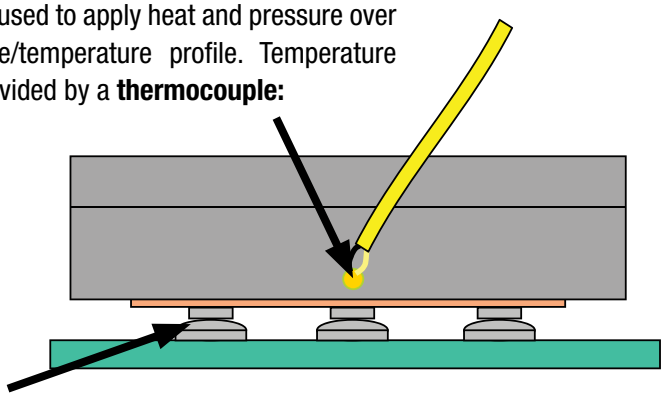
Fundamentals of Pulse Heated Reflow Soldering

"Pulse Heated Reflow Soldering is a process where two pre-fluxed, solder coated parts are heated to a temperature sufficient to cause the solder to melt and flow, and then cooled under pressure, to form a permanent electro-mechanical bond between the parts and solder."

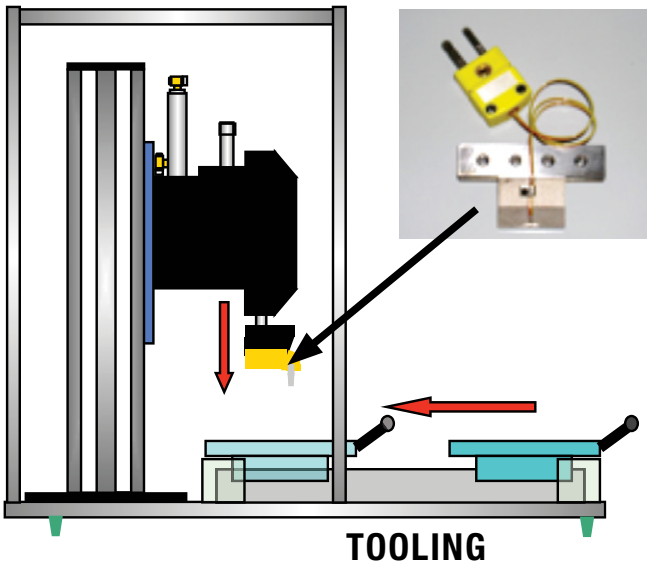
A **thermode** is used to apply heat and pressure over a specific time/temperature profile. Temperature feedback is provided by a **thermocouple:**



Goal: Heat the **solder** to 400 C above melting point temperature for 2-3 seconds to achieve proper wetting and flow.

Equipment

REFLOW HEAD



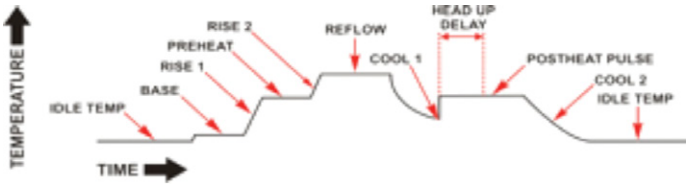
THERMODE

POWER SUPPLY (CONTROL UNIT)

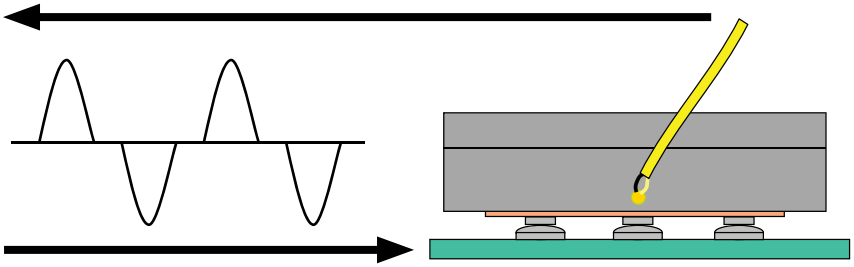
TOOLING

Thermode Heating

TIME & TEMPERATURE PROFILE:



Thermocouple provides temperature feedback to Power Supply

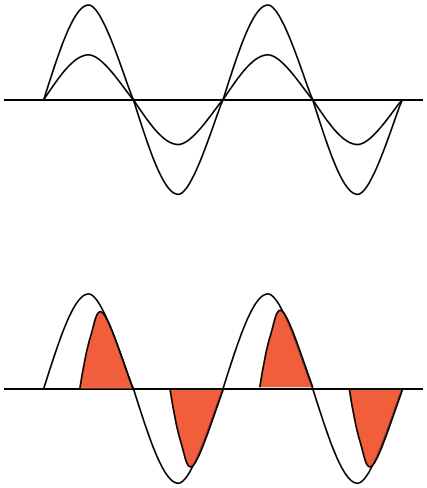


Power Supply delivers AC current to Thermode

Heat is generated due to electrical resistance of Thermode

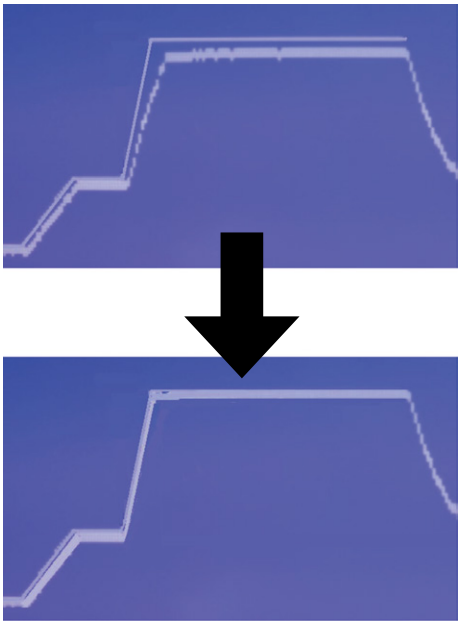
Heating Rates

Coarse Heating Rate adjustment changes transformer taps:



PID Tuning

PID Tuning can be used to optimize the rise time and stability of the output:



