The ORC v4 Manual

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Contents

Chapter 1
Introduction

1.1 Motivation and Design Goals

The Orc hardware, now in its 4th revision, was designed to support the MASLab Robotics Competition, held yearly at MIT. It is intended to simplify the task of building robots, balancing cost and flexibility.

Figure 1.1: MASLab 2004. The OrcBoard was design for use in MIT's Mobile Autonomous Systems Laboratory (MASLab) robotics competition.

The OrcBoard was inspired by the HandyBoard, produced for MIT's 6.270 robotics competition. The HandyBoard was remarkable in its day, but it is now a 20 year-old design, and does not make good use of the high-density devices available today.

A fundamental design decision behind the OrcBoard is to separate the computational machinery ("compute") from the robotics interface. The OrcBoard is the robotics interface– allowing the compute to read and control sensors and actuators. Factoring the design in this way allows robot implementors to pick a compute engine that is appropriate for them. The compute can be any device with a serial or USB port, ranging from a lowly PIC to a laptop.

The OrcBoard was also designed for maximum hackability. The board is constructed using hobbyist-accessible technologies, using only simple SMT devices and socketed DIPs whenever possible. In addition, the firmware on the OrcBoard can be readily modified to change the functionality. For example, it is possible to support over a dozen servos by sacrificing other capabilities.

The OrcBoard has a companion, the OrcPad, which provides a rich user interface, including a 128x64 pixel LCD panel, a two-axis analog joystick, and three push buttons (including an "emergency stop" button). The OrcPad is extremely useful for robots whose compute lacks a display, as well as for dumping diagnostic information. The OrcPad is attached to the OrcBoard via a tether that can extend up to three meters. In addition, the OrcBoard contains firmware for performing basic diagnostic functions on the OrcBoard's ports, as well as experimenting with motors and sensors. For example, without any compute engine, it is possible to drive a robot around using built-in firmware.

1.2 Hardware Overview

The Orc hardware can be broken down into three basic categories: communication, I/O, and motor drivers.

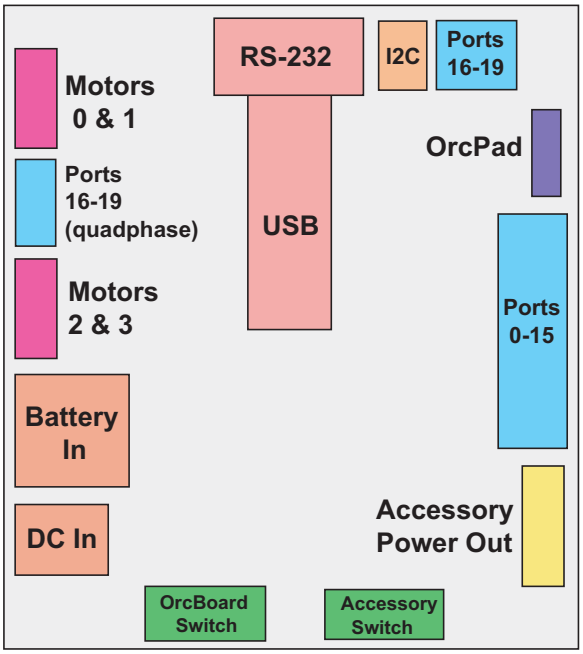


Figure 1.2: OrcBoard Floorplan. The OrcBoard combines 20 multipurpose I/O ports with 4 high-current motor drivers, and flexible power and communication capabilities.

1.2.1 Communication

The OrcBoard communicates with the host via either RS-232 or USB. RS-232 is supported at up to 230.4kbps, while TTL-level RS-232 or USB is supported at up to 250kbps.

I2C devices can be connected to the OrcBoard and controlled from the host. This allows the OrcBoard to serve as an interface to many other devices.

1.2.2 I/O Capabilities

The ORC board has a total of 20 I/O ports with varying capabilities, plus 4 high-current

motor ports. Many of the I/O ports can be used in different ways; for example, port 0 can be used as an analog input, a servo controller, or a digital in/out pin. Naturally, a pin can only be used one way at any given time, but all configuration is done in software, so on-the-fly reconfiguration is possible. See Table 1.1.

