Easy Bake Solder Reflow Oven

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Features

- 400 Watt, 120 VAC, resistive disk heater
- Zero-cross, AC solid state relay (drives heater)
- Type J thermocouples (temperature feedback)
- 12 V bipolar motor (drives convection fan)
- ATmega168A microcontroller
- fused, snubbed, and earth grounded (electrical safety)
- 7-segment display & push-buttons (set point programming)
- RS232 and AVR ISP connections available

Introduction

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2.1 Standard Reflow Profile

A typical solder reflow profile is shown in figure 1. The optimal peak temperature depends on package thickness and, more significantly, on the use of leaded solder.

$$T_p = \begin{cases} 220 - 235^oC & \text{Leaded solder} \\ 245 - 260^oC & \text{Pb-free} \end{cases}$$

$$t_p = \begin{cases} 20s & \text{Leaded solder} \\ 30s & \text{Pb-free} \end{cases}$$

Easy Bake Oven was designed from the ground-up as a thermodynamic system for faithfully producing these reflow profiles.

2.2 Conceptual Design

Many electronics hobbyists have not taken a thermodynamics course, so this section will describe the mechanisms of heat transfer and why Easy Bake is a convection oven.

Heat, denoted Q with units Joules, is the thermal energy of a system. From a microscopic point of view, heat is the kinetic energy of each particle, summed over every particle in the system. Temperature, T, is a measure of heat density. A glacier has an enourmous amount of heat, but low heat density.

In general, there are three mechanisms of heat transfer: *conduction*, *convection*, and *radiation*.

Conduction of heat is caused by molecular interactions, such as vibrations in the bonds of solids or elastic collisions between molecules of air.

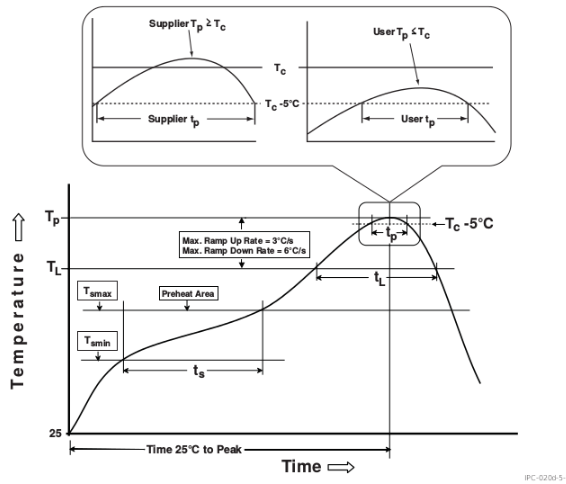

Figure 1: Typical Solder Reflow Profile; taken from JEDEC standard J-STD-020D.1

The empirical relation for conduction is Fourier's Law, which says the rate of heat transfer is proportional to both the difference in temperature, and the media.

$$\vec{q} = -k\vec{\nabla}T$$

where $\vec{q}$ is the rate of heat transfer per unit surface area and k is thermal conductivity of the medium. In integral form,

$$\frac{dQ}{dt} = -k \oint_S \vec{\nabla}T * d\vec{A}$$

And in the one-dimensional case,

$$\frac{\delta Q}{\delta t} = -kA\frac{\delta T}{\delta x} \qquad (1)$$

Convection is the second mechanism of heat transfer, involving the bulk movement of particles driven by diffusion.

Every air molecule is moving in a random direction with random kinetic energy, but a region of air with higher average kinetic energy (temperature) will see more molecules leaving than entering, because those leaving are moving faster than those entering.

Note that in convection, no molecules gain or lose energy; molecules of different energy simply trade places.

A lot of resources say that Newton's Law of Cooling is the empirical relation for convection, but I am skeptical. Nevertheless, here it is:

$$\frac{dQ}{dt} = hA\Delta T \tag{2}$$

where h is the heat transfer coefficient with units W/m^2K and ΔT is the temperature difference between two bodies.

Radiation, the third mechanism of heat transfer, is more familiar for electrical engineers. In any atomic or bonded material, electrons have discrete amounts of energy based on the wave patterns that can exist for the atomic geometry. When an electron spontaneously falls to a less energetic pattern, the energy is emitted as a photon of light.

The classis, physics–history example is black body radiation, when a metal is heated to high temperature and glows. A more modern example is the LED.

The governing relation for radiation is the Stefan-Boltzmann Law, which says that the total energy radiated, over all wavelengths and per unit surface area, is proportional to the fourth power of the body's temperature.

$$j^* = \sigma T^4 \tag{3}$$

where σ is a proportionality constant derived from other constants of nature.

Mechanisms & Media Usually one mechanism of heat transfer is dominant in a particular medium, so much so that we can ignore the other two. Typically this means conduction in solids, convection in fluids,[1] and radiation in air. However sometimes the picture is more complicated, including two cases in an oven.

1. At the boundary of metal and air, where conduction and convection are both important.

2. In a thermocouple loop, where thermal diffusion (convection) of electrons in metal is more important to us than conduction.

Ovens seek to transfer heat to an object through the air around it, so typically either *radiation or convection* is the dominant functional mechanism and conduction exists only in detrimental ways, like heat leaking out of the oven frame.

Radiation or Convection

IR radiation is the primary mechanism used in most hobbyist reflow ovens, simply because hobbyists are hackers–and your kitchen toaster oven is just begging to be hacked.

Toaster ovens have the right size, temperature range, and heating rate; however, IR radiation tends to cause uneven heating. For example, black IC components may absorb more energy while solder reflects and some solder may not lie in the IR lamps' line-of-sight.

Getting an IR oven to solder correctly is more of a religion than a science. You'll worry about things like "heat shadows" caused by dark spirits. Fires might break out. Anyway, if you're not a Baratheon, and you don't want to sacrifice your firstborn PCB to the Lord of Light, then a convection oven is the way to go.

[1] Note that thermodynamic fluids include liquids and gasses.

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