



Heat Sink Basics and DFM Guidelines for Customers

Lunch ☺ 'n Learn☺ Notes

Chris Sutton

Rev March 1, 2009



Vette Summary



Heat Sink Foundry

Vertically Integrated

7 China Facilities

1000 Employees

450,000 square feet

Heat Pipe Manufacturer

DC Fan Manufacturer

Extensive Customer Base

ISO, TUV, UL, Sony Green

Cisco PSL Supplier

500+ Cisco AVL Parts

Cisco Supplier >5 years

Global Support

US, Asia, Europe

Factory Dedicated Teams

Applications Engineer

CFD Analysis

Local Reps



Welcome to the 16th Annual
Supplier Appreciation Event

September 12, 2007



Award Categories

John Groom Excellence in Quality
Strengthening the quality link between
Cisco and the end customer's experience

Nomination Requirement

100% quality record for
the last twelve months

Cisco has 750+ suppliers

Nominees





Factory Contacts



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What to expect

NPI Orders – 3 to 4 weeks, working to get down to 2 weeks

Tooling Charges – typically \$400-\$800 depending on part size

Tooling Orders – 5 FAI and 30 Cpk parts

Quotes – 1 week for simple parts

Prototypes – 2 weeks for EDM parts

Thermal Analysis – 1 week or less, depends on workload

Drawings – 1 week or less

Production – 3 weeks typical

Pricing – monolithic pricing where possible

Continual Improvements



Natural Convection

air movement with out an air mover (typically a fan), key factors are:

Fin Surface Area

more is better

Fin Spacing

fins must be spaced apart, low back pressure needed

Fin Finish

radiation can be up to 25% of the heat dissipation, surface emissivity of the finish is important, typically parts should be anodized.

Fin Orientation

fins must allow not prevent airflow

Forced Convection

powered air flow, cooling is further enhanced by:

Ducting

keep the air flow in the heat sink, limit by-pass air

Fin Orientation

fins must not prevent air flow

Fan Back Pressure

design the heat sink that is optimized for airflow and pressure drop

No Air Shadow

do not block airflow in front or behind the heat sink

More Air, More Air

more air is good, more air is good, more air is good

Parallel not Series

heat sinks need to be placed in parallel not in series

Go Wider

wider heat sinks into more air are usually better than taller or longer



Passive HS Construction

General
Notes

Stampings < 5W

Typical applications are TO-220's , parts stamped form sheet metal, low cost

MicroForged <30W

High NRE and part cost

Small Extrusions <30W

Board level such as BGA, Northbridge chip sets, DC/DC

Straight Fin used with known airflow direction

Pin Fin used with natural convection or unknown flow, or turbulent airflow

Medium Extrusions <60W

lots of airflow

Heat sinks with maximum volume, fin area, large heat sources,

Large Extrusions <200W

Very large components, IGBT's, SCR's, UPS

Zipper Fin <150W

high fin density parts such a microprocessors

Skived Fin <80W

alternate to Zipper fin, low NRE, higher cost, design limits

Bonded Fin <200W

high fin density for large components, usually in power applications



Active HS Construction

General
Notes

Fan Sink < 40W Typical applications are old processors, fan mounted directly on heat sink

Zipper Fan Sink <80W Microprocessor applications

Heat Pipe <140W Microprocessor applications

Straight Fin used with known airflow direction

Pin Fin used with natural convection or unknown flow, or turbulent airflow

Vapor Chamber <80W heat sink with heat pipe type function but the base typically contains the working fluid, hardly used

LCS (Liquid Cooling) <200W High heat flux applications, expensive, typically 10X the cost of a heat pipe solution.

Thermal Siphon <1000W extreme power applications

Peltiere Devices <80W inefficient, limited cooling, expensive

New Stuff <??? New ideas every day but not always cost efficient or practical



Thermal Conductivities

General
Notes

Common Materials

W/m ° K.

Diamond	1,000	AL (pure)	225	Iron	76
Graphite*	500	AL 1100	218	Tin	63
Copper	385	AL 6063	209	Lead	33
Brass	120	AL 6061	167	Zinc	112
Nickel	61	AL 201(cast)	121	Air	<.03

Thermal Interfaces

W/m ° K.

Tapes	xxx	Chomerics T411
PCM	0.73	Thermagon 105
Gap Fillers	11.0	FujiPoly 100Xe
Grease	>4.5	Shin Etsu G751
Graphite*	4	Furon C695
Epoxy	0.76	Loctite 384

TIM TESTING
ASTM E1530 ?
ASTM D5470 ?
ISO 8302 ?
PSI ??
PSI ??
PSI ??

TIM's are usually rated by thermal resistance, thickness, pressure and area

Aspect Ratio = Fin Height / Fin Gap = FH/FG

- < 7:1 No problem
- <10:1 Slower extrusion through put
- <15:1 Selected balanced shapes only
- <20:1 Consult factory
- >20:1 Very Select shapes only

[THE Heat Sink Alloy – Aluminum 6063-T5](#)

Fin Features

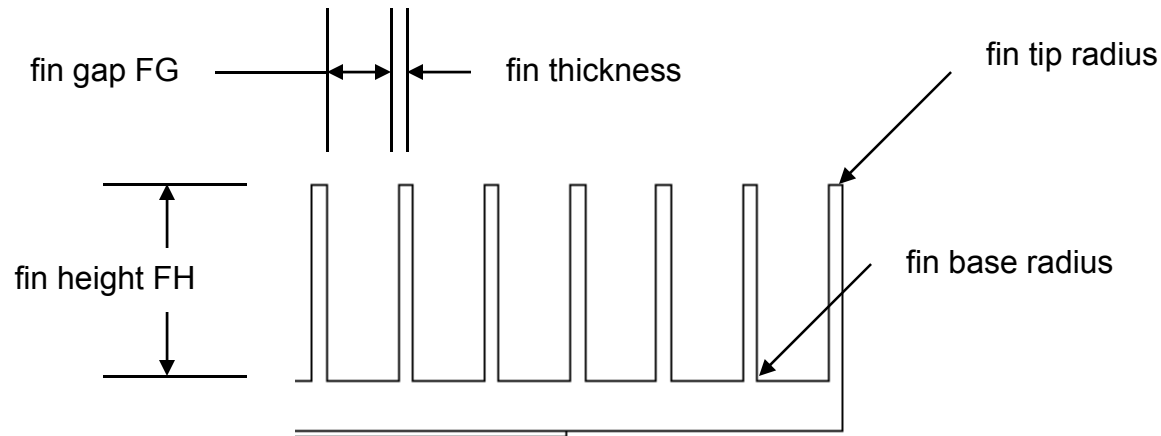
.032" min thickness preferred for machining ease and speed, under .032" is a TFE (Thin Fin Extrusion)

.020" min thickness under most circumstances.

