Reflow Soldering for the Radio Amateur

How to use modern production soldering techniques at home.

Jim Koehler, VE5FP

I've always been interested in homebrewing equipment and I think I have probably tried every form of electronic assembly at one time or another. As a young lad, I built crystal sets on wooden planks using wood screws to hold down components; this is the classic *breadboard* form of construction. After I got my first license in 1952, and for many years afterward, I constructed vacuum tube equipment in what was then the standard way — components mounted on a metal chassis with punched holes for tube sockets. When transistors came along in the late 1950s and early 1960s, I gradually moved in using printed circuit (PC) boards. Later, in my career as an experimental physicist, I designed electronic equipment using PC boards and oversaw the construction of complex electronic devices using these boards, all using through-hole mounted components.

After I retired, I continued to design and build equipment using PC boards but, despite reading an excellent introduction to amateur use of surface mounted components, I resisted using them for several years because it just looked to be too difficult.[1] Nevertheless, it was becoming apparent that the latest devices were likely to be only available in surface mounted packages.

I decided to see if I really could assemble surface mount components to a PC board. To my great surprise, I found that it is easier and quicker to assemble a PC board using surface mount components than it is using through-hole parts. If you're designing boards, there is the additional advantage that surface mount boards can be smaller, lighter and cheaper to fabricate because when having them made, you pay at a rate depending on the surface area of the board. Now I wouldn't dream of going back to through-hole components on a PC board.

It really is not difficult to acquire the necessary skill in hand soldering surface mount components if they are not too small; I try to design boards for 0805 sized resistors and capacitors; these are 0.08 × 0.05 inches length × width. With a fine-tipped soldering iron, a low-power dissecting microscope and a little practice, even my somewhat shaky hands, combined with 72 year old hand-eye coordination can do it quickly and reliably.

There is nothing I can add to the excellent instructions given by Sam Ulbing, N4UAU, in the earlier referenced article, except to say that high magnification, in the form of a dissecting microscope, is an invaluable aid. I find that 7 power is about right. The large distance between the board and the objective lens of the microscope means that you can easily manipulate soldering iron, solder and tweezers in the field of view. It is not the aim of this article to proselytize surface mount usage, however, but rather to describe how to go to the next step.

While it is easy to hand solder a board, it becomes a bit tedious if you decide to make the same board several times over, perhaps for friends or as part of a club project. That is when you start thinking about mass production techniques.

Reflow Soldering

Reflow soldering is the most common method of producing surface mount PC boards in commercial quantities. It is the technique that is universally used to make computer equipment, radios, MP3 players and, indeed, virtually all modern electronic equipment. You can see an example of the results of this method by looking inside any

Figure 2 — Inexpensive multimeter with type-K thermocouple probe.

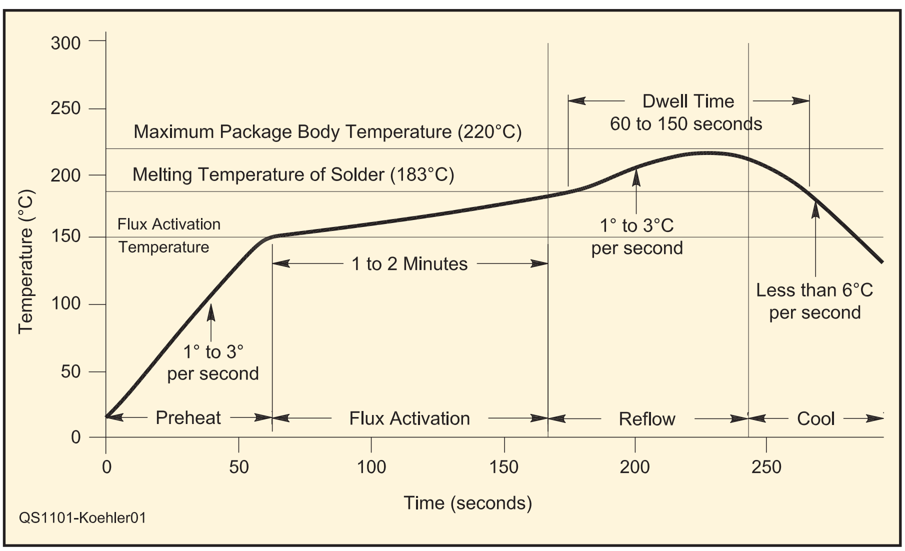


Figure 1 — Temperature profile redrawn from data in Altera Application Note AN081.

