“Jobeaux” Processor

Technical Manual

First Review Draft

May 18, 2011

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Introduction

The "Jobeaux" processor is an open-design/open-source rotary film/print processor. The functionality is based on the processors formerly produced by the company JOBO International GmbH.

The processor provides a temperature-controlled water bath and a motor to rotate the drum containing the film or print and developing chemicals. Motor speed is selectable. In addition, this processor includes a simple timer, a feature not provided by the Jobo processors.

This document describes the electronics and firmware of the "Jobeaux" processor, hopefully in sufficient detail that an interested person can make modifications to suit his/her own needs, or substitute parts in the event that the specified parts become unavailable.

The processor consists of the following subsystems, each described separately:

- Power Supply
- Motor Subsystem
- Heater Subsystem
- Microcontroller
- Display

Tools

This document was created with OpenOffice software from Oracle (version 3.2.1). The software is a free download from openoffice.org.

The schematics were created with the ExpressSCH software from ExpressPCB (version 7.0.1). The software is a free download from expresspcb.com.

The PC board layout was created with the ExpressPCB software from ExpressPCB (version 7.0.1). This software is also available as a free download from expresspcb.com.

Transparent Copies

The latest transparent copy of this document (ODT file) can be found at:

https://docs.google.com/leaf?id=0B8EiYGJYoQhqN2EwNmQxOWYtYjYzZC00YmFiLThhOWQtMTBmZTNkMDc2OWU3&hl=en&authkey=CK-T0scL

The latest transparent copy of the schematic (SCH file) can be found at:

https://docs.google.com/leaf?id=0B8EiYGJYoQhqNDNiMWMyZWQtM2FkNy00NzlmLWE3ZjMtZjZlYTgwMzhkZDU1&hl=en&authkey=CKK0uXA

The latest transparent copy of the PC board layout (PCB file) can be found at:

https://docs.google.com/leaf?id=0B8EiYGJYoQhqMzkxOTM2OGYtNGI1YS00ZDJhLWJmYTQtNzc1ODI4MmY5NzY3&hl=en&authkey=CIa4quQK

ELECTRONICS

Power Supply

The power supply supplies 24 VDC to operate the gear motor and 5VDC to operate the electronic components. It also supplies a fused 120 VAC to the heater subsystem.

The Power Entry Module, PEM1, provides a standard IEC connection to the mains power. A power on/off switch is included in the specified module.

24VDC power is supplied by an off-the-shelf switching power supply that is rated at 2.7A output. This power supply operates from 90 ~ 264VAC, 47 ~ 440Hz, or 127 ~ 370VDC input, so is capable of operating worldwide (but see below).

5VDC power is provided by an efficient DC-DC converter (U1). Although this device is pin-compatible with the standard 7805 voltage regulator, the 7805 is a linear regulator and should not be substituted, as it would require a large heat sink to dissipate the waste heat.

Using the specified components, the device is designed for 120VAC operation only. Even though the specified heating element is designed to operate at 240V and the triac (Q1) can operate at 240V, the current drawn by the specified heating element will exceed the rating of the triac at 240V. Therefore, a higher current triac and/or a different heating element will be required to support 240V operation. In addition, the MOC3010 should be replaced with a MOC3021. The 24 VDC power supply can operate on 240V AC and the 5V DC power supply operates off the 24V supply, so the heating element should be the only change necessary. Selection of an appropriate heating element is left as an exercise to the implementer.

Motor Subsystem

The motor subsystem consists of a speed selector, a rotation sensor, and a motor driver circuit.

The speed selector allows two speed operation. Most processing is done at the highest speed, but Cibachrome/Ilfochrome print processing benefits from a lower speed. Implementers who do not require the lower speed may eliminate the switch (SW1) at a cost savings of $1.18.

The rotation sensor provides an input to the microcontroller to tell it when to reverse the motor direction. It can also be used by the microcontroller to determine if the motor is even turning. The circuit as shown consists of a photoelectric interrupter switch. The interrupter is typically a disc with a hole or notch in it that is connected to the motor shaft. When the notch passes through the sensor, the output transistor is turned on and the microcontroller can read this change of state. Other types of sensors (e.g., hall effect, mechanical) could be substituted.

The motor driver (U3) is a DRV8801 chip from Texas Instruments. This chip contains the necessary circuitry to drive a DC motor operating at up to 36 volts and 2.8 amps. The microcontroller just has to supply logic-level signals for direction and braking. The Enable input of the DRV8801 (shown as Motor Ctl in the schematic) can be pulse-width modulated (PWM) to control the motor speed. There is a fault indicator that is used to drive an LED and indicate a problem with the motor[1]. Transient Voltage Suppressor (TVS) diode Z1 is used to protect the driver electronics from voltage spikes from RFI, static discharge, or back-EMF from the motor.

Although the processor has the ability to drive an H-bridge with processor outputs, this functionality is not used. There are a couple of reasons for this:

1. It would require 4 output pins rather than the 3 that the DRV8801 uses. This would require the use of a different processor with more pins
2. It would still require an external H-bridge and possibly FET drivers. This would end up costing more than just using the TI chip.

The motor is a 24VDC reversible gear motor with a rotational speed in the range of 50-75RPM. Motors other than the specified one may be used provided that they do not exceed the specifications of the DRV8801 chip.

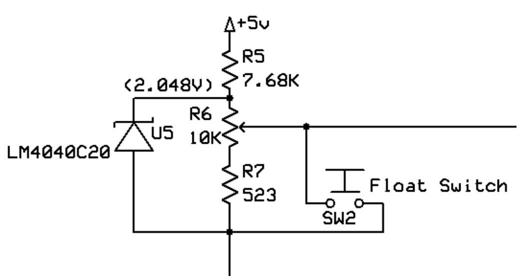
1 The fault signal is not sent to the microcontroller due to a lack of available input pins.

Heater Subsystem

The heater subsystem consists of a desired temperature selection circuit, a water temperature measurement circuit, and a circuit to turn the AC heater element on and off from the microcontroller.

Desired Temperature Selection

The desired temperature is selected by a potentiometer. This produces an analog signal which can be read by an analog-to-digital converter (ADC) input on the microcontroller. The selected temperature will be displayed on the LCD display (see Processor/Display description, below). The minimum voltage that can be selected by the potentiometer is approximately 100mV. This corresponds to a temperature of 59.5°F. As a safety measure, a float switch is incorporated in the design to prevent operation with low or no water level. The low water level signal is piggybacked on the temperature select input – if the float switch turns on, it will pull the voltage down to 0V. The microcontroller will recognize this as a fault condition and disable the heater.