Tapered fins, preferred for strength, especially on thin fins parts.

Radii increase tool life, reduce part and tool stress

Serrated fins greatly increase tool back pressure, not recommended.



Dimensional Tolerances for Aluminum Extrusions

VetteCorp's aluminum extrusion comply with the standard commercial tolerances established by The Aluminum Associations, INC. The tolerances for an extrusion dimension is a function of the die size of the particular dimension and the diameter of the extrusion die. Table B is a guide for most dimensional tolerances. The illustration shown is a typical flat back Extrusion. Tolerances for some extreme ration and some of the larger sizes tend to exceed the tolerances listed on this table and, conversely some of the smaller (less than 7 inch diagonal) can be supplied with half of the commercial Tolerances.

When defining machined flatness, use the statement of .001"/in. to preclude steps allowable with other methods of defining flatness. See Table A.

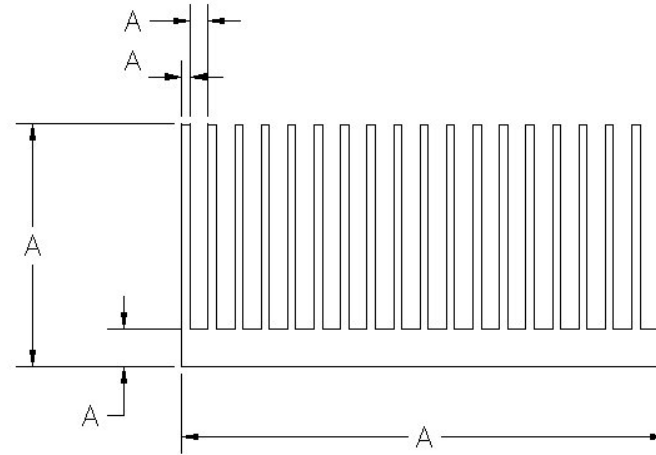


TABLE A
TYPICAL TOLERANCES FOR FLATNESS AND ROUGHNESS

ALUMINUM SURFACE	FLATNESS [IN/IN] (mm/25.4mm)	SURFACE ROUGHNESS [RMS]
As Extruded	004 (0.10)	125-64 (3.2-1.6)
Sanding	.002-.003 (0.51-0.76)	64-32 (1.6-0.8)
Machined	.001 (.025)	64 - or better (1.6 -)

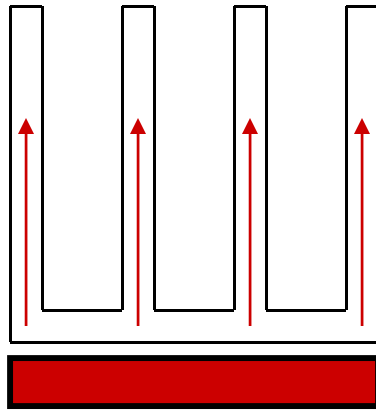
TABLE B
TYPICAL TOLERANCES FOR 6063-T5 EXTRUDED ALUMINUM ALLOY

Dimension A (inches)/(mm)	+/- Tolerance (up to 10" circle size) (inches)/(mm)
0.000- 0.125 / 0.00-3.18	.006 / 0.15
0.125-0.249 / 3.18-6.35	.007 / 0.18
0.250-0.499 / 6.35-12.70	.008 / 0.20
0.500-0.749 / 12.70-19.05	.009 / 0.23
0.750-0.999 / 19.05-25.40	.010 / 0.25
1.000-1.499 / 25.40-38.10	.012 / 0.30
1.500-1.999 / 38.10-50.80	.014 / 0.35
2.000-3.999 / 50.80-101.60	.024 / 0.61
4.000-5.999 / 101.60-152.40	.034 / 0.86
6.000-7.999 / 152.40-203.20	.044 / 1.12
8.000-9.999 / 203.20-254.00	.054 / 1.37

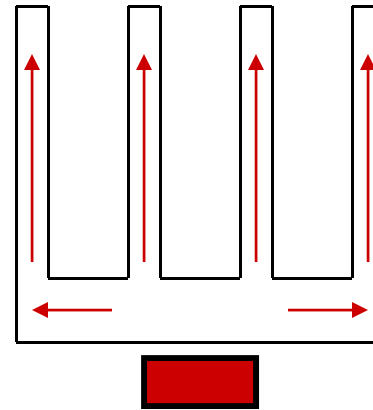
Base Spreading

When the heat source is smaller than the heat sink, the heat sink base thickness must be optimized to allow heat to flow through the base to the outer fins.

THE Heat Sink Alloy – Aluminum 6063-T5



Heat Sink = Heat Source



Heat Sink > Heat Source



Fin Notes

General
Notes

Straight Fin

Best thermal performance, lowest cost, low back pressure, airflow to be in the fin direction

Pin Fin

Good performance, higher back pressure, best for unknown / turbulent / natural convection airflows

Round Pin Fin

Usually on die cast or microforged parts, usually more costly and lower performing

Elliptical / Tapered Fin

Good for very low back pressure, high NRE, high part cost. Microforged parts can have very thin fins.

Too Many Fins

High back pressure, air may not flow through the parts.

Natural Convection

Fins must be widely spaced, ex .200 inch or heat will radiate from one fin to the next.