PID Table

Less Overshoot, Less Oscillation, Increased Noise

Faster Rise Time, More Overshoot, More Oscillation

A	100	101	102	103	104	105	106	107	108	109
B	110	111	112	113	114	115	116	117	118	119
C	120	121	122	123	124	125	126	127	128	129
D	130	131	132	133	134	135	136	137	138	139
E	140	141	142	143	144	145	146	147	148	149
F	150	151	152	153	154	155	156	157	158	159
G	160	161	162	163	164	165	166	167	168	169
H	170	171	172	173	174	175	176	177	178	179
I	180	181	182	183	184	185	186	187	188	189
J	190	191	192	193	194	195	196	197	198	199
K	200	201	202	203	204	205	206	207	208	209
L	*210*	*211*	*212*	*213*	*214*	*215*	*216*	*217*	*218*	*219*
M	*220*	*221*	*222*	*223*	*224*	*225*	*226*	*227*	*228*	*229*
N	*230*	*231*	*232*	*233*	*234*	*235*	*236*	*237*	*238*	*239*
0	*240*	*241*	*242*	*243*	*244*	*245*	*246*	*247*	*248*	*249*
P	*250*	*251*	*252*	*253*	*254*	*255*	*256*	*257*	*258*	*259*
Q	*260*	*261*	*262*	*263*	*264*	*265*	*266*	*267*	*268*	*269*

Note: Using PID setting “99” will emulate Uniflow 2 and 3’s default PID settings

PID Tuning

Typical PID and Coarse Heat Settings

Thermode Type	Heat Rate Setting	PID
Peg Tip	Very slow	155, 243
Big blade > 1"	Medium	175
Small blade < 1"	Very slow	200, 268, 185
Big TD > 1"	Fast	105
MID TD	Fast	155
Small TD < 0.5"	Medium	185

Materials: Solders and Fluxes

ABOUT SOLDER

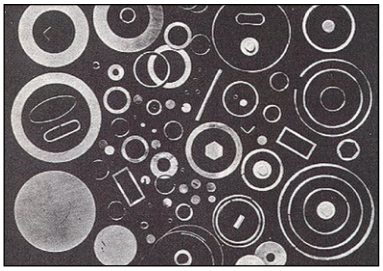
- Solders are **alloys:** chemical mixture of two or more metals
- Alloy type and characteristics are determined by the proportions (% by weight) of their constituent metals
- Common “lead free” alloys used in electronics manufacturing:
  - – tin-silver-copper: SAC305: Sn96.5Ag3Cu0.5 (Melting Point 2180 C)
  - – tin-silver Sn96Ag4 (Melting Point 2210 C)
  - – tin-copper-nickel Sn100C (Melting Point 2270 C)
- Leaded solder (rarely used today):
  - – tin-lead: Sn63Pb37 (Melting Point 1830 C)

SELECTING SOLDER ALLOYS

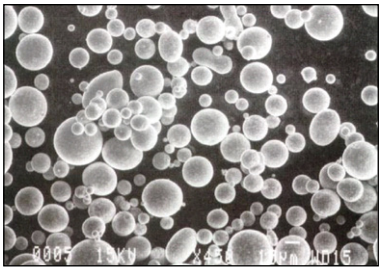
- Alloys are selected for specific properties depending on the electronics assembly
- Melting point
- Mechanical stress characteristics
- Wettability
- Presence of Lead

PHYSICAL FORMS OF SOLDER

Rosin Core Wire Solder in various sizes and flux types



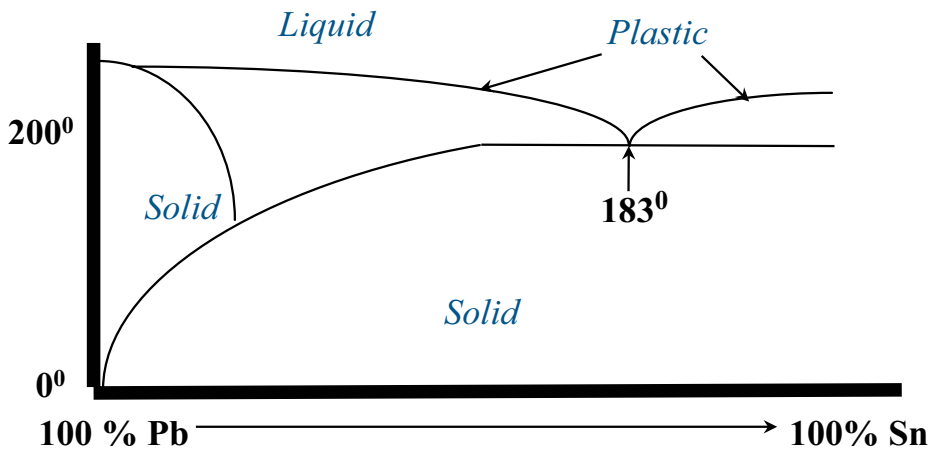
Pre-Forms are manufactured to specific volumes and geometries of solder



Solder Paste spherical metal particles suspended in flux

SOLDER AND PHASE DIAGRAMS

- Each alloy has unique physical characteristics during heating and cooling
- The phase diagram illustrates the “state” of the alloy over a range of temperatures

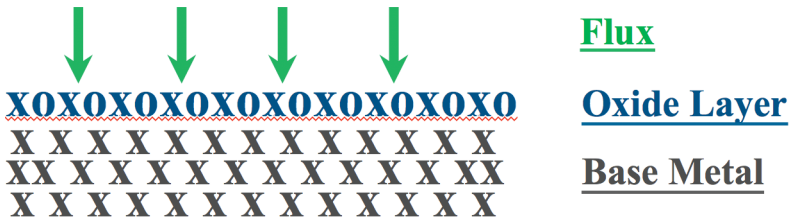


EUTECTIC SOLDERS

- Eutectic solders
  - Transitions from **solid** to **liquid** at a fixed temperature
  - Lower melting point than parent metals
    - Example: Sn96Ag4 (Melting Point 2210 C)
      - Melting Point of Tin: 2320 C
      - Melting Point of Silver: 9620 C
- Eutectic solder increases process predictability
  - Melting point of the solder
  - Flow (wetting) action behavior

FLUX

- Flux is a chemical agent used for improving the wetting action of solder
  - **Removes** and **prevents** oxide formation during soldering
  - Lowers the **surface tension** of solder
  - **Catalyst** (not part of final metal composition