Port	Capabilities
0	Digital I/O, Servo, Analog In, Port Current Sense
1	Digital I/O, Servo, Port Current Sense
2	Digital I/O, Servo
3	Digital I/O, Servo, Analog In
4	Digital I/O, SonarPulse
5	Digital I/O, SonarEcho
6	Digital I/O, SonarPulse
7	Digital I/O, SonarEcho
8	Digital I/O, Analog In
9	Digital I/O, Analog In
10	Digital I/O, Analog In
11	Digital I/O, Analog In
12	Digital I/O, Analog In, Analog Out
13	Digital I/O, Analog In
14	Digital I/O, Analog In, PWM Out
15	Digital I/O, Analog In, Gyro Integrator
16	Digital I/O, QuadPhase 0A, MonoPhase
17	Digital I/O, QuadPhase 0B
18	Digital I/O, QuadPhase 1A, MonoPhase
19	Digital I/O, QuadPhase 1B

Table 1.1: OrcBoard I/O Capabilities

Detailed descriptions of the various features are given in Chapter 2.

1.2.3 Motor Drivers

The OrcBoard also has four motor drivers; see Table 1.2.

Category	Specification
Maximum Current	1.5A continuous, 3A (heat limited)
Control Mode	PWM-based voltage control
Feedback	Current Sense (and/or encoders via I/O)
Slew Rate	Programmable

Table 1.2: Capabilities of each of the OrcBoard's four motor drivers

Chapter 2
User Guide

The OrcBoard and OrcPad have extensive functionality built into them. The boards actually contain a total of three microcontrollers. These microcontrollers, known as Programmable Systems on a Chip (PSoCs) are manufactured by Cypress Microsystems. They run at 24MHz, executing a typical instruction in around 6 cycles; they also have 2KB of RAM and 32KB of FLASH.

Rather than providing crude I/O capabilities, the microcontrollers are put to work, providing higher-level functionality and simplifying the task of the user.

A major concern in robotics are real-time constraints. Some events require very precise timing, and if the required timing is not achieved, some type of failure can occur. The OrcBoard is designed to handle most of a robot's real-time activities; this is where the "hidden" CPU power of the OrcBoard comes in handy. The host controller can worry about high-level control issues, leaving the timing-sensitive tasks to the OrcBoard.

2.1 Getting Started

Before using the OrcBoard/OrcPad:

- Inspect the board for missing or bridged solder joints.
- Review the power requirements section.
- Ensure that the battery is fused.
- Disconnect all motors and sensors.

When the OrcBoard starts up, the OrcPad will display a splash screen, and should display the text "Self-tests passed". If self-tests fail, or no message regarding self-tests appears, then the OrcBoard is malfunctioning. Do not proceed until the problem is diagnosed and corrected.

If the tests pass, proceed to configure and calibrate the OrcBoard and OrcPad.

2.2 Built-in Diagnostics and Configuration

The OrcBoard and OrcPad persistently maintain configuration information which governs their operation. This data will be lost when firmware is upgraded, but it *will* survive power-cycling. In addition, the firmware contains various utilities which can be useful when working on a robot.

2.2.1 OrcPad Calibration

The OrcPad calibration should be performed first, in order to calibrate the joystick; otherwise, navigating other menus may prove difficult.

To enter the OrcPad calibration, hold down the menu button for four seconds. After one second, the OrcBoard configuration screen will pop up; this will be described in the next section. Ignore this screen and continue to hold down the menu button until four seconds have passed.

Follow the on-screen prompts to calibrate the joystick. Make sure that the joystick travels around its full range of motion, and be sure to leave the joystick centered before tapping "menu" and proceeding to the next configuration screen.

The second step of OrcPad calibration is to fine-tune the battery voltage sensor. Use a multimeter to measure the voltage currently being applied to the OrcBoard, be it from a battery or wall adapter. Use the joystick to adjust the displayed voltage until it matches the reading on the multimeter.

Confirm that you are done calibrating by tapping menu again. The changes will be written to the OrcPad's FLASH memory.

2.2.2 OrcBoard Diagnostics and Configuration

Enter the OrcBoard configuration screen by holding down the OrcPad's "menu" button for one second. A menu will be displayed with various options for examining the state of the OrcBoard. Most of these options are self-explanatory, however two deserve special mention.

Drive Mode

Most differentially-driven robots (those with two motors, each connected to a wheel on opposite sides of the robot) can be driven from the OrcBoard's firmware, without writing any code.

Drive Mode assumes that the drive motors are connected to ports 0 and 2. Movements of the joystick are translated into PWM control signals to the joystick.

Configuration

Communication parameters, such as baud rate, can be configured in the OrcBoard firmware. These changes are written to FLASH, and so are remembered every time the OrcBoard starts up.

2.3 Connecting to the OrcBoard

The OrcBoard can be accessed in three ways.

