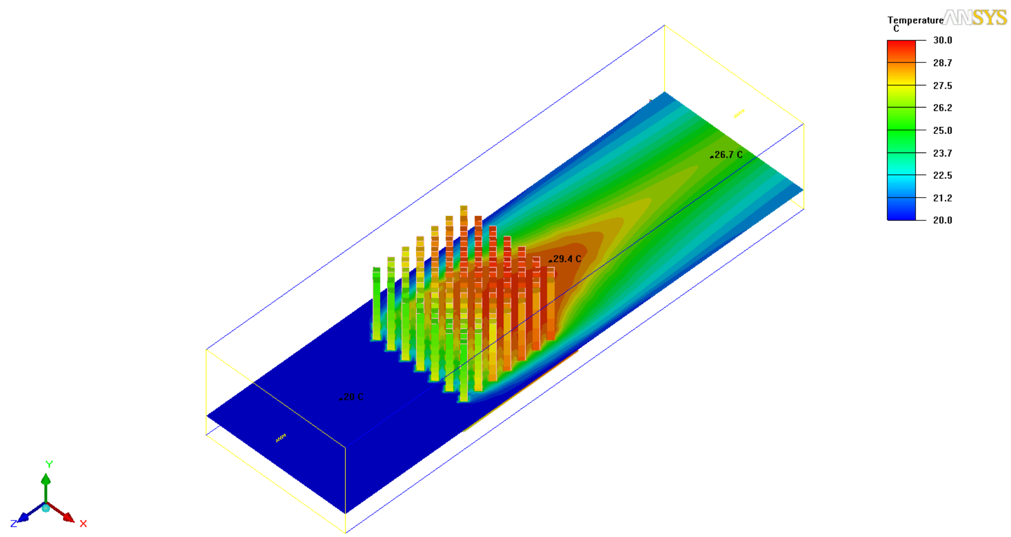


Figure 35. 37.5mmx37.5mmx25mm

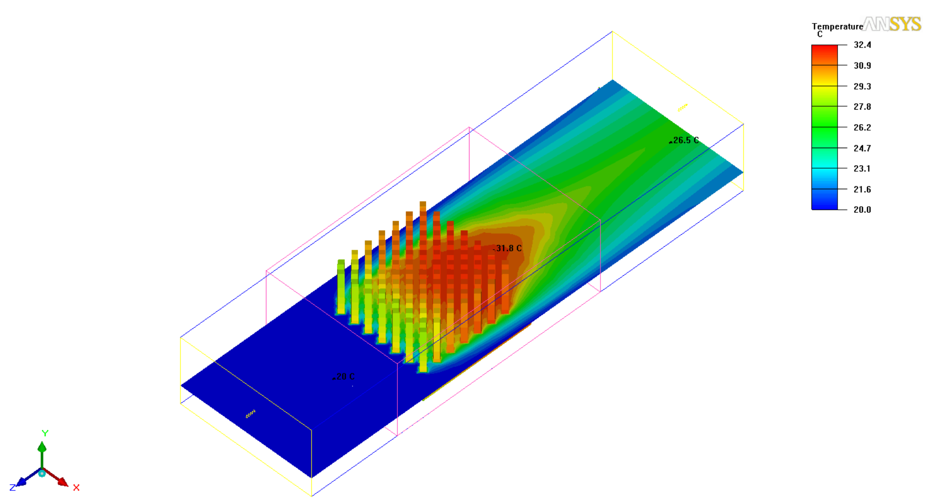


Figure 36. 37.5mmx37.5mmx20mm

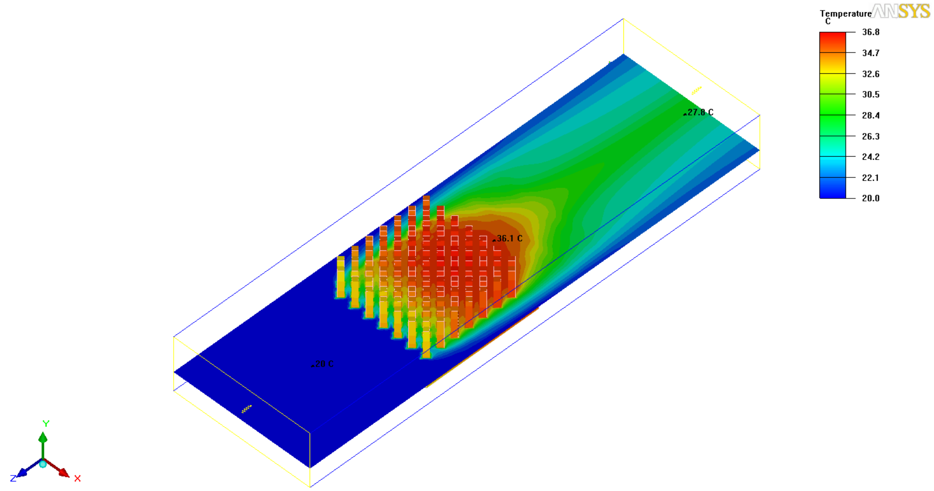


Figure 37. 37.5mmx37.5mmx15mm

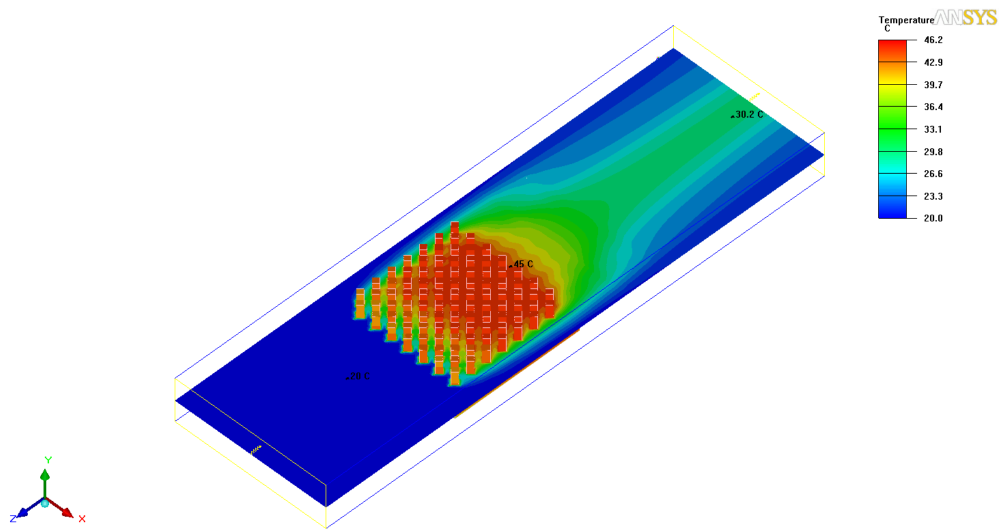


Figure 38. 37.5mmx37.5mmx10mm

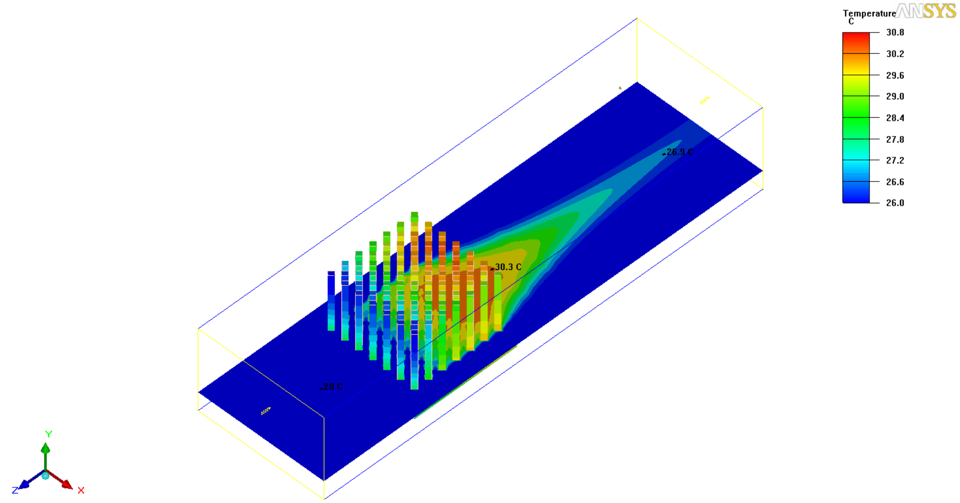


Figure 39. 35mmx35mmx25mm

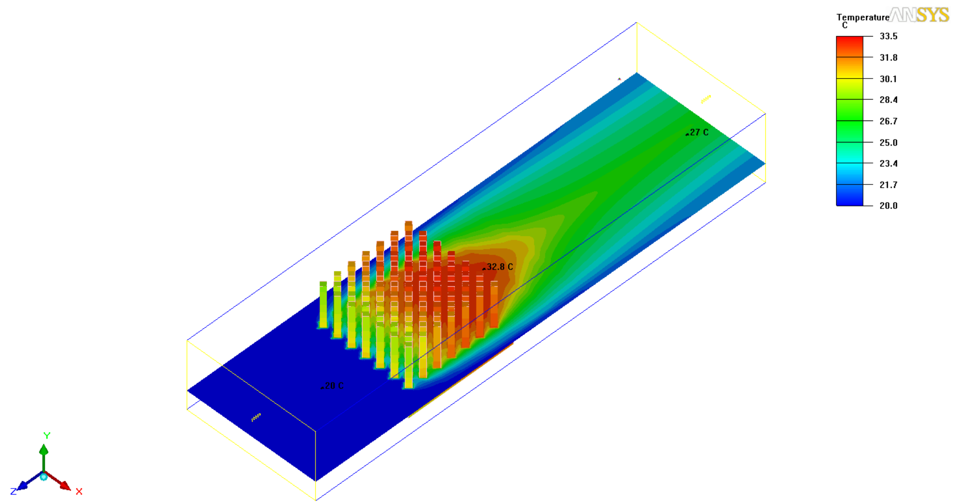


Figure 40. 35mmx35mmx20mm

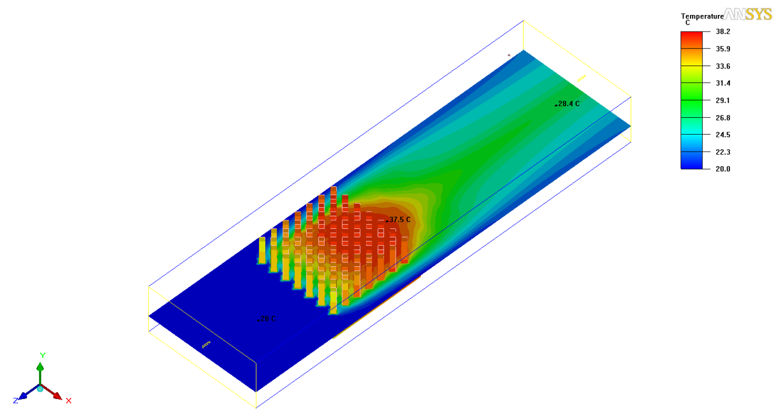


Figure 41. 35mmx35mmx15mm

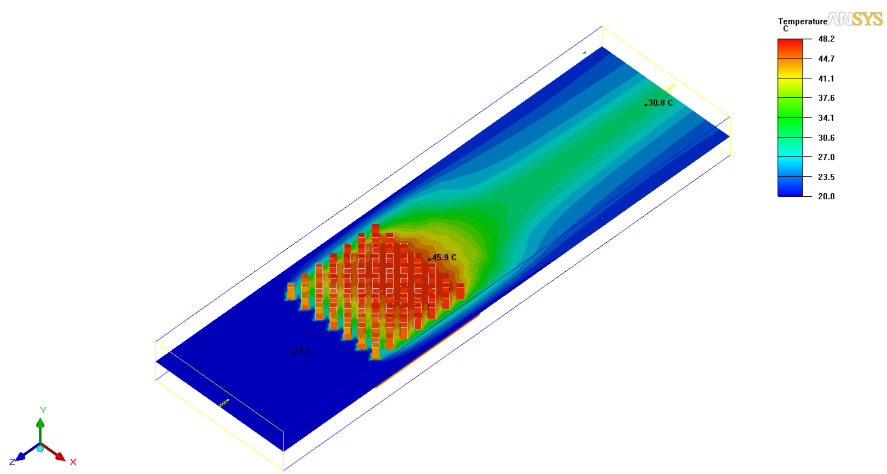


Figure 42. 35mmx35mmx10mm

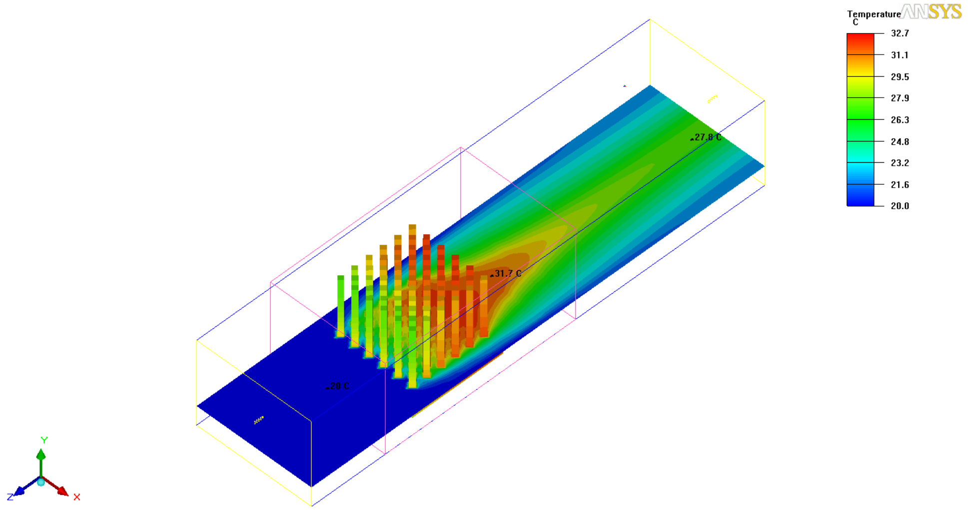


Figure 43. 30mmx30mmx25mm

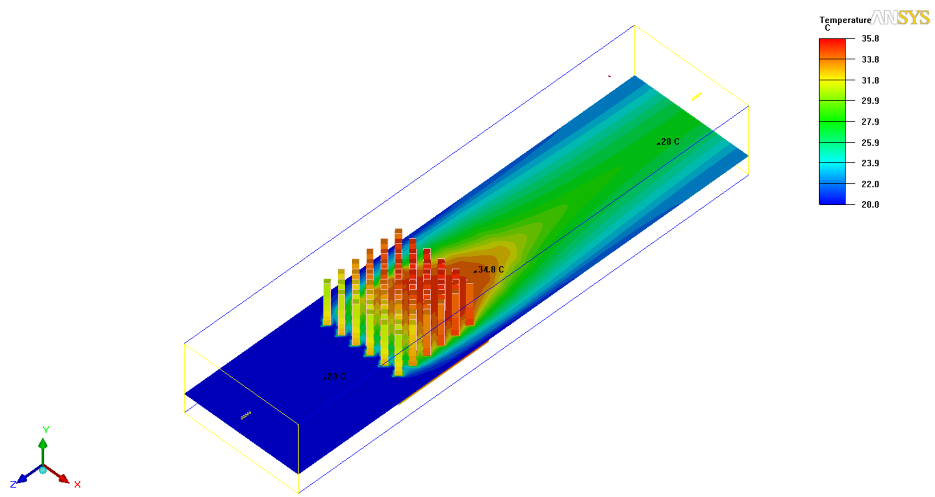


Figure 44. 30mmx30mmx20mm

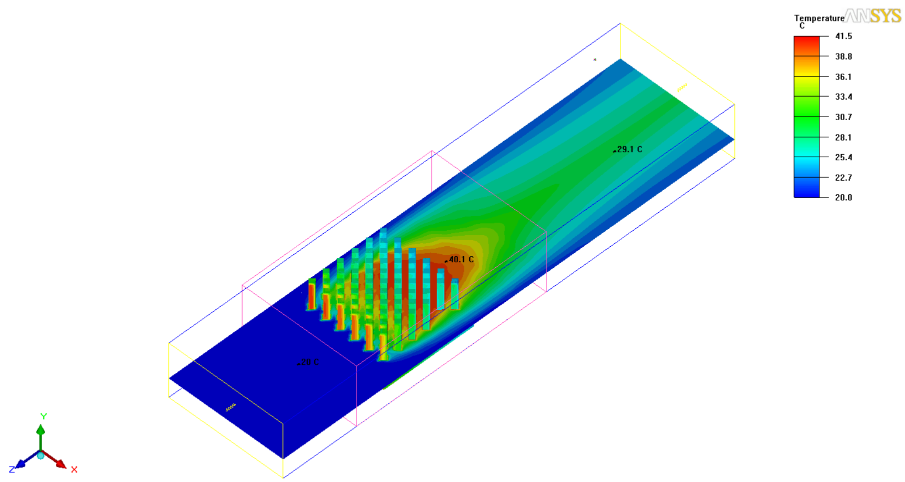


Figure 45. 30mmx30mmx15mm

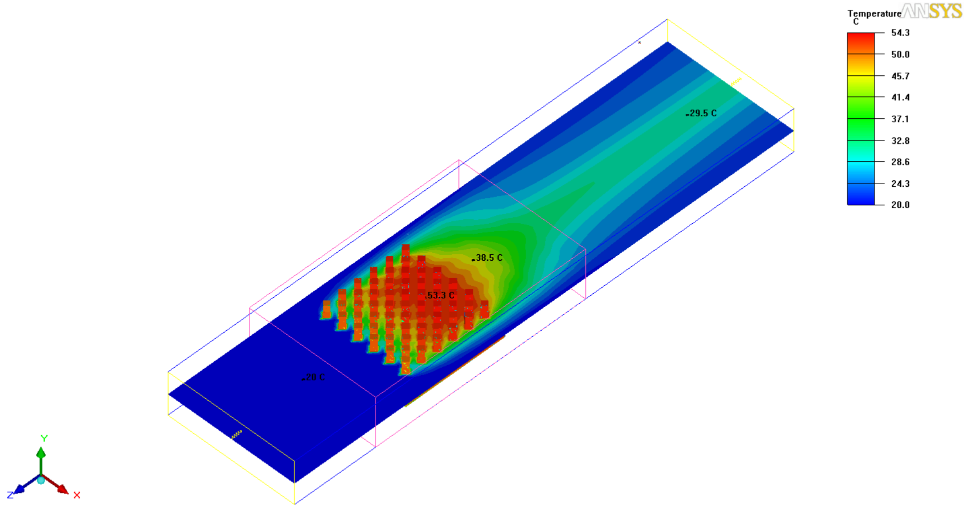


Figure 46. 30mmx30mmx10mm

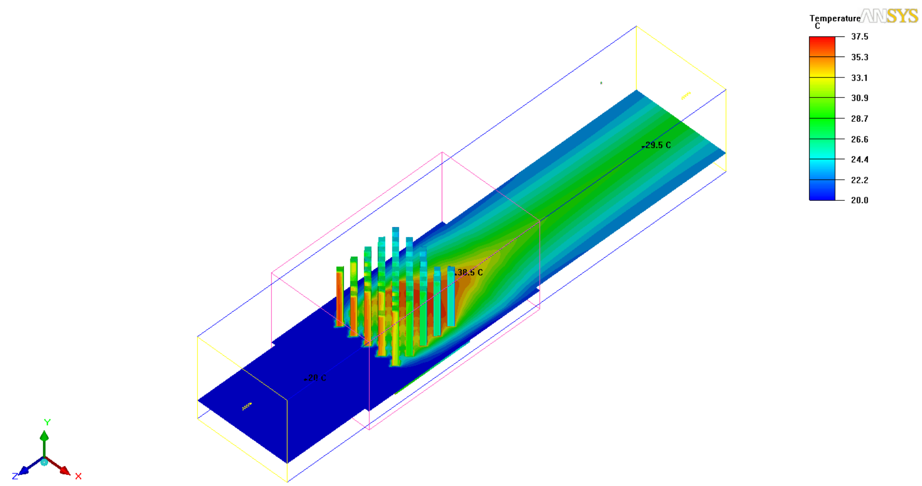


Figure 47. HTSP-HSK-301 25.4mmx25.4mmx25mm

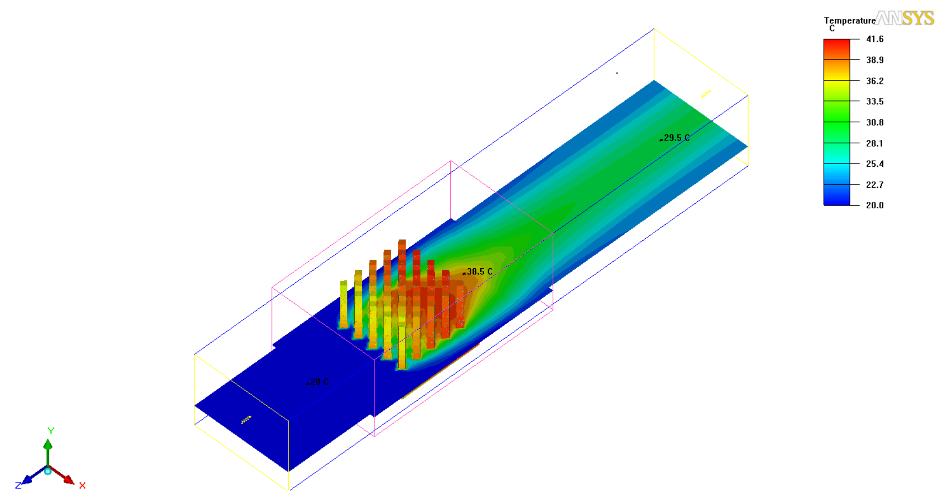


Figure 48. HTSP-HSK-301 25.4mmx25.4mmx20mm

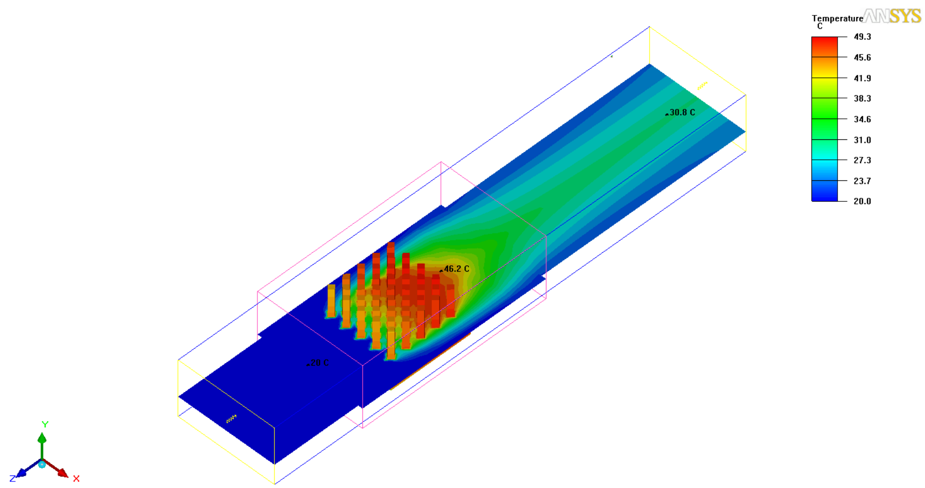


Figure 49. 25.4mmx25.4mmx15mm

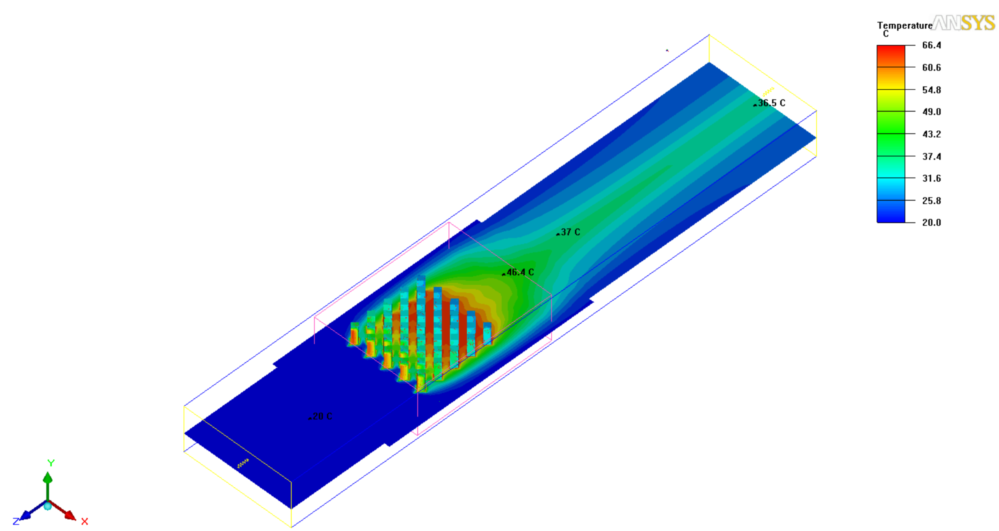


Figure 50. HTSP-HSK-301 25.4mmx25.4mmx10mm

Appendix C: Thermal Testing Results from ICEPAK

Table 1. Thermal Analysis of 30mmx30mm

