Design and Construction of a Reflow Soldering Oven

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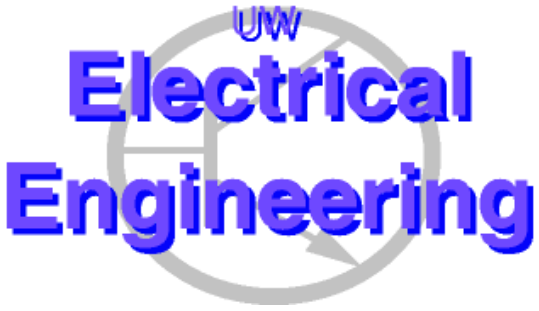

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DESIGN AND CONSTRUCTION OF A REFLOW SOLDERING OVEN

PREPARED BY THE SUPER HIGH INTELLIGENCE TEAM:

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JUNE 2, 2006

Dedicated to:

All those great souls that have touched our lives…

…and in doing so made them better.

EXECUTIVE SUMMARY

Within this summary, the goals, methods, and results of the design and construction of a reflow soldering oven will be discussed.

The goal of this project was simply to produce a reflow soldering oven for the Professor Blake Hannaford's Biorobotics Lab at the University of Washington. It had to track a temperature profile to produce superiorly soldered joints on surface mounted components. The development team decided to convert a conventional toaster oven to this purpose. While initially only for one particular lab, the customer decided to transfer the oven to the entire electrical engineering department for general use. It now is located in Bill Lynes laboratory.

The physical construction of the toaster oven was key in the design process. After all, all the transfer functions and modeling would be based on the oven's physical properties. Modifications included removing the dials and much of the internal circuitry. Only three holes were made into the oven case. Two of these holes accommodated the temperature sensor while the last allowed for connections to be made with the solid-state power relay. Later, a protective box was bolted into the side of the toaster to house the relay, circuit boards, and provide for an attachment point of an I/O card.

Once the oven was ready, testing was conducted to determine the various parameters in its mathematical model. These measurements included the rise time of the oven, the time delay in the heating elements, and the oven's heating/cooling rate. At the same time, modeling was done with estimated parameters in preparation for arrival of the actual. Simulations were done on the step and ramp responses of the oven with these estimated parameters. When the actual parameters were determined, they were input into the pre-existing models and simulated as well. Overall, the simulations showed that the oven was capable of accomplishing its performance criteria.

Actual tests on step inputs showed the oven's response to either be underdamped with large ring or overdamped with a large settling time. Ramp inputs did not perform well either. Both inputs also never fully utilized the limits of the oven so the control was split between open and closed loop. During the rising of the temperature open loop would be used to turn the oven "all on" such that the minimal rise time could be reached. In between rises, during areas of relative plateaus, a closed loop controller was used to careful control the temperature. At the end of the process, the open loop control was shutdown the heating elements.

Cooling proved to be a concern with the oven. While a convection fan distributed heat equally throughout the oven, it did not expedite cooling when the heating elements were turned off. Therefore, it was decided that a small level of user input would be needed. Through a graphical user interface (GUI), the user would be told to open the oven door to help cool the interior of the oven and any parts therein.

Programming was done to create the controllers in MATLAB. In addition, the GUI was also done in MATLAB. A small amount of circuit design was also done to integrate all the hardware together.

Ultimately, the results of the oven were very good. The oven was used to solder the boards of another development team in charge of a shaker table. Though slightly overcooked, their boards worked perfectly. Upon further refinement of the temperature profile, another board belonging to Professor Eric Klavin's Self Organizing Systems Lab was also done—this time with no sign of board discoloration. In all cases, the solder joints were comparable to those done in a professional setting and no difference between the two was observed.

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INTRODUCTION

Reflow solder is used to attach surface mounted components to a circuit board. The desired effect is adherence of these components to the board by melting the solder particles in the applied paste, allowing their surfaces to wet and join together, and finally solidifying as soon as the heat is removed. Resulting from this process is a strong metallurgical bond between the components and the board. The process is also faster and less expensive than soldering individually components by hand with an iron. It is therefore economically practical to obtain such reflow soldering ovens if their capabilities are used with relatively high frequency.

CUSTOMER

The organizational customer for the reflow oven was the Biorobotics Lab of the Electrical Engineering Department at the University of Washington. The points of contact were Professor Blake Hannaford, Phil Roan, and Jesse Dosher. The purpose of this project was to develop a reflow soldering oven for printed circuit boards suitable for use in small batch prototyping in Professor Hannaford's Biorobotics Lab at the University of Washington. The device may be used by other laboratories as well. It allows for an adjustable temperature profile via a graphical user interface on a connected computer.

PERFORMANCE CRITERIA

The project team developed a reflow soldering oven using a domestically available toaster oven and temperature controller, which was also designed and constructed. Further, the required temperature cycle calls for accurate control and temperature changes in the range of 20 to 50 °C per minute. The oven must also be large enough to accommodate small PC boards and reach temperatures high enough to melt a range of solders. Finally, the oven must be able to cool with sufficient speed in order to avoid damage to the electronics on the board being soldered. A graphical user interface will also be developed to aid the user in the use of the oven.

A generic temperature profile of the oven with respect to time is shown in Figure 1-1. The profile was also customizable. That is, preheat, flux activation, reflow, and cool times were to be adjustable.

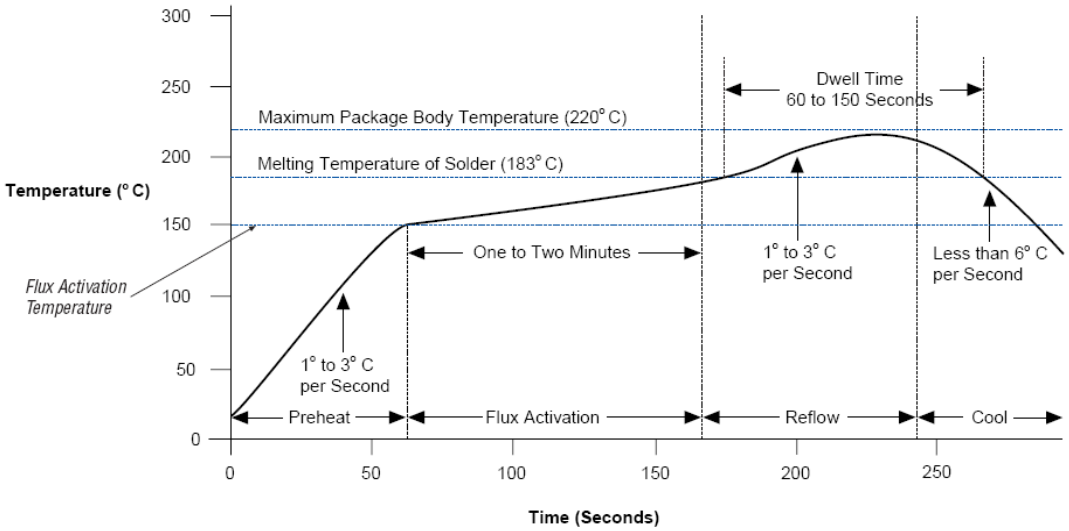

Figure 1-1: Temperature Profile for Convection Reflow[1]

PLANT AND CONTROLLER IDENTIFICATION AND DESCRIPTION

For the reflow soldering oven, the heating elements will be the primary plant as this project involves controlling the heat of the system. If the oven is unable to cool relatively quickly, then the added fans will be the secondary plants. In place of fans, simply opening the door may suffice for cooling. For both of these systems, controllers may necessary and the systems will be placed in unity feedback creating a closed loop system.

A temperature sensor also makes an appearance in the overall system and is integral in the control process. Lastly, an analog-to-digital converter will be used to convert the sensor readings into digital data for a computer to process.

COST AND SCHEDULE CONSTRAINTS

Available budget was limited to roughly 200 USD. The oven was to be delivered by the beginning of June 2006. No real schedule constraints were foreseen. Time, in the magnitude of one to two weeks, was all that was required for parts to arrive. The oven itself was procured in relatively little time once a quick trade study was completed. The bill of materials is shown in Table 1-1.

Table 1-1: Bill of Materials for Reflow Solder Oven

Item	Description	Cost (USD)
Toaster Oven	Black and Decker Convection Toaster Oven, Black	40
Power Relay	Solid State Power Relay with Large Heat Sink, Used	30
Thermocouple	T-Type Digikey Thermocouple	39
Conditioner	K-Type AD595 Digikey Conditioner	20
Protoboard	Used	15
Op-Amp	Chip Contains Four Op-Amps, Borrowed	0
I/O Card	USB 1208FS I/O Card, Borrowed	120
	Total Cost Excluding Barrowed Items (USD)	***144***

[1] Altera Corporation. "Reflow Soldering Guidelines for Surface-Mount Devices." June 2002. Version 4.

SYSTEM INPUTS AND INTERFACES

Inputs to the system will be the desired temperature and error signal upon taking a difference with respect to the temperature sensors. The output is a pulse-width modulated (PWM) wave to the heating elements and possibly a step output to the fans. The width of the PWM signal varies depending on the desired temperature. The software system interface consists of a start button, profile-adjust dial, and temperature display. It was implemented in MATLAB but will be made into an executable for convenience.

PROJECT PLAN

The goal of the project is to develop a reflow soldering oven for printed circuit boards suitable for use in small batch prototyping. It will allow for an adjustable temperature profile via a graphical user interface on a connected computer. The organizational customer for the reflow oven is the Biorobotics Lab of the Electrical Engineering Department at the University of Washington. The points of contact are Professor Blake Hannaford, Phil Roan, and Jesse Dosher. This project will develop a reflow soldering oven using a domestic toaster oven and professional grade temperature controller. Further, the required temperature cycle calls for accurate control and temperature changes in the range of 20 to 50 °C per minute. The oven must also be large enough to accommodate small PC boards and reach temperatures high enough to melt a range of solders. Finally, the oven must be able to cool with sufficient speed in order to avoid damage to the electronics on the board being soldered. A graphical user interface will also be developed to aid the user in the use of the oven. The work breakdown for the design and construction of the reflow solder oven is shown in Table 1-2.

Table 1-2: Reflow Solder Oven Work Breakdown

Task No.	Task	Lead	Start Date	End Date	Dependant Tasks	Prerequisite Tasks
1.0	Project Plan	All	3-Apr	7-Apr	All	N/A
2.0	Research of Professional Solder Techniques	All	8-Apr	11-Apr	2.1	N/A
2.1	Controller Specification Derivation	All	11-Apr	14-Apr	3.0, 4.2, 6.1	2.0
3.0	Hardware Research	Josh, Keith	11-Apr	13-Apr	3.1	2.0, 2.1
3.1	Hardware Request	Josh, Keith	13-Apr	14-Apr	3.2	3.0
3.2	Hardware Reception	N/A	14-Apr	21-Apr	4.0, 5.0	3.1
4.0	Plant Transfer Function Determination	Solomon, Clement	29-Apr	2-May	4.1	3.2
4.1	System Modeling	Solomon, Clement	3-May	5-May	4.2	4.0
4.2	Controller Design	Solomon, Clement	6-May	12-May	6.0	2.1, 4.1
5.0	Hardware Assembly	Josh, Keith	22-Apr	25-Apr	5.1	3.2
5.1	Computer Interface	Keith	26-Apr	28-Apr	7.0	5.0
6.0	Control Software Development	Josh	13-May	19-May	7.0	4.2
6.1	GUI Development	Josh	13-May	19-May	7.0	2.1
7.0	System Testing	All	20-May	23-May	7.1	5.1, 6.0, 6.1
7.1	System Revision	All	24-May	30-May	8.0	7.0

8.0	Report Compilation	Clement	25-May	1-Jun	N/A	All

The task descriptions are discussed below.

1.0) Project Plan: Determine objective, tasks, and path of completion for the project.

2.0) Research of Professional Solder Techniques: Determine necessary hardware components and techniques for reflow soldering.

2.1) Controller Specification Derivation: Determine rise time, overshoot, system order, etc.

3.0) Hardware Research: Find hardware capable of achieving specifications.

3.1) Hardware Request: Place order for delivery of all necessary hardware.

3.2) Hardware Reception: Final procurement of all necessary hardware.

4.0) Plant Transfer Function Determination: Run tests to determine the transfer function of the toaster oven.

4.1) System Modeling: Use MATLAB to build a realistic model of the system.

4.2) Controller Design: Use MATLAB and associated tools to build a controller for the toaster oven.

5.0) Hardware Assembly: Make necessary modifications to toaster and implement a sensor.

5.1) Computer Interface: Connect toaster oven to computer via an interface so that software can run from the computer to control temperature.

6.0) Control Software Development: Build the controller in MATLAB.

6.1) GUI Development: Build a GUI to interface with the toaster oven so that a user does not need to deal directly with code. Eventually there should be an executable.

7.0) System Testing: Test the hardware and software for functionality.

7.1) System Revision: Troubleshoot and debug problems in the system.

8.0) Report Compilation: Compiling the report from previous milestone reports detailing the specifics and development of the final product.

For task dependencies, see Table 1-2.

The development group consists of four senior undergraduates in Electrical Engineering. Their skills are rated below in Table 1-2. They are rated on a scale from 0 to 3. Zero having absolutely no ability in that area whatsoever and three, having achieved complete and utter mastery.

Table 1-3: Rated Skills of Reflow Solder Oven Personnel

	Electromechanical Hardware Skills	Computer Skill	Electronics Skill	MATLAB Skill	Theoretical Ability
S. Gebre	2	2	2	3	3
K. Johnson	2	2	2	1	1
W. Russell	3	3	2	2	1
C. Sun	1	2	2	2	2

In addition to the personnel skills, the estimated skill requirements for the tasks listed in Table 1-2 are shown in Table 1-4.

Available budget is limited to roughly 200 USD. However, private funds will be accessed if need be. The development team will rely partly on sampled products in the construction of the reflow solder

oven. Such components will take several weeks to arrive. However, the oven itself can be procured in little time at a cost exceeding no more than 50 USD. A trade study will be conducted by contractors to determine the best brand and model.

The development team will utilize laboratories in Sieg Hall and the Electrical Engineering Building on the University of Washington campus. These facilities are believed to be ample in available space and no conflicts with other groups are expected.

Table 1-4: Skill Requirements for Development Tasks

Task No.	Electromechanical Hardware Skills	Computer Skill	Electronics Skill	MATLAB Skill	Theoretical Skill
1.0	0	0	0	0	2
2.0	0	0	0	0	1
2.1	2	0	1	0	2
3.0	2	0	1	0	2
3.1	0	0	0	0	0
3.2	0	0	0	0	0
4.0	3	0	3	0	3
4.1	0	0	0	2	3
4.2	0	0	0	2	2
5.0	3	0	3	0	1
5.1	1	2	2	2	1
6.0	0	3	0	3	2
6.1	0	3	0	3	1
7.0	1	1	1	1	1
7.1	3	3	3	3	3
8.0	1	1	1	1	1

All group members will be responsible for entering tasks in the online project management plan. With regard to task status, group members will update their own status. Mr. Johnson will be responsible for updating the wiki twice per week on Tuesdays and Fridays by 5:00 pm. Mr. Sun will provide web space for the reports.