FLUX ACTIVATION

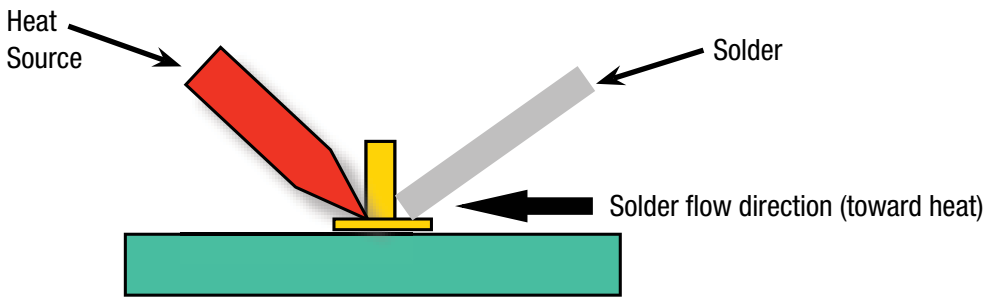
- Flux for electronics applications
  - – must be heated to remove oxides
  - – relatively “inert” at room temperatures
- Flux **”activation”** or **“working” temperature**
  - – optimum range of temperatures where it chemically reacts with oxidized metal surfaces

ELECTRONICS FLUXES

- No Clean
  - – Least active type of flux
  - – Reflow process must occur within 5 minutes of application
  - – Low solids content leaves little residue
  - – No cleaning required or possible
- Rosin Mildly Activated (RMA)
  - – Promotes good wetting on oxidized surfaces
  - – Requires saponifier (chemical) and hot water to clean
- Rosin Activated (RA)
  - – Very active flux
  - – Requires saponifier (chemical) and hot water to clean
- Water Soluble
  - – Most active type of flux
  - – Residue is corrosive and conductive
  - – Requires cleaning equipment and hot water treatment

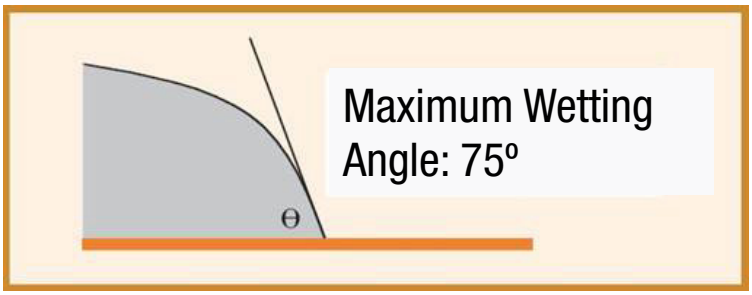
SOLDERS AND WETTING

- When solder melts it tends to flow over and towards heated surfaces
  - – This action is called **wetting**
- Flow or wetting occurs more readily over oxide-free surfaces or “clean”

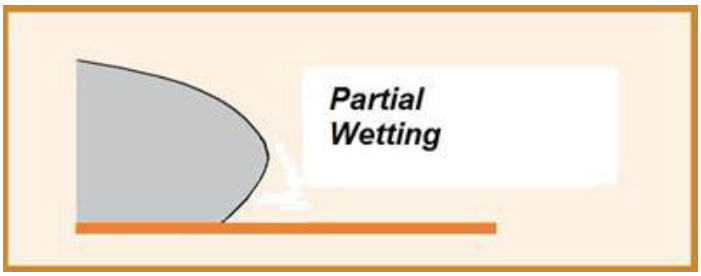


WETTING ANGLE

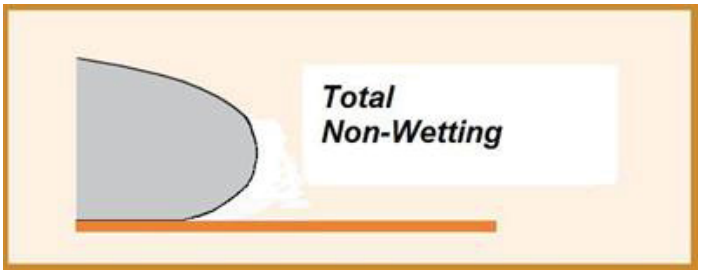
- To establish a reliable solder joint the solder joint or **wetting angle** can be measured
- The wetting angle should be 75º maximum



POOR WETTING ANGLES



Insufficient flux action
or insufficient heating

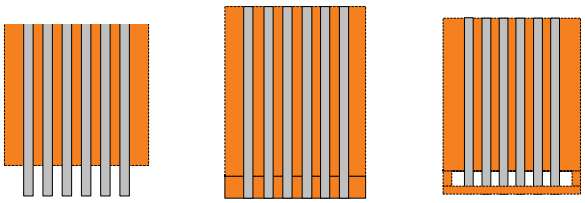


Heavy oxidation,
poor flux action,
or poor heating

MATERIALS:
FLEX CIRCUITS AND PCB'S

FLEX CIRCUITS

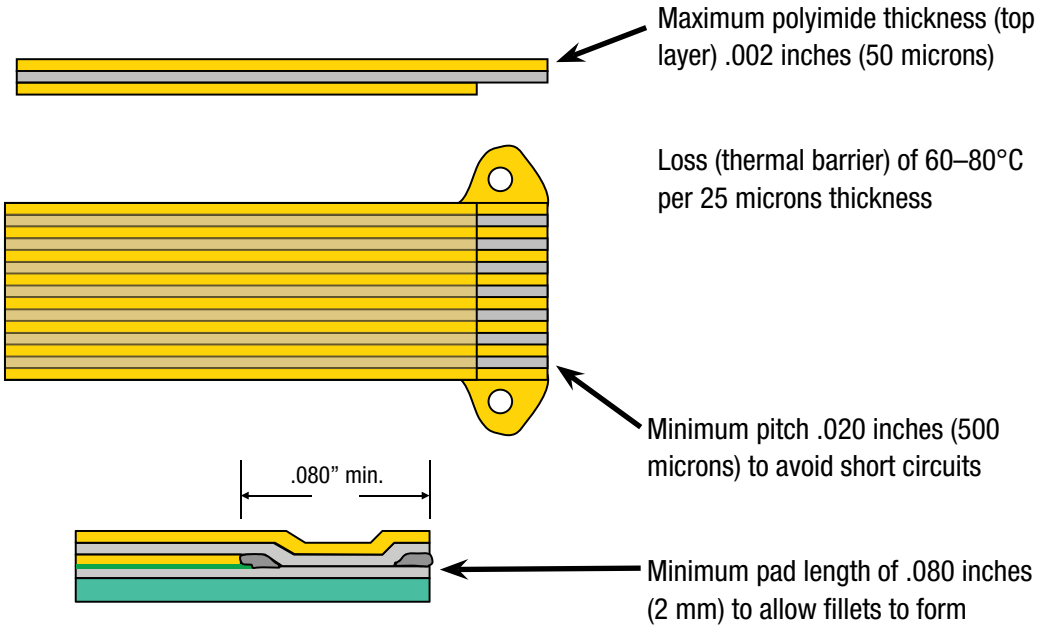
- Most common type is polyimide (also known under the trade name of Kapton)
- Two layers of polyimide encapsulate the copper traces (normally 0.5–3.0 oz)
- Copper is Rolled Annealed or Electro-Deposited (most cost effective and widely used)
- Thickness of copper traces ranges from 0.0007–0.0042 inches (18-107 microns)
- Operating temperatures ranging from 130–200°C (can withstand soldering temperatures up to 300°C for a short time)
- Thickness of the polyimide ranges from 0.001–0.0047 inches (25-120 microns)