- The DB-9 connector provides an RS-232 interface with +/- 10V signaling.
- TTL-level RS-232 signals can be accessed from header. This is intended for small compute platforms (PICs, Basic STAMPs), avoiding the need for them to use a charge pump.
- The OrcBoard can be outfitted with a USBMOD3 device, which will provide a USB interface to the board.

Despite the extremely-high bandwidth available over USB, the OrcBoard in general performs a little worse over USB than a serial connection. There are two causes: the first (and most important) cause is the very high latency of the USB bus, which artificially adds delays to packet reception. The second reason is that the OrcBoard only communicates with the USB module at 250kbps, limiting the maximum achievable bandwidth to a small fraction of USB's theoretical capacity. While OrcBoard/Host communication is slower than it *could* be, it is plenty fast for virtually any robotics application.

If the OrcBoard is being used via USB, placing it on the same USB bus as a high-bandwidth device such as a camera should be avoided.

Once a physical connection is made to the OrcBoard, most users will use prewritten libraries to actually issue requests and receive data. These libraries vary from platform to platform and are consequently documented separately. However, these libraries all implement the protocols described in this document in Chapters 4 and 5.

2.4 Detailed Feature Descriptions

When writing software for the OrcBoard, the first step is to decide which features are needed, and to decide which combination of pin configurations will be best.

The host controller should initialize each pin before it begins controlling the robot. This must be done every time the OrcBoard is reset; the OrcBoard always starts-up in a "safe" configuration which will probably not match your robot's requirements.

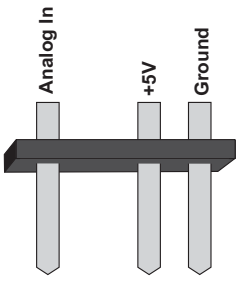
Each pin can be used in a variety of modes. The set of modes available on each pin varies; see Table 1.1 for a list of capabilities. The modes are described in more detail below.

Warning! It is possible to damage the OrcBoard or sensors attached to it by incorrectly configuring ports or plugging in sensors incorrectly. The most dangerous modes are those that cause a pin to be an "output". If an "output" pin (e.g., Analog Out, Digital Out, Servo, Sonar Pulse, PWM Generator) is connected to another device which is also an "output" (e.g., analog range finder, digital switches), damage to either the device and/or the OrcBoard can occur!

For example, connecting an analog range finder to a port configured as a digital out causes *contention*: two devices both trying to make the same signal have the same voltage. Just like shorting power and ground, this can cause a lot of current to flow and can damage the device.

2.4.1 Analog In

Analog values are always represented by 16 bit numbers, scaled so that 0 represents 0V and 65535 represents 5V. Ports 8-15 are 14 bit A/Ds sampled at about 1kHz. Ports 0, 3, 16, and 19 are 6 bit A/Ds sampled at about 8KHz.



Analog In Pinout

Every port has an independently programmable low pass filter, implemented in software with an infinite impulse response (IIR) filter. A single parameter f describes the behavior of the filter. The OrcBoard supports integer values of f from [0, 15]. The IIR filter is:

$$y[n] = (1 - 2^{-f})y[n-1] + 2^{-f}x[n] \tag{2.1}$$

The Z-transform can be written:

$$H(z) = \frac{Y}{X} = \frac{2^{-f}}{1 - (1 - 2^{-f})z^{-1}} \tag{2.2}$$

Larger values of f lead to lower-pass filters, with 8 being a practical upper limit. The filter can be disabled by setting $f = 0$.

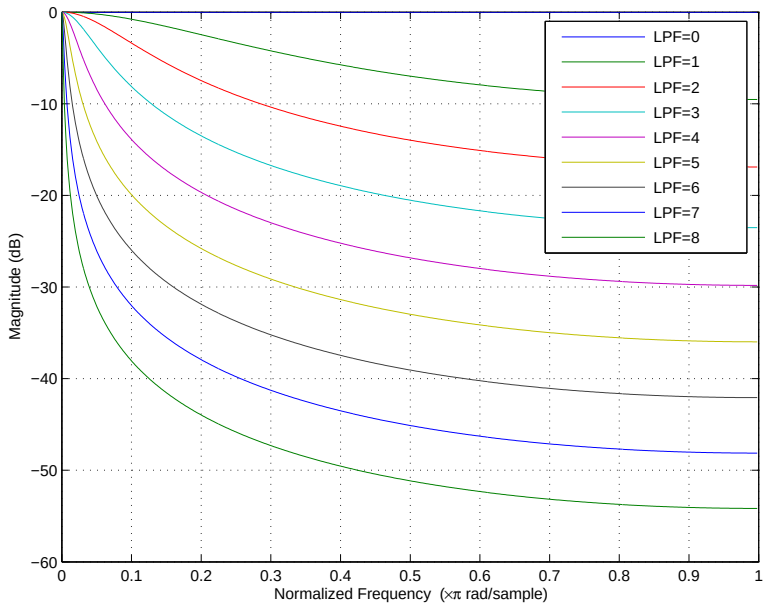
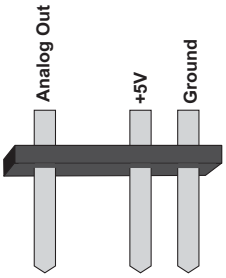