TECHNICAL OBSTACLES

No technical obstacles were faced in the first two weeks of the project.

TEAM MANAGEMENT

The development team members were on speaking terms. Work was equally distributed and communication between individuals was civil and most polite.

CHAPTER 2: SYSTEM MODELING

INTRODUCTION

The most critical component of any control design is to obtain approximated linear models of the various parts of the equipment. This chapter deals with the modeling of the system. For the reflow solder oven, the system is composed of the oven heating element, which also serves as the actuator, the controller, the sensor, and the computer interface input/output card.

SYSTEM MODEL

The system model is not overly complicated. It is shown below in Figure 2-1.

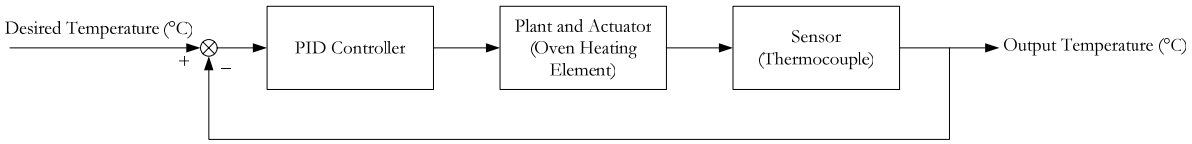

Figure 2-1: Reflow Solder Oven High Level System Model

PLANT/ACTUATOR MODEL

The toaster oven that will be given the new task of soldering circuit boards has not yet been acquired. However, it is expected to be a forced air convection oven to distribute the heat uniformly through out the PCB. The transfer function of the heating element is expected to be similar to that of the Temperature Control Laboratory (TCL) board from EE 448: Actuators and Sensors. That model assumes the plant transfer function to be linear and have the form of Equation 2-1.

Since the toaster oven deals with the dispersion and introduction of heat to a system, a simple yet effective model would follow Newton's Law of Cooling, a first order differential equation. Modified for purposes of this project, Equation 2-1 represents the system with additional constants and variables.

$$\tau_b \dot{x} + x = Ku \tag{2-1}$$

The variable, u, in Equation 2-1 represents the duty factor of the pulse-width modulated (PWM) input signal. The variable, x, represents temperature where $x = T_{\text{oven temperature}}$. By taking the Laplace Transform of Equation 2-1 the result is Equation 2-2.

$$\tau_b s X(s) + X(s) = KU(s) \tag{2-2}$$

The frequency domain transfer function derived from Equation 2-2 is shown in Equation 2-3.

$$G(s) = \frac{Y(s)}{U(s)} = K\frac{e^{-s\tau_d}X(s)}{\tau_b s X(s) + X(s)} = \frac{K}{\tau_b s + 1}e^{-s\tau_d} \tag{2-3}$$

Hence, the toaster oven is modeled by the transfer function in Equation 2-3. To complete the system model, the values for K, τ_b, and τ_d must be determined. In the future, the oven can be controlled by using Equation 2-3 as the model for the system. In our case we will assume K will be dependent on the power output of the oven and the temperature at full blast. If we assume the rated power output of the oven being around 1500 W and at full blast the oven temperature can reach 300 °C hence, $K \approx 5$. Originally we assumed the value of τ_b to be 20 seconds and τ_d to be 5 seconds.

In determining the actual value of K, the steady state temperature of the oven must be compared to the duty factor of the PWM signal that is input into the system. To determine τ_d, the delay between the time when the PWM is input and when the sensors begin to detect a change in temperature is measured. Finally, in determining τ_b, the intersection of the steady state temperature and the line created by drawing a straight line up along the maximum slope of the temperature output $y(t)$ must be found. Figure 2-2 shows the resultant K value found through the method described earlier. From the slope, K = 2.29 °C/% Duty Factor which can be translated to 0.1702 °C/W.

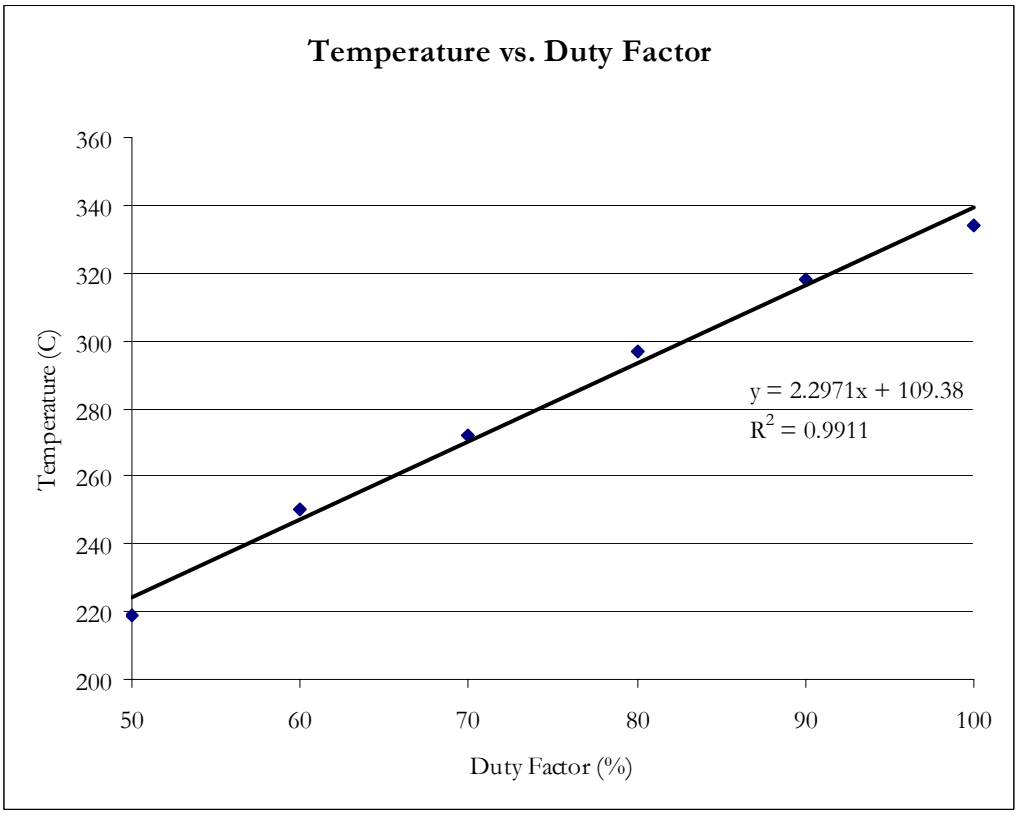

Figure 2-2: K Value Determination

Since the duty factor is an actual percentage of the maximum voltage, it is possible to extract the relationships between temperature, duty factor, and wattage. Table 2-1 shows these relationships.

Table 2-1: Relationship Between Duty Factor, Power, and Temperature

Temperature (°C)	Duty Factor (%)	Power (W)
219	50	675
250	60	810
272	70	945
297	80	1080
318	90	1215
334	100	1350

Similarly, the two time constants were found. The data used to find them and the values themselves are shown in Table 2-2.

Table 2-2: Determination of τ_b and τ_d

Duty Factor (%)	t_i (s)	t_f (s)	τ_b (Δt) (s)	τ_d (s)
50	31	694	663	31
60	35	631	596	35
70	35	580	545	35
80	40	572	532	40
90	40	566	526	40
100	39	496	457	39
		Average	***553.17***	***36.67***
		Standard Deviation	***69.86***	***3.61***

CONTROLLER MODEL

The development group believed that a PID controller similar to the temperature control lab in EE 448: Actuators and Sensors would suffice. As with all controllers which utilize an integrator, an anti-windup system is necessary to reduce accumulated integration error. All that need be done is redesign of the gains. The general schematic for the PID controller is as shown in Figure 2-3.

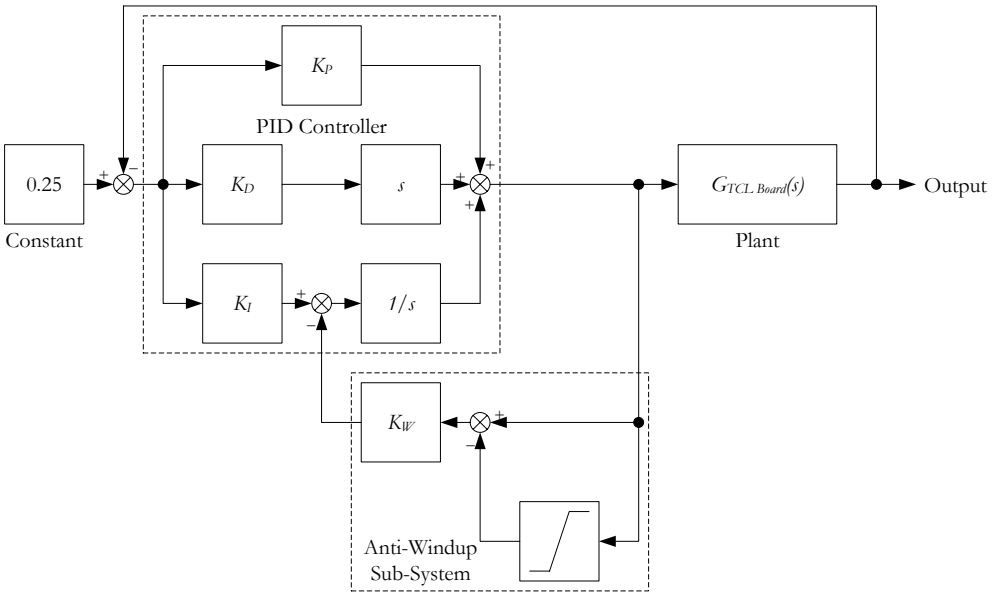

Figure 2-3: PID Controller Schematic from EE 448 Temperature Control

Unfortunately, upon testing the controller with the actual hardware, it was determined through much trial and error that a PID controller was overkill. That is, the differential term was not necessary. This is discussed in more detail in the next chapter. However, the MATLAB used to perform the control calculations retains the parameter in case the customer wishes to make changes to the controller. For the current system however, K_d is set to zero thus effectively removing it from the transfer function and all control calculations.

SISOTOOL was used to determine the gains of the PID controller for the approximated parameters of the plant model. The result of the step response is as shown in Figure 2-4. The SISOTOOL result has a nice rise time of 0.567 s and settling time of 4.01 s with a slight overshoot of 1.46%. It should be noted that extremely high gains were used and that future experiments had gains reduced while maintaining the ratios between them and have the luxury of better model parameters.

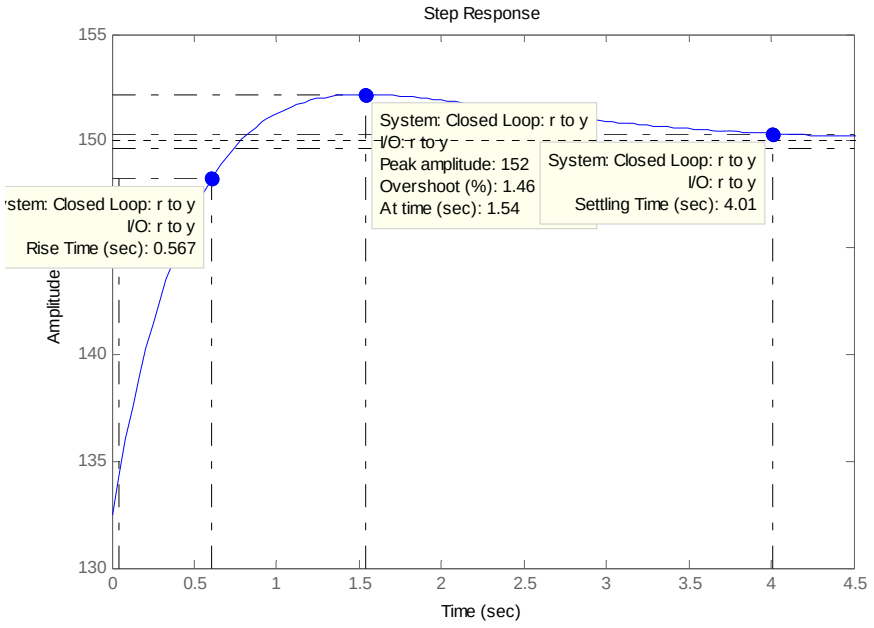

Figure 2-4: Step Response of Toaster Oven Using SISOTOOL

SENSOR MODEL

Based on the specifications, the voltage of the device changes in relation with temperature and is extremely linear over a large range of temperatures. Unfortunately, the voltage output is extremely small. An AD595 conditioner integrated circuit allows the thermocouple to be used. From the datasheets provided by the manufacturers of the thermocouple and conditioner, it is possible to correct the "incompatibility" of the T and K type devices through a series of output voltage conversions. A table was constructed which will allow a person or program to look up the correct temperature when provided an output from the conditioner, it can be seen in its truncated form in Table 2-3. The model for the temperature sensor is shown in Figure 2-5.s