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-304 BASE: 30x30mm FIN HEIGHT:10mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	121.5	20.3	53	0.26	0.46	0.002
150	67.83	9.566	31.17	0.79	2.81	0.011
250	54.26	6.852	26.79	1.32	6.81	0.027
350	47.77	5.554	24.96	1.86	12.44	0.050
450	43.89	4.778	23.9	2.39	19.74	0.079

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-305 BASE: 30x30mm FIN HEIGHT:15mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	88	13.6	43.86	0.36	0.56	0.002
150	50.39	6.078	28.05	1.1	3.62	0.015
250	41.49	4.298	24.9	1.84	8.94	0.036
350	37.33	3.466	23.62	2.57	16.9	0.068
450	34.86	2.972	22.89	3.31	27.36	0.110

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-306 BASE: 30x30mm FIN HEIGHT:20mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	71.2	10.24	38.57	0.47	0.61	0.002
150	42.37	4.474	26.2	1.41	4.07	0.016
250	35.76	3.152	23.83	2.35	10.29	0.041
350	32.7	2.54	22.83	3.29	19.35	0.078
450	30.91	2.182	22.26	4.23	31.19	0.125

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-307 BASE: 30x30mm FIN HEIGHT:25mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	61.39	8.278	35.25	0.57	0.65	0.003
150	37.94	3.588	25.08	1.71	4.44	0.018
250	32.69	2.538	23.1	2.86	11.34	0.045
350	30.27	2.054	22.33	4	21.52	0.086