Exposed Lead *Single Sided* *Open Windowed*

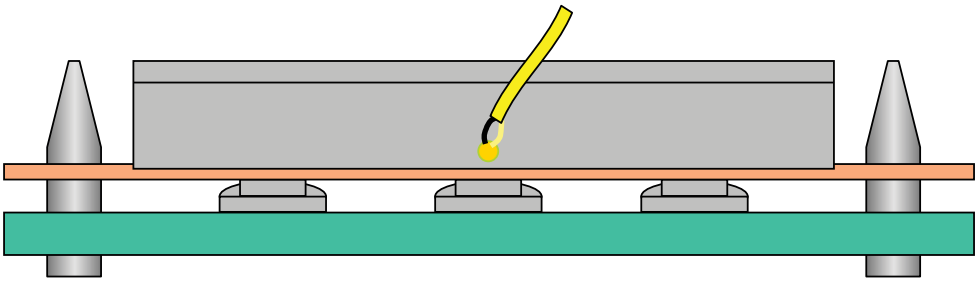
Type	Advantages	Disadvantages
Exposed Lead	Lower thermode temperatures.	Flux contamination on thermode. Leads can be damaged or bent when handled.
Single Sided	Easy to handle. Minimal flux contamination on thermode.	Higher thermode temperatures due to thermal barrier.
Open Windowed	Lower thermode temperatures.	Flux contamination on thermode. Part alignment is critical.

SINGLE SIDED FLEX CIRCUITS



PCB DESIGN

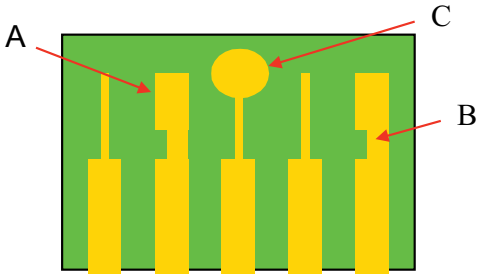
- Most PCB materials such as FR2 and FR4 are very resilient to the local application of heat during reflow process
- Width of the PCB trace should be 50% of the pitch to avoid short circuits
- Make PCB traces wider than flex traces to allow solder to flow and fillets to form
- Tooling holes in PCB and Flex allow easy alignment of traces
- Provide room for thermode to overhang both ends of pad area by a minimum of 0.040" (1 mm)
- The opposite side of the PCB, directly under the reflow area should be free of components as they can interfere with the support tooling



PCB DESIGN

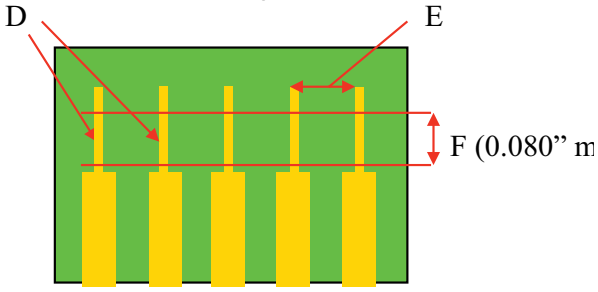
- Differences in heat sinking from pad to pad can cause uneven heating:

Large landmass, increased trace width and plated through-holes draw heat from the joint area and cause uneven heat distribution.



Design Problems

Equally sized and spaced small traces act as a thermal dams and ensure equal heating across joint area. Recommended minimum spacing of 0.080" with no heat sinks around pads.

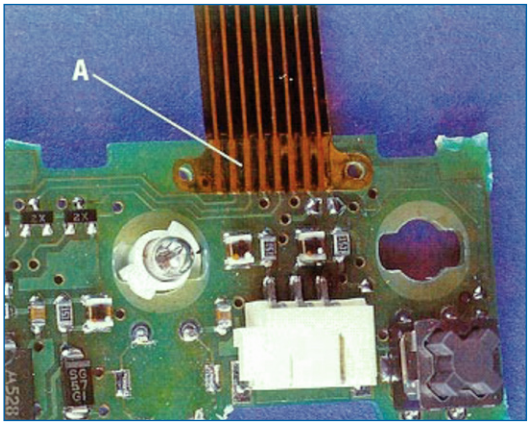


Design Solutions

- For multi-layer boards, restrict the traces under the bonding area to the smallest width (signal) traces and spread equally under the pads on the PCB. Any shielding on the PCB should have an equal effect along the joint area.

Alternate design for thermal dams

FLEX TO PCB EXAMPLE

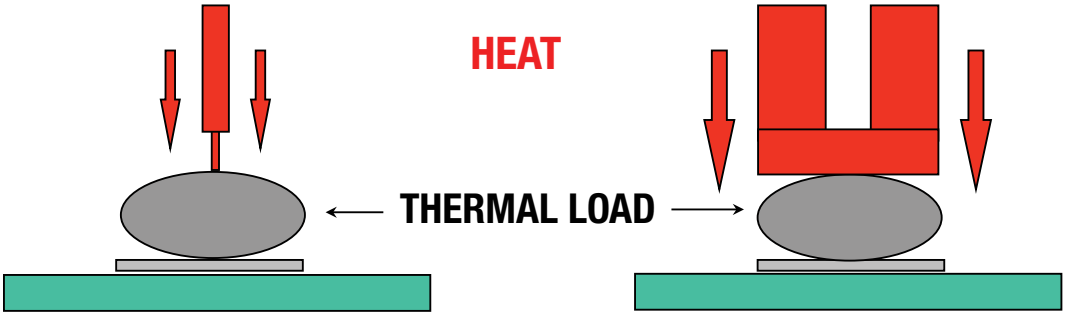


“A” above shows flex circuit attachment

THERMODES:
DESIGN AND MAINTENANCE

BASIC HEAT TRANSFER PRINCIPLE

Source heat generation must be greater than the thermal load heat absorption

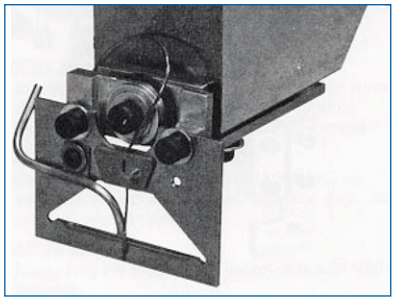


Inadequate- Heat source with limited surface area

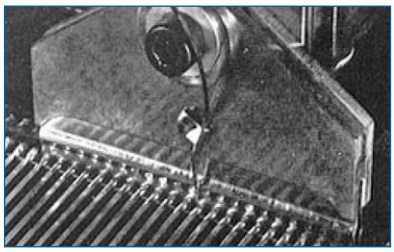
Required- Heat source with adequate surface area for heat transfer to load