Cross Cuts

Break the static air flow boundary later

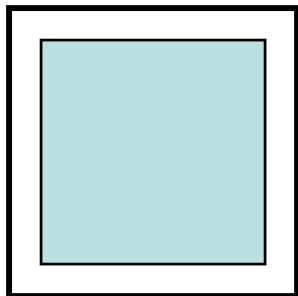
Flatness = \$\$\$ Specify the flatness that you need but only where you need it
Cisco Standard is .002"/" in the heat source area

TABLE 5 Flatness (Flat Surfaces)①—Bar, Solid Profiles and Semihollow Profiles

EXCEPT FOR PROFILES IN O®, T3510, T4510, T6510, T73510, T76510 and T8510 TEMPER®

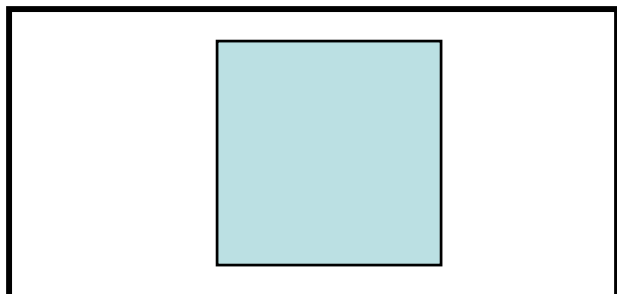
MINIMUM THICKNESS OF METAL FORMING THE SURFACE in.	SURFACE WIDTH—in.										
	UP TO 5.999	6.000 TO 7.999	8.000 TO 9.999	10.000 TO 11.999	12.000 TO 13.999	14.000 TO 15.999	16.000 TO 17.999	18.000 TO 19.999	20.000 TO 21.999	22.000 TO 23.999	24.000 AND UP
	TOLERANCE										
Up thru .0124	.004	.006	.010	.014	..	..	.014	..	..	..	..
0.125-0.187	.004	.006	.008	.012	.014	.014	.014	..	..	..	..
0.188-0.249	.004	.006	.008	.010	.012	.012	.012	.014	.014	..	..
0.250-0.374	.004	.006	.006	.008	.010	.010	.012	.012	.012	.014	..
0.375-0.499	.004	.004	.006	.008	.008	.008	.010	.010	.010	.012	.014
0.500-0.749	.004	.004	.006	.006	.008	.008	.008	.008	.008	.010	.012
0.750-0.999	.004	.004	.006	.006	.008	.008	.008	.008	.008	.008	.010
1.000-1.499	.004	.004	.004	.006	.006	.008	.008	.008	.008	.008	.008
1.500-1.999	.004	.004	.004	.004	.006	.006	.006	.008	.008	.008	.008
2.000 and up	.004	.004	.004	.004	.004	.006	.006	.006	.008	.008	.008

For all numbered footnotes, see page 27.



Single flatness callout is fine
Small parts will probably be $< .002''$ as extruded

Flatness = \$\$\$



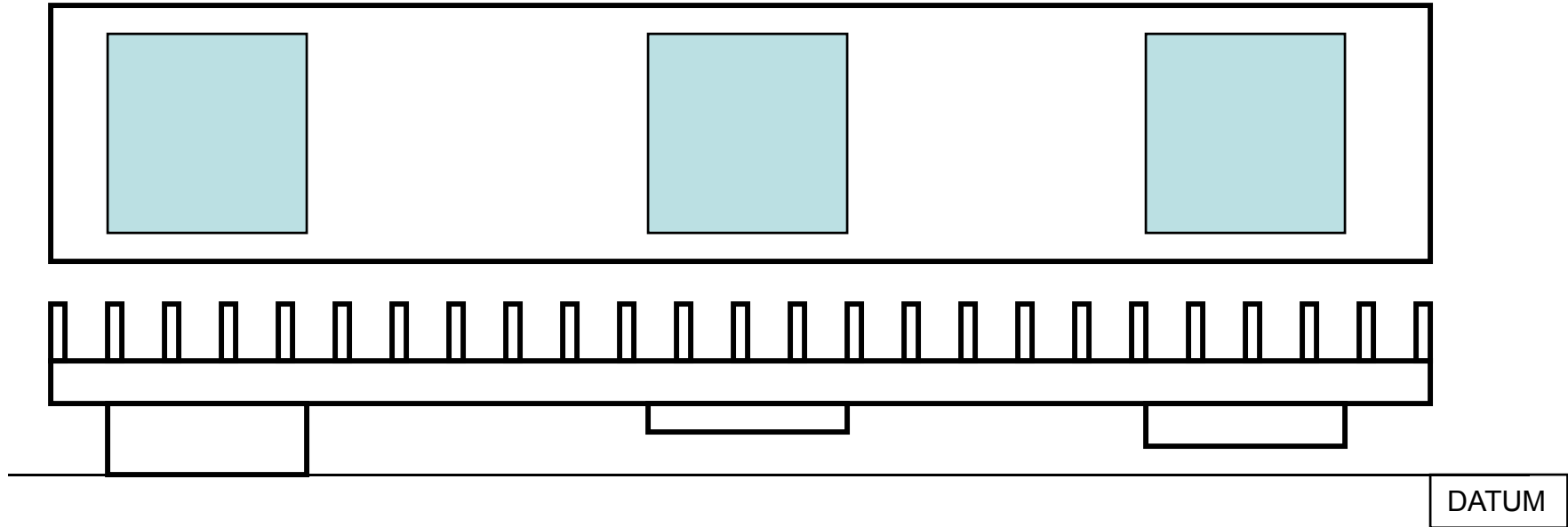
Specify flatness in heat source area
Go with standard callout on the rest of the part