450	28.87	1.774	21.86	5.15	34.96	0.140

Table 2. Thermal Analysis of 35mmx35mm

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-308 BASE: 35x35mm FIN HEIGHT:10mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	irflow (CFM	P (N/m2	P ("h20
50	103.77	16.754	49.31	0.3	0.53	0.002
150	59.43	7.886	29.34	0.9	3.19	0.013
250	48.17	5.634	26.06	1.5	7.68	0.031
350	42.78	4.556	24.43	2.1	13.97	0.056
450	39.56	3.912	23.53	2.7	22.12	0.089

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-309 BASE: 35x35mm FIN HEIGHT:15mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	irflow (CFM	P (N/m2	P ("h20
50	77.36	11.472	41.22	0.41	0.64	0.003
150	45.7	5.14	27.18	1.24	4.13	0.017
250	38.18	3.636	24.4	2.08	10.21	0.041
350	34.6	2.92	23.25	2.91	18.91	0.076
450	32.48	2.496	22.59	3.74	30.3	0.122

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-310 BASE: 35x35mm FIN HEIGHT:20mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	irflow (CFM	P (N/m2	P ("h20
50	63.58	8.716	36.63	0.53	0.71	0.003
150	39.12	3.824	35.59	1.59	4.79	0.019
250	33.45	2.69	23.45	2.66	12.07	0.048
350	30.8	2.16	22.56	3.72	22.59	0.091
450	29.24	1.848	22.05	4.79	36.38	0.146

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-311 BASE: 35x35mm FIN HEIGHT:25mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	irflow (CFM	P (N/m2	P ("h20
