Thermocouple Attachment

A Primer

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INTRODUCTION

I've yet to find anyone who enjoys instrumenting circuit boards with thermocouples. It is traditionally a painstaking, time consuming task, which can easily result in damage to the board when applying or removing the thermocouples. Yet despite these problems, thermocouples are the preferred choice for accurately monitoring the temperature of critical points on circuit board assemblies during the soldering process.
The alternatives, heat dots or crayons, IR sensors, or guessing, each have drawbacks. Heat dots or crayons show only the peak temperature they experience, (usually in unsuitably large 5 to 10°C increments), with no indication of the heating rate or time at temperature. They also can distort the heat absorption of the test area they cover, particularly if there is a significant component of radiant heating. IR sensors require careful adjustment for the emissivity characteristics of each different surface they must monitor. This is often done by carefully instrumenting the critical points on the board with thermocouples, then re- measuring each point with an IR sensor, and adjusting the corresponding readings to match. Also, the field of view may take in surfaces other than the one to be measured (example: the bare board surrounding a pad). Finally, if the board must be removed from the heat source to be IR monitored, the indicated temperatures will be a function of how long it has been away from the heat source.

Kapton Tape Thermocouple Attachment*

So when the time comes that you have to instrument a PCB with thermocouples, what you want is reliable thermal data and quick, easy, convenient installation that does not damage the PCB. To complicate things, some of your thermocouple sites may place restrictions on the installation method. For example, unsolderable surfaces such as FR4 board material or ceramic or plastic component bodies may preclude the use of high temperature solder. Tight locations on high density circuit boards can make Kapton* tape impractical, and accessing a component die through a small hole in the body can be a challenge.

Let's look at the different methods for attaching thermocouples, and how to implement them for best results. We'll also discuss their strengths, weaknesses and most suitable applications.

**Kapton is a registered trademark of E. I. Dupont de Nemours.*

Thermocouple Attachment Methods

First, a couple of general rules for obtaining reliable data from your thermocouples.

The thermocouple junction must make direct, reliable thermal contact with the surface to be monitored. Otherwise, there is an unknown thermal impedance between the thermocouple junction and the surface. This results in temperature readings more closely related to the material surrounding the thermocouple, than to the surface temperature. The extreme example is when Kapton tape loses its grip at oven temperature, and the thermocouple lifts off the surface and starts to sense the surrounding air temperature.

The mass of material surrounding the thermocouple junction, and holding it to the surface, should be minimal. The effect of this material is to add thermal mass to the junction, and insulation to the surface beneath the material, both of which cause the thermocouple to lag the true surface temperature when the oven temperature ramps up or down. This effect can show a 5° to 10°C lag when temperature is ramped at 2°C/sec, which means that the sharp temperature peak of the typical reflow profile can be understated by that much.

Now let's look at the pros and cons of the available thermocouple attachment methods. This will help in selecting the preferred method for particular applications and using it properly for the most reliable results.

High Temperature Solder

Typically, this is at least 93% lead solder with a melting point above 295-305°C, so it will not melt during reflow.

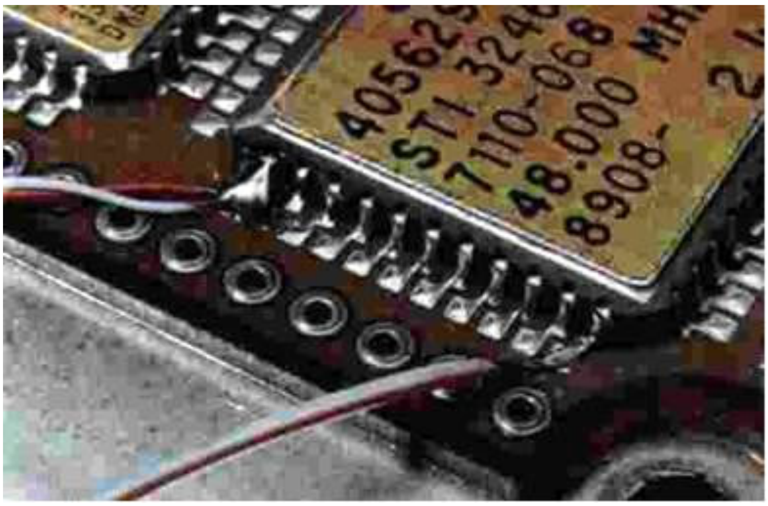

Figure 1: High Temperature Solder Thermocouple Attachment

Figure 1 shows a 50 mil pitch component with a properly installed thermocouple on the right. Note that there is almost no added solder.
The thermocouple on the left is poorly installed, with a large blob of solder that greatly increases the thermal mass of the leg.