[1]Notes appear on page 35.

piece of mass-produced electronic hardware that has been built in the last 5 to 10 years.

Reflow soldering uses solder paste, a mixture of microscopic spheres of solder mixed with a semi liquid, viscous flux. A small dab of solder paste is placed on each pad of the PC board and then the components are all placed onto the pads. Finally, the board plus solder paste and components is placed into an oven. The oven heats the boards and components until the solder paste turns into liquid solder. The board is then allowed to cool and the solder solidifies again. Because all the soldering is done at the same time, the process can be very quick.

Of course, it is not quite that simple. The process of heating and cooling the board with its load of solder paste and components needs to be fairly closely controlled in order to get reliable results. Figure 1 shows the temperatures needed in a typical cycle of heating and cooling. As you can see, the board and its load are first heated quickly to a point close to the melting point of solder. It is then held at this temperature for a time to allow all the components to get to the same temperature — this is called the heat *soak* period. The oven is then raised to a temperature high enough to ensure that all the solder melts and, with the melted flux, forms a good bond. Then the whole assembly is cooled relatively quickly, but not so quickly that it will cause thermal stresses that could break some components. The whole process is over in just a few minutes.

The commercial ovens used for reflow soldering are large, complex devices costing tens of thousands of dollars. In them, the PC board travels on a conveyor belt through regions of different temperature in order to produce the temperature sequence shown in Figure 1. This is somewhat similar to the way pizzas are made in the big franchised pizza stores.

There are also smaller tabletop versions of reflow ovens, for amateur use or for small production lines, that go through a heating and cooling cycle with the PC board stationary.[2] I am going to describe how you can build an even simpler, but still usable, reflow oven in an afternoon and for little cost and trouble.

The Poor Man's Reflow Oven

One day, while shopping for groceries, I saw a pallet of Black and Decker toaster ovens (catalog number TR0964) in a local supermarket for $20 each. They appeared to be made of stainless steel, their power rating was 1.2 kW and the oven was not too large. It occurred to me that, with the aid of a simple electronic thermometer, one could easily approximate the type of heat cycle shown in Figure 1, without the complexity of a PID (proportional integral derivative) controller.

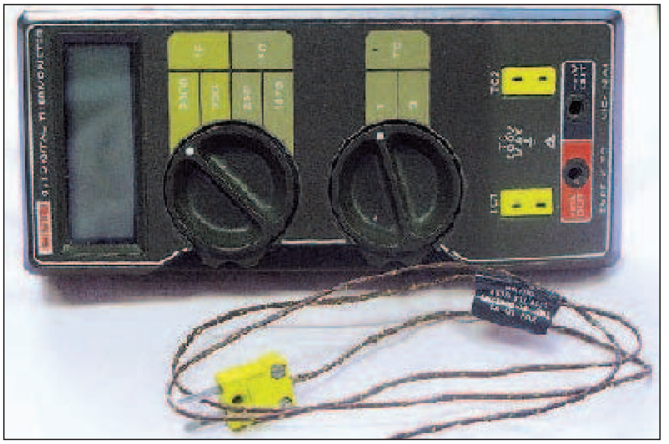


Figure 3 — Keithley electronic thermometer with type-K thermocouple probe.

Figure 4 — Tip of type K thermocouple from Keithley instrument with a pin for comparison.

Besides an electric toaster oven, you need an electronic thermometer. These are widely available at low cost. A few years ago, I bought a digital multimeter at a discount electronics warehouse in Phoenix that had a type K thermocouple temperature probe. It is shown in Figure 2. I have recently seen a similar one advertised online for about $25. On another occasion, I bought a used Keithley electronic thermometer, also with a type K thermocouple probe, on an Internet auction site for about $25 (see Figure 3).