Flatness = \$\$\$



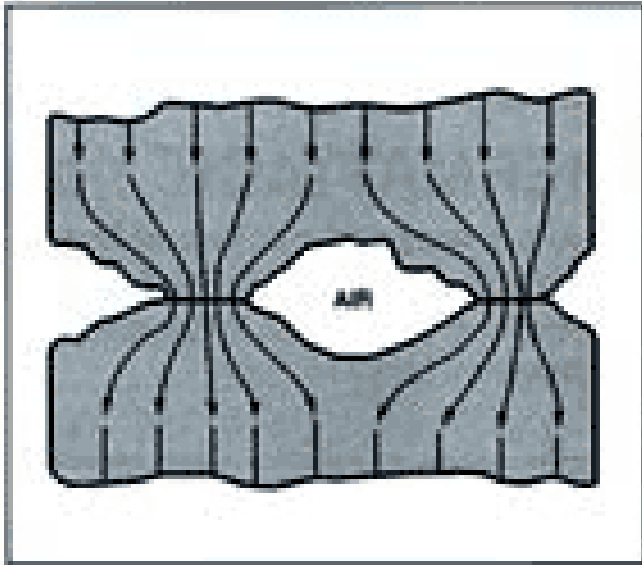
Specify flatness in source areas
Do they need to be related ??
Standard callout on the rest of the part

Flatness = \$\$\$



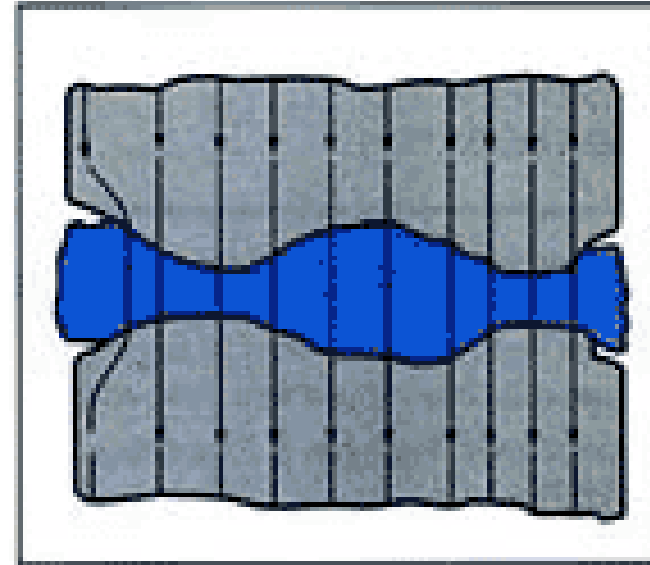
1. Parts are CNC machined from the bottom.
2. Datum the lowest machined pedestal surface NOT the base of the heat sink.
3. Will the center heat source always contact the heat sink ??
4. Gap filler TIMs (.020"+) are expensive.
5. Machined standoffs have the same dimensioning problems.
6. We machine it flat but when we open the vise, the part may spring back.
7. Thin base parts flex, how do we measure a part with flex ??

Magnified Sketch of the Interface between Heat Source and Heat Sink



Poor Heat Transfer

Small heat conduction area
and insulating air pockets



Good Heat Transfer

Larger heat conduction
area and no air pockets
(PCM example)



Thermal Interface Types

General
Notes

Double Sided PSA Pressure Sensitive Adhesive used to adhere heat sink to the heat source, heat sink and heat source are should be with 50%. Easy to assemble, pull tabs available on most materials. Need to select a specific tape for mounting surface i.e. metal, plastic, ceramic, silicon, etc. Typically .005-.010" thick

Single Sided PSA provides interface adhered to the heat sink only. Mechanical fastening of the heat sink is needed i.e. push pins, wire clips, band clips, screws, plastic clip, etc. Typically .005-.010" thick

SSA Single Sided Adhesive, alternate terminology.

Graphite commonly used on DC/DC converters, usually .005" and .010" thick.

PCM Phase Change Material, higher performance TIM that reflows with heat to fill all the interface voids, difficult to apply, usually supplied with a pull tab/release liner . Typically .002-.004" thick.

Gap Filler typically .020" and thicker pad with some compressability, used to fill varying gap sizes, mechanical fastening is required.

Epoxy thermally loaded filler adhesive system, provides permanent and strong mechanical attachment, often not favored by assemblers due to the possible prep work and inability to rework.

Grease excellent thermals, void filling capability and very thin interface, mechanical attachment required, but can be messy and is not favored by assemblers. Can be silk screened on by the factory but parts need covers to prevent dust and dirt contamination. Typically .001"-.002" thick

Pull Tabs release liner feature which makes assembly much easier, not available on all TIMs

Urethane Gaskets commonly used on small heat source flip chip parts to reduce chip breakage

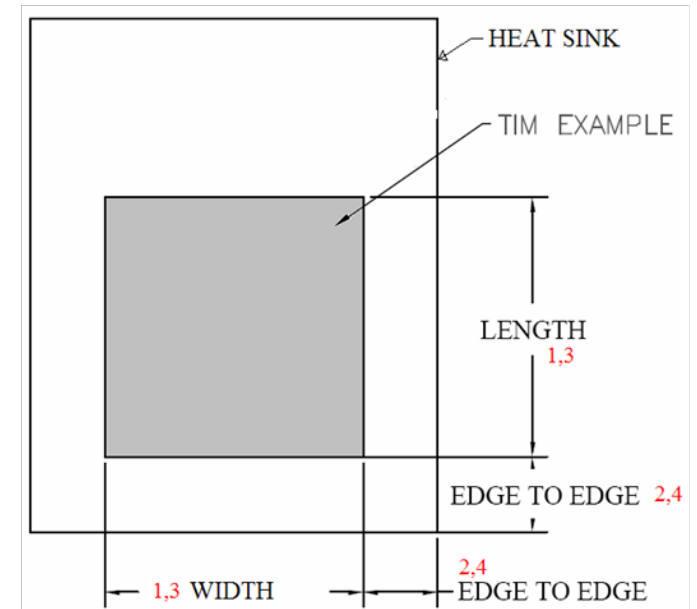
Tolerance Summary

Item	Feature	Units	Tolerance	Notes
1	TIM Pad Size (length or width)	mm	±0.25	1
2	TIM Pad Position (edge-to-edge)	mm	±0.50	1
3	TIM Grease Size (length or width)	mm	±0.50	1
4	TIM Grease Location (edge-to-edge)	mm	±0.50	1

Notes:

1. Tolerance reflects material state at point of manufacture.
2. Conversion: 1.0" = 25.4mm

Feature Diagram





Heat sink Attachment

General
Notes

Double Sided PSA Pressure Sensitive Adhesive used to adhere heat sink to the heat source.