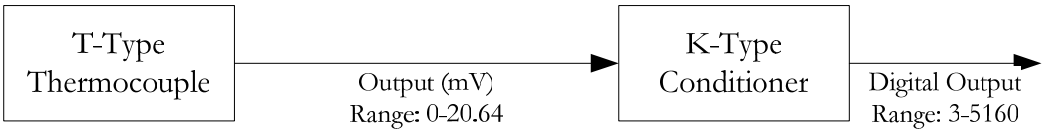

Figure 2-5: Temperature Sensor Model

Table 2-3: Temperature at Thermocouple Based on Conditioner Output

Temp. (°C)	Conditioner Output	Temp. (°C)	Conditioner Output	Temp. (°C)	Conditioner Output	Temp. (°C)	Conditioner Output	Temp. (°C)	Conditioner Output	Temp. (°C)	Conditioner Output	Temp. (°C)	Conditioner Output
20	198	61	624	102	1084	143	1574	184	2091	225	2637	266	3197
21	208	62	635	103	1095	144	1587	185	2104	226	2650	267	3212
22	218	63	646	104	1107	145	1599	186	2117	227	2664	268	3226
23	228	64	656	105	1118	146	1611	187	2130	228	2677	269	3240
24	238	65	667	106	1130	147	1624	188	2143	229	2691	270	3254
25	248	66	678	107	1142	148	1636	189	2156	230	2704	271	3268
26	258	67	689	108	1154	149	1649	190	2169	231	2718	272	3282
27	268	68	700	109	1165	150	1661	191	2182	232	2732	273	3296
28	278	69	711	110	1177	151	1673	192	2195	233	2745	274	3310
29	288	70	722	111	1189	152	1686	193	2208	234	2759	275	3324
30	298	71	733	112	1201	153	1698	194	2221	235	2772	276	3338
31	309	72	744	113	1213	154	1711	195	2234	236	2786	277	3352
32	319	73	753	114	1224	155	1723	196	2247	237	2800	278	3367
33	329	74	766	115	1236	156	1736	197	2260	238	2814	279	3381
34	339	75	777	116	1248	157	1749	198	2274	239	2828	280	3398
35	350	76	788	117	1260	158	1761	199	2287	240	2837	281	3412
36	360	77	799	118	1272	159	1774	200	2299	241	2851	282	3426
37	370	78	810	119	1284	160	1785	201	2312	242	2864	283	3440
38	380	79	821	120	1296	161	1798	202	2326	243	2878	284	3455
39	391	80	833	121	1308	162	1810	203	2339	244	2892	285	3469
40	401	81	844	122	1320	163	1822	204	2352	245	2905	286	3483
41	411	82	855	123	1332	164	1835	205	2365	246	2919	287	3497
42	422	83	866	124	1344	165	1848	206	2378	247	2933	288	3512
43	433	84	878	125	1355	166	1860	207	2392	248	2947	289	3526
44	443	85	889	126	1368	167	1873	208	2405	249	2960	290	3540
45	454	86	900	127	1379	168	1886	209	2418	250	2974	291	3555
46	464	87	912	128	1392	169	1898	210	2431	251	2988	292	3569
47	475	88	923	129	1404	170	1911	211	2444	252	3002	293	3583
48	485	89	934	130	1416	171	1923	212	2458	253	3016	294	3598
49	496	90	946	131	1428	172	1936	213	2471	254	3029	295	3612
50	506	91	957	132	1440	173	1949	214	2484	255	3043	296	3626
51	517	92	969	133	1452	174	1962	215	2498	256	3057	297	3640
52	528	93	980	134	1464	175	1974	216	2511	257	3071	298	3655
53	538	94	991	135	1476	176	1987	217	2525	258	3085	299	3670
54	549	95	1003	136	1488	177	2000	218	2538	259	3099	300	3679
55	559	96	1014	137	1501	178	2013	219	2551	260	3114	266	3197
56	570	97	1026	138	1513	179	2026	220	2569	261	3128	267	3212
57	581	98	1037	139	1525	180	2040	221	2583	262	3142	268	3226
58	591	99	1049	140	1537	181	2052	222	2596	263	3156	269	3240
59	602	100	1061	141	1550	182	2065	223	2609	264	3170	270	3254
60	613	101	1072	142	1562	183	2078	224	2623	265	3184	271	3268

TECHNICAL OBSTACLES

The issue at this juncture in time concerned the deployment of cooling fans. The development group planned on using computer-case fans mounted outside the oven. Louvers open if the fans are operational and close otherwise. The main problem with using computer-case fans is that they are susceptible to damage from high heat. Considering the temperatures at which reflow soldering is to occur, such fans may be irreparably damaged and thus rendered useless during the critical cooling process. It was a high priority to resolve this issue and with all haste.

MANAGEMENT REPORT

Since the components did not yet arrive, little work was done until later when the oven was purchased.

CHAPTER 3: CONTROL DESIGN

INTRODUCTION

Control design involves choosing a compensator or controller suitable for the system and which will help it achieve its performance specifications. For the reflow soldering oven, a PID active controller was decided most appropriate for the task at hand. The proportional (P), integral (I), and derivative (D) gains of the controller are difficult to find mathematically. Only simulation has proven to consistently produce good gains. Actual testing with physical hardware in temperature control can prove to be extremely time consuming, so simulation is a good way to reduce the time necessary by reducing the number of gain candidates into a relatively narrow range. With the acquisition of a well-tuned controller, the product would be well on its way to completion.

CONTROL GAIN CALCULATION

Unfortunately, no known method has yet been devised for calculating the variables of K_d, K_p, and K_i such that the system meets performance specifications of any kind, let alone no overshoot. Hence, they must be chosen intuitively—in other words at random—in a way that results in the most favorable response. This can be done through guessing the values and simulating the system in a program such as Simulink. The gains for the PID controller have been determined to be in the ratio of K_p=1:K_d=0.5:K_i=0.025. These numbers were obtained through simulation using Simulink in MATLAB. A realistic block diagram is shown below in Figure 3-1.

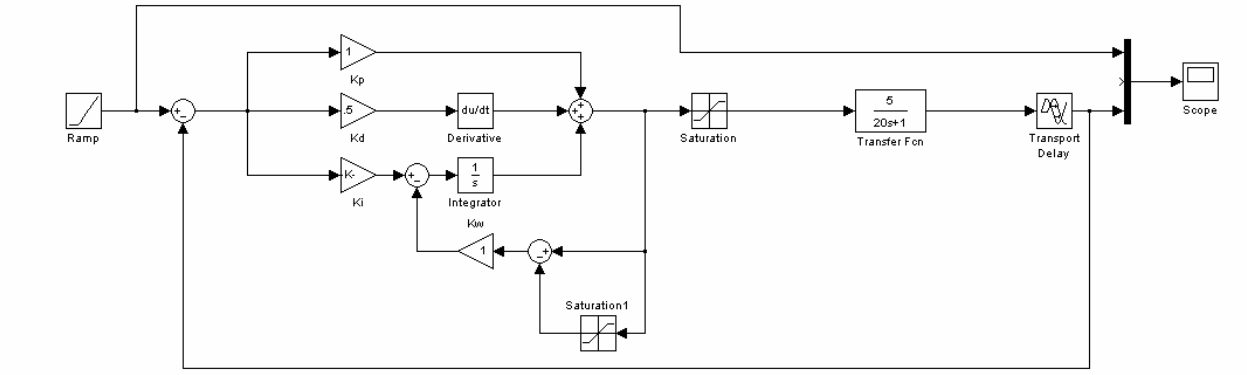

Figure 3-1: Realistic Simulink Block Diagram

While the rest of this chapter concerns findings with estimated model parameters, something must be said about the gain calculations used for the actual system. After many hours of testing with the

hardware, it was determined that the differential term was unnecessary for successful control of the oven's temperature. In addition, the average K value for the oven determined in the last chapter was not used in favor of 4.3794 which is the K value at high temperatures. While the system should track a ramp, a step response was considered with a rise time of 180 seconds and overshoot of one percent. From these performance specifications, the natural frequency ω_n has a value of 0.826 and the damping coefficient ζ of 0.031. The transfer function of the new PI controller in series with the oven transfer function is shown in Equation 3-1 and the system in unity feedback is described by Equation 3-2.

$$G(s) = \frac{K}{\tau_b s + 1} \frac{K_p s + K_d}{s} \tag{3-1}$$

$$T(s) = \frac{G(s)}{1 + G(s)} = \frac{\left(\frac{\omega_n^2}{a}\right)(s + a)}{s^2 + 2\zeta\omega s + \omega_n^2} \tag{3-2}$$

Eventually, the values of K_p and K_i were found to be 0.06234 and 0.0391, respectively. However, these were still not accurate and after even more trial and error, the final values used in the actual control were 0.01 for K_p and 0.0001 for K_i.

TIME DOMAIN SIMULATION

With the estimated parameters, the system is able to track a ramp input but with substantial delay error. Please see Figure 3-2. The yellow line represents the input ramp function of one degree Celsius every second. The blue line is the system. The two lines are very nearly parallel but offset from each other by the time delay of five seconds. This is due to the delay of five seconds.

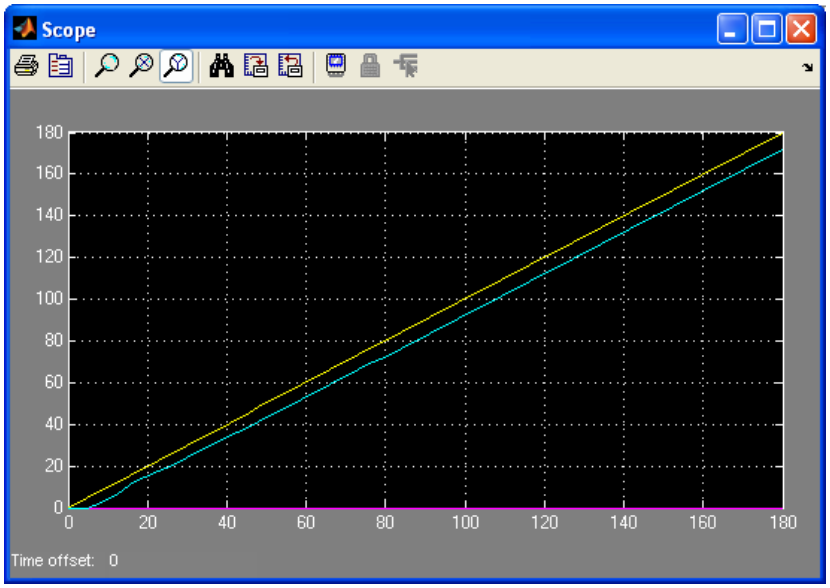

Figure 3-2: Ramp Response of Realistic Simulink Simulation

PERFORMANCE PREDICTION

Based on the step response of our system, the performance prediction for our system should be pretty good; i.e., in terms of percent overshoot, rise and settling time. According to Figure 3-3, for this system we do not have overshoot, and have fast rise and settling time.

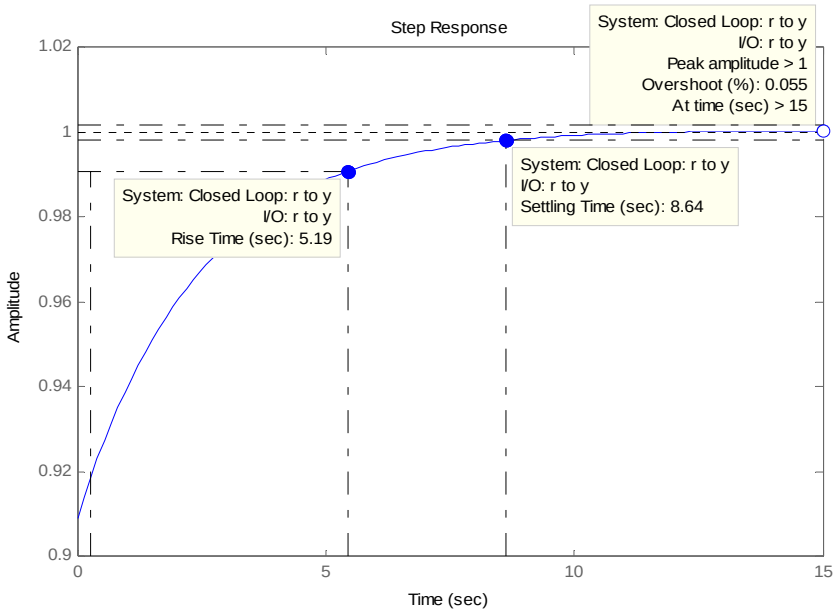

Figure 3-3: Step Response of the System Using SISOTOOL

STABILITY MARGINS

To find the stability margin of our system we need to find the gain and phase margin using the Bode diagram. According to Dorf and Bishop's *Modern Control Systems*, "the gain margin is a measure of how much the system gain would have to be increased for the GH(jω) locus to pass through the $(-1,0)$ point, thus resulting in an unstable system. The phase margin is a measure of the additional phase lag required before the system becomes unstable." So, as we can see from Figure 3-4 the system is stable for any gain and the phase margin is -96.5 deg at 3.97 radians/second.

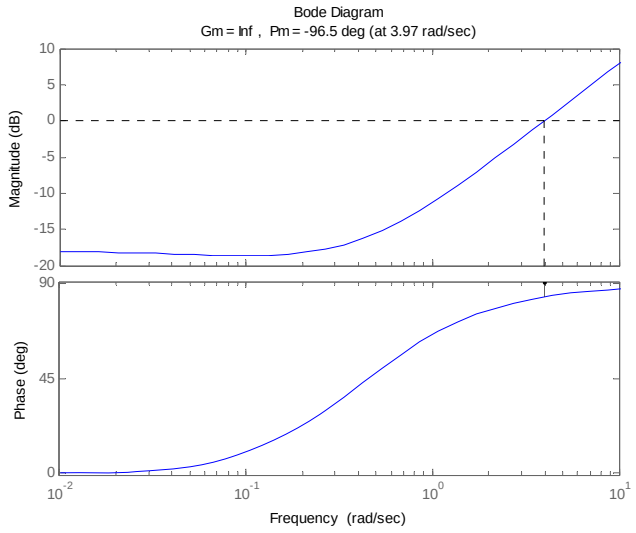

Figure 3-4: The Bode Diagram Used to Determine System Gain and Phase Margin

SENSATIVITY TO PARAMETER CHANGES

The sensitivity of the system to changes in the parameters K, τ_b, and τ_d can be mathematically shown. Sensitivity is defined in Equation 3-3 and the system transfer function in Equation 3-4.

$$S_a^T = \frac{\partial T}{\partial a}\frac{a}{T}, \text{ where } a \text{ is one parameter and } T \text{ represents the system} \quad \textbf{(3-3)}$$

$$T(s) = \frac{K(K_d s^2 + K_p s + K_i)}{s(\tau_b s + 1)e^{\tau_d s} + K(K_d s^2 + K_p s + K_i)} \quad \textbf{(3-4)}$$

Since the calculations for the sensitivity are very complex, a Texas Instruments TI-89 Titanium calculator was used. Equation 3-5 shows the sensitivity for K, Equation 3-6 shows sensitivity for τ_b, and Equation 3-7 shows sensitivity for τ_d.

$$S_K^T = \frac{s(\tau_b s + 1)e^{\tau_d s}}{s(\tau_b s + 1)e^{\tau_d s} + K(K_d s^2 + K_p s + Ki)} \quad \textbf{(3-5)}$$

$$S_{\tau_b}^T = \frac{-\tau_b s^2 e^{\tau_d s}}{\tau_b s^2 e^{\tau_d s} + s e^{\tau_d s} + K(K_d s^2 + K_p s + K_i)} \quad \textbf{(3-6)}$$

$$S_{\tau_d}^T = \frac{-\tau_d e^{\tau_d s} K s^2 (\tau_b s + 1)}{s(\tau_b s + 1)e^{\tau_d s} + K(K_d s^2 + K_p s + K_i)} \quad \textbf{(3-7)}$$

It appears that the system is most sensitive with an increased change in τ_b and, to a lesser extent, changes in either direction of K. This makes the most sense because the rise time of the oven is most critical to its performance whereas delay time and the heating element constant are not.

HARDWARE AND SOFTWARE ARCHITECTURE

All major hardware components are shown in Figure 3-5. Ultimately, the PC will control the oven heating profile as the controller is to be digital and implemented in MATLAB. The USB I/O card serves as the intermediate between the PC and the oven and temperature sensor. The temperature sensor requires a +5 V power supply to be provided by the I/O card. It outputs an analog signal in the range of 0.0 to 5.0 V. The I/O card will feed the input from the temperature sensor to the PC which will take the appropriate action in controlling the temperature of the oven. The MATLAB program will send a signal to the I/O which determines the duty factor of the PWM signal. When the duty cycle is high, +5 V will be placed across the relay allowing the AC current from the wall outlet to flow through the heating element. When the duty cycle is low, no voltage will be placed across the relay input and it will switch off the heating element by breaking the circuit.