The active part of these thermometers is a thermocouple, the tiny dissimilar metal junction at the tip of the probe as shown in Figure 4. As you can see, these probes are small and so require little heat to come to equilibrium with the temperature of the air. This means that the temperature of the probe tip is going to be close to the temperature of the air in its vicinity.

The idea I had was to drill a small hole in the back wall of the toaster oven and insert the thermocouple probe into it. Then, monitoring the temperature of the inside of the oven, I would just manually turn the oven on and off in order to approximate the heating profile needed to do the reflow soldering. I tried it, it worked wonderfully and it was simple to do.

Modifying the Toaster Oven

The toaster oven I bought was made by Black and Decker. It has two heating bars inside the oven, one at the top and one at the bottom. Both have a metal strip between them and the interior of the oven to provide some shade from the element so that things put inside the oven will not be heated directly by radiation but, instead, by convection of the air.

I made a small bushing from a piece of Teflon that I placed into a ¼ inch diameter hole I'd drilled in the back wall of the oven. This bushing is just to protect the insulated covering of the wire to the thermocouple probe from chafing at the edges of the hole. A small hole was drilled in the bushing to allow the probe to be inserted into the oven. The bushing is shown in Figure 5. Figure 6 shows the bushing inserted into the back wall of the oven. If you can't make a similar bushing, you could get the same result with a piece of sheet Teflon bolted to the rear panel and with a small hole in it going through a larger hole in the metal wall.

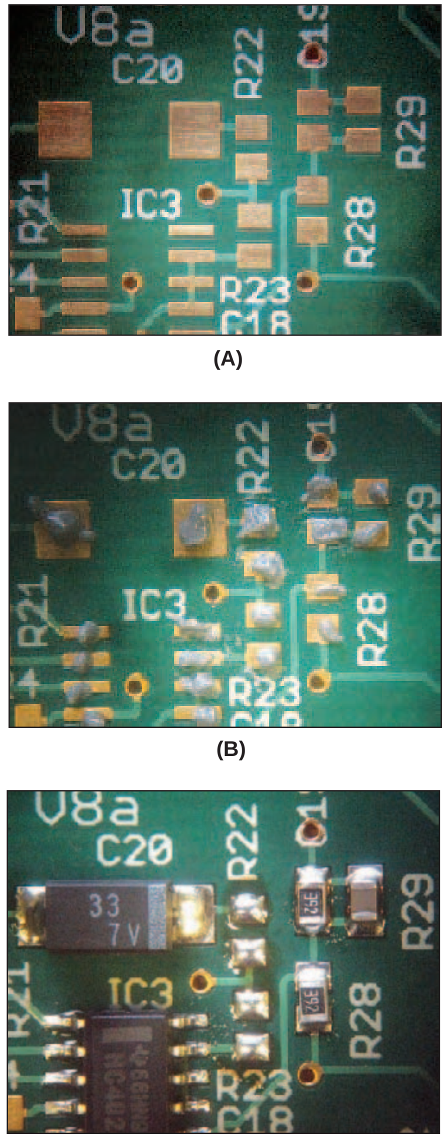
The oven door had a hook that connected to a sliding grill so that when the door was opened it would pull the grill forward slightly for easier access. I didn't want to have the grill move when the door was opened because I didn't want to shake the board while the solder was melted. I bent the hooks over so that they would not interfere with the grill. I did not use the metal pan that came with the oven.

The probe of the thermometer is inserted into the hole in the bushing and the wires are bent so that the junction at the tip of the probe is located about ½ inch above the surface of the grill and near the center. Circuit boards will be placed just under this probe tip. That completes the preparation of the oven.

Applying the Solder Paste

Solder paste can be bought in small quantities from suppliers such as Digikey, Mouser or Allied. If you order it, you will get a warning that it can only be shipped by courier because the usable lifetime of the paste is short unless it is refrigerated. My impression is that this warning is there because the viscosity and texture of the paste are important in the commercial methods used to put it on the pads of the PC boards. Also, if the temperature gets too warm, the little balls of solder tend to separate from the flux paste in which they are embedded. For an amateur, the exact viscosity is not

Figure 5 — Teflon bushing ready to be inserted in hole in rear of oven.