Push Pins

Plastic low cost, 0-3 lbs per pin, low cost, use Nylon 66, requires holes in PCB.

Brass for heavier parts to meet drop test, 4x times cost of a plastic pin.

Wire Clips low cost, 0-6 lbs, needs PCB anchors (solder or omega pin).

Band Clips high force, high cost, high NRE.

Screws/Springs good solution on custom parts, requires inserts in PCB

Plastic Clips no board space required but high NRE and no flexibility

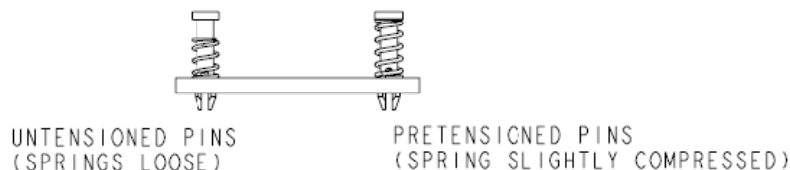
Materials and Tolerances

Springs

- ✓ Music Wire
- ✓ Stainless Steel

Tolerances

- ✓ **Free Length $\pm 0.050''$ (1.27mm)**
- ✓ Wire Diameter $\pm 0.002''$ (.05mm)
- ✓ Spring Rate $\pm 15%$ of stated value



Design Criteria:
Pins should always be pre-tensioned

Determining spring length:

- Deflection 4mm, desired force 9N
- Heat sink base 3mm \pm .25mm
- Choose a pin length so that the pin head is level to or below heat sink height after installation. Working length= 14mm \pm .2mm
- Using a plastic Pin calculate required spring rate: force/deflection =2.25N/mm
- Do a tolerance study to determine best/worst case free length

$$\text{Working length} + \text{tol} - \text{heatsink} - \text{tol} = \text{XXmm}$$

$$\text{Working length} - \text{tol} - \text{heatsink} + \text{tol} = \text{XXmm}$$

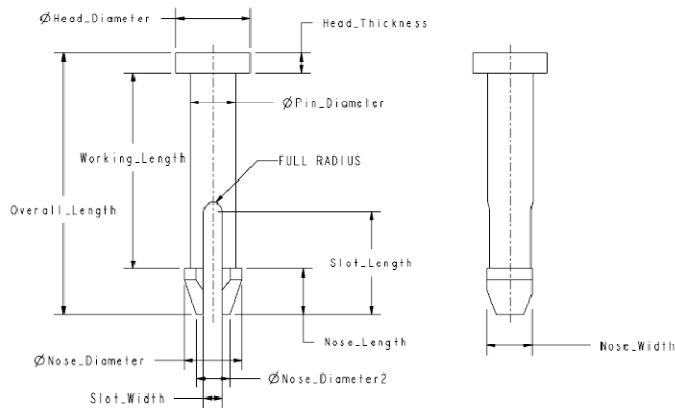
Refer to standard spring catalogs (www.leespring.com/www.asraymond.com) to find next **longest** spring with **closest** spring rate. In this case C0180-022-0500M or LC-022-5-M.

Push Pin Design

Materials and Recommended Forces

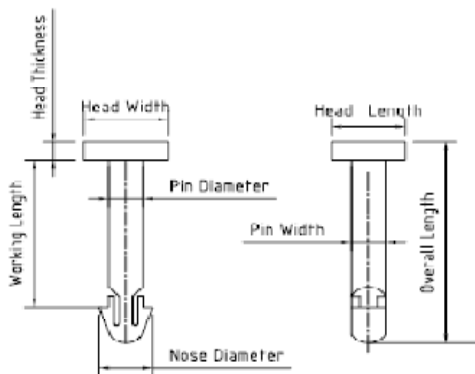
Pins

- ✚ Plastic (Nylon based) Forces 0-3lbs (0-13.5 N)
- ✚ Metal (Brass) Forces 0-5 lbs (0 – 22N)



Metal Pin Definition and Tolerances

- Head Diameter should be equal to or greater than the spring outer diameter
- Pin Diameter should be less than the spring inner diameter
- Nose Length should be at least .080”(2mm), the longer the better
- Nose Diameter should be .140”(3.56mm) for PCB holes of .118”(3.0mm) to .125”(3.2mm)
- Nose Diameter2 should be about .04”(1mm) smaller than PCB hole size
- Slot Width should be sized to allow Nose Diameter to fit into the PCB hole
- Slot Length should be determined via mechanical analysis to determine yield stress of the pin
- Nose Width should be equal to Pin Diameter
- Tolerances: all tolerances typically $\pm .005$ ”(0.13mm)



Plastic Pin Definition and Tolerances

- Head Width/Head Length should be equal to or greater than the spring outer diameter
- Pin Diameter should be less than the spring inner diameter
- Nose Diameter should be .140”(3.56mm) for PCB holes of .118”(3.0mm) to .125”(3.2mm)
- Nose Width should be equal to Pin Diameter
- Tolerances: all tolerances typically $\pm .008$ ”(0.20mm)