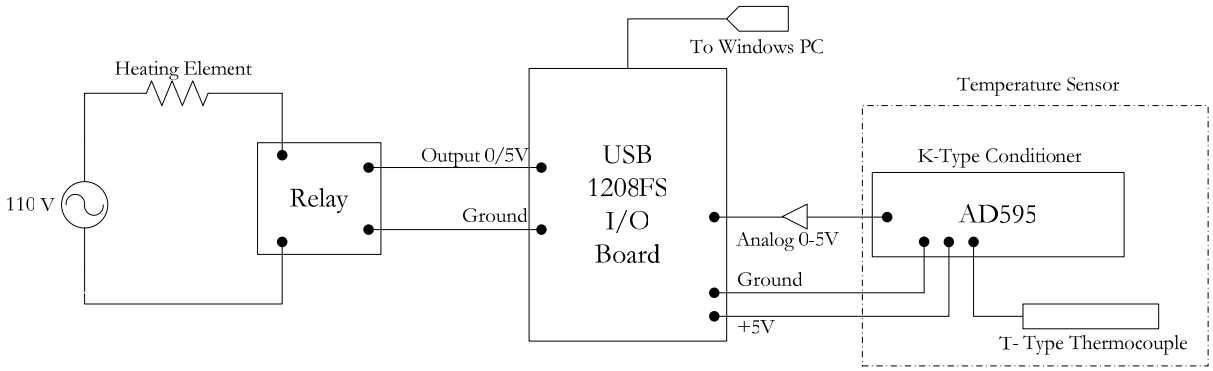

Figure 3-5: Hardware Schematic of Reflow Soldering Oven

Software is to be implemented in MATLAB which is to all be encapsulated within the automatically generated Graphical User Interface file. Included within the code will be the PID controller in addition to the anti-windup subsystem.

Invariably, the next step would be to convert the controller into a form which can be used to test the actual physical hardware. This is done by taking the inverse transform of the transfer function in the frequency domain and bringing it into the time domain. Equations 3-8 and 3-9 show this process.

$$U(s) = K_p E(s) + K_p \frac{1}{s} E(s) + K_i s\, E(s) \tag{3-8}$$

$$u(t) = K_p e(t) + \int_0^t \left(e(t)Ki\right)dt + K_d \frac{d}{dt} e(t) = K_p e(t) + \tilde{z}(t) + K_d \frac{\Delta e(t)}{\Delta t} \tag{3-9}$$

The anti-windup would be included within the integral term. Even now, however, the function cannot be used due to the fact that it is continuous. Computers are digital creatures and the previous equations must therefore be digested in order for them to be able to be simulated. This process happens to be called "discretization" and the product is discrete rather than continuous in nature. The software pseudo code and architecture is shown below in Figures 3-6 and 3-7, respectively.

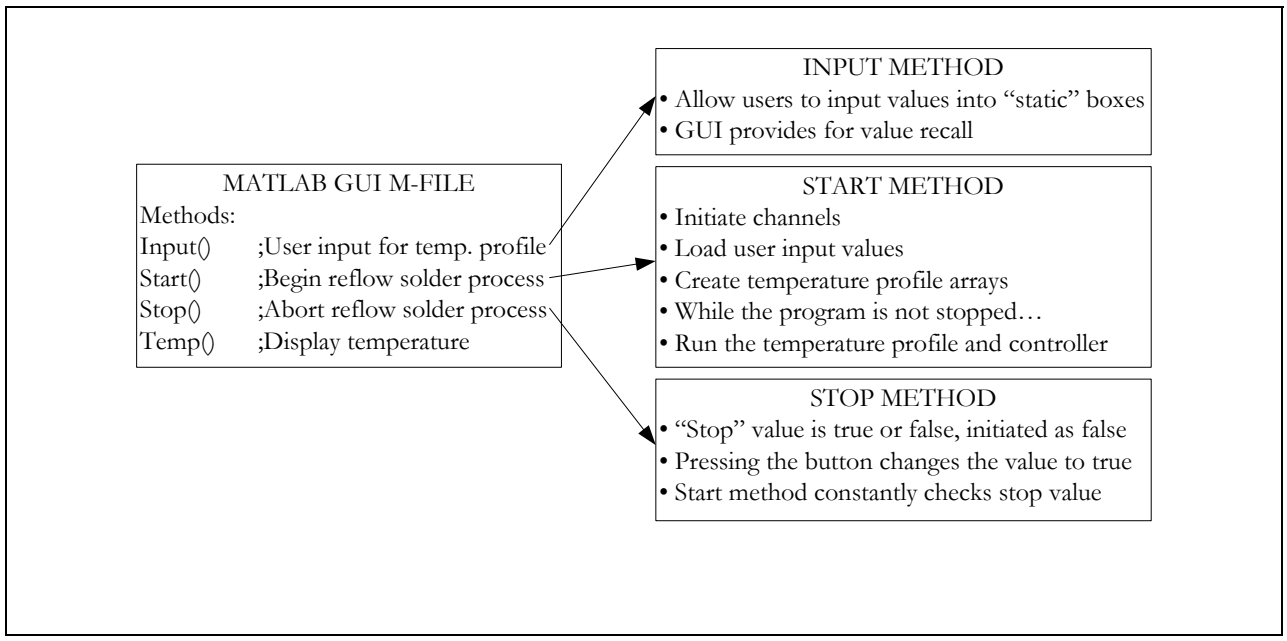

Figure 3-6: Software Pseudocode for Oven Temperature Control

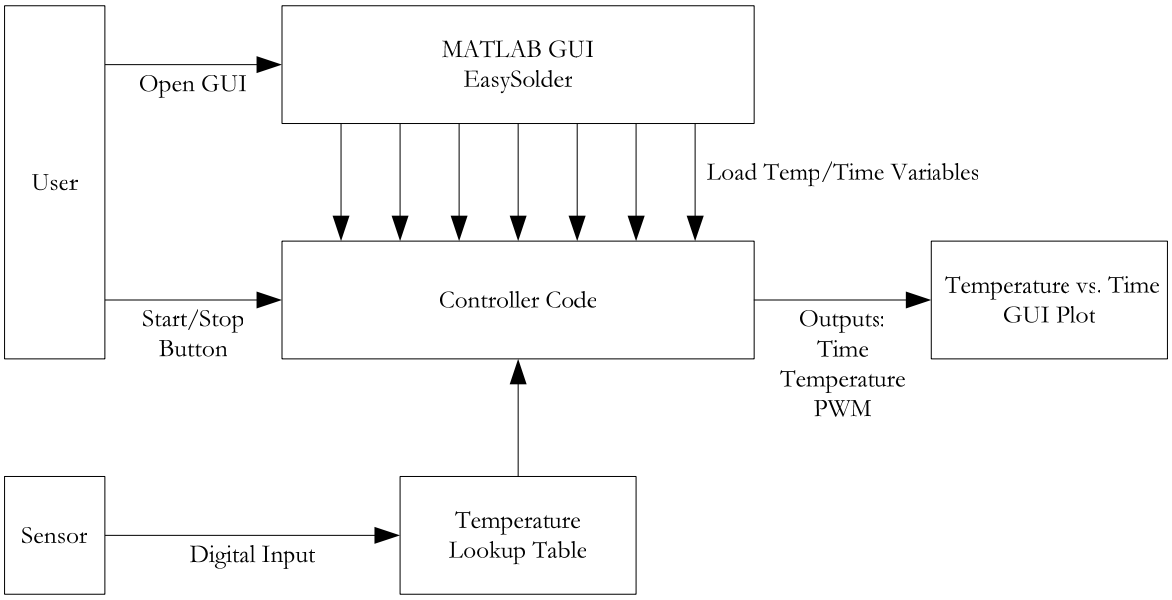

Figure 3-7: Software Architecture for Oven Temperature Control

Notice that no "pause" feature is present as such an option would complicate the reflow solder process. Reflow soldering should be continuously and any discontinuity in the process might produce an undesired product.

Within the start method, code will exist to initialize channels and prepare the temperature profile as defined by the user. Once everything is set-up, an "infinite" loop will begin in which code will be run, control calculations will be done, and the desired PWM output will be sent to the I/O card. The loop will continue until told to stop when the user presses the stop button on the GUI.

A temperature display will also be implemented in the GUI for the convenience of the user. The user will be given five hard coded inputs for which three are allocated toward temperature and two toward time.

RISK AND HAZARD ANALYSIS

Two hazards involve dealing with high output voltage from wall outlets and the temperature of the heating elements. All due diligence will be made toward properly connecting the power source with various elements in the oven such as the power relay. Testers and users will be adequately shielded from live high-voltage wires through proper insulation solutions. Along with this goes protection against electrical fire and possibly electrocution. All group members possess cell phones and are capable of using them to request medical assistance and/or other emergency pertinent authorities.

In addition to power management, users must be aware of heat damage and burns resulting from exceedingly close contact with the heating element and/or interior of the oven itself. These injuries can be avoided by removing the power supply and allowing the oven and heating elements to cool to a maximum temperature of 140° F. The temperature sensor can be used to determine the temperature or a quick wave of the hand through the air enclosed within the oven.

REVISED PROJECT PLAN

The project plan has been revised concerning tasks remaining to be done beginning May 5, 2006 and appears below in Table 3-1.

Table 3-1: Revised Reflow Solder Oven Work Breakdown

Task No.	Task	Lead	Start Date	End Date	Dependant Tasks	Prerequisite Tasks
4.0	Plant Transfer Function Determination	Clement	5-May	7-May	6.0, 4.1	5.0
4.1	Controller Design	Solomon	6-May	12-May	6.0	N/A
5.0	Hardware Assembly	Josh	4-May	12-May	5.1	N/A
5.1	Computer Interface	Keith	6-May	12-May	6.0, 7.0	5.0
6.0	Control Software Development	Josh	6-May	20-May	6.1	5.0, 5.1
6.1	GUI Development	Josh	16-May	20-May	7.0	6.0
7.0	System Testing	Keith	20-May	23-May	7.1	6.1
7.1	System Revision	Clement	24-May	30-May	8.0	7.0
8.0	Report Compilation	Clement	25-May	1-Jun	N/A	All

A flow chart has been created to illustrate the critical path of the project. It can be seen below in Figure 3-8.

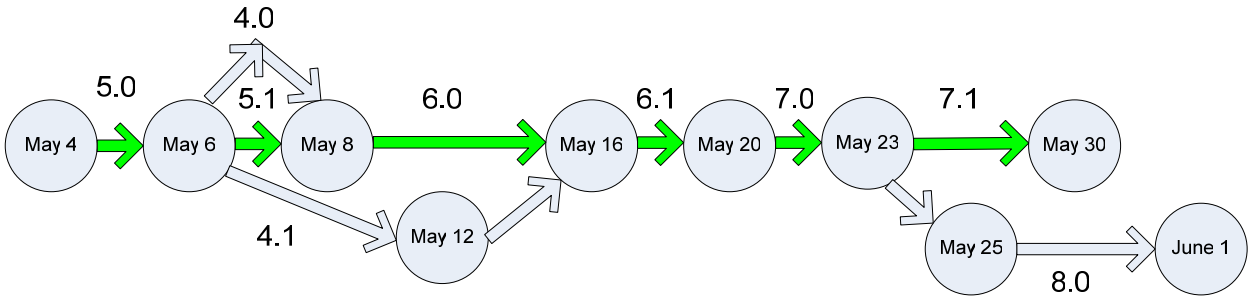

Figure 3-8: Revised Project Plan Flow Chart and Critical Path in Green

TECHNICAL OBSTACLES

There are no technical obstacles which obstructed the progress of the reflow toaster oven.

MANAGEMENT REPORT

Work was conducted diligently and with full participation of all group members. All tasks were completed on time.

CHAPTER 4: DETAILED DESIGN

INTRODUCTION

Detailed design of the hardware and software is discussed in this chapter. The software used to control the temperature of the oven using a digital PI controller also appears within the chapter.

ELECTRICAL HARDWARE AND WIRING DESIGN

The electrical hardware wiring diagram appears below in Figure 4-1.

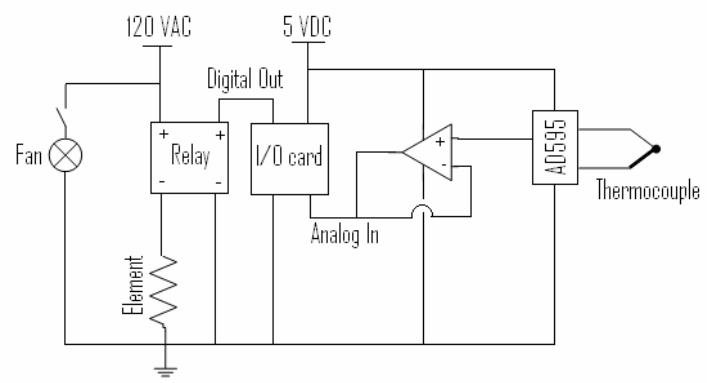

Figure 4-1: Hardware Wiring Diagram

The reflow oven utilizes several components in its control. The most important of which, and most expensive, is a USB 1208FS I/O card. This device provides a digital output in the range of 0 and 5 V to the solid state relay. When no voltage is placed over the relay, the switch is turned off and no current from the wall is allowed to pass through the heating elements of the oven. Likewise, when 5 V is placed across the relay, the switch is turned on, allowing current to flow. A manual switch allows the user to turn on and off the convection fan. For the purposes of reflow soldering, the fan should never be turned off during the reflow soldering process.

The next component to note is the T-Type thermocouple interfaced with a K-Type conditioner. Because of the incompatibility between these two parts, software will need to be written to correct for this. The thermocouple and condition work together as a unit to provide analog temperature data to the I/O card. The I/O card provides a power supply of 5 V to the unit. The thermocouple-conditioner set sends its data to the analog input of the I/O, through a buffer. The buffer is

necessary to block outgoing current from the I/O as such current would interfere with the functionality of the conditioner.

SOFTWARE PROGRAMMING

Control software programming was performed in MATLAB and can be seen in Figure 4-2. The code consists of three major parts. The first part is the initialization of input and output channels in addition to the various variables needed for calculations. The second and third parts occur with a loop which terminates on command of the user. The second part involves ramping up the temperature as fast as possible. Here there is no control of temperature. The temperature is raised to a set "preheat" value. Since this is hardcode, it must be changed in the code itself and no option to do so will be given in the GUI.

The third part is the actual controller. When the temperature is not rising rapidly, the controller will be allowed to take control of the temperature. Using a discretized set of equations for the integrator and differentiator the gains are used to calculate the necessary output in the form of a PWM.