(A)

(B)

(C)

Figure 7 — Soldering the PC board in three stages. At (A) the bare board, at (B) the board with solder paste applied by hypodermic syringe, at (C) the board with the components in place after reflow soldering.

important. I have had the same 35 gram tube of solder paste in my refrigerator for several years and it seems to work just as well today as it did when I bought it. I probably have made several dozen boards and still have only used a fraction of the 35 grams.

In commercial houses, solder paste is placed on the board by using stencils with cutouts over all the pads that are to be soldered. Then solder paste is squeegeed over it in the same manner as silk screen printing is done. A method used in large scale production is to have a machine controlled head move over each pad on the PC board and dispense a fixed amount of solder paste through a nozzle. Neither of these methods is really suitable for an amateur who wants to make a few boards.

I bought a small hypodermic syringe at a drug store and ordered a few dispensing tips from Digikey (**www.digikey.com**). I found that a tip with a #18 AWG hole was suitable for putting solder paste onto the pads for 0805 sized components — this tip has Digikey part number KDS18TN25. I take the tube of solder paste from the refrigerator and place a small amount into the hypodermic syringe with the dispensing tip on it. I then place the tube back into the refrigerator for future use.

Then looking at the board with my dissecting microscope and using the hypodermic syringe with the dispensing tip, I place a little dab of solder paste onto each pad. I find that the pressure needed to dispense a tiny bit of solder paste onto a pad with the hypodermic syringe is quite a lot unless you let the solder paste warm up a bit. It doesn't have to be very hot; if you hold the syringe in your hand for a while so that the solder paste comes up to body temperature, it seems to work just fine.

Figure 7 shows a sequence of three photos of a small section of a PC board. In 7(A), you see the bare pads where surface mount components will be placed. In 7(B), you see a small blob of solder paste applied to the pads using a hypodermic syringe as described above. Figure 7(C) shows the resulting bond to the surface mounted components after the oven has been used as I will describe in the next section. The solder joints are quite nice, clean and electrically sound.

Figure 6 — Teflon bushing in the back of the oven.

Calibrating the Oven

Before you use the oven, it is necessary to make one calibration measurement. If the oven is turned on, the temperature will start to rise and will finally get to a relatively constant rate of increase of temperature; so many degrees per second. If it is then switched off, the temperature inside the oven will continue to rise because of the thermal inertia of the heating elements. It is necessary to measure how far the temperature *coasts* after turning off the oven. So, you need to do the following:

- Turn on the oven heating elements,
- Monitor the temperature and, when the temperature gets to 180°C,
- Turn off the heating elements and observe the maximum temperature that the oven reaches.

Make a note of the amount of this temperature overshoot. For example, if you turned the oven off at 180°C and it reached 195°C, then the overshoot was 15°C. This amount of overshoot will be approximately valid for the temperature region around 180°C.

Making Your First Reflow Soldered Board

First, you need to prepare the PC board with solder paste, as described above, put the components in their places and then put the board into the oven, being very careful not to jostle the components from their places on the board. Then carefully close the oven door and turn on the heating elements. Watch the temperature increase and turn the heating elements off when the temperature gets to 170°C minus the overshoot (for example, if the overshoot is 15°C, then turn off the elements at 155°C). As you now watch the temperature, it will coast up toward 170°C.

This pause in the heating will produce a plateau in temperature similar to the one in Figure 1 before the peak. As the temperature starts to slow down in its approach to 170° but a few degrees before it actually gets there, you can turn on the heating elements again and the temperature will start to rise again. Watch the temperature and when it gets to 220° minus the overshoot (in our example, this would be 205°C), turn off the heating elements again. Now, the temperature should coast up to 220°C and then start to fall. You will now have gone past the temperature peak shown in Figure 1. As it keeps cooling, when it gets down to 160°C, you can open the door to the oven to allow the board to cool off more quickly. You're done! When the board has cooled off enough to handle, take it out and inspect the solder joints to make sure they are all good — they should be.