THERMODE TYPES

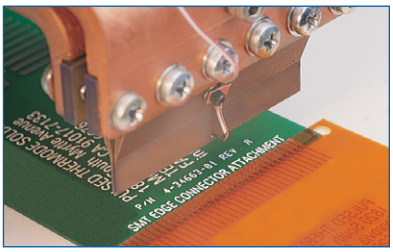
Peg Tip



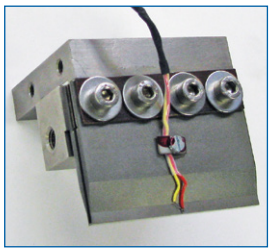
Blade



Fold Up



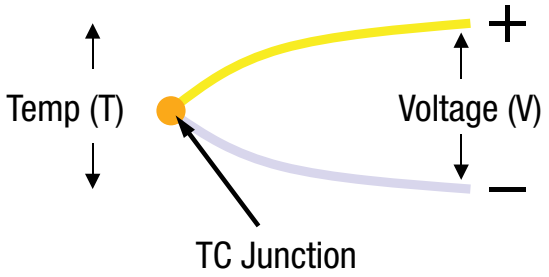
17TD 3D



69T 3D

THERMOCOUPLE BASICS

A thermocouple consists of two dissimilar alloys joined together at one end (TC Junction) and open at the other. A voltage potential (V) exists at the open end. The voltage level is a function of the temperature (T) at the closed end. As the temperature rises, the voltage level increases.



THERMOCOUPLE TYPES

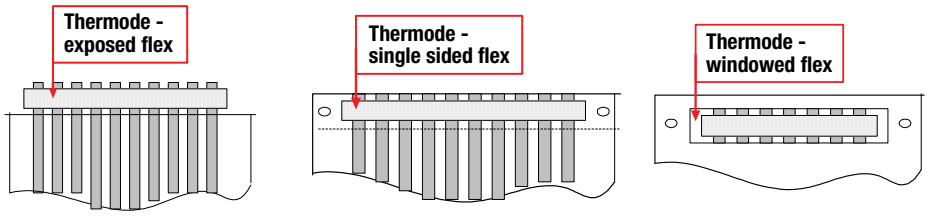
Type E: Chromel-Constantan (Purple Connector)

Type J: Iron-Constantan (Black Connector)

Type K: Chromel-Alumel (Yellow Connector)

THERMODE DESIGN

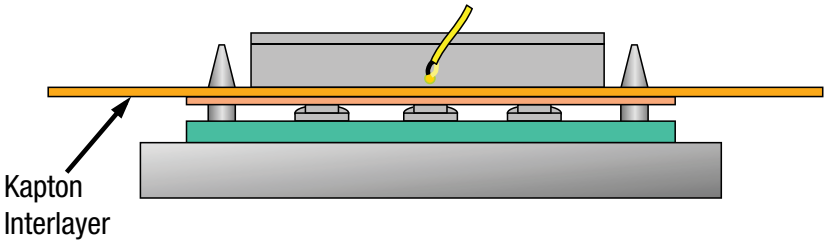
- Thermode face must be properly sized for application:



- Thermode should overhang both ends of pad area by 0.040" (1 mm)
- Thickness of thermode should be less than pad length to allow fillets to form
- Thermode face must be large enough to provide adequate heat transfer

THERMODE MAINTENANCE

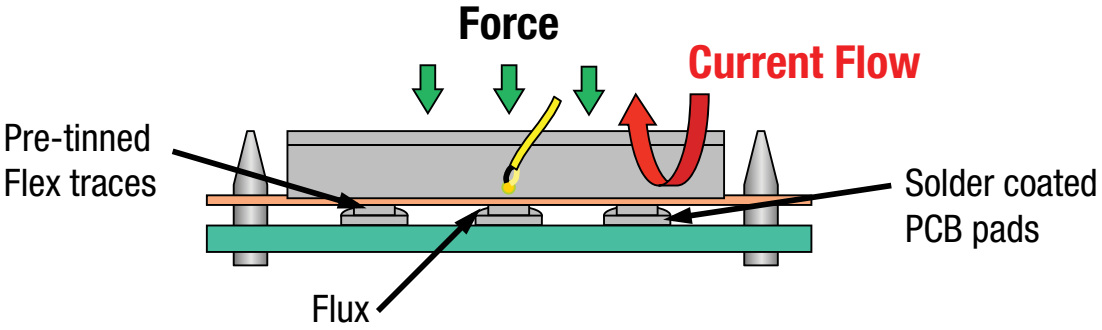
- Periodically remove baked on flux and polyimide material from thermode heating surface using Isopropyl Alcohol or Acetone
- Thermode face may be resurfaced with 600 grit silicon carbide paper at low force on flat surface
- Thermode face can be resurfaced using grinding wheel as long as sufficient material is present
- Improper thermode cleaning/resurfacing can result in damaged thermocouples and non-flat thermode faces
- Use interlayer to reduce or eliminate contamination of the thermode
- Automatic Kapton feeder can automatically advance between bonds