It must also be mentioned that the software corrects for the error between the conditioner and the thermocouple. A lookup table was created which translates a given voltage to a specific temperature. This array must be loaded before any temperature measurements take place.

```
targetTemp = 0;                 %temperature step size
PWMsamples = 1000;              %number of sapmles in PWM frame
startSoak = 0;
Kp = .01;                      %Proportional gain
Ki = .0001;                   %integration gain
Kd = 0;
dio=digitalio('mcc',0);         %initiate digital output
dline=addline(dio,0,'Out');     %add channel to output
ai=analoginput('mcc',0);        %initiate analog input
aichan=addchannel(ai, [0]); %add three channels to input
set(aichan(1), 'InputRange', [0 5]);   %near sensor
z = 0;                          %integrator
w = 0;                          %anti-wind up, amount output is
larger then 1
u = 0;                          %output non saturation
d = 0;                          %differential term
delta = 0;                      %change in time
ctrlOut = 0;                    %output of controller
temperature = [0 0];            %used for double buffer to plot
time = [0 0];                   %used for double buffer to plot
Vin = getsample(ai);            %three column vector
error = [0 0];                  %used for derivative
%set the first error, so d doesn't screw up
voltage = round(1000*getsample(ai));
i = 1;
while (voltage > lookup(i, 2)),
    i = i+1;
end
rounded = (lookup(i, 2) + lookup(i + 1, 2))/2;
if (voltage - lookup(i, 2)) < rounded;
    error(1) = targetTemp-lookup(i, 1);
else
    error(1) = targetTemp-lookup(i + 1, 1);
end
%new figure to plot
h=figure;
hold on;    %start time
tic();
while (round(1000*getsample(ai))) < 1062          %less then
100 degrees
    putvalue(dio, 1);

    time(2) = time(1);          %double buffer time
    time(1) = toc();
    delta = time(1)-time(2);
    temperature(2) = temperature(1);          %double buffer
input
    voltage = round(1000*getsample(ai));
    i = 1;
    while (voltage > lookup(i, 2)),
        i= i+1;
    end
    rounded = (lookup(i, 2) + lookup(i + 1, 2))/2;
    if (voltage - lookup(i, 2)) < rounded
        temperature(1) = lookup(i, 1);
    else
        temperature(1) = lookup(i + 1, 1);
    end
    plot([time(2), time(1)], [temperature(2), temperature(1)]);
    drawnow;                    %plot data as it arrives
end

putvalue(dio, 0);
targetTemp = 150;

while (round(1000*getsample(ai))) < 1660      %less then 150
degrees
    time(2) = time(1);          %double buffer time
    time(1) = toc();
    delta = time(1)-time(2);
    temperature(2) = temperature(1);          %double buffer
input
    voltage = round(1000*getsample(ai));
    i = 1;
    while (voltage > lookup(i, 2)),
        i= i+1;
    end
    rounded = (lookup(i, 2) + lookup(i + 1, 2))/2;
    if (voltage - lookup(i, 2)) < rounded
        temperature(1) = lookup(i, 1);
    else
        temperature(1) = lookup(i + 1, 1);
    end
    error(2) = error(1);
    error(1) = targetTemp-temperature(1);
    z = z + (Ki*error(1) - (ctrlOut-(u/PWMsamples)))*delta;
%integrate error
    d = (error(1)-error(2))/delta;
    ctrlOut = (Kp*error(1) + z + Kd*d);    %set output
    if ctrlOut > 1                        %if duty factor too
large
        u = PWMsamples                   %make duty factor 100%
    elseif ctrlOut < 0
        u = 0
    else
        u = round(ctrlOut*PWMsamples)
    end
    for count = 1:u             %for first part of PWM
        putvalue(dio, 1);       %output high
        Vin = getsample(ai);      %burn input data
    end
    for count = 1:(PWMsamples-u)%for second part of PWM
        putvalue(dio, 0);       %output low
        Vin = getsample(ai);      %burn input data
    end
    plot([time(2), time(1)], [temperature(2), temperature(1)]);
    drawnow;                    %plot data as it arrives
end
```

Figure 4-2: Simplifed MATLAB Code for Control of Reflow Oven

The finalized MATLAB code can be found in the Appendix. It contains GUI code in addition to the controller code. In the full version, there are actually fives sets of while loops. The first loop sets heating elements to 100% on while the temperature remains more than 50 °C from the soak temperature. Then, while the temperature is less than the soak temperature, the oven tracks a ramp. Once time is less than 30 seconds from the soak time, the ramp changes slope. Finally, the oven turns to full on until when the temperature comes to within 15 °C of the maximum temperature, in which case it turns full off

The MATLAB GUI is illustrated in Figure 4-3. The GUI functions simply. The user must enter the soak, solder, and maximum temperatures and soak and dwell times if they so desire. Otherwise, the defaults shown below will be used.

Once all the desired values have been entered, the user can begin the reflow solder process by pressing the start button in the "oven" panel. Similarly, the user presses the "stop" button when s/he wants to stop the process in order to readjust gains, the soak time, target temperature, or for emergencies. The temperature of the oven will be displayed in the "temperature" panel and the actual profile will appear in the large plot on the upper left of the GUI. A projected temperature profile will be shown in red and the actual temperature profile will appear in blue.

Once the target temperature is reached, the oven will turn off and the user will be prompted to open the door. The command will appear where the word "ready" does, below the target temperature and soak time inputs.

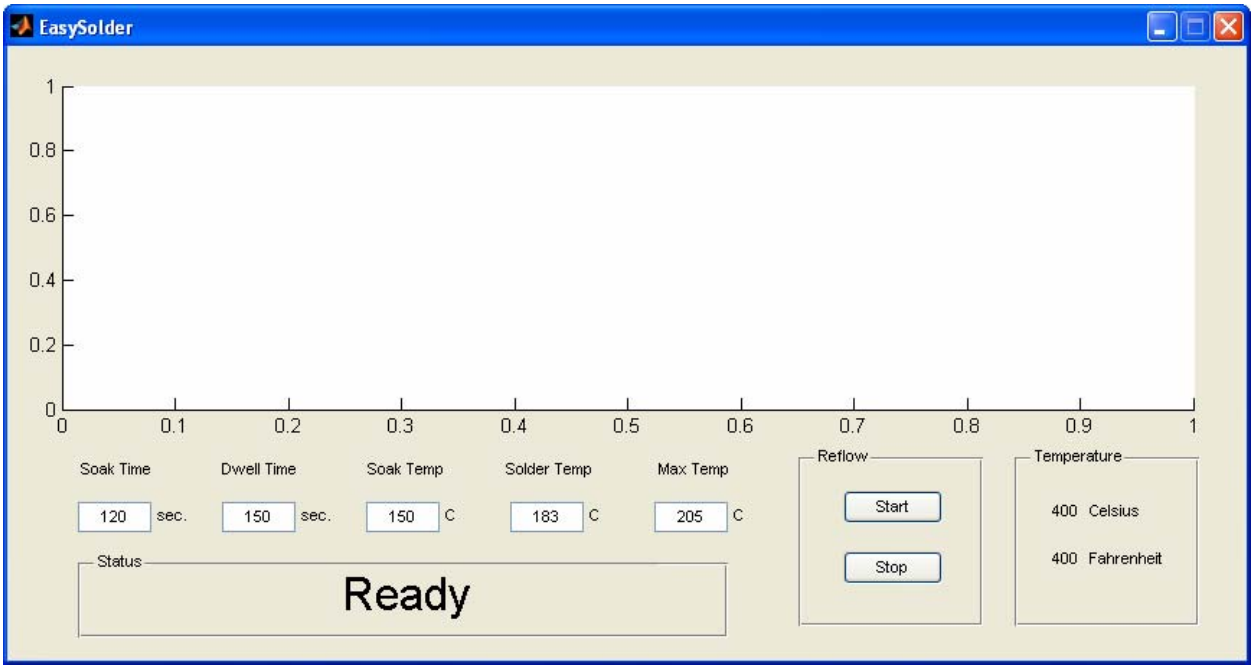

Figure 4-3: MATLAB GUI for Reflow Oven

MECHANICAL DESIGN

Mechanically, the project consists of a toaster oven with a box attached to the side that houses the control components. The box is offset from the side of the toaster oven to reduce the chances heat will affect the circuit. The box is also vented and a fan may be attached later if cooling becomes an issue. The I/O card is attached by Velcro to the top of the box for easy removal. A set screw is used to prevent the thermocouple from being pulled out of the oven. Also, great care was taken to

protect the wires running out of the oven and control box from being frayed. Edges are sharp so the protective sleeves provide protection.

SAFETY REVIEW AND PROTECTION SYSTEM DESIGN

The major safety concern was the 120V A/C voltage required to power the oven. The relay is housed inside the box to prevent people from inadvertently touching the power posts. It is not advised to place fingers or other body parts into the box as doing so may result in severe shock or electrocution. The oven case gets hot so it is advised not to touch the hot oven when it is in operation.

TECHNICAL OBSTACLES

There are no technical obstacles which obstructed the progress of the reflow toaster oven during the two weeks leading up to the fourth milestone.

MANAGEMENT REPORT

Work was conducted diligently and with full participation of all group members. All tasks were completed on time.

CHAPTER 5: PROJECT IMPLEMENTATION

INTRODUCTION

This chapter will cover how our hardware was constructed and also the results of testing. From the detailed discussion of the reflow oven, it is possible to accurately reproduce additional units. The test results also show the limitations of the oven and optimal operating conditions in which to perform reflow soldering.

SYSTEM CONSTRUCTION

The finished reflow oven, converted from a toaster oven, appears below in Figure 5-1.

Figure 5-1: Photograph of Reflow Oven, Temperature Sensor, and I/O Card

The Black and Decker toaster oven was disassembled and the various dials and bells removed. Two things were left intact: the convection fan switch and the safe mechanism that shuts off power to the heating elements when the door is opened completely. The wiring for the heating elements is a simple circuit consisting of four resistors: two resistors in series parallel with another set of two resistors in series. Alternating current passes into one end of the resistors and exits to ground from

the other. These two leads were taken and attached to the high voltage side of the solid-state power relay. The power relay was also screwed down to a large heat sink for the obvious purpose of heat dissipation. Figure 5-1 shows several wires exiting the right side of the oven into a black box bolted to the outer case. The power relay is situated, and secured by bolts, within the box. Note that the terminals are not protected and therefore there is a risk of shock and electrocution should any part of the body come in contact.

The next step in preparing the oven was to prepare a series of holes to accommodate the thermocouple temperature sensor. From Figure 5-1, it is seen that the holes were drilled in the left side through both the outer case and inner wall of the oven and just about the highest rack slot. Dimensionally, the hole has a diameter of 3/16 inches. The thermocouple's wire was run behind the oven and securely attached by three eye clips.

Within the black box, a protoboard is situated which accepts wires from the I/O card and thermocouple. For wiring schematics, please see the previous chapter. The box itself was originally part of a HAMM radio set and converted in a protected covering for the power relay. Four holes were drilled into the wings allowing for the box to be screwed to the side of the oven. In order to allow for additional cooling, spacers were added to create a one inch gap for air flow. Moreover, a series of holes were drilled in the other end of the box to create the potential for air flow over the heat sink. The I/O card is also set on top of the box and secured by Velcro. Tubing was used to protect wires from contact with the oven case on the route from the protoboard to the I/O card. The risk of heat damage to the wires, however, is very low as the oven case does not reach very high temperatures—except on top where all the heat rises.

For aesthetic purposes, the front of the oven was stray painted black to cover up the white dial markings for temperature and whatnot. The empty dial receptacles serve as ventilation for the interior of the case where all the wires enter and leave. LED displays for temperature and other indicators were considered in filling these openings but it was feared that the temperature might damage or destroy the circuitry.

INITIAL TESTING

Initial testing was done with range of results. At first, the oven was instructed to track stem inputs and this resulted in a very poor temperature profile often resulting in oscillations and long settling times. Figure 5-2 is an example of one such test.

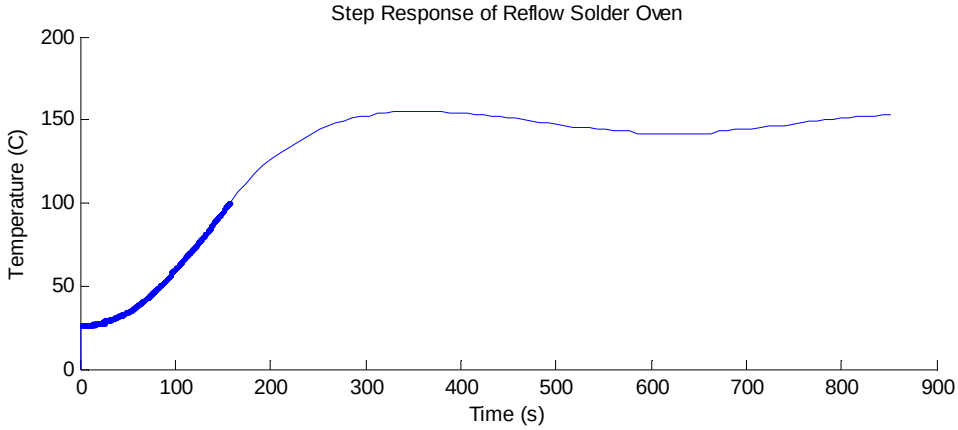

Figure 5-2: Response of Reflow Solder Oven to a 150 °C Step

Since the purpose of the oven is to follow a temperature profile resembling a series of ramps, it was through better to conduct tests using ramp inputs. Simulation showed a favorable response to a ramp and the actual response to ramps was not bad. The problem with a ramp input was that the temperature did not rise fast enough to minimize the time necessary for the reflow solder process. However, a ramp input was still better than a step and so it was decided to use a combination of open and closed loop control. The open loop system was used to cause a rapid climb in temperature and closed loop to carefully control the temperature between the use of open loop. Figure 5-3 shows the results of this combined open/closed loop controller.

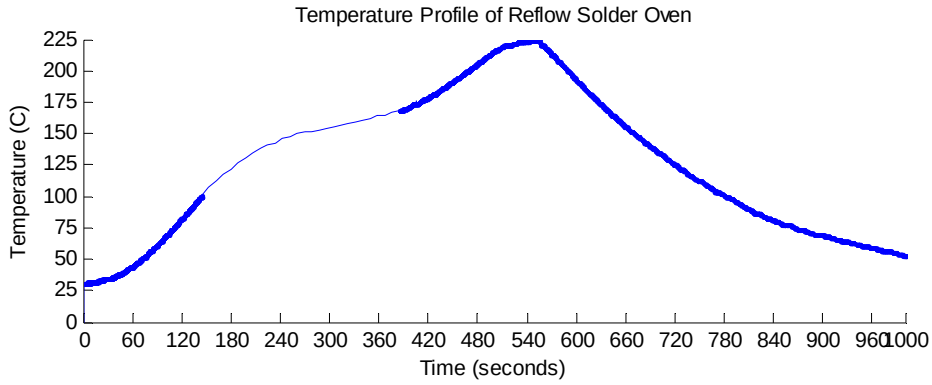

Figure 5-3: Temperature Profile of Combined Open/Closed Loop Control

Portions of the graph in Figure 5-3 which are smooth and narrow indicate the use of closed loop control, approximately between 150 and 400 seconds. The remainder of the plot consists of thick blue line indicating open loop control, either "all on" or "all off."

PERFORMANCE AND STABILITY TESTING

With the initial testing complete and a finalized controller, the limits of the system can be tested. Several tests were done on the oven to determine the optimal setup of oven, internally. This involved different configurations with the rack and oven tray and convection fan.