Figure 2.1: LPF Frequency Responses. Increasing values of the LPF increase the strength of the low-pass filter.

Note that when a port is left unconnected, it is natural for readings of that pin to "follow" the values of nearby pins. It does not indicate a hardware problem.

2.4.2 Analog Out

A single 8 bit digital-to-analog (DAC) converter is available on board. This DAC can only be updated by sending a transaction to the board, which limits the maximum rate at which it can change to a maximum of a couple hundred hertz. Consequently, it is not suitable for audio or other waveform replication tasks. It should not drive more than a 1mA load.



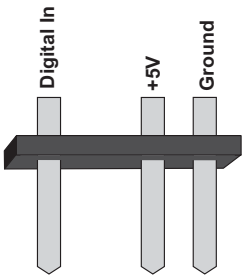
Analog Out Pinout

2.4.3 Digital In

Any port can be used as a digital input whose value can be queried on demand. The input can optionally be configured (in software) to have a 6k pullup, a 6k pulldown, or neither.

Switches (push buttons, whisker, and others) typically make use of Digital In ports. Ordinarily, a switch requires an external resistor, however the OrcBoard can use an internal resistor; simply configure the pin as a "pull up" port.

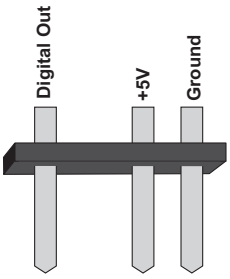
Using the "pull up" configuration, the correct way to wire a switch is to wire one end of the switch to the Digital Input pin and the other end to ground. The +5V connection *is not used.*



Digital In Pinout

2.4.4 Digital Out

Any port can be used as a digital output. The digital out ports cannot source more than 5mA each.



Digital Out Pinout

2.4.5 Gyroscope Integrator

The OrcBoard has built-in support for the ADXL300 gyroscope. The gyroscope produces a voltage that is proportional to angular rate; integrating this signal gives angular position. The gyroscope produces an output signal of 5mV per degree/second.

The gyroscope pin must be configured as an analog in port. The gyroscope integrator will then be automatically available. The connector is the same as for an analog input.

Every 1.95ms (512Hz), the analog value of the gyroscope is read. The low-pass-filter for that pin, if configured, will be taken into account. The value, ranging from 0-65535, is added to the accumulator. Since the nominal zero-rate output voltage is 2.5 volts, we then subtract 32768 from the accumulator; this reduces the rate at which the integrator will overflow. The 32 bit accumulator is freely allowed to overflow and wrap around.

If the accumulator is sampled sufficiently fast (the rate will be described in a moment) to ensure that the accumulator hasn't wrapped-around, the change in the accumulator can be correctly computed. From a change in the accumulator of N, we can compute a change in degrees. First note that the units of N are codes*samples.

$$codes * samples * \frac{5\ V}{65535\ codes} * \frac{1\ second}{512\ samples} * \frac{1\ degree/second}{5\ mV} = degrees \tag{2.3}$$

In other words, given an accumulator change of N, the orientation change is:

$$2.98 * 10^{-6} N\ degrees \tag{2.4}$$

If the accumulator is sampled too infrequently, it will be impossible to reliably determine the change in value. For a 32 bit accumulator, the change must be less than half the accumulator's range (0x80000000.) From above, we can compute that the accumulator will change by 335570 for every degree of rotation. The integrator will overflow after 6400 degrees of rotation.

Unfortunately, the gyro's zero-rate output voltage is not exactly 2.5V. If the robot is left stationary for some period of time, the angular drift rate can be computed and subtracted from future estimates of angular movement. Simply measure the value of the accumulator at the beginning and end of an accumulator and compute what the drift of the accumulator was per unit time. This drift can then be accounted for with future measurements.

In the computations above, it is important to know how much time elapsed. While the host may have its own timing facility, it is better to use the actual 512Hz clock used by the OrcBoard. The API provides a means of accessing this.