50	55.33	7.066	33.67	0.64	0.76	0.003
150	35.362	3.0724	24.57	1.94	5.26	0.021
250	30.82	2.164	22.83	3.23	13.44	0.054
350	28.73	1.746	22.11	4.53	25.38	0.102
450	27.49	1.498	21.69	5.83	41.12	0.165

Table 3. Thermal Analysis of 37.5mmx37.5mm

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-312 BASE: 37.5x37.5mm FIN HEIGHT:10mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	98	15.6	47.71	0.31	0.55	0.002
150	56.76	7.352	29.44	0.95	3.35	0.013
250	46.21	5.242	25.8	1.6	8.07	0.032
350	41.16	4.232	24.26	2.22	14.62	0.059
450	38.15	3.63	23.39	2.86	23.05	0.092

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-313 BASE: 37.5x37.5mm FIN HEIGHT:15mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	73.41	10.682	40.08	0.44	0.66	0.003
150	43.83	4.766	26.82	1.322	4.32	0.017
250	36.76	3.352	24.23	2.2	10.67	0.043
350	33.44	2.688	23.14	3.08	19.68	0.079
450	31.46	2.292	22.51	3.96	31.42	0.126

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-314 BASE: 37.5x37.5mm FIN HEIGHT:20mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	60.66	8.132	35.71	0.56	0.75	0.003
150	37.7	3.54	25.3	1.68	5.04	0.020
250	32.41	2.482	23.32	2.81	12.62	0.051
350	29.95	1.99	22.48	3.94	23.51	0.094
450	28.5	1.7	21.99	5.06	37.83	0.152