PRO:

- Good thermal conduction minimizes the error if the thermocouple junction is slightly off the surface.
- Strong mechanical attachment is reliable for many profiles, making it well suited for test boards.

CON:

- Soldering requires considerable skill and time to make small, low mass, thermocouple attachments, without overheating and damaging the board, pad or component. This is aggravated by the fact that high temperature solder does not wet or flow very well, even with an active flux. It is also difficult to remove the high temperature solder completely, without damaging the component, the solder joint or the pad.
- This method can't be used to attach thermocouples to unsolderable surfaces such as ceramic or plastic component cases or FR4 board.
- It is difficult to apply to fine pitch component legs prior to reflow.

Adhesives

There are two general classes of material commonly used to adhesive bond thermocouples. One is accelerator or UV activated adhesives that set in seconds, but are only rated for around 120°C. They do not hold up well in reflow, and are more commonly used for wave solder applications.
Special high temperature, two part epoxies are rated up to 260°C, but require several hours at elevated temperature to cure.

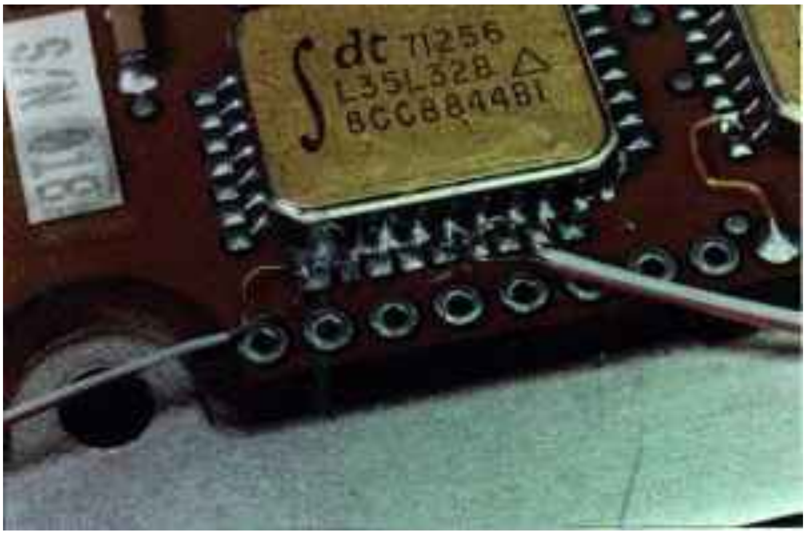

Figure 2: Adhesive Thermocouple Attachment

The thermocouple on the right in Figure 2 has been properly installed with a small amount of adhesive. The thermocouple on the left has an excessively large blob of adhesive

PRO:

- These products are easier to use than high temperature solder.
- The accelerator and UV activated products set quickly, to speed installation.
- High temperature, two part epoxies will withstand reflow temperatures for many cycles.
- Both products can attach thermocouples to unsolderable surfaces such as plastic or ceramic components or FR4 board. **CON:** (Accelerator or UV activated adhesives)

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- Their low temperature rating makes them prone to popping off during reflow, where peak temperatures are around 210°C.
- Their relatively poor thermal conduction makes it essential that the thermocouple junction be held securely against the surface to be measured while the adhesive is activated.
- They are usually easy to remove by "popping " them off with a knife. However, they do leave a film-like residue that is noticeable on FR4 and dark components, and can be difficult to remove. The most effective solvents, like acetone, also dissolve plastics, and can therefore damage circuit boards.

CON: (Epoxies)

- High temperature epoxy requires an oven cure of several hours. This is inconvenient, especially for quick trouble shooting. It also requires careful fixturing to insure that the thermocouple junction stays in contact with the surface to be measured, throughout the oven cure cycle. It is difficult to remove this material cleanly, without damaging the board or component.
- Quick curing epoxies like "5 minute" epoxy are rated in the range of 130°C, so they often pop off during reflow.