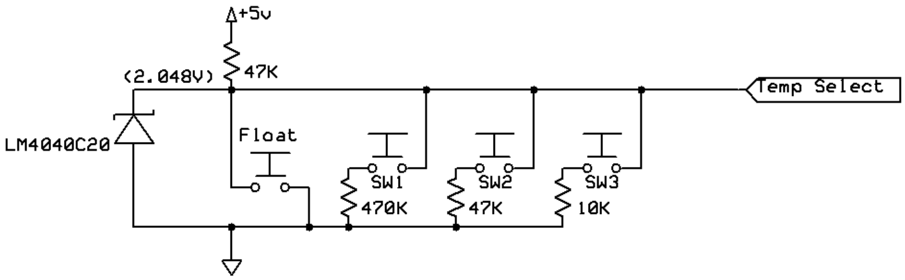


Temperature Selection

R6	Vout
0Ω	0.102V
10KΩ	2.048V

The use of a potentiometer allows the desired temperature to be dialed in quickly, but it can be somewhat difficult to dial in an exact temperature value and the tenths digit does have a tendency to bounce around a bit. For all practical purposes, this is not a problem, but alternative implementations could be considered by users who are annoyed by it. One possibility is to have a number of pushbuttons to increment/decrement the selected value (e.g., +10, +1, +.1, -.1, -1, -10). If each pushbutton causes a different analog voltage to be produced when it is pressed, then additional inputs are not needed and the same microcontroller can be used. The firmware would read the voltage on the input pin and either do nothing (if the voltage indicates no button is pressed), or perform the requested action and wait for the no button pressed condition to occur before looking for another press.

The example below illustrates this. If no button is pressed, the voltage will be 2.048V. As before, if the float switch turns on, the voltage will be 0V. If SW1 is pressed, the voltage will be 1.862V. If SW2 is pressed, the voltage will be 1.024V. If SW3 is pressed, the voltage will be 0.359V. The firmware could also allow for multiple buttons being pressed. For example, if SW2 and SW3 are pressed together, the voltage will be 0.306V.

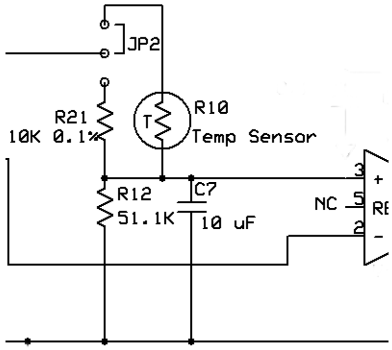


Example: Multiple Inputs on One Analog Port

Additional debouncing may be required in the firmware as well, but this is the basic idea. Also, the selected temperature value (or lookup table offset) would have to be stored in EEPROM so that it was retained when the power was turned off.

Water Temperature Measurement

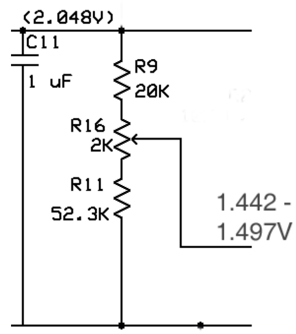
The water temperature measurement circuit utilizes a ruggedized, waterproof resistive probe accurate to ±0.2°C (±0.38°F) across the range where it will be operating. A bridge circuit is used to produce a voltage in the range of the analog input on the microcontroller (0-2.048V) across the operating temperature range (50°F-110°F). The temperature sensor's leads are not shielded, so are prone to noise pickup (including power-line noise). Capacitor C7 shunts this noise to ground so that it does not affect temperature readings. A precision voltage reference (U4) provides a stable, accurate 2.048 volts for the bridge circuit. This precision voltage reference is also fed to the processor's A/D voltage reference input. The processor does have an internal voltage reference which could be used, but it is less accurate and less stable than the REF5020, so the more stable reference is used. The voltage divider that includes the sensor (R10) and the resistor R12 produces a voltage between 1.474V and 1.877V, a range of 0.403V.



Temperature Sensor

Temp	R10	Voltage
50°F	19900Ω	1.474V
110°F	4662Ω	1.877V

The INA332 instrumentation amplifier (U8) is used to subtract a reference voltage (approximately 1.47V) from the voltage produced in the voltage divider that includes the temperature sensor, resulting in a value between 0 and 0.403V. It then multiplies the result by 5, thus making (very nearly) full use of the 2.048V range that the ADC allows. A calibration trimpot allows adjustment of the reference voltage approximately ±1.5% to correct for errors introduced by the chip and inexact tolerances in the components.



Reference Voltage

A precision (±0.1%) resistor (R21) provides a reference for calibration. Jumper JP2 substitutes this precision resistor in place of the temperature sensor during calibration.

Heater Control

The heater element runs on 120VAC. The microcontroller cannot provide the required power directly, so a triac is used to switch the AC power on and off under processor control. A MOC3010 (U7) triac driver provides the interface between the processor and the triac. An optoisolator contained in the MOC3010 isolates the control circuitry from the AC power line (note: some microcontroller circuits actually connect the DC power to the hot side of the AC power line. This eliminates the need for the MOC3010 or equivalent, but it's not a good idea if someone might go poking around inside the box!)

Microcontroller

The microcontroller is a PIC16F1827 from Microchip Technology, Inc. This is a low-cost processor ($1.71 in single quantities as of this writing) that provides all the capability to control the device. It is highly configurable, and in this device is configured as follows:

3 digital inputs (Counter Reset, Speed, Rotation)
3 digital outputs (Direction, Brake, Heater Ctl)
2 analog inputs (Temp Select, Temp Sense)
1 A/D Converter voltage reference
1 pulse-width modulator (PWM) output (Motor Ctl)
1 SPI bus to control LCD display
internal processor clock (running at 4 MHz)
32,768 Hz crystal-controlled timer clock
allows on-board programming

The Schottky diode, D1, isolates the CPU power from the rest of the electronics during on-board programming. Jumper JP1 must be moved to the Program position during on-board programming to protect the crystal X1.

Display

The LCD display is a 3-line x 24 character display that the CPU communicates with through a Serial Peripheral Interface (SPI) bus. It is used to display the selected temperature, the current water temperature, and an HH:MM:SS timer. The timer runs continuously, counting up from 00:00:00. It can be reset to 00:00:00 by pressing the Timer Reset button. Although it might be nice to have a timer that counts down and can keep track of multiple process steps, this should be perfectly adequate for most users and means they don't have to go searching for the stopwatch (or a new battery for the stopwatch) when wanting to develop some film. Additionally, those using this processor as a replacement for an existing processor already have a means for timing their processes, and will likely prefer to continue to use that. We do not wish to burden them with the cost of features they don't need.

The LED2 module is an amber backlight for the LCD display. This module is optional – a reflective version of the display is available (DOGM163L-A). Different backlight colors are also available, but using a different color will require different values for R13 and R14, as shown below.