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-315 BASE: 37.5x37.5mm FIN HEIGHT:25mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	52.89	6.578	32.85	0.68	0.81	0.003
150	34.19	2.838	24.32	2.05	5.55	0.022
250	29.97	1.994	22.71	3.42	14.07	0.056
350	28.02	1.604	22.04	4.79	26.47	0.106
450	26.88	1.376	21.64	6.17	42.75	0.171

Table 4. Thermal Analysis of 40mmx40mm

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-316 BASE: 40x40mm FIN HEIGHT:10mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	86.3	13.26	46.47	0.33	0.63	0.003
150	51.04	6.208	29.01	1	3.81	0.015
250	42.08	4.416	25.51	1.67	9.08	0.036
350	37.8	3.56	24.03	2.35	16.36	0.066
450	35.78	3.156	23.2	3.02	25.68	0.103

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-317 BASE: 40x40mm FIN HEIGHT:15mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	64.78	8.956	33.2	0.46	0.81	0.003
150	39.96	3.992	26.52	1.39	5.09	0.020
250	34.04	2.808	24.03	2.32	11.336	0.045
350	31.26	2.252	22.97	3.25	22.81	0.091
450	29.6	1.92	22.37	4.18	36.27	0.145

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-318 BASE: 40x40mm FIN HEIGHT:20mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	53.87	6.774	35.03	0.59	0.92	0.004
150	34.8	2.96	25.07	1.78	6.08	0.024
250	30.39	2.078	23.64	2.97	15.07	0.060
350	28.34	1.668	22.36	4.15	27.99	0.112
450	27.13	1.426	21.89	5.34	44.85	0.180

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-319 BASE: 40x40mm FIN HEIGHT:25mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	47.2	5.44	32.26	0.72	1.02	0.004
150	31.8	2.36	24.12	2.17	6.8	0.027
250	28.31	1.662	22.57	3.61	17.11	0.069
350	26.7	1.34	21.94	5.06	32.01	0.128
450	25.75	1.15	21.56	6.51	51.61	0.207

Table 5. Thermal Analysis of 45mmx45mm

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-320 BASE: 45x45mm FIN HEIGHT:10mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	82.14	12.428	37.7	0.51	0.54	0.002
150	49.23	5.846	26.1	1.54	3.39	0.014
250	40.8	4.16	23.92	2.56	8.18	0.033
350	36.77	3.354	22.99	3.59	14.8	0.059
450	34.37	2.874	22.43	4.62	23.29	0.093

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-321 BASE: 45x45mm FIN HEIGHT:15mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	59.21	7.842	36.46	0.51	0.89	0.004
150	37.65	3.53	25.93	1.54	5.63	0.023
250	32.5	2.5	23.67	2.56	13.65	0.055
350	30.07	2.014	22.71	3.59	24.92	0.100
450	28.63	1.726	22.16	4.62	39.46	0.158

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-322 BASE: 45x45mm FIN HEIGHT:20mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	49.89	5.978	33.71	0.65	1.03	0.004
150	33.21	2.642	24.63	1.96	6.74	0.027
250	29.35	1.87	22.89	3.28	16.67	0.067
350	27.55	1.51	22.16	4.59	30.8	0.124
450	26.48	1.296	22.15	5.9	49.11	0.197

ALL RUNS DONE AT 5 WATTS, 20C	HTSP-HSK-323 BASE: 45x45mm FIN HEIGHT:25mm					
AIR FLOW (FPM)	Tcase (C)	Theta SA (C/W)	Exit Air Temp.	Airflow (CFM)	dP (N/m2)	dP ("h20)
50	44.11	4.822	31.2	0.79	1.14	0.005
150	30.6	2.12	23.76	2.39	7.59	0.030
250	27.53	1.506	22.36	3.99	19.02	0.076
350	26.11	1.222	21.78	5.59	35.36	0.142
450	25.26	1.052	21.77	7.18	56.85	0.228

Appendix D: Paramount Tech Quotes

Table 6. Paramount Technology Co.,LTD Example Quote from 35mmx35mm

PARAMOUNT TECHNOLOGY CO., LTD

TEL:86-769-82057277 FAX: 86-769-82057377

Quotation

Client : Heatscape
ATTN : Ali
Tel :
Fax :
Add :

Project : pin fin heatsink
Date : 2009.07.07
Quotation No.: 2009070703
sales: lamon Lamon_lee@paramountech.com.cn

Item	Parts No.	Description	UNIT	unit price/ 500pcs	unit price/ 1000pcs	unit price/ 2000pcs	unit price /5000pcs	Delivery	Remark
1	HTSP-HSK-308	35*10mm Al black anodied	USD	0.53	0.47	0.43	0.40	FOB HongKong	tooling cost 560
2	HTSP-HSK-309	35*15mm al black anodied		0.58	0.52	0.48	0.45		tooling cost 560
3	HTSP-HSK-310	35*20mm al black anodied		0.63	0.57	0.53	0.50		tooling cost 560
4	HTSP-HSK-311	35*25mm al black anodied		0.68	0.62	0.58	0.55		tooling cost 560

Table 7. Example of Heatsink Quotes from Paramount

		PARAMOUNT QUOTE				
HEATSINK	**DESCRIPTION**	**UNIT PRICE: 500 PIECES**	**UNIT PRICE: 1000 PIECES**	**UNIT PRICE: 2000 PIECES**	**UNIT PRICE: 5000 PIECES**	**T**
HTSP-HSK-2510	25.4 X 10mm AL Black Anodied	0.51	0.44	0.4	0.37	
HTSP-HSK-2515	25.4 X 15mm AL Black Anodied	0.52	0.45	0.41	0.38	
HTSP-HSK-2520	25.4 X 20mm AL Black Anodied	0.53	0.46	0.42	0.39	
HTSP-HSK-2525	25.4 X 25mm AL Black Anodied	0.54	0.47	0.43	0.4	
HTSP-HSK-3010	30 X 10mm AL Black Anodied	0.51	0.44	0.41	0.38	
HTSP-HSK-3015	30 X 15mm AL Black Anodied	0.52	0.46	0.42	0.39	
HTSP-HSK-3020	30 X 20mm AL Black Anodied	0.54	0.49	0.45	0.42	
HTSP-HSK-3025	30 X 25mm AL Black Anodied	0.56	0.52	0.48	0.45	
HTSP-HSK-3510	35 X 10mm AL Black Anodied	0.53	0.47	0.43	0.4	
HTSP-HSK-3515	35 X 15mm AL Black Anodied	0.58	0.52	0.48	0.45	
HTSP-HSK-3520	35 X 20mm AL Black Anodied	0.63	0.57	0.53	0.5	
HTSP-HSK-3525	35 X 25mm AL Black Anodied	0.68	0.62	0.58	0.55	