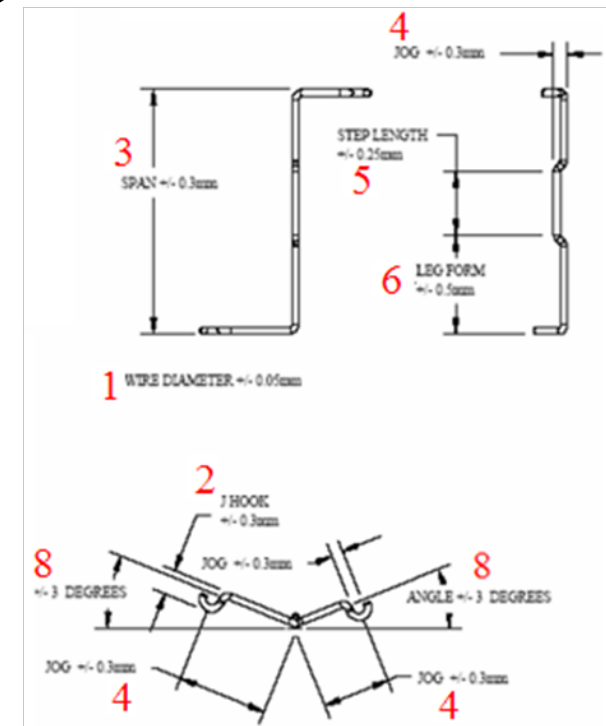
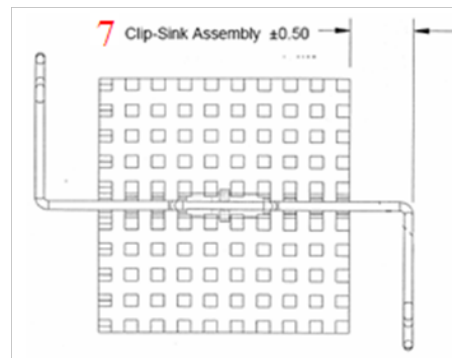
Tolerance Summary

Item	Feature	Units	Tolerance	Notes
1	Wire Dia	mm	± 0.05	-
2	J Hook	mm	± 0.30	-
3	Total Span	mm	± 0.30	-
4	Clip Jogs	mm	± 0.30	-
5	Step Length	mm	± 0.25	1
6	Leg Form	mm	± 0.50	2
7	Assembly to heat sink	mm	± 0.50	-
8	Bend Angle	°	± 3.0	-

Notes:

1. Tolerance is of straight section only, radii not included
2. Tolerance does include radii
3. Conversion: 1.0" = 25.4mm

Feature Diagram



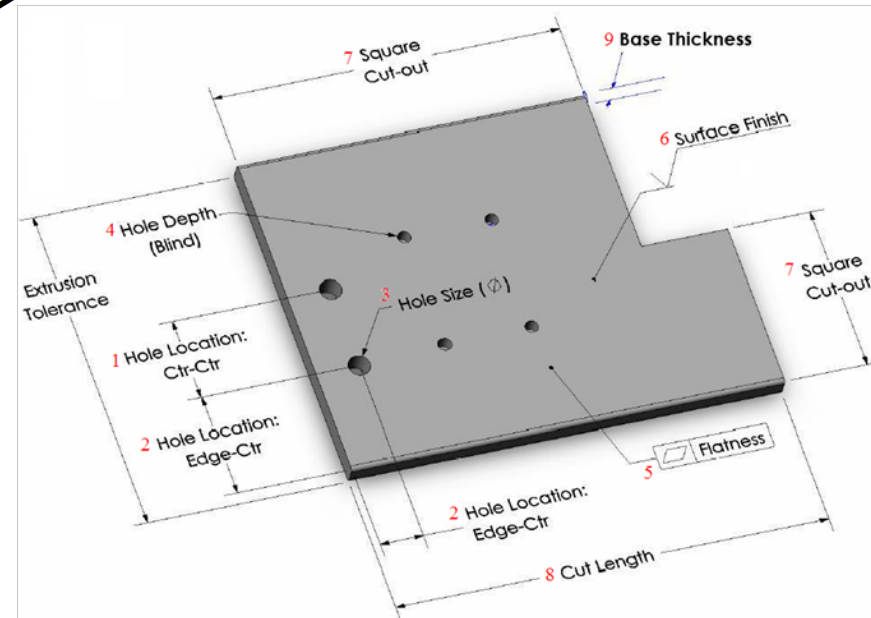
Tolerance Summary

Item	Feature	Units	Tolerance		Notes
			Precision	Economy	
1	Hole Location: Ctr-to-Ctr	mm	±0.15	±0.30	-
2	Hole Location: Edge-to-Ctr	mm	±0.25	±0.30	-
3	Hole Size (Ø)	mm	±0.10	±0.15	1, 2
4	Hole Depth (Blind)	mm	±0.30	±0.50	-
5	Surface Flatness	mm/mm	0.002	0.005	1, 2
6	Surface Roughness/Finish	RMS, µm	0.8~1.6	1.6~3.2	2
7	Square Cut-out	mm	±0.15	±0.40	-
8	Cut to Length	mm	±0.25	±0.38	-
9	Base Thickness	mm	±0.15	±0.25	3

Notes:

1. Process tolerance may vary with material type & temper.
2. Process capability will vary with thickness
3. Bases thickness over 12.7mm may have increased associated tolerance
4. Conversion: 1.0" = 25.4mm

Feature Diagram



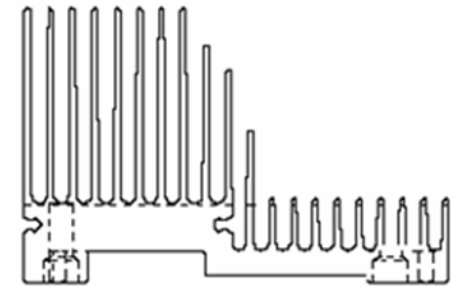
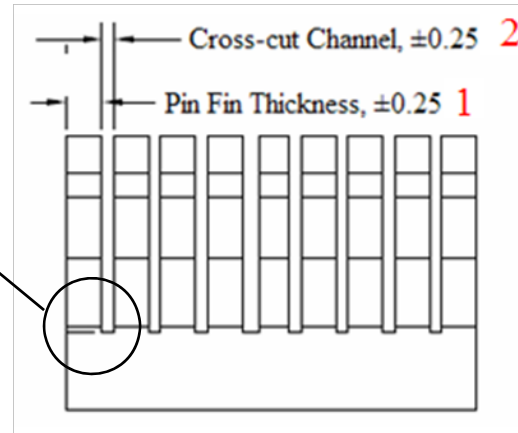
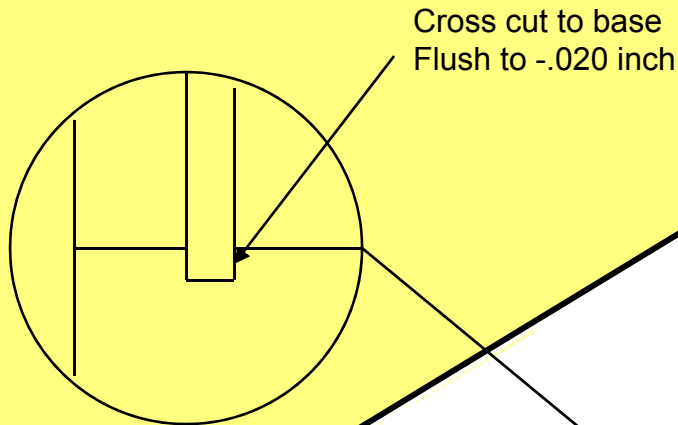
Tolerance Summary