Color	Part #	R13 & R14 Value
Amber	LED55X31-A	64.9Ω
Blue	LED55X31-B	60.4Ω
Red	LED55X31-R	73.2Ω
White	LED55X31-W	60.4Ω
Yellow/Green	LED55X31-G	69.8Ω

FIRMWARE

Modules

The firmware is developed using the MPLAB IDE. It is released separately under the GNU General Public License (GPL) and consists of the following modules:

jobeaux.inc	Include file that defines port usage and other configuration information.
main.asm	Contains initialization, main interrupt handler, and program main control loop.
motor.asm	Contains the code to read the motor speed select switch and control the motor operation.
temp.asm	Contains the code to read the selected temperature and to control the heater.
timer.asm	Contains the code to operate and reset the HH:MM:SS timer.
display.asm	Contains the code to initialize and operate the LCD display. Actual display routines for temperature and timer are contained in their respective modules.
eeprom.asm	Contains the code to store the display configuration information (whether to display in Fahrenheit or Celsius) in non-volatile memory.

Data Storage

The microcontroller has 384 bytes of RAM, spread across five register banks. Sixteen of these 384 bytes are available in all pages (“shared data memory”). In addition, 256 bytes on non-volatile memory are provided in EEPROM.

The firmware makes maximum use of the shared data memory. Variables that are accessed by interrupt routines or shared across modules are kept in shared data memory. This reduces the overhead involved with making sure the correct register bank is selected. Variables that are internal to a module (and not accessed by that module's interrupt handler) are stored in non-shared RAM, and an appropriate `banksel` call is made before accessing them. Only 40 bytes of RAM (which includes the 16 bytes of shared RAM) are used in this release.

EEPROM is used to store configuration data only in this release, and only two bytes are used.

jobeaux.inc

This header file contains configuration and tuning parameters used by the firmware. It is included by all .asm modules.

main.asm

Reset Vector

The reset vector is located at code location 0. The microcontroller starts the code here at power on or other reset. This jumps to the code at the label named `Start`, which initializes the processor and then enters a main polling loop.

Interrupt Vector

The processor makes use of interrupts for the timer and the motor rotation sensor. The interrupt vector is located at code position 4. It jumps to the interrupt handler at label `IntHandler`, which then dispatches to CPU to the interrupt handlers for the various interrupts. Note that the `IntHandler` code makes no attempt to determine the cause of the interrupt, or to clear the interrupt condition – it is simply a dispatcher. Each interrupt handler has the responsibility of determining if the interrupt condition it handles has actually occurred, and clearing the interrupt condition before returning to the dispatcher.

Initialization Code

Each code module (with the exception of eeprom.asm) contains an initialization routine. The `InitWorld` routine calls all of the individual module initialization functions. The processor is initialized first, in the routine `InitCPU`. This configures all the I/O ports as well as the timers/clocks. The CPU is configured to run at 4MHz using the internal oscillator.

Once the hardware initialization is done, the startup code checks to see if the timer reset button is pressed. If so, it calls the `ConfigureUnits` function in the temp.asm module to allow the user to configure the display for Fahrenheit (°F) or Celsius (°C). Other configuration functions could potentially be called here as well, for those looking to add additional items to the configuration.

Main Program Loop

The main program loop does no real work itself. It merely dispatches to the other modules, calling functions to read the inputs (selected motor speed, selected temperature, timer reset button), then to “tend” to the motor, heater and display subsystems.

motor.asm

Direction Control

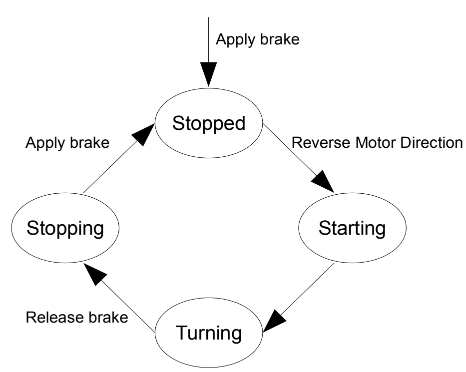
The motor control implements a simple state machine. There are four states:

Stopped The motor is stopped with the brake applied. The motor stays in the Stopped state for ½ to ¾ of a second (`STOP_TIME` timer ticks, defined in jobeaux.inc – the variation is because stopping the motor is not synchronized to the clock, so the time may enter this state at any point between timer ticks) before reversing direction and moving to the Starting state.

Starting The motor is starting. To ensure two full rotations of the motor before reversing, the motor stays in this state until it sees a falling edge from the rotation sensor. It then moves to the Turning state, where it counts rotations.

Turning The motor is turning. It stays in this state until it sees two (or other value defined by `REVERSE_COUNT` in jobeaux.inc) rising edges from the rotation sensor, at which point it moves to the Stopping state.

Stopping The motor is coasting (brake not applied). It is allowed to coast for a period of ½ to ¾ of a second (`COAST_TIME` timer ticks, defined in jobeaux.inc) before applying the brakes. As above, the actual time will vary because the transition into this state is not synchronized to the clock.



Motor State Diagram

Speed Control

Motor speed is controlled by sending a Pulse-Width Modulated (PWM) signal to the Enable input of the motor driver. The motor operates at two speeds, controlled by the `PWM_PERIOD`, `PWM_DUTY_SLOW`, and `PWM_DUTY_FAST` values defined in jobeaux.inc. The values of 7, 4, and 8 give full motor speed for the fast setting and half motor speed for the slow setting. Motor speed changes only take effect when the motor enters the Starting state.

The PWM uses a prescaler value of 4 on Timer2. This gives a PWM period of 32 μsec, which corresponds to a 31.250 Khz square wave at 50% duty cycle. This is well above the limits of human hearing, avoiding the motor whine that can occur if too low a frequency is used.

It would be possible to allow more than two motor speeds by configuring the Speed input on the microcontroller as an analog input and replacing the high/low switch with a potentiometer or resistor ladder/rotary switch.

Rotation Sensor Interrupt Handler

The interrupt handler is called on a rising or falling edge from the rotation sensor. It determines which edge caused the interrupt and decrements the rotation counter (`Rotate` variable) on rising edges (but only if the counter does not already have a value of 0).

The nature of the rotation sensor means that some "bounce" or false interrupts may occur. The interrupt handler debounces the input by ignoring an apparent detected edge that is the same as the last edge seen. The `Phase` variable is used to keep track of the last edge seen. This variable uses bit values so simple bit tests (`btfss`/`btfsc` instructions) can be used to determine the validity of an interrupt request.

temp.asm

Temperature Range

The temperature range[2] supported by the processor is 50°F-110.5°F (10°C-43.5°C). This covers the range of standard processing temperatures[3]:

Black & White	Typically 65°F-75°F (18°C-24°C)
E6	100.4°F (38°C)
C41	100.0°F (37.8°C)
RA-4	95°F (35°C)
Ilfochrome (P3)	86°F (30°C)
Ilfochrome (P4)	102°F (39°C)

The analog-to-digital converters (ADCs) on the microcontroller are 10-bit devices. This gives 1024 discrete values that can represent the 60.5 degree (F) range. This is sufficient to allow the processor to measure to a precision of 0.1°F.

Lookup Tables

Conversion between ADC value and temperature is done through lookup tables. Two tables are used: one for Fahrenheit and one for Celsius. This eliminates the need for the code to do a mathematical conversion between one and the other. It should be noted that the lookup tables are used only to display the temperature value. Internally the firmware uses the 10-bit ADC value when comparing the selected temperature against the current temperature to determine when the desired temperature has been reached, or if it needs to turn the heater on.