The reflow soldering process takes just a few minutes so it is a good way to make a large number of boards in a batch. You do not have to wait till the oven cools down to room temperature between boards. As soon as it gets cool enough so you can put in another prepared board without burning yourself, you can start the process again.

Good luck and happy reflow soldering!

Notes

[1]Sam Ulbing, N4UAU, "Surface Mount Technology — You Can Work with It," *QST*, Apr 1999, p 33. This is part one of a four part article.

[2]Elektor SMT Reflow Oven, Elektor Shop, **www.elektor.com/shop**.

Photos by the author.

ARRL International Member Jim Koehler, VE5FP, was first licensed in 1952 at age 15. He graduated from the Australian National University with a PhD in astronomy and went on to become a professor of physics and engineering physics at the University of Saskatchewan in Canada. He taught classes in instrumentation design and conducted research in upper atmospheric physics until he retired in 1996.

Jim now lives on Vancouver Island where he indulges in his hobbies of electronics, model aircraft and photography. You can reach Jim at 2258 June Rd, Courtenay, BC V9J 1X9, Canada or at **jark@shaw.ca**.

Going Once, Going Twice, GONE!

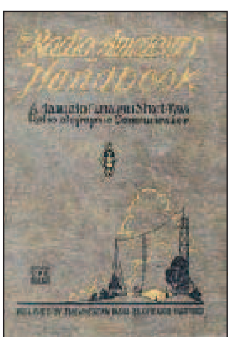
In its five year history, the ARRL On-Line Auction has raised almost $200,000 to promote educational activities.

S. Khrystyne Keane, K1SFA
ARRL News Editor

With almost 200 items up for bid — and almost 1000 bids placed — the Fifth Annual ARRL On-Line Auction closed on October 25 with winning bids on every auction item. ARRL Business Services Manager Deb Jahnke, K1DAJ, was happy with the responses the auction received during its run. The generosity of many donors, Jahnke says, made it possible for the auction to offer a diverse list of items that included transceivers, ARRL Lab-tested and reviewed equipment, vintage gear, one-of-a-kind treasures and mystery "junque" boxes.

Items that appeared in *QST*'s Product Review column included an RF Concepts Alpha 9500 HF Linear Amplifier, a Yaesu FTdx9000MP and an ICOM ID-880H Dual Band Transceiver with D-STAR. In all, 38 product review items were sold. The Yaesu FTdx9000MP attracted five bids and sold for the highest amount in the Auction — $7680. Among the items in this year's Auction was a rare First Edition *ARRL Handbook*. Originally listed for $40, this collectible book from 1926 sold for $775 after garnering 22 bids, the most in the auction!

Among the most popular items in this year's auction were the three "junque boxes," donated by the ARRL Lab. Garnering 38 bids between them, these Amateur Radio treasure troves went for more than $200 each, raising almost $650. "We featured the 'junque boxes' in our first auction, and they proved to be extremely popular with our bidders," Jahnke said. "We've brought them back each year, and once again, we couldn't believe how they were all the rage. I can't even begin to describe how well received they were this year." The contents of each box are a mystery, Jahnke said, known only to the ARRL Lab staff. "And they won't tell!" she said.



After 22 bids, this First Edition *ARRL Handbook* from 1926 went for $775.

Jahnke said that donors also added to the Auction excitement by donating gear and products and services. Thanks to our 2010 ARRL On-Line Auction donors: A&A Engineering, ASA Inc, Barker Specialty Company, Engraved Memories, Hotpress Ham Hats, K8RA Iambic & Single Lever CW Keys, KB3IFH QSL Cards and TNT Electrical Trades Gift Store. Special thanks to Hi-Q Antennas, the ARRL On-Line Auction Golden Gavel Sponsor.

Proceeds from the auction benefit various ARRL education programs, as well as fund efforts to license new hams, programs to strengthen Amateur Radio's emergency service training and the creation of new instructional materials. The proceeds also allow the League to offer continuing technical and operating education.