Appendix E: Heatscape Inc. Brochure

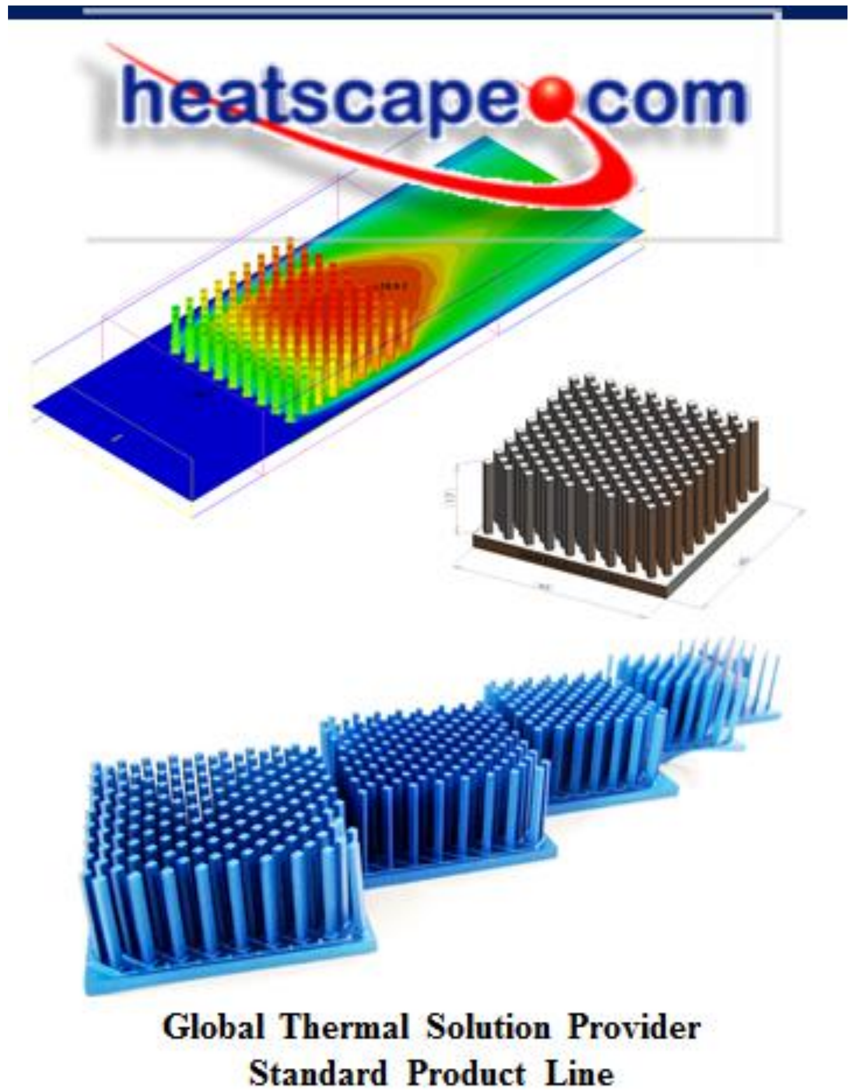
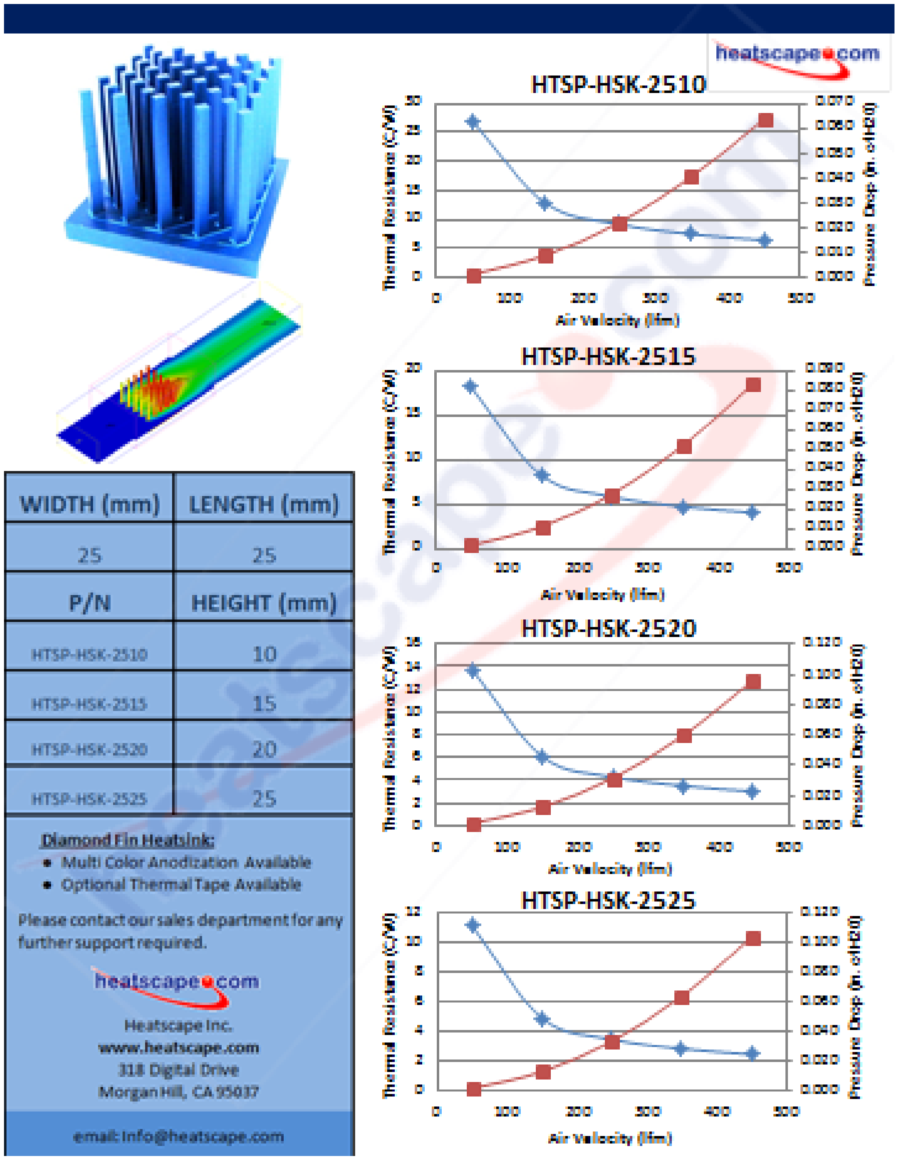