The Steinhart-Hart Thermistor Equation can be used to determine the resistance vs. temperature relationship of the temperature probe. This equation is shown below:

$$1/T = A + B \cdot \ln(R) + C \cdot (\ln(R))^3$$

2 This refers to the water temperature measurement and heater control range, not the operating range of the electronic parts themselves.

3 As specified in Kodak and Ilford literature

where:

T = Temperature in Kelvin (K = °C + 273.15)

R = Resistance in ohms at temperature *T*

A, *B*, and *C* are material-specific constants. For the temperature sensor used:

$A = 1.12924\times10^{-3}$

$B = 2.34108\times10^{-4}$

$C = 8.77550\times10^{-8}$

(as specified by the manufacturer).

Doing the heavy floating point math required to perform the conversion would be too much of a burden for the microcontroller, so a spreadsheet was used to perform the necessary calculations and determine the table values. The values were calculated at 0.5° intervals, and the microcontroller does linear interpolation for inputs between the computed values. The tables are reproduced in Appendix B. If a different temperature probe with different material-specific constants is substituted for the temperature sensor, these tables will have to be recomputed. Once the resistance is known for each 0.5° temperature value, the ADC value can be calculated by the following formula:

$$\text{ADC Value} = 5120 \bullet \frac{\text{R12}}{\text{R10} + \text{R12}} - 3673$$

where R10 is the probe resistance and R12 is 51100 (as shown in the schematic). The result of this calculation is rounded to the nearest integer.

Temperature Selection

The desired temperature is selected by adjusting potentiometer R6. This forms a voltage divider with R5 and R7, producing an analog voltage between 102 mV and 2.048V. The 10-bit value is read from the ADC and saved in the `DesiredHi/DesiredLo` variables.

Heater Control

The heater controller uses a very simple algorithm which appears to give adequate temperature control. If this algorithm ultimately proves to be inadequate, a proportional-integral-derivate (PID) design may be implemented.

The algorithm performs successive approximations on initial heating to reach the desired temperature without excessive overshoot.

There are four heater states:

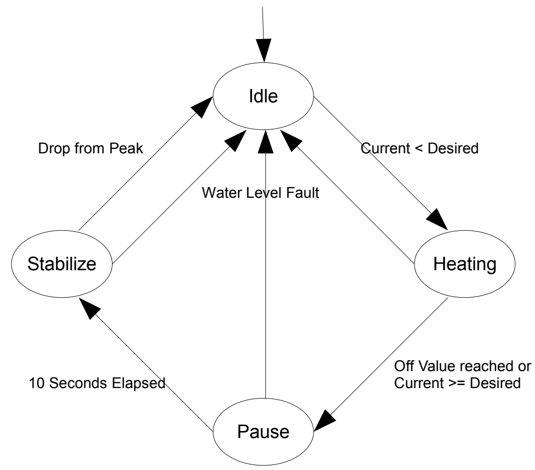
Idle The heater is off. The 10-bit ADC values for the current water tempaerature and desired temperature are compared. If the current water temperature is greater than or equal to the desired temperature, or within a defined constant value (`TOO_COLD_COUNT`) less than the desired temperature, no action is taken. If the current water temperature is less than the desired temperature by more than `TOO_COLD_COUNT`, an off value is computed and the heater is turned on. The state moves to the Heating state. The off value is the 10-bit ADC value that will cause the heater to be turned off when the current temperature reaches it. It is less than the desired temperature because there is retained heat in the heating element when it is turned off, and the temperature probe has a non-zero response time. The off value is approximately ¾ of the difference between the current temperature and the desired temperature.

Heating The heater is on. The heater remains on until the current temperature reaches or exceeds the desired temperature or the off value calculated above. The desired temperature comparison is made because the desired temperature may be changed while the water is heating. The code currently has no mechanism to detect such a change and recalculate the off value, so if the desired temperature is set to a value lower than the computed off value, this prevents what could be a significant overshoot.

Pause The heater is off. This state merely waits for a period of time before moving to the Stabilizing state. The measured temperature typically continues to climb in this state due to the retained heat in the heating element. The delay time is approximately 10 seconds. This is not assumed to be the period of time that heating continues after turning off the power to the heater, but typically temperature readings are fluctuating during this period as the warm water in the immediate vicinity of the heater element mixes with the cooler water surrounding it. This delay allows things to settle down a bit.

Stabilize The heater is off. This state waits until the temperature drops by a defined amount (`STABLE_COUNT`) from its most recent peak. Once this happens, it moves back to the Idle state where a new heating cycle may occur.

As a safety measure, if the float switch indicates a low water condition in any state, the heater is turned off and set to the Idle state. The heater will remain off until the condition is cleared.



Heater State Diagram

timer.asm

Internal vs. External Timer

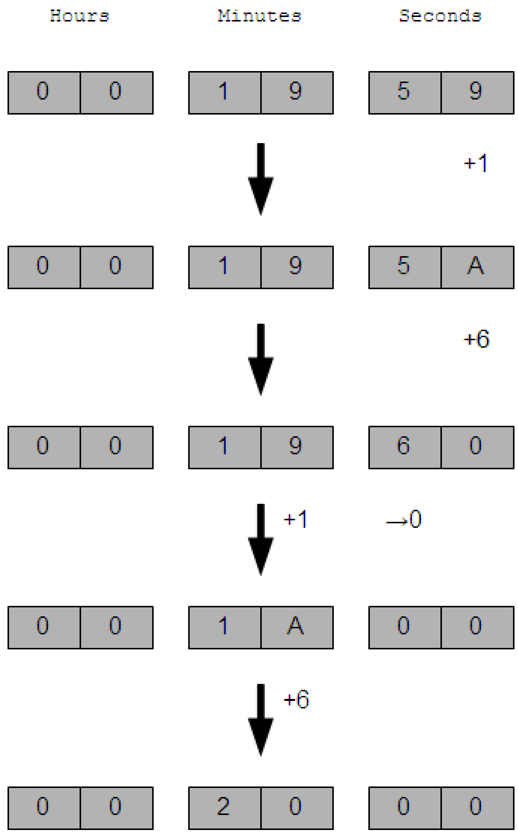
The timer can operate in two modes: either an external 32.768 Khz crystal is used, or the internal clock is used. The crystal will provide better accuracy (typically ±20ppm for the crystal vs. ±1% for the internal clock) if included but this does increase the cost of the system slightly. The microcontroller does provide a means to improve the accuracy of the internal clock (OSCTUNE register), but there is no mechanism implemented in the firmware to provide this capability to the end user. The internal clock is probably accurate and repeatable enough for most practical uses. In any case, the initialization code in main.asm determines whether the crystal is attached and operating, and uses it if available. Otherwise, it uses the internal clock. No configuration or code change is required.