Figure 5-4 illustrates the results of turning off the convention fan. While it may seem that the absence of the fan does not affect the profile, what is not shown is the inconsistency and unequal distribution of heat within the oven. It is not suggested to disable the convection fan—even for the sake of peace and quiet—while the oven is in operation and a board is being soldered.

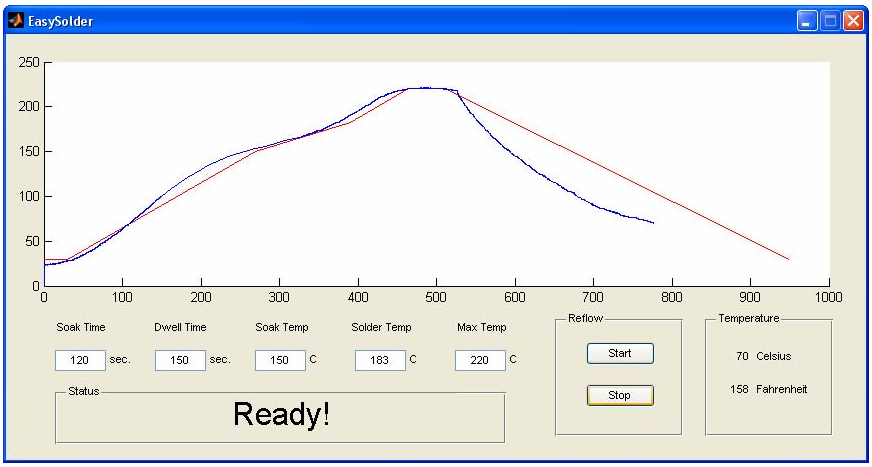

Figure 5-4: Temperature Profile without Fan and Tray in Lowest Position

Figure 5-5 shows the temperature profile that is obtained from the oven when the rack is moved to the highest position in the oven and the tray is removed. The convention fan was operational. From the plot, the temperature changes very quickly without the tray as a barrier to rising heat. This makes sense because the thermocouple is located high up in the oven and therefore registers the change in temperature much more rapidly than it would otherwise. Removing the tray, however, is also not recommended for reasons to become apparent later.

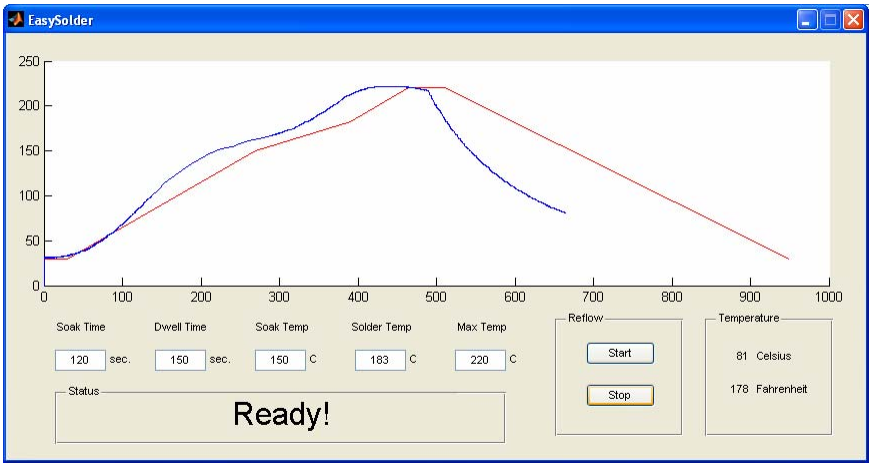

Figure 5-5: Temperature Profile with Rack on Highest Position without Tray

One of the most important tests that were conducted was for the soldering of an actual board with surface mounted components. This, of course, is the intent of the reflow soldering oven and its primary purpose. The board was placed in the metal tray on the rack in the lowest position. The convection fan was left on. Figure 5-6 shows the projected temperature profile in red and the actual in blue. The overall profile was good and the resulting board was not burned. The solder joints were also nicely done and the components that were mounted still functioned after the process. This is the optimal configuration and the one used for the extraction of model parameters and simulation.

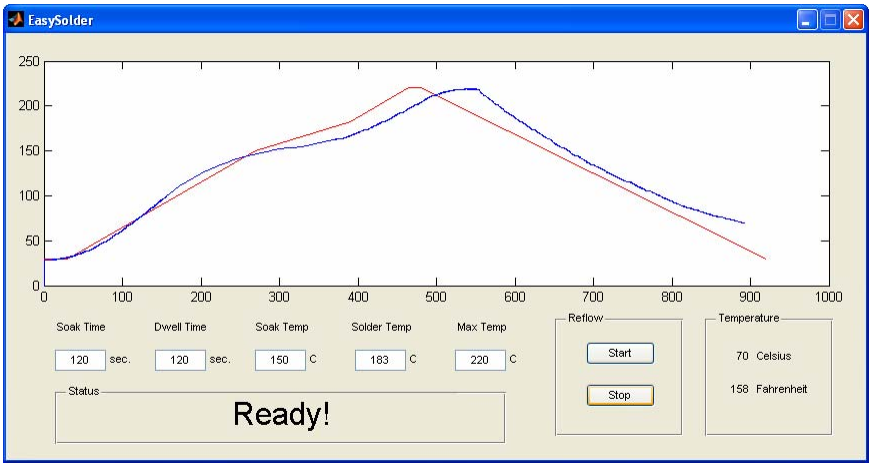

Figure 5-6: Temperature Profile with Board and Tray in Lowest position and with Fan

However, if the optimal conditions are not used as in Figure 5-5, the result is a grilled board with non-working parts though the joints remain good. Figure 5-7 shows another successful solder job with a different maximum temperature of 205 °C instead of 220 °C. The boards used for these two successful tests were obtained from Sandy Chan, Eric Carlson, and Sharon Cheung.

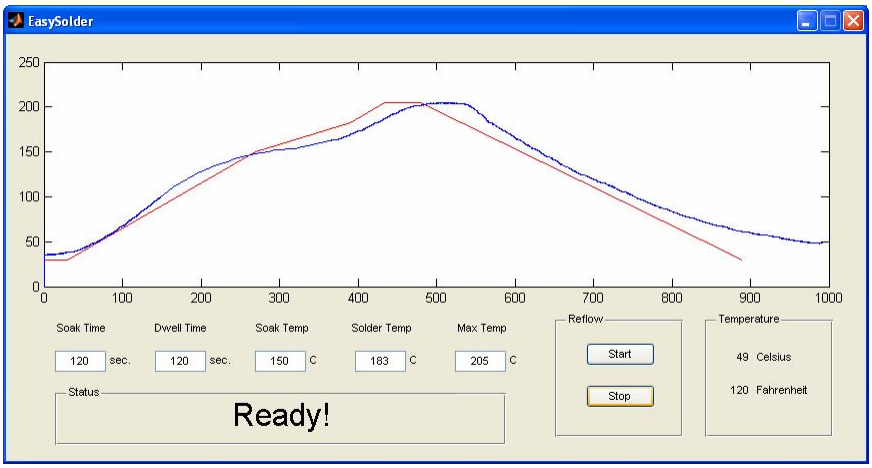

Figure 5-7: Temperature Profile with Board and Tray in Lowest Position and Fan

Last among the various tests was that of system robustness. To test the ability to recover from an unexpected external event, a massive disturbance was added to the oven. The disturbance consisted in fully opening the oven door and introducing a large volume of outside air into the oven cavity by means of rapid exhalation from a pair of human lungs. Figure 5-8 records this event at roughly 190 seconds into the process at a time of closed loop control. The system recovered fully from the disturbance though it is still suggested not to perform this test while soldering a board.

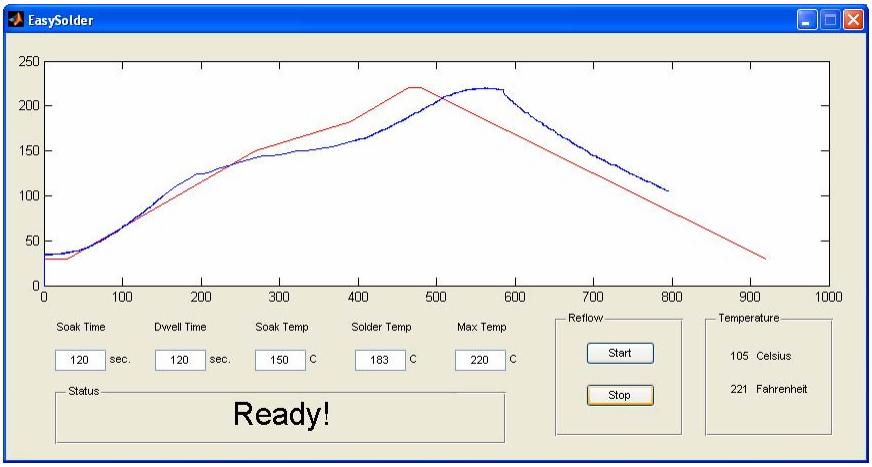

Figure 5-8: Temperature Profile with Optimal Settings and Major Door-Open Disturbance

The two boards in Figure 5-9 show the results of successful reflow soldering runs.

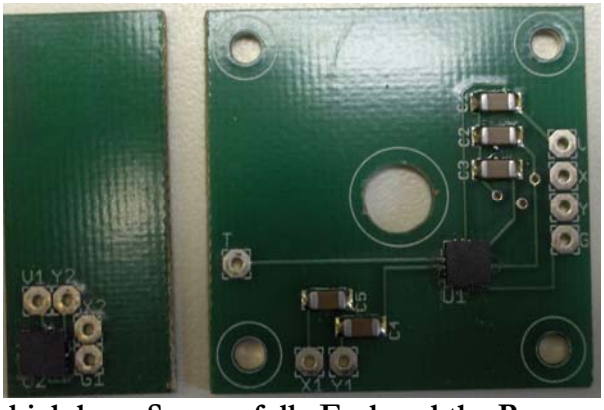

Figure 5-9: Boards which have Successfully Endured the Process of Reflow Soldering

For the customer demo, Nils Napp working for Professor Klavins in the Self Organizing Systems Lab volunteered to allow the build team to solder one of his boards. Figure 5-10 shows the soldered board and components. The solder joints are comparable to those done in a professional shop.

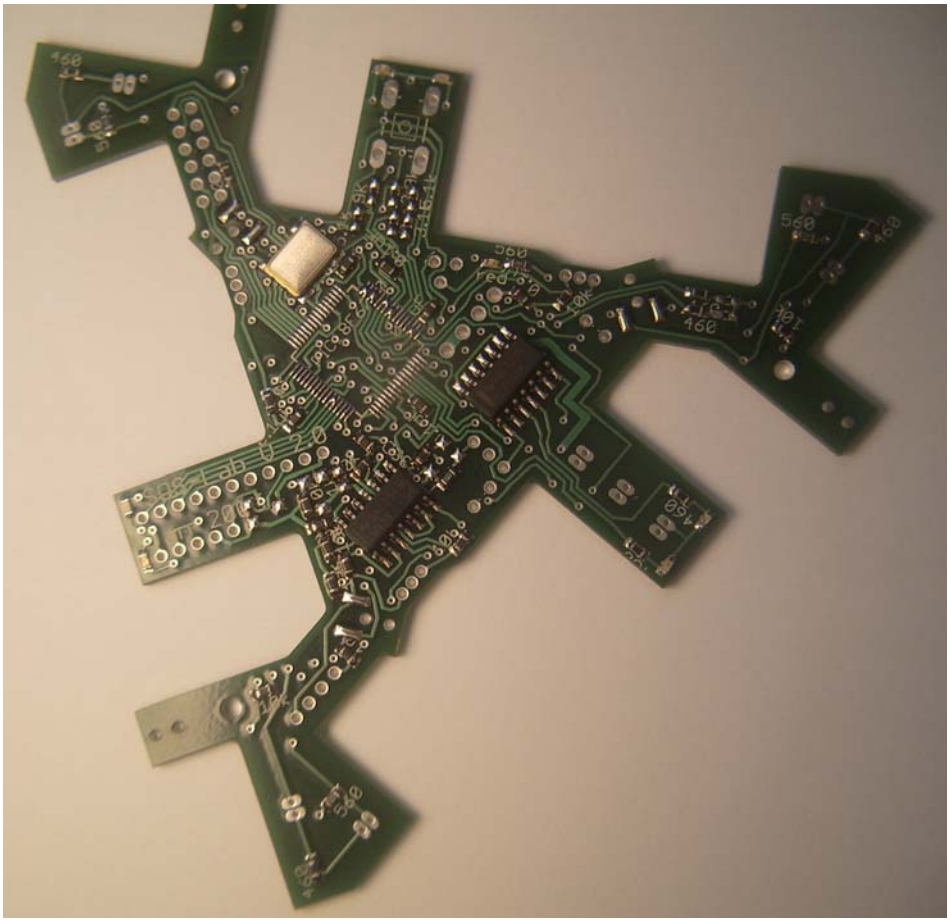

Figure 5-10: Finished PCB Board

To further improve the amount of data that can be gathered from the GUI, additional plots for the PWM signal were added as seen in Figure 5-11. Open loop control consists of either "all on" or "all off." The PWM signal for such a case is green and appears between 100 and 0 on the *y*-axis. The PWM is a percentage with 100% indicating "all on" and 0% meaning "all off." When the system enters closed loop mode, the PWM plot turns black. The default maximum temperature was changed from 220 °C to 205 °C.

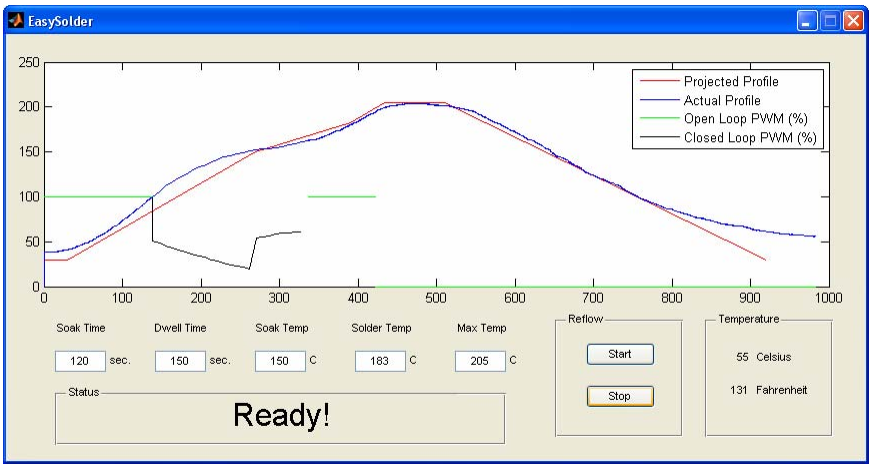

Figure 5-11: Finalized GUI Showing Performance of Oven

CUSTOMER RECEPTION

To the best knowledge of the development group, the customer appears to be satisfied with the final product. Actually, the word "satisfied" is an understatement, the customer is ecstatic. Not surprisingly, other persons within the University of Washington's electrical engineering department are more excited about the reflow oven than even the intended customer and express a great desire to use it for their own purposes. The oven will be placed in Bill Lynes' lab for department general use.