Figure 2. HTSP-HSK-301 25.4mmx25.4mmx15mm



WIDTH (mm)	LENGTH (mm)
25	25
P/N	**HEIGHT (mm)**
HTSP-HSK-2510	10
HTSP-HSK-2515	15
HTSP-HSK-2520	20
HTSP-HSK-2525	25

Figure 2. 25.4mmx25.4mm

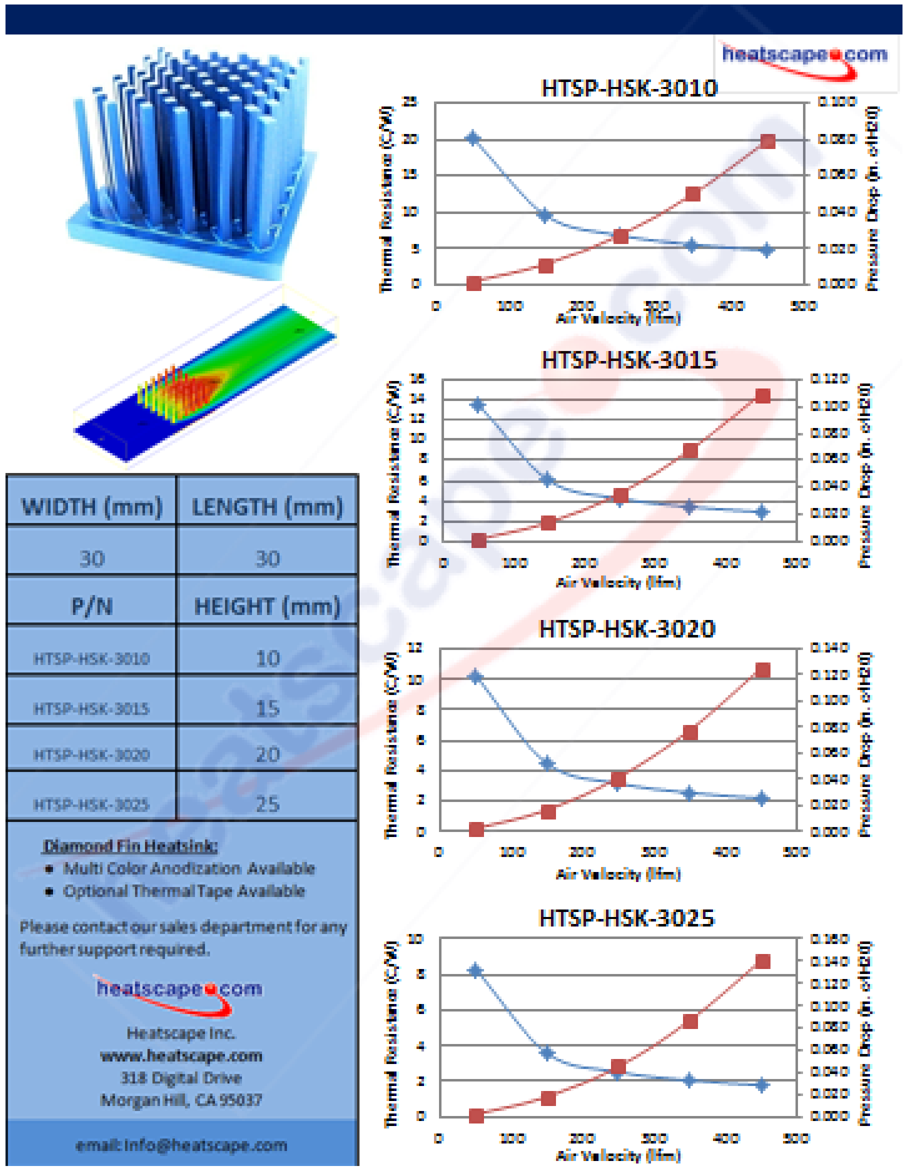


Figure 2. 30mmx30mm

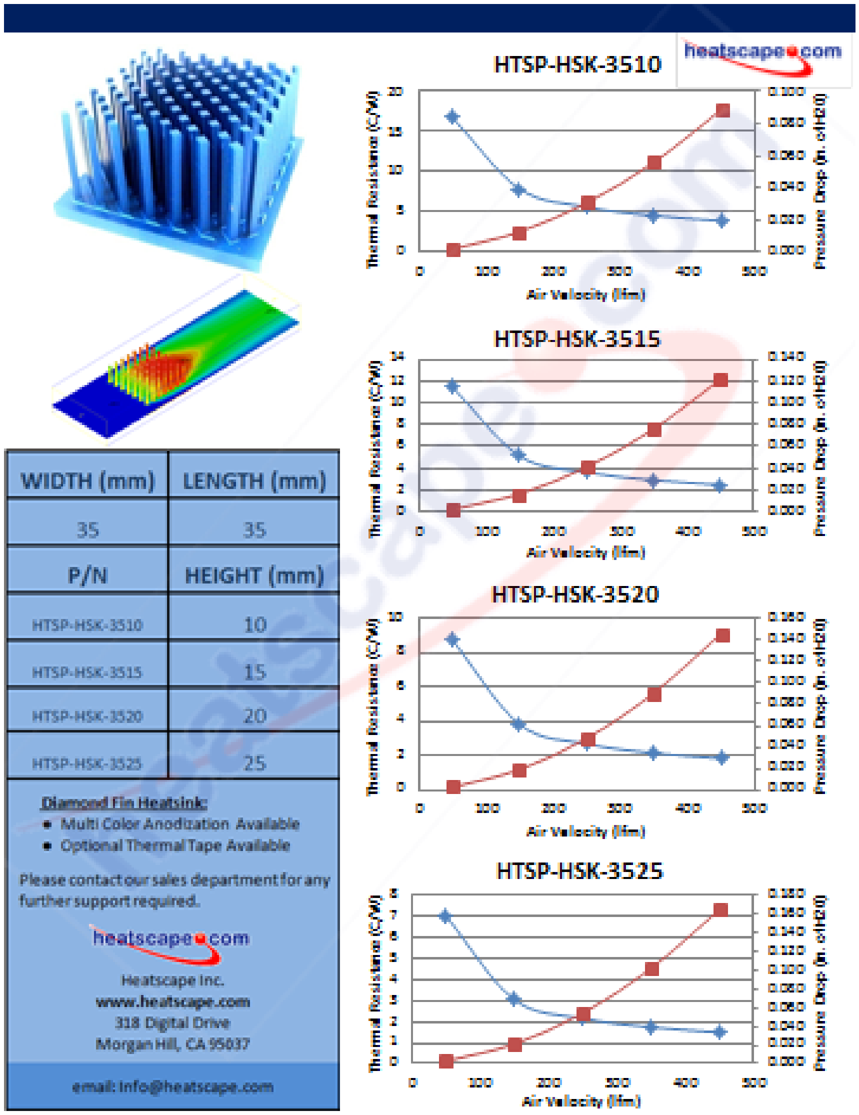
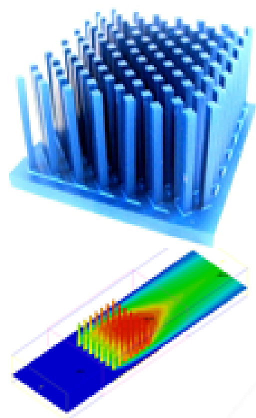


Figure 2. 35mmx



WIDTH (mm)	LENGTH (mm)
37.5	37.5
P/N	**HEIGHT (mm)**
HTSP-HSK-3710	10
HTSP-HSK-3715	15
HTSP-HSK-3720	20
HTSP-HSK-3725	25

Diamond Fin Heatsink:

- Multi Color Anodization Available
- Optional Thermal Tape Available

Please contact our sales department for any further support required.