The timer is set to interrupt 4 times per second. The specific counter value varies depending on which clock is being used. These values are defined in jobeaux.inc: `T1_LP_START_HI/T1_LP_START_LO` for the crystal controlled clock, and `T1_IC_START_HI/T1_IC_START_LO` for the internal clock.

BCD Timer

The timer value is kept as a Binary Coded Decimal (BCD) value in memory. One byte is used for each of the hours, minutes, and seconds values, and each byte contains the two BCD digits. Keeping the timer as a BCD value makes incrementing the timer value a little more involved, but it vastly simplifies the display routine which would otherwise have to know how to divide by 10, and possibly by 6 as well (depending on how the binary value was stored).

The example below shows an example of incrementing the timer from 00:19:59 to 00:20:00. The values in each byte are displayed in hexadecimal in this example. The code actually combines the +1 and +6 steps by checking the ones value before incrementing, and adding 7 instead of 1 if the ones value is currently equal to 9.



Incrementing BCD Time Values

display.asm

SPI Device

The LCD display is an SPI device, and the code uses the microcontroller's Master Synchronous Serial Port (MSSP) to send data to the display. The microcontroller is configured as the Master and the display is configured as the Slave. Although the SPI specification allows for bidirectional operation, it is used in unidirectional mode here – no data comes back from the display module.

The SPI clock is configured to operate at 1 MHz. This means that it requires approximately 10 µsec to send each byte. The `LCDOut` function allows an additional 20 µsec for the display to act on the data sent. Updating the display always sends all 48 characters, so each display update takes on the order of 1500 µsec. By itself, this limits the main program loop to less than 700 iterations per second, but this is still at least an order of magnitude faster than it needs to be for this application.

No interrupt is used during data transmission. The microcontroller polls to determine when to send the next byte by checking the Buffer Full (BF) flag of the status register. Even though no data is being sent by the display, a receive operation occurs and sets this flag.

Update Frequency

The display normally updates on each timer tick (4 times per second). An immediate (i.e., the next time the `TendDisplay` function is called) update occurs when the timer is reset. This results in a very responsive but not too busy display.

eeprom.asm

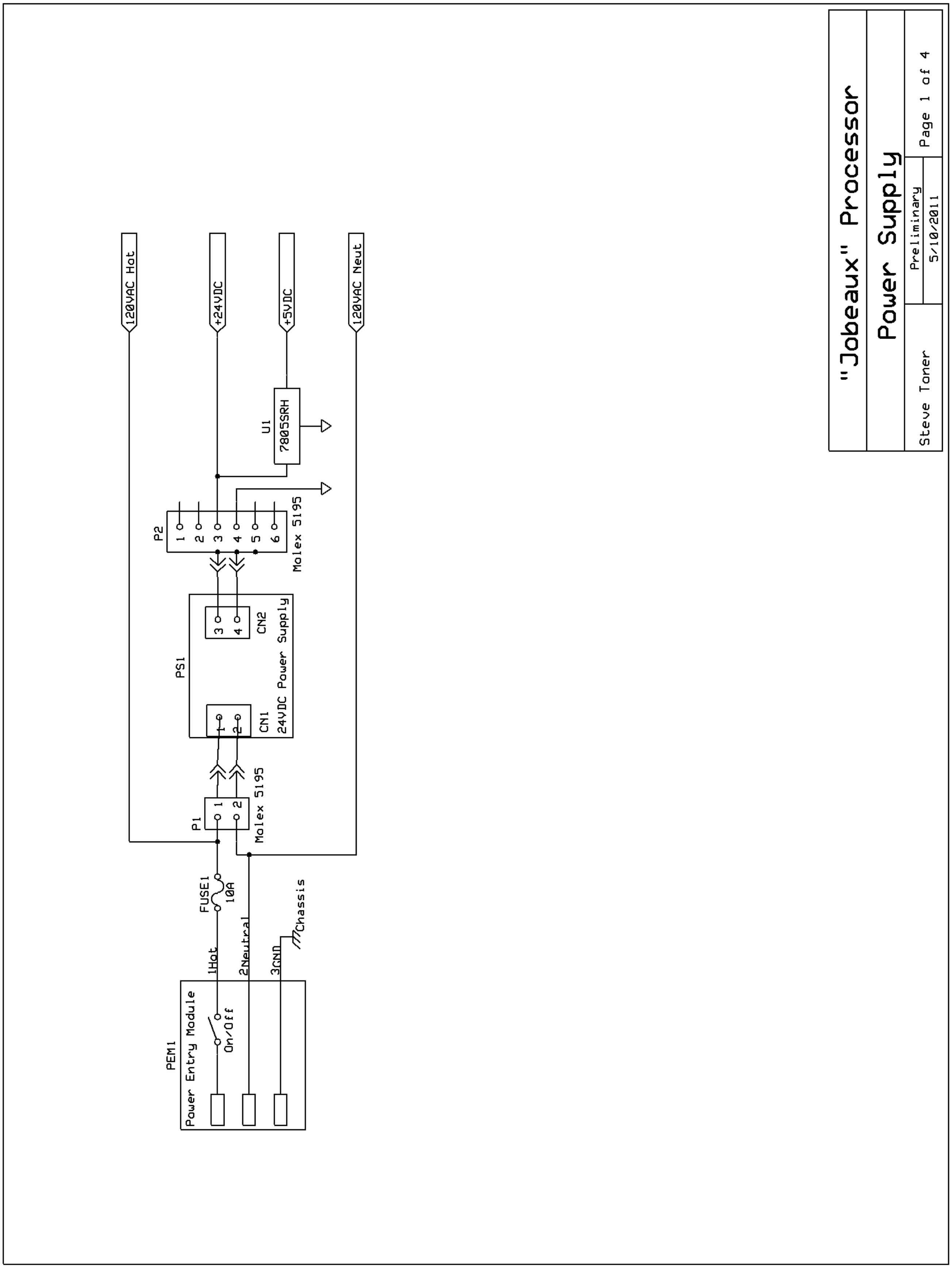
EEPROM is used to store configuration data. The only data being stored in this release is the display units (Fahrenheit or Celsius), but a version byte is also defined to allow for future expansion. The configuration data is stored starting at offset 0 in the EEPROM.