TECHNICAL OBSTACLES

There were no technical obstacles encountered during the progress of the reflow toaster oven in the final two weeks prior to the fifth milestone report due on June 2, 2006.

MANAGEMENT REPORT

Work was conducted diligently and with full participation of all group members.

APPENDIX

MATLAB CODE

The following is the full MATLAB code for the GUI and control of the reflow soldering oven. The MATLAB figure for the GUI appears in Chapter 4 in Figure 4-3.

```
function varargout = EasySolder(varargin)
% EASYSOLDER M-file for EasySolder.fig
%      EASYSOLDER, by itself, creates a new EASYSOLDER or raises the existing
%      singleton*.
%
%      H = EASYSOLDER returns the handle to a new EASYSOLDER or the handle to
%      the existing singleton*.
%
%      EASYSOLDER('CALLBACK',hObject,eventData,handles,...) calls the local
%      function named CALLBACK in EASYSOLDER.M with the given input arguments.
%
%      EASYSOLDER('Property','Value',...) creates a new EASYSOLDER or raises the
%      existing singleton*.  Starting from the left, property value pairs are
%      applied to the GUI before EasySolder_OpeningFunction gets called.  An
%      unrecognized property name or invalid value makes property application
%      stop.  All inputs are passed to EasySolder_OpeningFcn via varargin.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help EasySolder

% Last Modified by GUIDE v2.5 21-May-2006 17:37:03

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @EasySolder_OpeningFcn, ...
                   'gui_OutputFcn',  @EasySolder_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT
```

```
% --- Executes just before EasySolder is made visible.
function EasySolder_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to EasySolder (see VARARGIN)

% Choose default command line output for EasySolder
handles.output = hObject;
set(handles.startButton,'Userdata', false);
set(handles.stopButton,'Userdata', false);

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes EasySolder wait for user response (see UIRESUME)
% uiwait(handles.figure1);


% --- Outputs from this function are returned to the command line.
function varargout = EasySolder_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;


% --- Executes on button press in startButton.
function startButton_Callback(hObject, eventdata, handles)
% hObject    handle to startButton (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
set(handles.stopButton, 'UserData', false);

lookup =  [0           3
           1          12
           2          22
           3          32
           4          41
           5          51
           6          61
           7          70
           8          80
           9          90
          10         100
          11         109
          12         119
          13         129
          14         139
          15         148
          16         158
          17         168
          18         178
          19         188
          20         198
          21         208
          22         218
          23         228
          24         238
          25         248
          26         258
          27         268
          28         278
          29         288
          30         298
          31         309
          32         319
          33         329
```

34	339
35	350
36	360
37	370
38	380
39	391
40	401
41	411
42	422
43	433
44	443
45	454
46	464
47	475
48	485
49	496
50	506
51	517
52	528
53	538
54	549
55	559
56	570
57	581
58	591
59	602
60	613
61	624
62	635
63	646
64	656
65	667
66	678
67	689
68	700
69	711
70	722
71	733
72	744
73	753
74	766
75	777
76	788
77	799
78	810
79	821
80	833
81	844
82	855
83	866
84	878
85	889
86	900
87	912
88	923
89	934
90	946
91	957
92	969
93	980
94	991
95	1003
96	1014
97	1026
98	1037
99	1049
100	1061
101	1072
102	1084
103	1095
104	1107
105	1118

106	1130
107	1142
108	1154
109	1165
110	1177
111	1189
112	1201
113	1213
114	1224
115	1236
116	1248
117	1260
118	1272
119	1284
120	1296
121	1308
122	1320
123	1332
124	1344
125	1355
126	1368
127	1379
128	1392
129	1404
130	1416
131	1428
132	1440
133	1452
134	1464
135	1476
136	1488
137	1501
138	1513
139	1525
140	1537
141	1550
142	1562
143	1574
144	1587
145	1599
146	1611
147	1624
148	1636
149	1649
150	1661
151	1673
152	1686
153	1698
154	1711
155	1723
156	1736
157	1749
158	1761
159	1774
160	1785
161	1798
162	1810
163	1822
164	1835
165	1848
166	1860
167	1873
168	1886
169	1898
170	1911
171	1923
172	1936
173	1949
174	1962
175	1974
176	1987
177	2000

178	2013
179	2026
180	2040
181	2052
182	2065
183	2078
184	2091
185	2104
186	2117
187	2130
188	2143
189	2156
190	2169
191	2182
192	2195
193	2208
194	2221
195	2234
196	2247
197	2260
198	2274
199	2287
200	2299
201	2312
202	2326
203	2339
204	2352
205	2365
206	2378
207	2392
208	2405
209	2418
210	2431
211	2444
212	2458
213	2471
214	2484
215	2498
216	2511
217	2525
218	2538
219	2551
220	2569
221	2583
222	2596
223	2609
224	2623
225	2637
226	2650
227	2664
228	2677
229	2691
230	2704
231	2718
232	2732
233	2745
234	2759
235	2772
236	2786
237	2800
238	2814
239	2828
240	2837
241	2851
242	2864
243	2878
244	2892
245	2905
246	2919
247	2933
248	2947
249	2960

250	2974
251	2988
252	3002
253	3016
254	3029
255	3043
256	3057
257	3071
258	3085
259	3099
260	3114
261	3128
262	3142
263	3156
264	3170
265	3184
266	3197
267	3212
268	3226
269	3240
270	3254
271	3268
272	3282
273	3296
274	3310
275	3324
276	3338
277	3352
278	3367
279	3381
280	3398
281	3412
282	3426
283	3440
284	3455
285	3469
286	3483
287	3497
288	3512
289	3526
290	3540
291	3555
292	3569
293	3583
294	3598
295	3612
296	3626
297	3640
298	3655
299	3670
300	3679
301	3694
302	3708
303	3722
304	3737
305	3751
306	3765
307	3780
308	3794
309	3809
310	3823
311	3838
312	3852
313	3867
314	3881
315	3896
316	3910
317	3925
318	3939
319	3953
320	3972
321	3986