PROCESS: SET-UP AND CONTROL

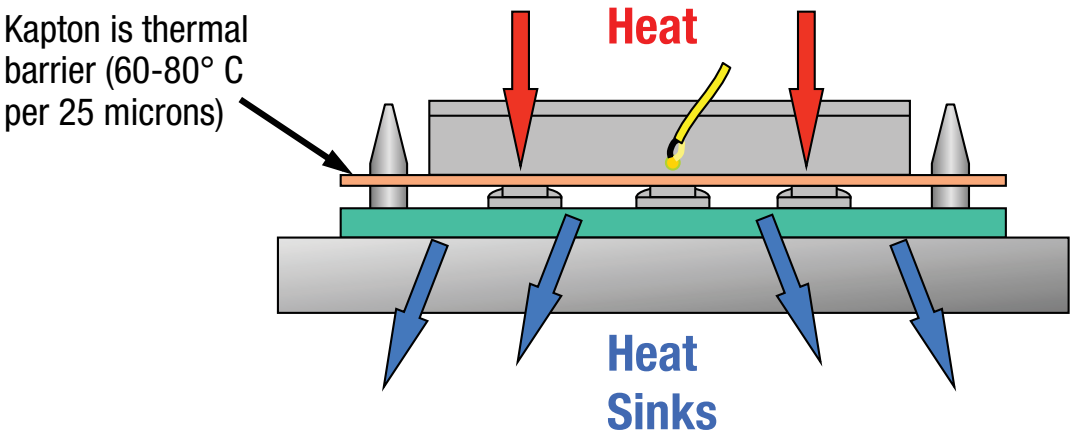
REFLOW SOLDERING PROCESS

- Heat is produced by passing **electrical current** through a **resistive heating element** (thermode)
- Heat is conducted from the thermode to the part with the application of **force**
- **Flux** is used to remove and prevent oxide formation
- The **solder** should reach a temperature of 40° C above it's melting point for 2-3 seconds to achieve proper wetting and flow



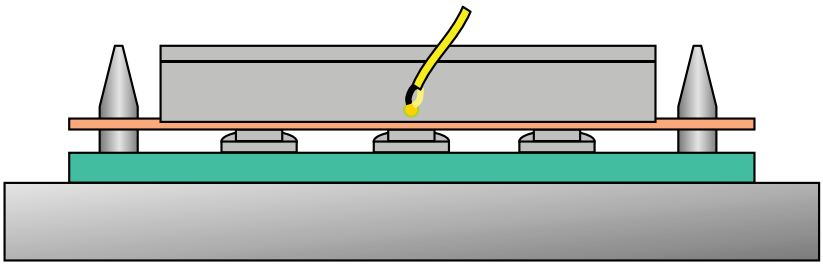
THERMAL LOAD

Thermal Barriers and Heat Sinks both contribute to Thermal Load



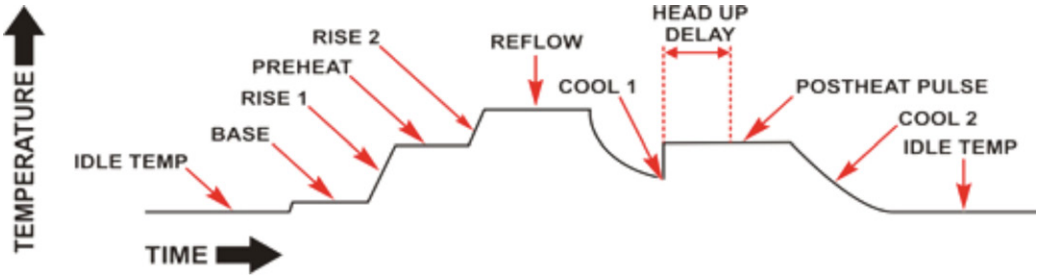
PROCESS VARIABLES

- Temperature
- Time
- Force
- Contact
- Alignment
- Materials
- Heat Sinks



TEMPERATURE AND TIME

- The **Thermal Profile** optimizes the time & temperature relationship to create a reliable bond
  - **Flux activation-** flux requires heat and time to remove oxides
  - **Solder wetting-** the solder must melt after flux activation to properly wet
  - **Cooling-** the solder must cool after sufficient flow to avoid cold solder joints



❑ **IDLE:**

Used to keep the thermode temperature above room temperature between bonding cycles to increase production rate.

❑ **BASE:**

Used to bring each part up to a consistent temperature in cases where environmental factors affect bonding consistency.

Note: BASE temperature must be set to a level below the flux activation temperature

❑ **RISE 1:**

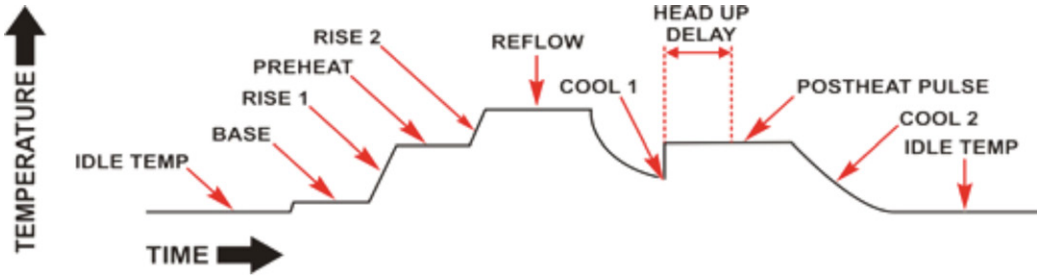
Ensures smooth transition between BASE and PREHEAT with no overshoot.

❑ **PREHEAT:**

It takes approximately two seconds to heat a modern designed thermode of up to 2” in length to soldering temperature.

PREHEAT is best used where there are excessive heat sinks affecting the thermode or where the application has delicate substrates, like ceramic that need to be heated in a more controlled fashion to avoid cracking.

During PREHEAT, the flux activates and starts to promote wetting by removal of the oxide layer.



- **RISE 2:**

  Ensures smooth transition between PREHEAT and REFLOW with no overshoot.

- **REFLOW:**

  Time and temperature should be programmed so that the solder reaches a temperature of 40° C above it's melting point for 2-3 seconds.

  Although SAC305 solder will reflow at 218° C, the REFLOW temperature must be set higher due to the thermal transfer losses.

  A typical single sided flex will require between 350 - 400° C due to the thermal losses in the Kapton material and heat sinks below.

  It is preferred to use the minimum time and temperature to achieve the desired joint, so as to minimize the parts exposure to heat and chance of damage.

- **COOL 1:**

  If a POSTHEAT PULSE is not being used, COOL 1 is the temperature at which the control unit will actuate a pneumatic head to the up position.

  This temperature is set to just below the solder solidification temperature. As soon as the solder becomes solid the process is ended and a joint is formed.

  The cooling process can be shortened by the use of forced air cooling. The control unit can be programmed to turn on a valve that controls the flow of air at the end of the reflow period to cool the joint and thermode rapidly.