Heatscape Inc.
www.heatscape.com
318 Digital Drive
Morgan Hill, CA 95037

email: info@heatscape.com

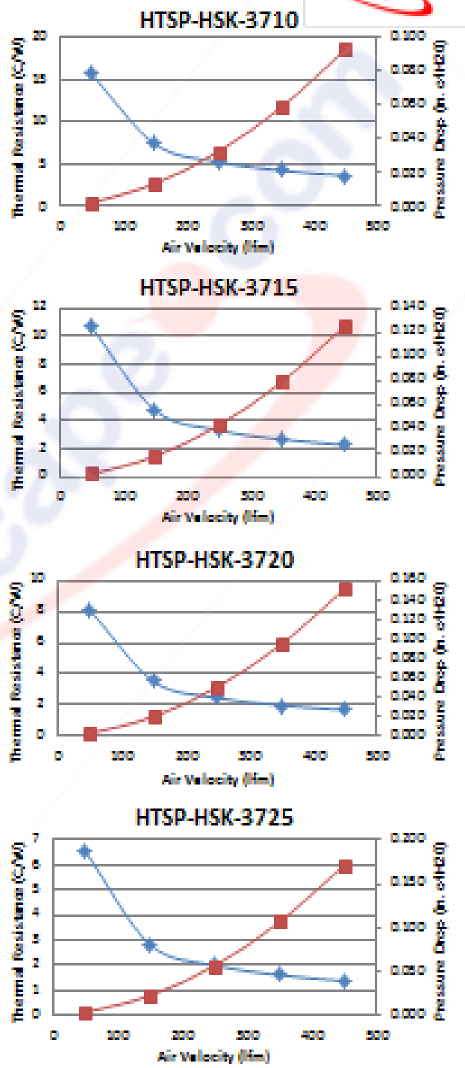
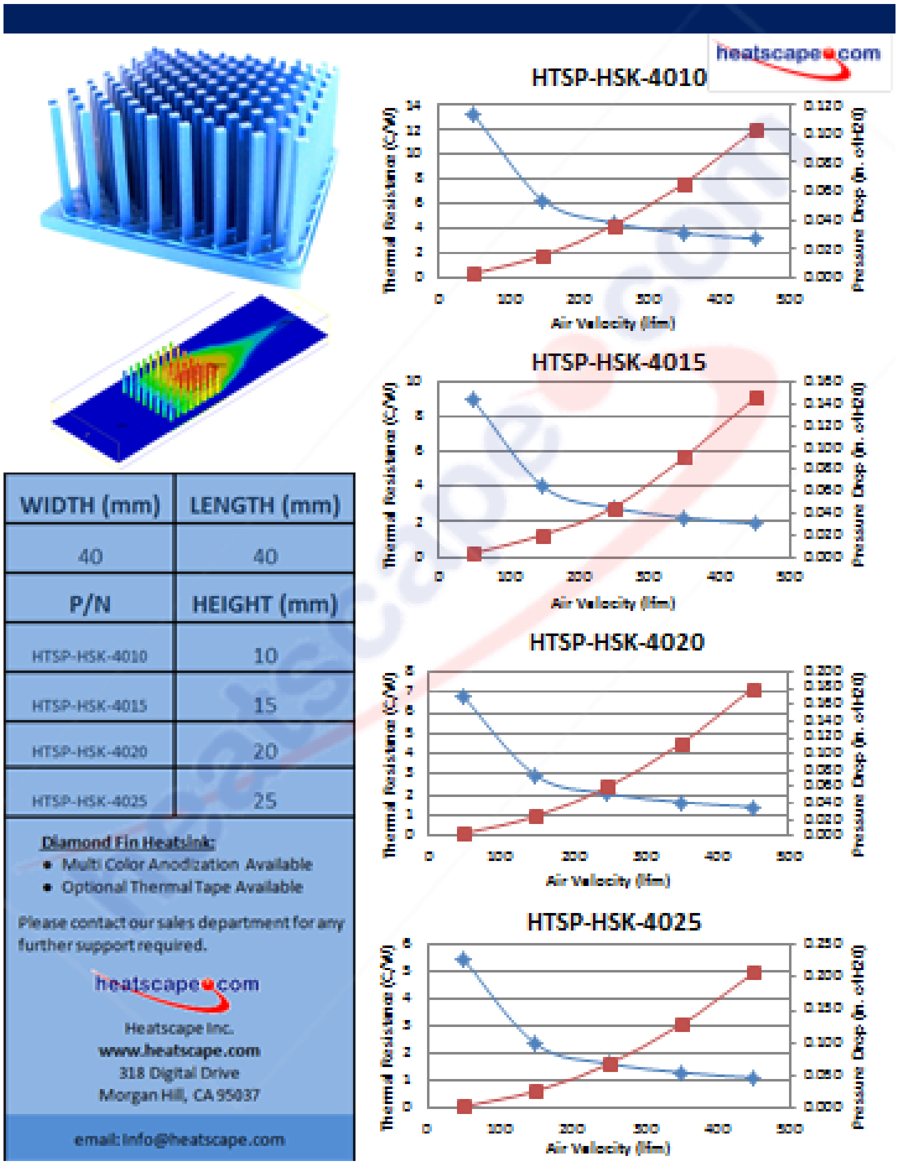


Figure 2. 37.5mmx37.5mm



WIDTH (mm)	LENGTH (mm)
40	40
P/N	HEIGHT (mm)
HTSP-HSK-4010	10
HTSP-HSK-4015	15
HTSP-HSK-4020	20
HTSP-HSK-4025	25

Diamond Fin Heatsink:
- Multi Color Anodization Available
- Optional Thermal Tape Available

Please contact our sales department for any further support required.

heatscape.com

Heatscape Inc.
www.heatscape.com
318 Digital Drive
Morgan Hill, CA 95037

email: info@heatscape.com

Figure 2. 40mmx40mm

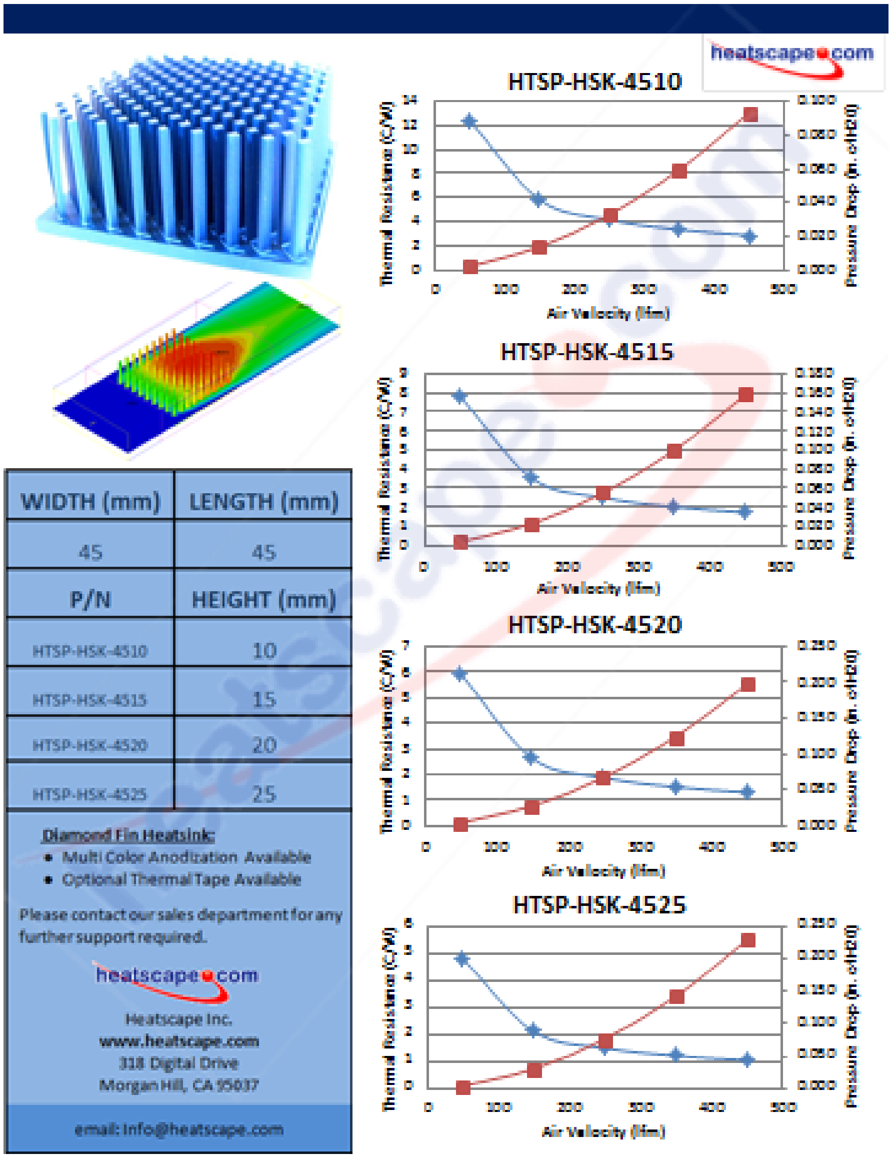


Figure 2. 45mmx45mm

Figure 2. Back Cover of Brochure

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