322	4001
323	4016
324	4030
325	4045
326	4060
327	4074
328	4089
329	4104
330	4119
331	4133
332	4148
333	4163
334	4177
335	4192
336	4207
337	4222
338	4237
339	4251
340	4264
341	4279
342	4294
343	4309
344	4323
345	4338
346	4353
347	4368
348	4383
349	4398
350	4413
351	4428
352	4442
353	4457
354	4472
355	4487
356	4502
357	4517
358	4532
359	4547
360	4560
361	4575
362	4590
363	4605
364	4620
365	4635
366	4650
367	4665
368	4680
369	4695
370	4710
371	4725
372	4740
373	4756
374	4771
375	4786
376	4801
377	4816
378	4831
379	4846
380	4857
381	4872
382	4887
383	4902
384	4917
385	4932
386	4947
387	4963
388	4978
389	4993
390	5008
391	5023
392	5038
393	5054

```
          394        5069
          395        5084
          396        5099
          397        5115
          398        5130
          399        5145
          400        5160];

%editable variables
soakTemp = str2double(get(handles.soakTemp,'String'));             %degree C
soakTime = str2double(get(handles.soakTime,'String'));             %in seconds
maxTemp = str2double(get(handles.maxTemp,'String'));              %degree C
dwellTime = str2double(get(handles.dwellTime,'String'));            %in seconds
solderMeltTemp = str2double(get(handles.solderTemp,'String'));       %degree C

%system variables
targetTemp = 0;             %input to controller
startSoak = 0;              %time soakTemp is reached
startDwell = 0;             %time solderMeltTemp is reached
openDoor = 0;               %flag to open door for cool off
stop = false;

%controller parameters
Kp = .01;                    %Proportional gain
Ki = .0001;                  %integration gain
PWMsamples = 1000;           %number of sapmles in PWM frame

%I/O card initiation
dio=digitalio('mcc',0);                 %initiate digital output
dline=addline(dio,0,'Out');             %add channel to output
ai=analoginput('mcc',0);                %initiate analog input
aichan=addchannel(ai, [0]);             %add channel to input
set(aichan(1), 'InputRange', [0 5]);    %set voltage range for input

%system variable initialization
z = 0;                         %integrator
w = 0;                         %anti-wind up, amount output is larger then 1
u = 0;                         %output non saturation
delta = 0;                     %change in time
ctrlOut = 0;                   %output of controller
temperature = [0 0];           %used for double buffer to plot
time = [0 0];                  %used for double buffer to plot
error = 0;                     %used for derivative

%new figure to plot
hold off;    %start time

%plot trajectory
p0 = [0;30];
p1 = [30;30];
p2 = [2*(soakTemp-30)+30;soakTemp];
p3 = [p2(1)+soakTime;solderMeltTemp];
p4 = [p3(1)+2*(maxTemp-solderMeltTemp);maxTemp];
p5 = [p3(1)+dwellTime-30;maxTemp];
p6 = [p5(1)+maxTemp*2;30];
traj = [p0 p1 p2 p3 p4 p5 p6];
plot(traj(1,:), traj(2,:), 'r');
hold on;

tic();

set(handles.status,'String','Running');
%run to soakTemp - 50
while (temperature(1)) < soakTemp-50 & (stop == false)    %more then 50 degrees from soakTemp
    putvalue(dio, 1);                   %always on
    time(2) = time(1);                  %double buffer time
    time(1) = toc();

    temperature(2) = temperature(1);    %double buffer input
    voltage = round(1000*getsample(ai));%voltage in

    %look up temperature
```

```
    i = 1;
    while (voltage > lookup(i, 2)),
        i= i+1;
    end
    rounded = (lookup(i, 2) + lookup(i + 1, 2))/2;
    if (voltage - lookup(i, 2)) < rounded
        temperature(1) = lookup(i, 1);
    else
        temperature(1) = lookup(i + 1, 1);
    end

    set(handles.tempC,'String',num2str(temperature(1)));%Display temp. (C)
    farenheit = round((9/5)*temperature(1) + 32);              %Convert C to F
    set(handles.tempF,'String',num2str(farenheit));     %Display temp. (F)

    %plot data as it arrives
    plot([time(2), time(1)], [temperature(2), temperature(1)]);
    plot(time(1), 100, 'g');
    plot(0, 0, 'k');
    legend('Projected Profile', 'Actual Profile', 'Open Loop PWM (%)', 'Closed Loop PWM (%)');
    drawnow;
    stop = get(handles.stopButton,'Userdata');
end

putvalue(dio, 0);
targetTemp = soakTemp;

%controll to soakTemp
uold = 100;
while (temperature(1) < soakTemp) & (stop == false)   %less then soakTemp
    time(2) = time(1);              %double buffer time
    time(1) = toc();
    delta = time(1)-time(2);
    temperature(2) = temperature(1);    %double buffer input
    voltage = round(1000*getsample(ai));%voltage in

    %look up temperature
    i = 1;
    while (voltage > lookup(i, 2)),
        i= i+1;
    end

    rounded = (lookup(i, 2) + lookup(i + 1, 2))/2;

    if (voltage - lookup(i, 2)) < rounded
        temperature(1) = lookup(i, 1);
    else
        temperature(1) = lookup(i + 1, 1);
    end

    set(handles.tempC,'String',num2str(temperature(1)));%Display temp. (C)
    farenheit = round((9/5)*temperature(1) + 32);              %Convert C to F
    set(handles.tempF,'String',num2str(farenheit));     %Display temp. (F)

    error = targetTemp-temperature(1);  %compute error
    z = z + (Ki*error - (ctrlOut-(u/PWMsamples)))*delta;    %integrate error
    ctrlOut = (Kp*error + z );          %compute output

    if ctrlOut > 1                      %if duty factor too large
       u = PWMsamples                   %make duty factor 100%
    elseif ctrlOut < 0                  %if duty too small
       u = 0;                           %make duty 0%
    else                                %otherwise
       u = round(ctrlOut*PWMsamples);   %duty stays same
    end

    for count = 1:u             %for first part of PWM
        putvalue(dio, 1);       %output high
        getsample(ai);          %burn input data
    end

    for count = 1:(PWMsamples-u)%for second part of PWM
```

```
        putvalue(dio, 0);       %output low
        getsample(ai);          %burn input data
    end

    plot([time(2), time(1)], [temperature(2), temperature(1)]);
    plot([time(2), time(1)], [uold, u/10], 'k');
    drawnow;                    %plot data as it arrives
    stop = get(handles.stopButton,'Userdata');
    uold = u/10;
end

startSoak = toc;
targetTemp = solderMeltTemp;

%ramp up to solder melt temp
while toc < (startSoak+soakTime-60) & (stop == false) %for thirty seconds less then soakTime
    time(2) = time(1);              %double buffer time
    time(1) = toc();
    delta = time(1)-time(2);

    temperature(2) = temperature(1);%double buffer input
    voltage = round(1000*getsample(ai));

    %look up temperature
    i = 1;
    while (voltage > lookup(i, 2)),
        i= i+1;
    end
    rounded = (lookup(i, 2) + lookup(i + 1, 2))/2;
    if (voltage - lookup(i, 2)) < rounded
        temperature(1) = lookup(i, 1);
    else
        temperature(1) = lookup(i + 1, 1);
    end

    set(handles.tempC,'String',num2str(temperature(1)));%Display temp. (C)
    farenheit = round((9/5)*temperature(1) + 32);              %Convert C to F
    set(handles.tempF,'String',num2str(farenheit));     %Display temp. (F)

    error = targetTemp-temperature(1);  %compute error
    z = z + (Ki*error - (ctrlOut-(u/PWMsamples)))*delta;    %integrate error
    ctrlOut = (Kp*error + z );          %compute output

    if ctrlOut > 1                      %if duty factor too large
       u = PWMsamples                   %make duty factor 100%
    elseif ctrlOut < 0                  %if duty too small
       u = 0;                           %make duty 0%
    else                                %otherwise
       u = round(ctrlOut*PWMsamples);   %duty stays same
    end

    for count = 1:u             %for first part of PWM
        putvalue(dio, 1);       %output high
        getsample(ai);          %burn input data
    end

    for count = 1:(PWMsamples-u)%for second part of PWM
        putvalue(dio, 0);       %output low
        getsample(ai);          %burn input data
    end

    plot([time(2), time(1)], [temperature(2), temperature(1)]);
    plot([time(2), time(1)], [uold, u/10], 'k');
    drawnow;                    %plot data as it arrives
    stop = get(handles.stopButton,'Userdata');
    uold = u/10;
end

%upto 15 degrees from max
while ((temperature(1)<maxTemp-10)&(openDoor == 0)) & (stop == false)
    putvalue(dio, 1);   %all on
```

```
    if((startDwell == 0)&(temperature(1)>=solderMeltTemp))   %if above melt temp
        startDwell = toc;                                   %time at melt temp
    elseif ((startDwell ~= 0)&(time(1)>(startDwell+dwellTime))) %if past dwell time
        openDoor = 1;                                        %open door
        set(handles.status,'String','Open Door');
    end

    time(2) = time(1);                  %double buffer time
    time(1) = toc();
    delta = time(1)-time(2);

    temperature(2) = temperature(1);    %double buffer input
    voltage = round(1000*getsample(ai));
    %look up temperature
    i = 1;
    while (voltage > lookup(i, 2)),
        i= i+1;
    end

    rounded = (lookup(i, 2) + lookup(i + 1, 2))/2;
    if (voltage - lookup(i, 2)) < rounded
        temperature(1) = lookup(i, 1);
    else
        temperature(1) = lookup(i + 1, 1);
    end

    set(handles.tempC,'String',num2str(temperature(1)));%Display temp. (C)
    farenheit = round((9/5)*temperature(1) + 32);             %Convert C to F
    set(handles.tempF,'String',num2str(farenheit));     %Display temp. (F)

    plot([time(2), time(1)], [temperature(2), temperature(1)]);
    plot(time(1), 100, 'g');
    drawnow;                    %plot data as it arrives
    stop = get(handles.stopButton,'Userdata');
end

%reflow done, open cool down cycle
while (stop == false)  %more then 50 degrees
    putvalue(dio, 0);       %all off

    if ((startDwell ~= 0)&(time(1)>(startDwell+dwellTime))) %if past dwell time
        openDoor = 1;                                        %open door
        set(handles.status,'String','Open Door');
    end

    time(2) = time(1);                  %double buffer time
    time(1) = toc();
    delta = time(1)-time(2);

    temperature(2) = temperature(1);    %double buffer input
    voltage = round(1000*getsample(ai));
    %lookup temperature
    i = 1;
    while (voltage > lookup(i, 2)),
        i= i+1;
    end
    rounded = (lookup(i, 2) + lookup(i + 1, 2))/2;
    if (voltage - lookup(i, 2)) < rounded
        temperature(1) = lookup(i, 1);
    else
        temperature(1) = lookup(i + 1, 1);
    end

    set(handles.tempC,'String',num2str(temperature(1)));%Display temp. (C)
    farenheit = round((9/5)*temperature(1) + 32);             %Convert C to F
    set(handles.tempF,'String',num2str(farenheit));     %Display temp. (F)

    plot([time(2), time(1)], [temperature(2), temperature(1)]);
    plot(time(1), 0, 'g');
    drawnow;                    %plot data as it arrives
    stop = get(handles.stopButton,'Userdata');
end
```

```
% --- Executes on button press in stopButton.
function stopButton_Callback(hObject, eventdata, handles)
% hObject    handle to stopButton (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
set(hObject,'Userdata', true);
set(handles.status,'String','Stopped');
pause(5);
set(handles.status,'String','Ready!');
% Update handles structure
guidata(hObject, handles);

function soakTime_Callback(hObject, eventdata, handles)
% hObject    handle to soakTime (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of soakTime as text
%        str2double(get(hObject,'String')) returns contents of soakTime as a double


% --- Executes during object creation, after setting all properties.
function soakTime_CreateFcn(hObject, eventdata, handles)
% hObject    handle to soakTime (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function dwellTime_Callback(hObject, eventdata, handles)
% hObject    handle to dwellTime (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of dwellTime as text
%        str2double(get(hObject,'String')) returns contents of dwellTime as a double


% --- Executes during object creation, after setting all properties.
function dwellTime_CreateFcn(hObject, eventdata, handles)
% hObject    handle to dwellTime (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function soakTemp_Callback(hObject, eventdata, handles)
% hObject    handle to soakTemp (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of soakTemp as text
%        str2double(get(hObject,'String')) returns contents of soakTemp as a double


% --- Executes during object creation, after setting all properties.
function soakTemp_CreateFcn(hObject, eventdata, handles)
% hObject    handle to soakTemp (see GCBO)
```

```
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function solderTemp_Callback(hObject, eventdata, handles)
% hObject    handle to solderTemp (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of solderTemp as text
%        str2double(get(hObject,'String')) returns contents of solderTemp as a double


% --- Executes during object creation, after setting all properties.
function solderTemp_CreateFcn(hObject, eventdata, handles)
% hObject    handle to solderTemp (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function maxTemp_Callback(hObject, eventdata, handles)
% hObject    handle to maxTemp (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of maxTemp as text
%        str2double(get(hObject,'String')) returns contents of maxTemp as a double


% --- Executes during object creation, after setting all properties.
function maxTemp_CreateFcn(hObject, eventdata, handles)
% hObject    handle to maxTemp (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

Introduction

Welcome to the world of automated reflow soldering. With this easy to use Reflow Solder Oven you will be able to solder surface mount parts and other circuit components with the click of a button. The following procedures should be used to setup and operate the reflow solder oven. Following these procedures will help prevent damage to circuit components and possible dangers to the operator.

Precautions

First of all, safety is a priority when using the reflow solder oven. There are a few hazards the operator needs to be aware of to prevent any unwanted injury and possible death.

WARNING: HOT – The reflow solder oven is an oven. By nature, ovens produce heat and tend to get hot even on the outside. **DO NOT TOUCH THE OVEN WHEN IT IS ON. IT IS HOT.** The glass door is also very hot so use the provided handle to open the oven. After the oven is on it will remain hot for a while. It is best to always assume the oven is hot.

DANGER: 120V AC – The reflow oven components all run on 120V AC. **DO NOT PUT YOUR FINGERS INSIDE THE ATTACHED CONTROL BOX. THIS COULD KILL YOU.** The small box attached to the right side of the reflow oven is the control box. This box holds the thermocouple conditioner and relay. The relay is connected to 120V AC so it can shock you or worse. Refrain from putting anything in the control box.

Setup Procedure

Setting up the reflow oven requires a few steps. There are some hardware and software requirements to get the oven working for the first time. Once setup is complete, the oven just requires the GUI to be up for operation.

Hardware Setup

To operate the oven it must be hooked up properly. First, connect the wires coming out of the control box to the USB 1208FS I/O card if it is not already connected. Table 1 shows what each wire connection.

Table 1: Wires from Control Box and Corresponding I/O card Port

Wire	Wire Color	USB 1208FS I/O Card Port
Thermocouple Conditioner Out	Yellow	A0
Relay +	White/Black Stripe	D0
Relay -	White	DGnd
Ground	Black	DGnd
+5V	Gray	+5V

In addition to the above connections, ports DGnd, AGnd, and A1 on the USB 1208FS I/O card need to be connected together. The I/O card is then connected to the PC using a USB cable. See the card manual if you have problems setting up. Plug the reflow oven into a wall outlet to provide the 120V AC required.

Figure 1 shows all connections that need to be made.

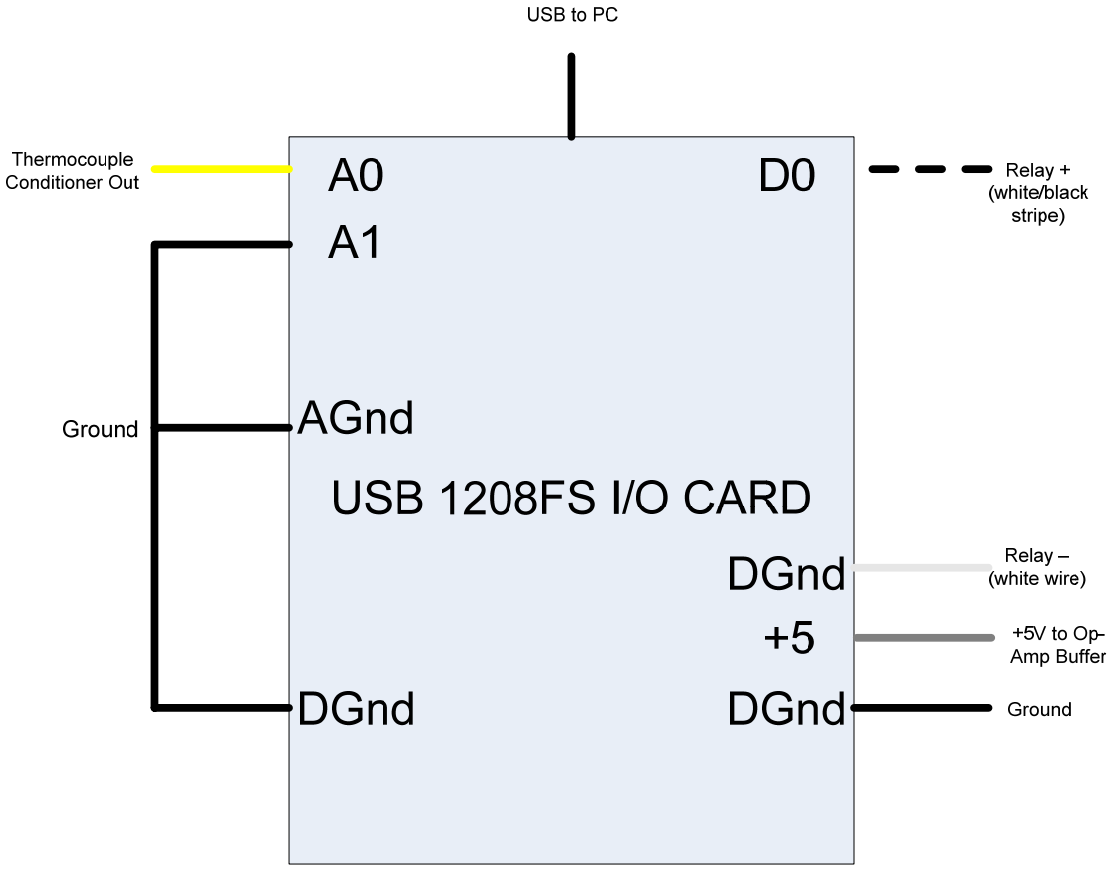

Figure 1: USB Connections

Software Setup

To use the reflow oven you need to have ***InstaCal*** and ***Matlab*** software installed on your PC. Once these are installed you must also make sure you have the most up to date mwmcc.ini file installed in you C:\Program_Files\Matlab\Toolbox\DAQ\DAQ\Private\ directory. We have included the mwmcc.ini we used for this project.

Copy the files for the oven GUI to the PC. The files are called:
EasySolder.fig
EasySolder.m

InstaCal

If your Plug and Play board has been properly detected by the system, ***InstaCal*** will display a Board Detection dialog box listing the board you are installing and any boards that have been detected in the system. Once installed, the properties (configuration) of the board may be changed by double clicking on the board name. Test to make sure the I/O card is working properly by flashing the LED.

Matlab

You can start the oven GUI by double clicking on the EasySolder.m file.

EasySolder GUI

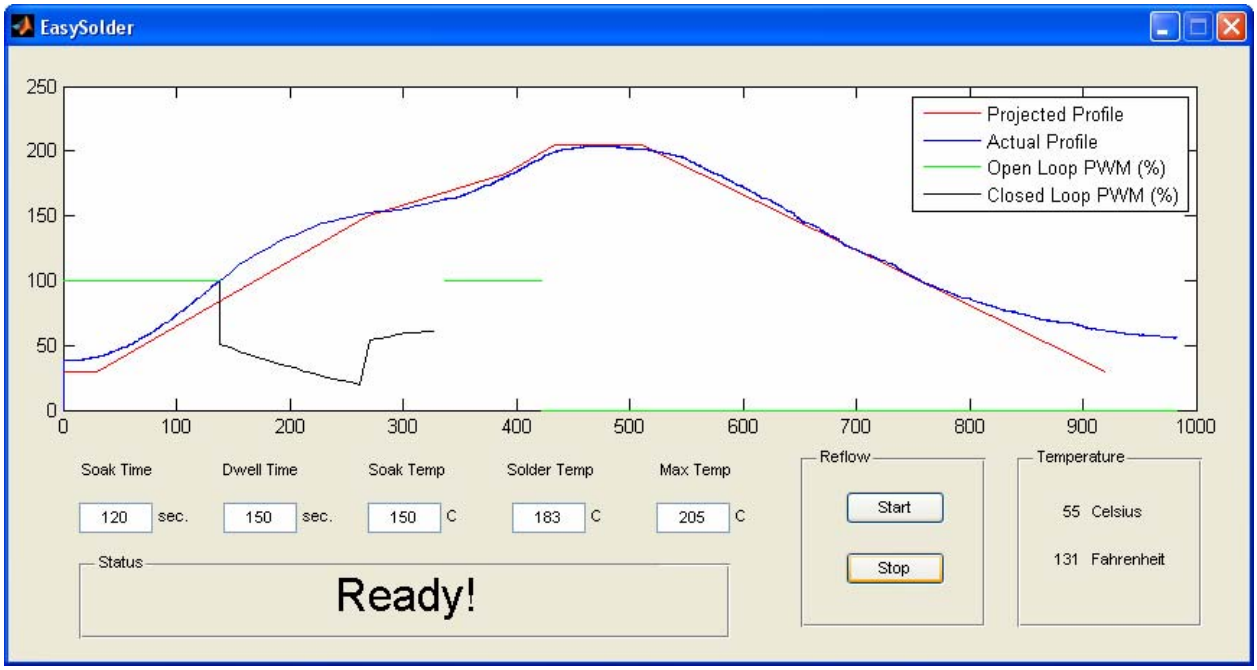

Figure 2: The Easy Solder GUI

The GUI will allow you to set profile characteristics such as Soak Time, Dwell Time, Soak Temp, Solder Temp and Max Temp. It will start with default values that have been tested and work. There are no limits to the values so some values will create a messed up looking profile. If you change the

profile settings, first hit start, then stop, to view the profile you created. If it looks like the profile that you desire then proceed; otherwise enter new values and try again. You can always restart the program to get the defaults back.

Once you have a profile you are ready to put your PCB and pasted components on the tray and insert the tray into the oven.

Turn on the oven convection fan using the switch on the front of the oven. This will help to create an even temperature in the oven and help with cooling during the ramp down cycle. The fan is loud so you have an audible clue that the oven is working.

The GUI will display "Ready!" in the lower text box. Clicking the "Start" button will start the reflow process. Clicking "Stop" at anytime will stop the process. While the process is running: "Running…" will appear in the lower text box. Once the profile reaches the end of the solder cycle you will be prompted to "Open Door" (lower text box). At this time open the oven door to help with cooling.

The plot will display the desired profile in red, the actual temperature in blue, and the control signal in green/black (open-loop/closed-loop). The current temperature readings in degrees C and F are found in the lower right corner.

Modification to the *Matlab* file can be made to change how the oven operate and how the GUI works. It is recommended to make a backup file before changing anything. Also the files are currently set to read-only to prevent accidental modification.

Turn off the fan when done.

Caring for Your Reflow Solder Oven

The Reflow Solder Oven needs love to function properly. Taking proper care of your oven will help work reliably for many years.

To clean the oven use soap and water on a towel. This will get those nasty finger prints off the glass.

When picking up the oven, **DO NOT pick it up by the thermocouple or the control box**. The thermocouple it somewhat fragile and may bend or break. The control box is head on by some small-headed bolts that may rip out of the side of the oven if too much weight is being supported. To pick up the oven, put your hands on the oven. Be careful that the oven is not hot. Bend at the knees and all is good.

Hopefully you will have many good years of reflow fun with your new oven.

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