The Gyro has a 9 pin connector, but only three pins are used with the OrcBoard. Connect the gyro as follows, using an Analog-In style connector.

Pin	Description	Orc Port Connection
1	ST1	(no connect)
2	ST2	(no connect)
3	TEMP	(no connect)
4	AGND	Ground
5	V2.5	(no connect)
6	CMD	(no connect)
7	SUMJ	Analog Input
8	RATE OUT	(no connect)
9	AVCC	+5V (VCC)

2.4.6 Motor Control

Four high-current motor drivers are available on the OrcBoard. Each is capable of supplying 1.5A continuously, or 3A intermittently.

The motors are controlled by an 8 bit PWM with a frequency of approximately 32kHz. This puts any magnetostriction related noise above the range of human hearing, and puts the PWM frequency safely faster than the mechanical and electrical time constant of any motor.

Each motor channel has an independent 8-bit PWM controller. The PWM control toggles the output voltage between the battery voltage and ground, at roughly 32kHz. This is in contrast to the system on other platforms, in which the PWM toggles the output voltage between the battery voltage and *open circuit*. It is much easier to implement control systems on the OrcBoard as a result since the voltage applied to the motor is more tightly controlled.

The current consumption of each channel is also measured with a low-valued resistor placed in the ground path. These have programmable low-pass filters identical to those used by the analog inputs. The measured voltages are very small, and the effective resolution of the current consumption is around 50mA.

The OrcBoard's A/Ds suffer from offset error, which produces a non-zero voltage even when no current is flowing. The offset error is estimated by the firmware as the minimum value read by the analog/digital converter. This minimum value is subtracted from all current measurements in order to provide the user with a more useful measurement.

With all but the smallest motors, rapidly slewing (changing the value of) the motor's PWM can cause large voltage and current transients. These can blow fuses, brown out the processors, and generally cause all sorts of problems. The solution to this problem is the gradually change the value of the PWM. All four motor channels have independent slew-rate control. At the slowest setting, slewing the motor from -100% to +100% can take up to eight seconds. At the fastest setting, the slew-rate is virtually instantaneous. The slew-rate can be reprogrammed at run-time.

The OrcBoard can be queried for the current "goal" PWM and direction, as well as the actual PWM and direction. The latter will generally lag behind the goal values due to the slew rate limiting.

PWM updates are performed at 64Hz. The maximum change to the PWM value during any interval is the slew value. If the slew value is 50, then it will take five iterations (78ms) to change the PWM from 0 to 250.

Some motors are equipped with rotary encoders. The OrcBoard supports these as well; see below.

2.4.7 PWM Generator

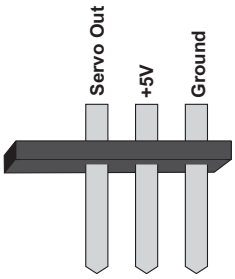
A general-purpose PWM output, independent of board's other features, is provided. The driving clock can be selected between 48MHz and 32.768KHz, with a programmable period and pulse width.

The OrcBoard does not have a crystal-derived clock source, so the frequency cannot be relied upon to be extremely accurate. Empirically, frequencies are accurate within about 2%.

The pinout is the same for a digital output.

2.4.8 Servo Control

Up to four Futaba-style servos can be controlled on the OrcBoard. Servos are implemented with 16 bit PWM, clocked at 16MHz. A single PWM module is time-multiplexed between the four servo outputs. Consequently, the maximum duty cycle for any servo is 25%.



Servo Pinout

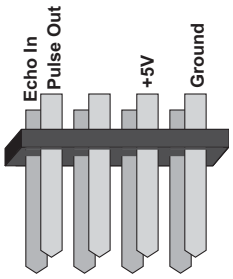
Ports 0 and 1 support a current-sense feature, designed to measure the current consumption of servos. Current consumption is directly proportional to torque, so the current-sense can be used to detect how much resistance the servo is experiencing.

Servos draw current in pulses, so a hardware low-pass filter (an RC filter with a time constant of 33ms) is used to produce a more readily useful measurement.

The servo connectors are designed to be easily interfaced with the three-pin connectors found on most servos. However, both the servo's connector and the OrcBoard connector are female. Rather than replacing the servo's connector, we suggest using a 3x1 section of wire-wrap header, which can reliably serve as a coupler.

2.4.9 Sonar

Up to two Devantech SRF04-style sonar sensors are supported on the OrcBoard. They require a pulse to initiate a range measurement, and return a pulse proportional to range. Consequently, each sonar connector requires two pins. With some minor hackery, these ports can be used with Polaroid-style rangers.