Adhesive Tape

High temperature adhesive tape such as Kapton tape is appealingly easy to use. However, care must be taken to ensure that the thermocouple junction is preloaded to maintain firm contact with the surface to be monitored. As there is no surrounding conductive material, (like solder), if the junction is even a thousandth of an inch off the surface, it will be reading primarily ambient air temperature, though somewhat influenced by thermal radiation.

One effective installation method is to bend the thermocouple wires into the shape of a small hook.

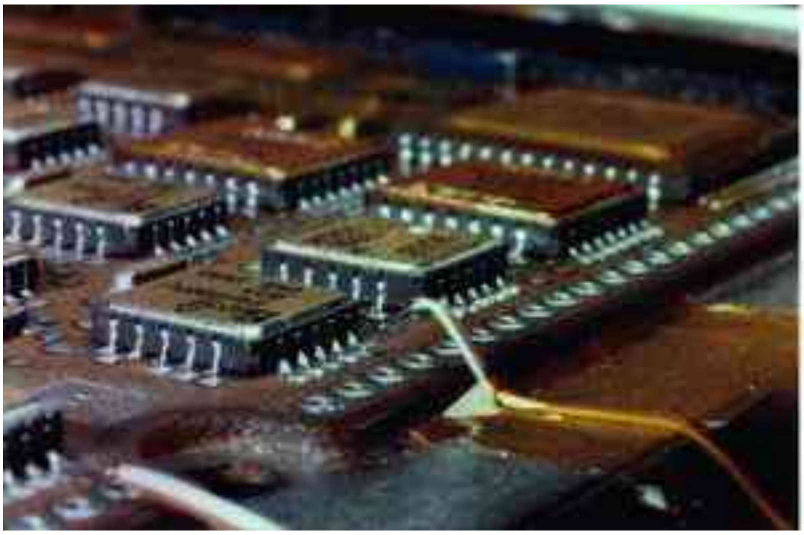

Figure 3: Thermocouple Held On Component Leg By High Temperature Adhesive Tape

Then tape the wire down just in back of the hook, so the junction is preloaded onto the surface, as shown in Figure 3.

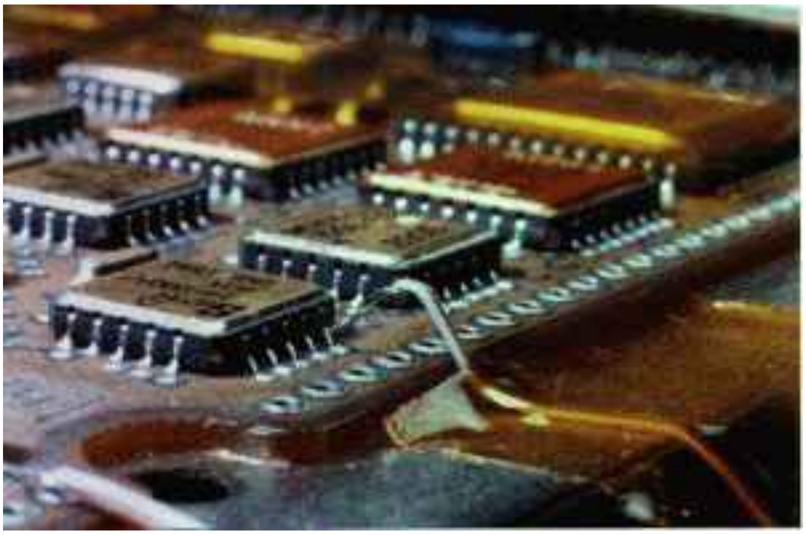

Figure 4: Tape Relaxed After Heating, Allowing The Thermocouple To Lift Off The Leg

Figure 4 shows how the adhesive on the tape can relax its grip at oven temperature and allow the thermocouple junction to lift off the contact surface.

PRO:

- In most situations tape is quick and easy to use. Thermocouples may be taped to any type of surface.

CON:

- Tape's adhesive grip weakens with increasing temperature. Consequently, at reflow temperature it relaxes the preload on the thermocouple, which can allow the thermocouple to lose contact with the surface being monitored, and read ambient temperature instead of surface temperature. It can be difficult or impossible to tape a thermocouple down reliably in tight places, such as between components.

Mechanical Attachment Two methods for mechanically attaching thermocouples represent extreme opposites - paper clips and screws. The third is TEMPROBE™*, a mechanical thermocouple support device, designed expressly to provide quick, reliable temperature readings on any type of surface.