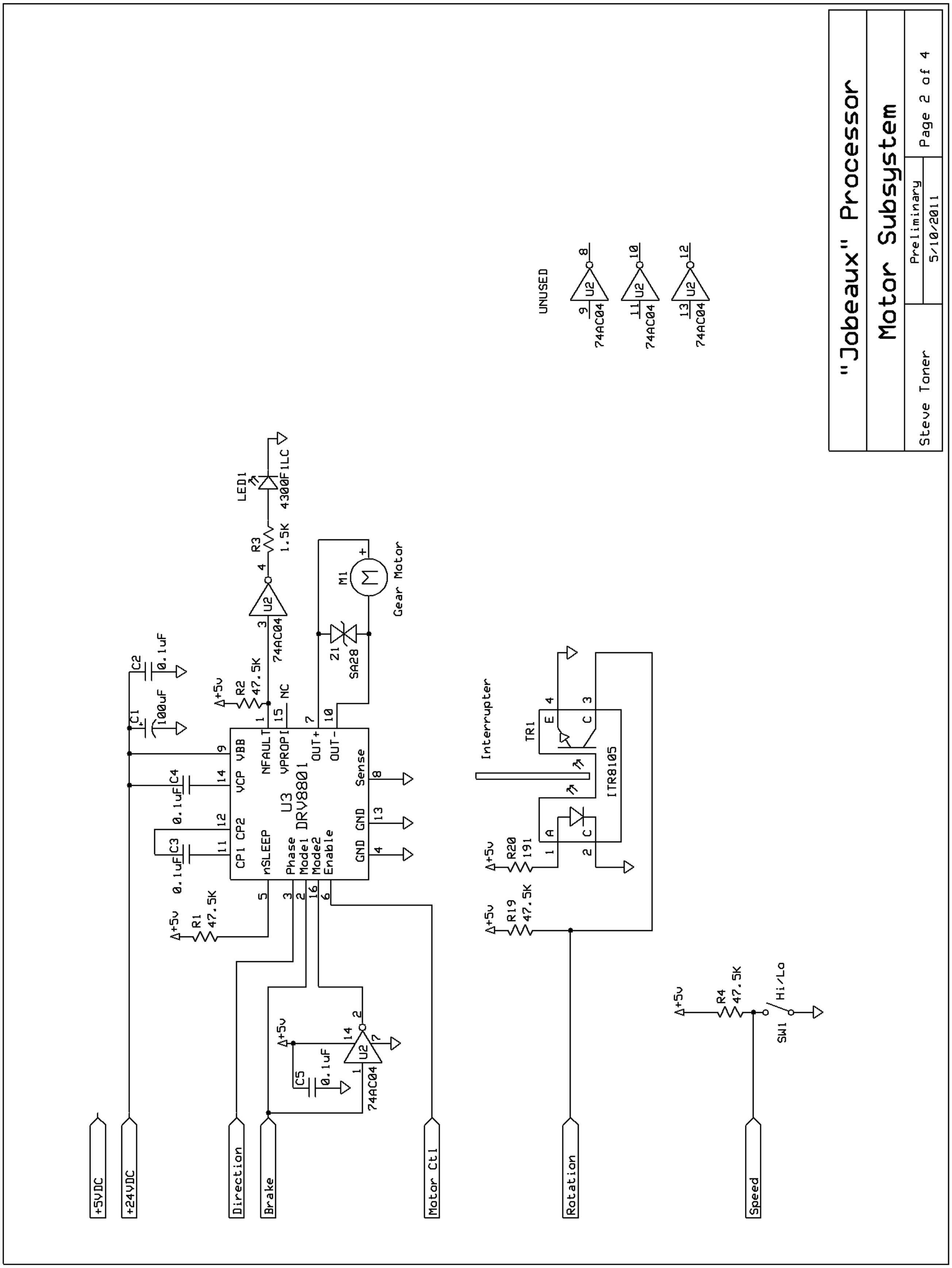
Offset	Data
0	Version
1	Units (0=Celsius, non-zero=Fahrenheit)

EEPROM Data Format (Version 0)

APPENDIX A:

SCHEMATICS


"Jobeaux" Processor
Power Supply
Steve Toner
Preliminary
5/10/2011
Page 1 of 4
120VAC Hot
+24VDC
+5VDC
120VAC Neut
U1
7805SRH
P2
Molex 5195
PS1
CN2
CN1
24VDC Power Supply
P1
Molex 5195
FUSE1
10A
Chassis
1Hot
2Neutral
3GND
PEM1
Power Entry Module
On/Off