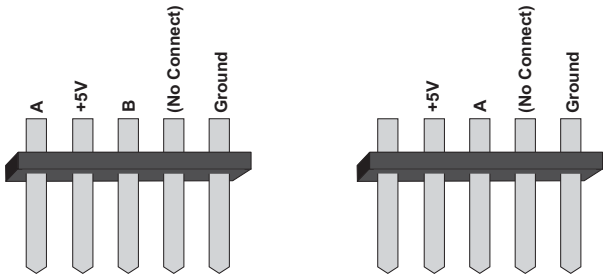
Sonar Pinout

When given a command to pulse, an approximately 10uS positive pulse is produced on the pulse output. When the pulse goes low, a timer is started which measures the elapsed time until a pulse on the echo input goes low. This timer uses a 1MHz clock, so if a value of 0x2400 is returned, 9.216ms has elapsed. The speed of sound is approximately 33,146 cm/s, so multiplying the timer value by 0.016573 will convert the elapsed time to a distance in centimeters. (Note that the measured time interval is a round-trip, accounting for an extra factor of 2.)

Warning! Use great care when inserting a sonar connector. It must be plugged into Ports 4/5 or Ports 6/7. Plugging it "off by one", such as 3/4, or 5/6 can damage the device. Also ensure that the ports have been properly configured!

2.4.10 Quadrature/Monophase Decoders

Intended for motor control applications, the OrcBoard supports two quadrature phase decoders. The OrcBoard also supports single-channel encoders, if quadphase encoders are not available.



Quadphase and Monophase Pinouts

When being used as monophase decoders, the unused two pins should be left unconnected, and cannot be used for other purposes.

Each encoder is implemented using a 16bit continuously wrapping counter. The host must poll the quadrature counters often enough to ensure that counts are not lost due to counter overflow.

Despite being implemented in software, the encoders are capable of very fast counting rates exceeding 15kHz. The software counts how many times illegal state transitions are performed (usually indicating that the quadrature phase signal is transitioning too quickly), and returns this error count in an 8 bit counter.

Warning! The quadrature phase headers are on the board *twice*, near the other I/O pins, and also near the motor drivers. The connectors near the motor drivers have a pinout designed to make it easy to attach HEDS-5500 style optical encoders. Under no circumstances should both sets of connectors be used simultaneously!

Chapter 3
Power

The OrcBoard provides an easy-to-use power design, using common 12V lead acid batteries, and supporting seamless in-system recharging. An accessory power output connector is also provided, which can be used to power external devices, such as embedded PCs (see Fig. 3).

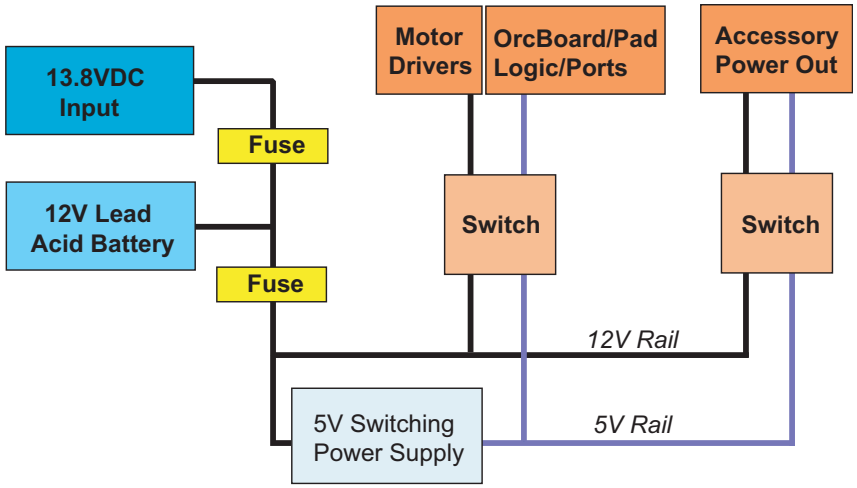


Figure 3.1: Power Block Diagram. The OrcBoard has two main power rails, a 12V rail (which actually ranges from 10-14V), and a regulated 5V rail. Two double-throw switches allow the OrcBoard logic and accessory power output connector to be individually controlled.

3.1 Input Power

There are two main power rails on the OrcBoard: a "12V" rail, derived from the battery and/or wall adapter, and a 5V rail, which is derived via a switching regulator from the 12V rail. The 12V rail actually ranges from about 10V-14.5V depending on operating conditions. When the system is running from a depleted battery, the voltage may dip to 10V or even lower. When running from an unloaded wall adapter (with a nominal rating of 13.8V), the rail may climb over 14V.