  The actual temperature in the solder is typically lower than the measured thermode temperature, so the COOL 1 temperature can be set to 180º C in most cases without the chance of encountering a dry joint.

- **POSTHEAT PULSE:**

  A POSTHEAT PULSE is typically only used for Heat Staking applications (not reflow soldering).

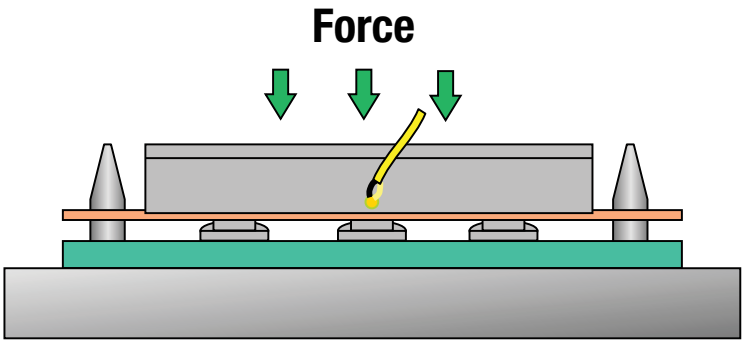
  The POSTHEAT PULSE extends the time at force beyond COOL 1 and heats the thermode up to a temperature sufficient to prohibit the thermode sticking to the heat staked parts. The Head Up Delay is used to set the time at which the control unit will actuate a pneumatic head to the up position.

- **COOL 2:**

  If a POSTHEAT PULSE is programmed, COOL 2 is the temperature at which the control unit will consider the cycle complete.

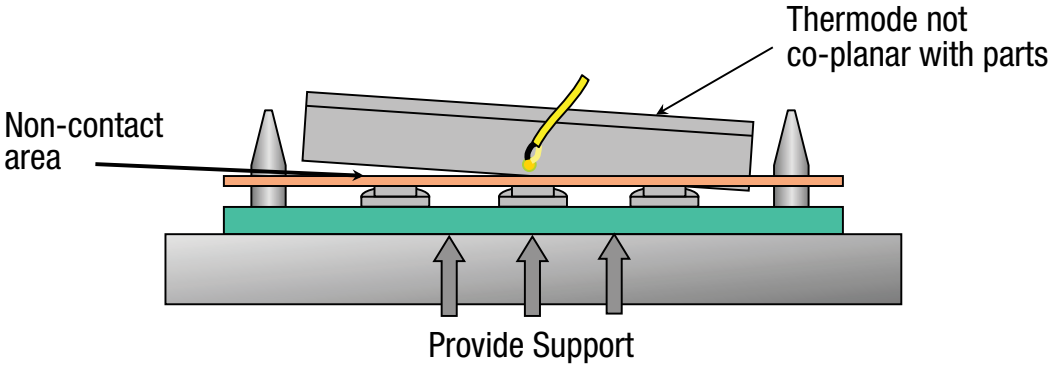
FORCE

- Adequate force must be applied to ensure proper heat transfer.
- Typical minimum pressure is 12 kg/cm^2 (170 lbs/in^2) across thermode face.
- Measure force using mechanical or electronic force gauge



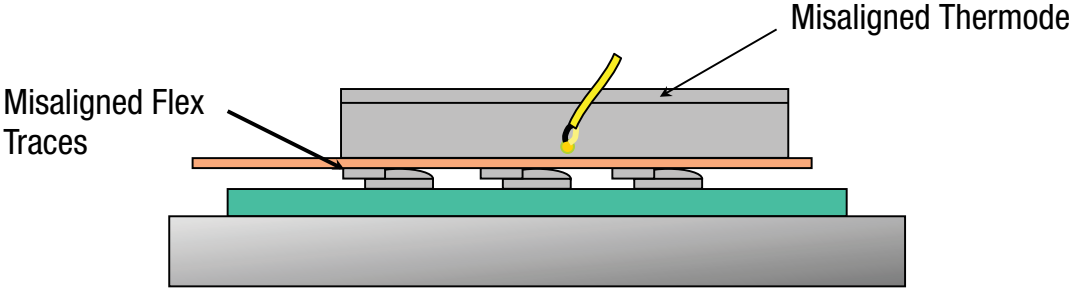
CONTACT

- Adjust thermode to be co-planar with all contacts to be heated
- Uneven contact will cause uneven heat transfer resulting in cold solder joints
- Adequate support under reflow area is required
- Test for co-planarity with Pressure Sensitive Paper or Burn Test



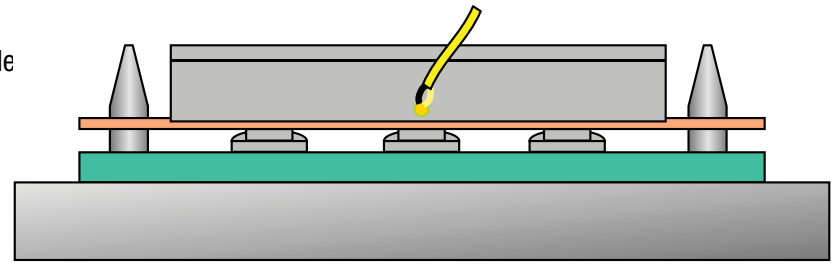
CONTACT

- Misalignment of Flex to PCB can cause short circuits
- Misalignment of Thermode can cause uneven heating and inconsistent results
- Proper part and tooling design is critical to success



MATERIALS

- Part Design, Material Control, and Materials Handling are critical:
  - ✓ Flex Circuit
  - ✓ PCB
  - ✓ Flux
  - ✓ Solde

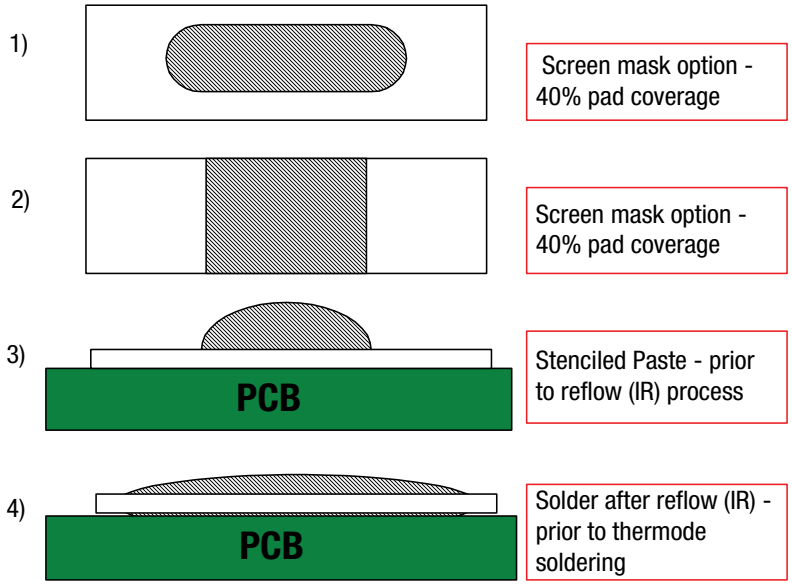


SOLDER DEPOSITION METHODS:

Primary Operation	Secondary Operation	Notes
Silkscreen Solder Paste	Reflow Oven	Can result in excess solder if volume is not controlled
Hot Dipping	Hot Air Leveling	Air knife must be very clean
Electro-plating	May be required to increase solder volume	Most accurate, but minimum solder volume, expensive
Apply Solder Paste	None	Many particles will not melt, this method is not advised
Wave Solder	Hand Touch-up (If Required)	Variations in solder volume can be present

MATERIALS

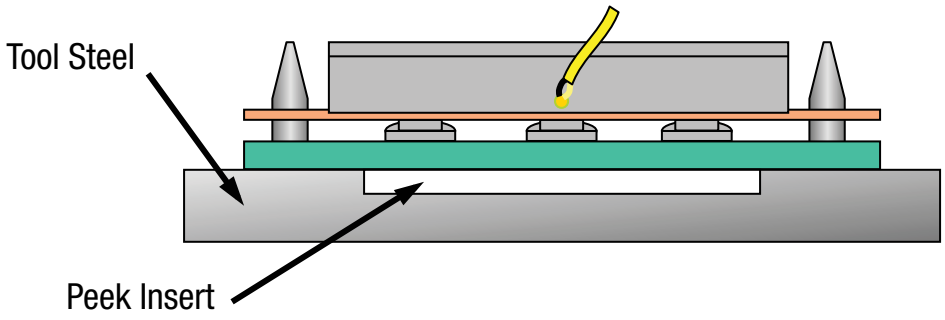
Recommended Volume for Silk-screening 0.127 mm (.005 inches) Thick Solder Paste:



HEAT SINKS

✓Avoid creating heat sinks

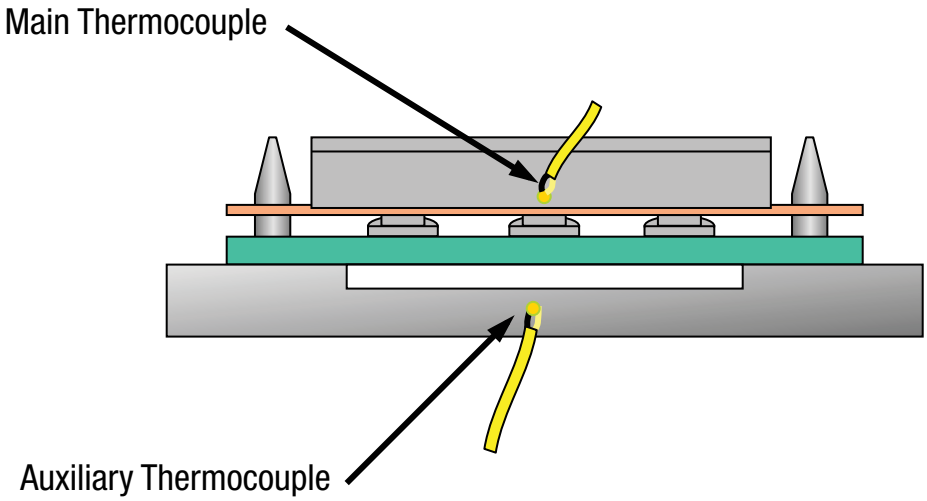
- Aluminum, brass, or copper fixtures conduct heat away from the thermode
- Tool Steel is typically used for fixtures
- Phenolic can be used, but will wear quickly
- Insert Peek material in tooling under reflow area
- Follow rules for Flex and PCB design
- Measure temperature of thermode face using Ultra-Flat Thermocouple



PROCESS MONITORING

❑ **Auxiliary Thermocouple:**

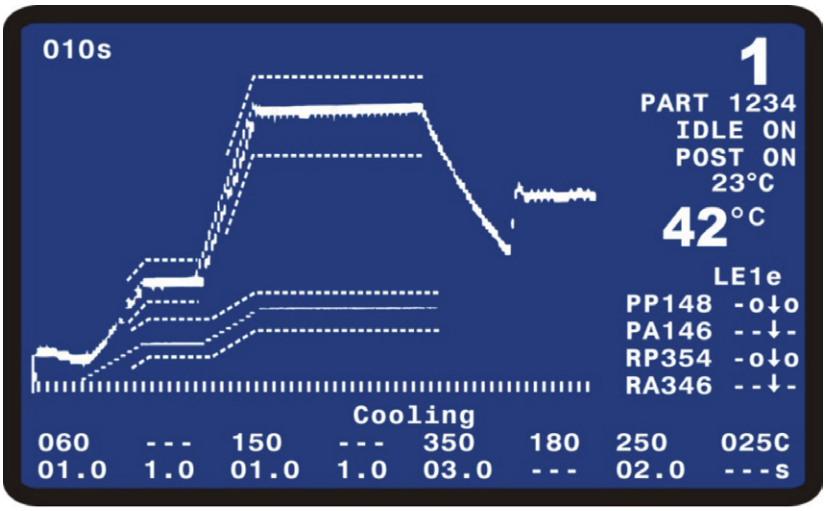
The auxiliary thermocouple can be used to monitor the temperature of the thermode during the reflow process to ensure that heat transfer occurred:



PROCESS MONITORING

❑ **Envelope and Numeric Limits:**

Limits can be programmed on the control unit to verify the consistency of the process:



INSPECTION

- Pressure is maintained as the joint is cooled. Therefore there is little chance of a dry joint occurring.
- The imprint of the thermode should be seen on the solder joint and be even in width and length. There should be visual evidence that reflow has occurred and when the parts are peeled apart the resulting joint will have a granular appearance over the soldered area.
- There should be no evidence of burning or delamination of the pads to board or flex.
- Where a single sided flex is used, there maybe marking or discoloration on the top of the polyimide but no burning or separation should be seen.
- Any flux residues can be cleaned after the reflow process.
- No clean, low residue fluxes do not require post cleaning.

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