"Jobeaux" Processor
Motor Subsystem
Steve Toner
Preliminary
5/10/2011
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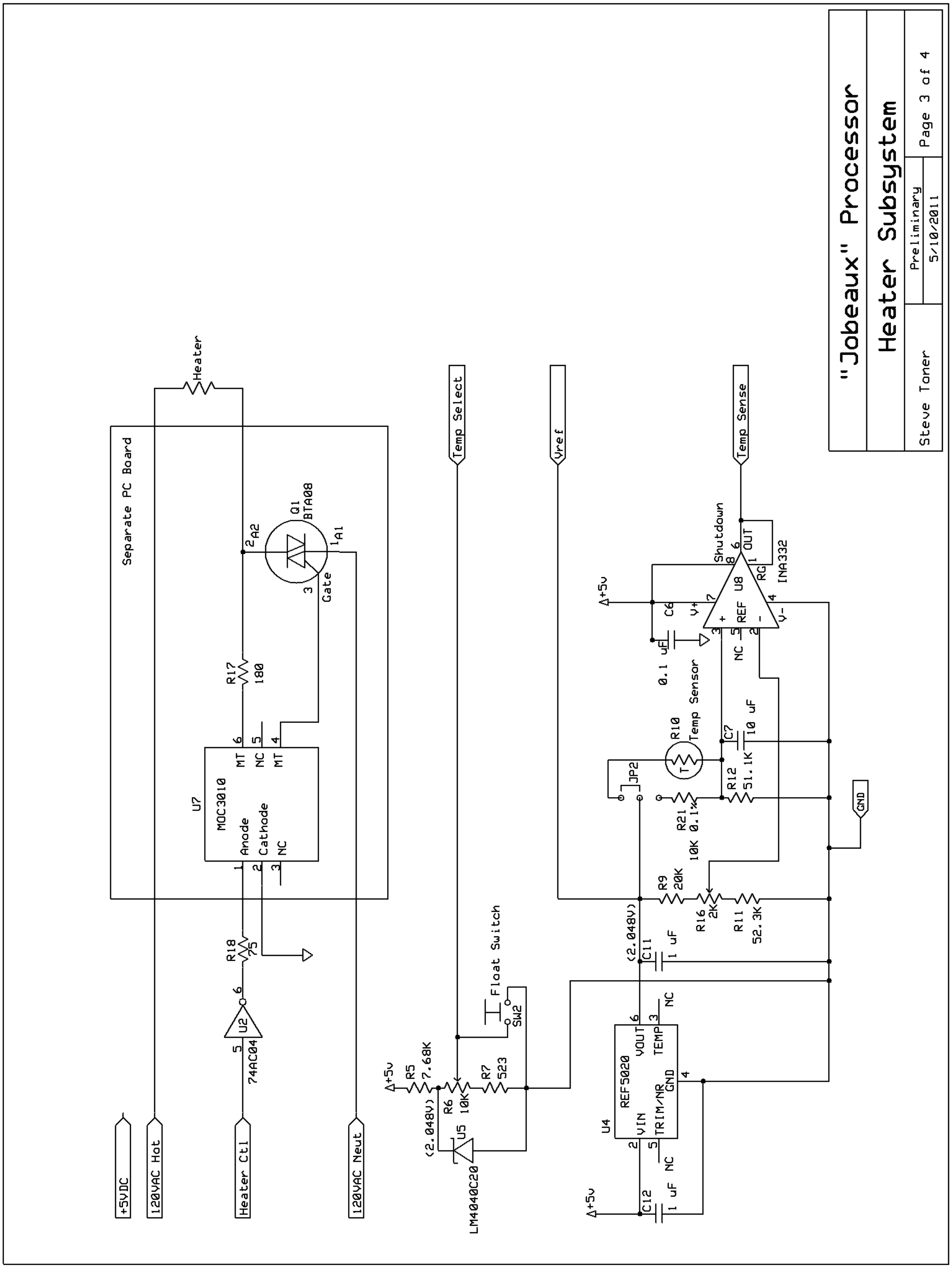
UNUSED
74AC04
U2
U3
DRV8801
VBB
VCP
CP1
CP2
nSLEEP
NFAULT
VPROPI
OUT+
OUT-
Sense
GND
Phase
Mode1
Mode2
Enable
NC
C1
100uF
C2
0.1uF
C3
0.1uF
C4
0.1uF
C5
0.1uF
R1
47.5K
R2
47.5K
R3
1.5K
R4
47.5K
R19
47.5K
R20
191
LED1
4300F1LC
Z1
SA28
M1
Gear Motor
Interrupter
TR1
ITR8105
SW1
Hi/Lo
+5v
+5VDC
+24VDC
Direction
Brake
Motor Ctl
Rotation
Speed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Heater Subsystem
Preliminary
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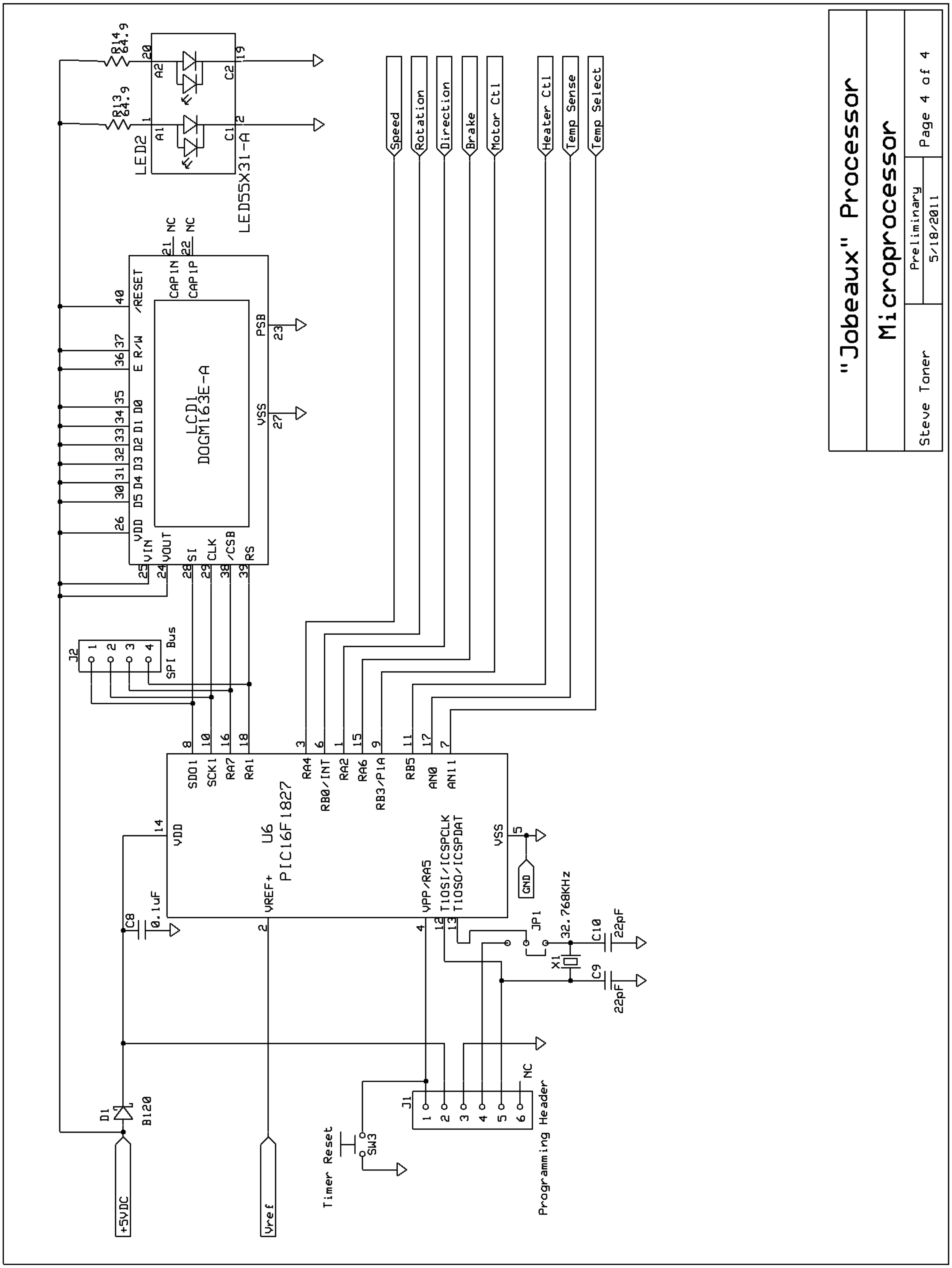
Steve Toner
Separate PC Board
Heater
Q1
BTA08
A2
A1
Gate
R17
180
U7
MOC3010
Anode
Cathode
NC
MT
R18
75
U2
74AC04
+5VDC
120VAC Hot
Heater Ctl
120VAC Neut
Temp Select
Vref
Temp Sense
Float Switch
SW2
R5
7.68K
R6
10K
R7
523
U5
LM4040C20
(2.048V)
U4
REF5020
VIN
TRIM/NR
GND
VOUT
TEMP
NC
C12
1 uF
C11
1 uF
R9
20K
R16
2K
R11
52.3K
R21
0.1%
10K
JP2
R10
Temp Sensor
R12
51.1K
C7
10 uF
0.1 uF
C6
U8
INA332
Shutdown
OUT
RG
REF
V+
V-
+5v
GND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Microprocessor
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U6
PIC16F1827
LCD1
DOGM163E-A
LED2
LED5X31-A
R13
64.9
R14
64.9
J2
SPI Bus
J1
Programming Header
NC
SW3
Timer Reset
D1
B120
C8
0.1uF
C9
22pF
C10
22pF
X1
32.768KHz
JP1
GND
+5VDC
Vref
Speed
Rotation
Direction
Brake
Motor Ctl
Heater Ctl
Temp Sense
Temp Select
VDD
VSS
VREF+
VPP/RA5
T1OSI/ICSPCLK
T1OSO/ICSPDAT
SDO1
SCK1
RA7
RA1
RA4
RB0/INT
RA2
RA6
RB3/P1A
RB5
AN0
AN11
/RESET
E R/W
D0 D1 D2 D3 D4 D5
VIN
VOUT
SI
CLK
/CSB
RS
CAP1N
CAP1P
PSB
A1
A2
C1
C2