The OrcBoard is designed to run from a bank of 12V sealed-gel lead acid batteries of not more than 20 Amp-Hour capacity. The OrcBoard can also be powered by a regulated 13.8VDC wall adapter, which has a separate connector. When both the wall adapter and

battery are plugged in, the battery will recharge; the two power sources are connected together internally on the OrcBoard via a fuse.

This battery charging scheme is simple and fairly reliable, though it has a number of limitations. First, if the battery is deeply discharged, then too much current might flow from the adapter into the battery, blowing a fuse or forcing the wall adapter into shutdown. If this happens, the battery should be recharged in a standalone battery charger that is able to supply the needed current.

The second limitation of this battery charging system is that in order to ensure that the battery is not over-charged (which can damage the battery), a relatively conservative charging voltage of 13.8V is used (this is where the 13.8VDC regulated wall adapter requirement comes from.) It will take a substantially longer time to recharge a robot using the OrcBoard than with a dedicated charger which can automatically increase and then decrease the charging voltage.

Note that the fuses on the OrcBoard are all poly-fuses, and that they reset automatically without needing to be replaced. To reset, they simply need to cool down, which can take up to a minute.

For safety reasons, users should always add an additional fuse to the leads of their batteries. This fuse should be populated with the smallest acceptable current rating, which will provide an added safety margin over the OrcBoard's permanently-attached, high-valued fuses.

Warning! Power safety should be taken seriously even when dealing with low voltages. Electrocution is not a hazard at 12V, however, lead-acid batteries can supply hundreds of watts of power, which can rapidly heat wires and surfaces. Consequently, it is quite easy to be badly burned. Fuse your batteries!

3.2 Peripheral Power

The OrcBoard includes a high-performance 5V switching power supply rated for up to 5A. This supply is shared by all of the board's electronics, as well as many of its peripherals.

The OrcBoard provides power to most of the devices connected to it, including sensors, motors, and a PC-style power connector. The PC-style power connector is an *output*, not an alternative way of supplying power *into* the OrcBoard. The intention of this connector is to make it easier to power embedded PCs from the OrcBoard without additional power supplies. A high-current switch is included, allowing the external PC to be easily switched on or off.

Warning! The PC-style power supply uses an *unregulated* 12V supply; it is connected to the OrcBoard's "12V" rail which may vary from 10-14V. If the motors cause large voltage transients, they might affect the entire 12V rail.

Since the OrcBoard's microcontrollers and most peripherals share the same 5V supply, it is critical that none draw an excessive amount current. Large servos, in particular, should be used with caution. If they draw too much current, it could brown out the microcontrollers, potentially causing a restart. This would be especially inconvenient if a PC were being powered from the OrcBoard.

The motor drivers are heat limited; the drivers themselves are rated for 2.8A continuous, 5.6A peak. However, the OrcBoard is not designed to support this current load.

The total power input to the OrcBoard should not exceed 4A@12V in steady-state.

3.3 Alternative Operating Voltages

The OrcBoard can actually operate over a range of 8-24 VDC. Under 8V, the motor drivers will go into a safety shutdown. At voltages over 12V, the power delivered by the motor drivers grows very rapidly (power grows as V^2/R), so great care should be taken to ensure that they do not overheat.

An alternative operating voltage can be achieved by building a battery pack out of smaller batteries. Three 6V batteries in series yields 18V, and two 12V batteries (again in series) yields 24V. These can be charged in-system as well, provided a wall adapter is suitably selected (it should be roughly 115% of the battery voltage.) However, these higher voltage systems can draw much more current, so it is probably wiser to give up on in-system recharging and use an external charger.

Using an alternative voltage will naturally affect the PC-style connector's "12V" power line. It would not be advisable to plug in a computer component if the 12V rail was actually 24V.

Chapter 4
Packet Communication

4.1 Packets

The OrcBoard/OrcPad is implemented using three separate microcontrollers. Packets are routed between the chips, with one chip (the "master" on the OrcBoard) serving as a hub for all communication. Multiple packets can be in flight simultaneously.

The master serves as a router, with dedicated serial connections to the slave, the pad, and the host. Each connection is constantly monitored for incoming packets. When one is received, it is forwarded to the appropriate destination device. If the destination device is the master, then the master processes the packet (it could be either a request or a response from another device.)

Packets (Table 4.1) are variable-length and contain various bookkeeping information.