*Figure 5: **The Temprobe™** has been newly redesigned to handle the high process requirements of Lead-Free.*

Figure 5 shows this device clipped to the edge of a circuit board with the thermocouple tip on the leg of a 50 mil pitch component.
** TEMPROBE is a trademark of Saunders Technology, Inc.*

PRO:

- Paper clips are certainly quick and easy, and screws provide a very rugged and reliable thermocouple attachment. Both will repeatedly withstand oven temperatures.
- It is quick and easy to clip the mechanical thermocouple support device to the edge of a board, and to position its thermocouple tip anywhere on the board, even in tight spaces between components.
- Spring tension holds the thermocouple tip of the device firmly in contact with any type of surface, to sense its temperature accurately and reliably .
- The low thermal mass thermocouple tip provides the quick temperature response of a carefully soldered thermocouple.
- As the device requires no bonding, there is no board damage, and removal takes just seconds.
- The small diameter tip of the device can easily be inserted through a small hole in a component body to measure die temperature.

CON:

- Paper clips generally limit you to monitoring near the edge of the board.
- Wire clips do not provide a secure, reliable thermocouple attachment. If the wire is accidentally pulled during handling, it can move the thermocouple. Heavy duty spring type clips hold the wire more securely, but their thermal mass and IR shadowing effect can impede the normal heating of the section of board inside the clip. <
- Screws obviously damage the board. Also, their thermal mass, and heat conduction from the opposite side of the board and/or internal copper

layers can distort the indicated temperature.

Are You Getting Accurate Readings?

One objective of this paper is to point out that there are lots of things that can happen during the installation of thermocouples which can result in inaccurate temperature profiles, and potential board damage. There are several methods of cross checking your installation technique by comparing it with a reliable reference. Such a reference can be "heat dots", which change color at prescribed temperatures, a grid type surface thermocouple, a carefully soldered thermocouple or a mechanical thermocouple support device.

Heat dots have some drawbacks. They are usually available in 5 to 10°C increments in the temperature range of up to 250°C. Also, they cover a significant surface area, which can distort the heat absorption of that area, particularly if there is a significant component of radiant heating. The grid type surface thermocouple typically covers at least 0.5sq. in, so it can also distort the heat absorption of the surface it is monitoring. A fine gage wire thermocouple, carefully installed with a minimal amount of high temperature solder, is a good choice, as is the mechanical thermocouple support device. Both have quick thermal response, and do not alter the heat absorption of the surface they are monitoring.

A word of caution. When you are comparing two or more thermocouple installation methods, it is essential that the thermal characteristics of the material to which they are attached must be identical under each of them. The ideal arrangement is to attach them to the same pad.

If this cannot be done, be careful of differences between the test sites, like buried ground planes and large adjacent components. These can cause a difference in the thermal response of the sites. i.e.: When the ambient temperature is ramping up or down, one site may lead or lag the other. To check for this, reverse the thermocouples and repeat the profile. If the profiles are the same, then the test sites have the same thermal response, and the thermocouple comparison is valid.

Conclusions

So what's the best thermocouple attachment method for you? It depends on your application. To summarize:

- To get the most accurate reading of the surface temperature, be sure to have the thermocouple junction in direct contact with the surface, and, if you're using solder or adhesive, keep it to a bare minimum.
- Run a comparison test of your preferred thermocouple attachment method with a reliable reference, as described above.
- Quick setting adhesives are easy to use, but best suited to lower temperature applications such as the A side in wave soldering and in rework applications.
- High temperature solder and epoxy require considerable skill and time to install properly, and to remove without damaging the board, but will give accurate results for many profiles in reflow, IR, and wave solder applications. They are well suited for test boards, but require too much time and effort to install and remove for most rework purposes.
- Paper clips will repeatedly withstand oven temperatures, but are restricted to the edge of the board, and tend to be unreliable in maintaining good thermocouple contact.

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- Screws are rugged and reliable at high temperature, but seriously damage the board, and can induce error by conducting heat from the opposite side of the board or internal ground planes.
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- The Temprobe™ mechanical thermocouple support device is quick and easy to install and remove, without damaging the board or component, and gives accurate, reliable results in reflow, IR, wave solder and rework applications. It can also can be used on any type of surface, and can reach into tight locations anywhere on the board.