APPENDIX B:

TEMPERATURE TABLES

°F	Resistance (Ω)	ADC Value
50.0	19902.722	12
50.5	19639.387	26
51.0	19379.974	39
51.5	19124.416	53
52.0	18872.653	66
52.5	18624.620	79
53.0	18380.257	93
53.5	18139.505	106
54.0	17902.303	119
54.5	17668.595	132
55.0	17438.324	144
55.5	17211.433	157
56.0	16987.868	170
56.5	16767.576	182
57.0	16550.502	195
57.5	16336.596	207
58.0	16125.806	219
58.5	15918.082	231
59.0	15713.374	243
59.5	15511.635	255
60.0	15312.817	267
60.5	15116.873	278
61.0	14923.756	290
61.5	14733.423	301
62.0	14545.828	313
62.5	14360.928	324
63.0	14178.681	335
63.5	13999.043	346
64.0	13821.975	357
64.5	13647.434	368
65.0	13475.382	379
65.5	13305.779	389
66.0	13138.586	400
66.5	12973.766	410
67.0	12811.282	421
67.5	12651.095	431
68.0	12493.172	441
68.5	12337.476	451
69.0	12183.972	461
69.5	12032.627	471
70.0	11883.407	481
70.5	11736.278	491

°F	Resistance (Ω)	ADC Value
71.0	11591.209	500
71.5	11448.167	510
72.0	11307.121	519
72.5	11168.041	529
73.0	11030.895	538
73.5	10895.654	547
74.0	10762.289	556
74.5	10630.771	565
75.0	10501.071	574
75.5	10373.162	583
76.0	10247.016	592
76.5	10122.61	601
77.0	9999.908	609
77.5	9878.892	618
78.0	9759.535	626
78.5	9641.811	634
79.0	9525.695	643
79.5	9411.163	651
80.0	9298.191	659
80.5	9186.755	667
81.0	9076.832	675
81.5	8968.400	683
82.0	8861.436	690
82.5	8755.918	698
83.0	8651.825	706
83.5	8549.134	713
84.0	8447.825	721
84.5	8347.878	728
85.0	8249.272	735
85.5	8151.987	743
86.0	8056.003	750
86.5	7961.301	757
87.0	7867.863	764
87.5	7775.669	771
88.0	7684.701	778
88.5	7594.940	785
89.0	7506.370	791
89.5	7418.973	798
90.0	7332.731	805
90.5	7247.627	811
91.0	7163.645	818
91.5	7080.768	824

°F	Resistance (Ω)	ADC Value
92.0	6998.981	830
92.5	6918.266	837
93.0	6838.610	843
93.5	6759.995	849
94.0	6682.407	855
94.5	6605.832	861
95.0	6530.254	867
95.5	6455.659	873
96.0	6382.032	879
96.5	6309.361	884
97.0	6237.631	890
97.5	6166.828	896
98.0	6096.939	901
98.5	6027.951	907
99.0	5959.852	912
99.5	5892.627	918
100.0	5826.266	923
100.5	5760.755	928
101.0	5696.083	934
101.5	5632.237	939
102.0	5569.206	944
102.5	5506.978	949
103.0	5445.542	954
103.5	5384.886	959
104.0	5325.000	964
104.5	5265.873	969
105.0	5207.494	974
105.5	5149.852	978
106.0	5092.937	983
106.5	5036.739	988
107.0	4981.248	992
107.5	4926.453	997
108.0	4872.346	1001
108.5	4818.917	1006
109.0	4766.155	1010
109.5	4714.053	1015
110.0	4662.600	1019
110.5	4611.788	1023

°C	Resistance (Ω)	ADC Value
10.0	19902.722	12
10.5	19431.546	37
11.0	18972.907	61
11.5	18526.438	85
12.0	18091.782	108
12.5	17668.595	132
13.0	17256.544	155
13.5	16855.304	177
14.0	16464.563	199
14.5	16084.017	221
15.0	15713.374	243
15.5	15352.349	264
16.0	15000.666	285
16.5	14658.059	306
17.0	14324.268	326
17.5	13999.043	346
18.0	13682.142	366
18.5	13373.329	385
19.0	13072.376	404
19.5	12779.062	423
20.0	12493.172	441
20.5	12214.499	459
21.0	11942.842	477
21.5	11678.005	495
22.0	11419.799	512
22.5	11168.041	529
23.0	10922.551	545
23.5	10683.158	562
24.0	10449.694	578
24.5	10221.996	594
25.0	9999.908	609
25.5	9783.275	624
26.0	9571.950	639
26.5	9365.788	654
27.0	9164.650	668
27.5	8968.400	683
28.0	8776.907	697
28.5	8590.043	710
29.0	8407.684	724
29.5	8229.710	737
30.0	8056.003	750
30.5	7886.45	763

°C	Resistance (Ω)	ADC Value
31.0	7720.942	775
31.5	7559.371	787
32.0	7401.633	799
32.5	7247.627	811
33.0	7097.256	823
33.5	6950.424	834
34.0	6807.040	845
34.5	6667.012	856
35.0	6530.254	867
35.5	6396.681	877
36.0	6266.211	888
36.5	6138.763	898
37.0	6014.261	908
37.5	5892.627	918
38.0	5773.790	927
38.5	5657.677	937
39.0	5544.219	946
39.5	5433.349	955
40.0	5325.000	964
40.5	5219.110	973
41.0	5115.616	981
41.5	5014.458	990
42.0	4915.577	998
42.5	4818.917	1006
43.0	4724.421	1014
43.5	4632.036	1022
44.0	4541.710	1029[4]

4 Not a valid ADC value, but used for interpolation.

Derivation of ADC Value Formula

The temperature sensor, R10, forms a voltage divider with resistor R12. The input voltage is 2.048V. The output of the voltage divider at R12 is therefore 2.048V • R12/(R10 + R12). Call this value V_1.

R9, R16, and R11 form a voltage divider that produces a reference voltage. The expected voltage is based on the assumption of perfect resistors and R16 set to the exact middle of its range. This is 2.048V • 53.3K/74.3K = 1.4692V.

The INA332 instrumentation amplifier subtracts the reference voltage from the R10/R12 voltage divider output, multiplies the result by 5 and presents this voltage to the ADC input.

The voltage reference to the ADC is 2.048 volts, and there are 1024 possible output values. Therefore, the resolution of the ADC is .002V (2 mV).

The ADC input value is therefore:

$$\frac{(V1 - 1.4692) \cdot 5}{.002}$$

Simplifying, we get:

$$(V1 - 1.4692) \cdot 2500$$

Expanding V1 and multiplying out:

$$\text{ADC Value} = 5120 \cdot \frac{R12}{R10 + R12} - 3673$$

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Version 1.3, 3 November 2008

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