Item	Feature	Units	Tolerance	Notes
1	Pin Fin Thickness	mm	± 0.25	1, 2
2	Cross-cut Channel	mm	± 0.25	1, 2

Notes:

1. Tolerances valid for fin heights < 50mm
2. Tolerance valid for Cross-cut channels > 1.5mm
3. Conversion: 1.0" = 25.4mm

Feature Diagram





Finishes

Anodizing

Aluminum oxide finish, excellent emissivity (important for natural convection), tough finish, low cost, electrically non-conductive, colors are dyed in and do not effect emissivity, black and clear are standard, several automatic lines. RoHS compliant.

Chromate aka Chemfilm, Irridite, Aludyne

Dip type finish that seals the pores in the metal, low cost, available in clear and yellow, electrically conductive, can be rubbed off.

Hexavalent Chromate, Cr-6 is non RoHS compliant, do not use

Trivalent Chromate, Cr-3 is RoHS compliant, use this. Clear only.

McDermitt Process, non Chromate Chromate, available.

Mill aka plain, wash, bare, wash and debur

Nickel solderable, may be needed depending on HS construction, good for tough environments

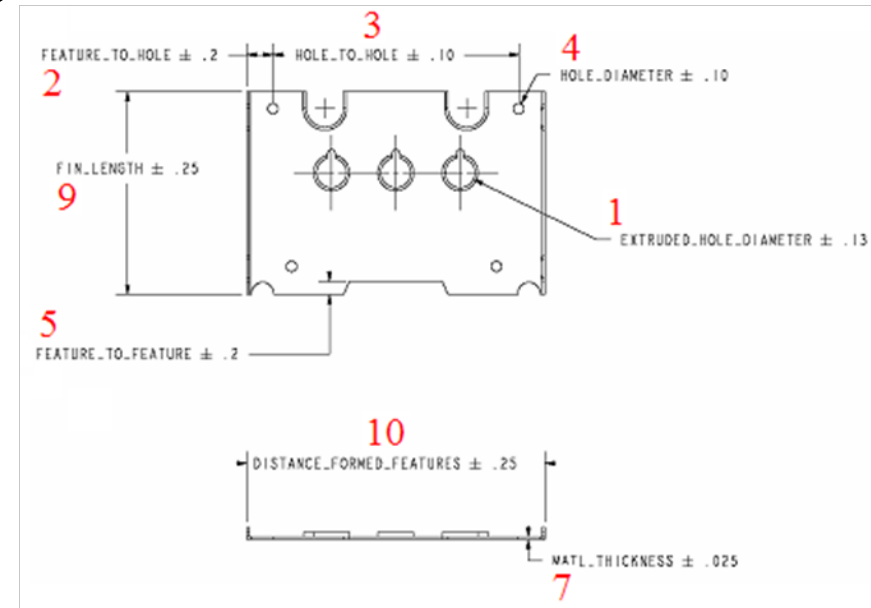
Tolerance Summary

Item	Feature	Units	Tolerance	Notes
1	Extruded Hole (Ø)	mm	±0.13	1
2	Non-Hole, Feature-to-Feature Location	mm	±0.20	1
3	Hole-to-Hole Location	mm	±0.10	1
4	Hole Size (Ø)	mm	±0.10	1
5	Feature Dimension (non-hole)	mm	±0.25	1
6	Solder Assembly (base edge-to-fin)	mm	±0.50	1
7	Fin Material Thickness	mm	±0.025	1
8	Assembled Fin Pack Width (stack)	mm	±0.50	1
9	Stamped Fin Length (height or length)	mm	±0.25	1
10	Distance between formed features	mm	±0.25	1

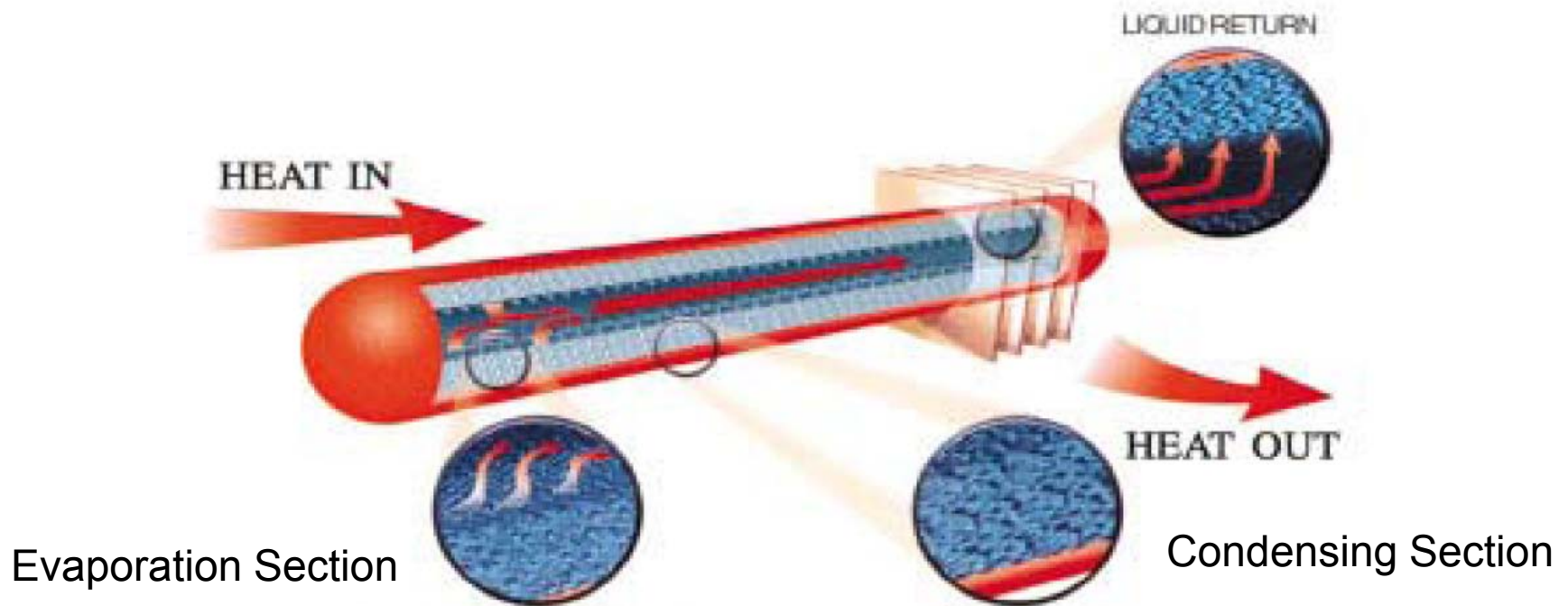
Notes:

1. Tolerances valid for base material < 1.0mm
2. Conversion: 1.0" = 25.4mm

Feature Diagram



Heat pipes do not dissipate heat
they move it to another location





Heat Pipe Construction

General
Notes

Sintered Copper best performance, sintered copper balls wicking mechanism, best for formed heat pipe shapes (bending and flattening), low internal back pressure as core area is wide open, wicking action 360 degrees around inside of the heat pipe.

Copper Powder alternate name for sintered copper.

Grooved low cost, part has internal grooves for wicking action but grooves are distorted when pipes are bent or formed, limiting wicking action. Suitable for straight pipe solutions.

Wick low cost, part has a lamp type wick inside

Fiber type of wick construction,

Wicking action ?

Spring coil spring inside copper housing.

Internal back pressure ?

Mesh low cost, part has a wire mesh inside.

Hybrid combination, such as grooved and wire mesh to improve wicking action.

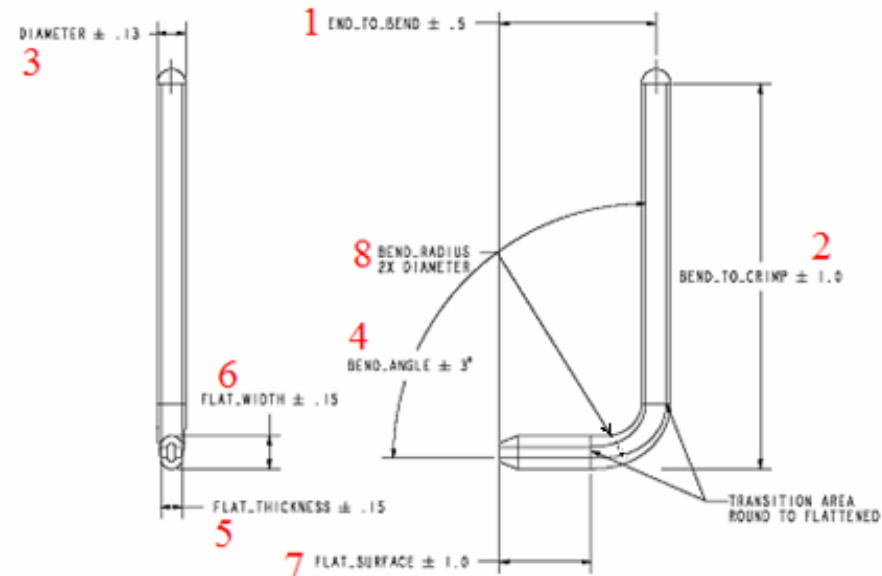
Tolerance Summary

Item	Feature	Units	Tolerance	Notes
1	Length (end of Pipe-to-bend)	mm	±0.50	-
2	Length (Bend-to-crimp)	mm	±1.00	-
3	Diameter of Pipe	mm	±0.13	-
4	Bend Angle	°	±3.0	-
5	Flattened Pipe (thickness)	mm	±0.15	-
6	Flattened Pipe (width)	mm	±0.15	-
7	Flatten Surface	mm	±1.00	-
8	Inside bend radius (minimum)		2 X Ø	-

Notes:

1. Conversion: 1.0" = 25.4mm

Feature Diagram





Materials & Treatments

Standard
Materials
& Finish

Sheet & Extrusion Alloys	Thickness & Diameter	RoHS Surface Treatments
<p>Aluminum</p> <p>Sheet & Coil: 1050, 1100 or 5052</p> <p>Extrusion: 6063-T5</p> <p>Cast Alloy: ADC10, ADC12</p>	<p>Sheet & Plate</p> <p>Thickness up to 1.0mm 0.2, 0.3, 0.5, 0.6, 0.8, 1.0</p> <p>Thickness 1.0 ~ 5.0mm 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0</p>	<p>Anodizing</p> <p>Standard Colors: Black & Clear Available: Blue, Green, Red, Gold</p>
<p>Copper</p> <p>Sheet & Extrusion: C1100</p>	<p>Wire</p> <p>Diameters up to 1.0mm 0.2, 0.3, 0.4, 0.5, 0.8, 1.0</p> <p>Diameters 1.0 ~ 3.0mm 1.0, 1.5, 2.0, 2.5, 3.0</p>	<p>Trivalent Chromate</p> <p>Color: Clear (OK for ROHS)</p> <p>Other Treatments</p> <ul style="list-style-type: none"> •Bare aka Wash aka Plain •Electroless Nickel •Copper Passivation (Anti-oxidant)
<p>Stainless Steel</p> <p>Sheet</p> <ul style="list-style-type: none"> •SK-7 (heat treatable, S410) •301 		<p>Finishes</p> <ul style="list-style-type: none"> •Mill Finish aka “as extruded” •Bead Blast •Grain aka Sanded •Polish aka Mirror Finish