Offset	**Description**
0	Always the value 237 (0xED)
1	The *length* of the packet
2	Flags (routing information and transaction ID)
3	First byte of data
...	(more data)
$length - 1$	Modified checksum byte

Table 4.1: Format of a packet

Each packet begins with a synchronization byte, which is always the value 0xED. A synchronization byte makes it easier to identify the beginning of a packet, skipping over corrupted data.

The second byte of every packet is the flags byte. The flags byte contains two fields: the routing field and the transaction ID. The high two bits are the routing flags. The lower six bits are a user-definable transaction id. When the OrcBoard is replying to a request, the reply message will have the same transaction ID as the request.

Note that transaction ID 0 is used for asynchronous broadcasts, and should not be used as a transaction ID by the user.

Note that *orcd*, the Orc communication manager software, rewrites all user packets, assigning them unique IDs (see Appendix D). When communicating with orcd, the requested transaction ID is transparently replaced with an ID guaranteed to not conflict with IDs used by another client. For the rest of this chapter, we will assume that orcd is *not* being used.

It is up to the user to ensure that transaction IDs are allocated in a reasonable manner.

Value	Description
00	Communication between Host and Master
01	Communication between Host and Slave
10	Communication between Host and OrcPad
11	(Used internally in OrcBoard)

Table 4.2: Routing flags

Note that the routing flags do not indicate the direction of the data flow; it is implicit in who sent/received the packet.

4.1.1 Checksum Algorithm

The checksum algorithm used by the OrcBoard is a simple checksum with a one-bit rotation after every byte. This checksum is very fast to compute, and gives reasonable protection against both bit errors and byte transposition errors.

The checksum is performed on every byte in the packet except the checksum byte itself. It can be incrementally computed one byte at a time using 8 bit arithmetic. The checksum is initialized to zero.

```
newchk = (chk << 1) + data + (chk & 0x80 ? 1 : 0);
```

4.1.2 Event Character Support

The hardware can be configured to generate event characters after each transmitted packet. This can be used in some applications to trigger buffer flushes, reducing communications latency. The event character is 0xEE.

The event character, when present, will simply appear to be an extraneous byte between packets, and can be trivially detected and dropped.

4.2 Transaction Management

The simplest way to communicate with the OrcBoard is to issue a transaction, wait for a response, and only then issue another transaction. This is simple to implement, however if USB is being used, the latency of USB can lead to a very low transaction rate. If serial is being used, then this scheme performs reasonably well.

To improve performance, multiple transactions can be initiated simultaneously. This simply means that multiple requests are sent before acknowledgments have been received for older requests. This clearly complicates the design of the client.

Since the OrcBoard is essentially a packet routing network, with different processors simultaneously processing packets bound to them, it is possible for acknowledgments to arrive in a different order than the requests.

4.2.1 Timeouts

All OrcBoard communications should use a timeout mechanism. If a packet is corrupted in transmission, the OrcBoard will silently drop it. If the application is waiting for a

response, it will never receive it. Therefore, communications should timeout, so that if a response is not received, the transaction can be restarted.

Determining the correct interval for the timeout is a bit of an art. The OrcBoard itself responds to most commands very quickly. However, latency in the rest of the system, be it the USB subsystem, or serial interrupts, or the host's multithreading scheduler, can add occasionally add a great deal of delay.

If no additional transactions are outstanding, the slowest OrcBoard transactions take less than 10 ms. If multiple requests are pending, the processing of other requests may also add to the delay.

In general, a timeout of around 100 ms is "long enough". Higher performance can be achieved under some cases by timing out faster and re-requesting a transaction.

The host is a major bottleneck in many systems, adding tens or hundreds of milliseconds of latency to transactions. Increasing the priority of the process that is communicating with the OrcBoard can help tremendously. For example, under Linux, latency can be effectively bounded by using the SCHED_RR scheduler.

4.2.2 Buffer Management

The OrcBoard has a finite buffer size, which limits the amount of data that can be queued up, both for incoming requests and for outgoing acknowledgments. The incoming and outgoing buffers are guaranteed to have only 128 bytes.

If multiple requests totaling more than 128 bytes are pending simultaneously, it is possible to overflow the OrcBoard's buffers. In this case, one or more packets will be silently dropped.

In fact, the buffers on the OrcBoard are somewhat larger than 128 bytes, but the OrcBoard is performing transactions internally, and these transactions consume some of the space.

The largest requests on the OrcBoard are those that write to the LCD panel in the maximum permissible block size, currently 32 bytes. The largest responses from the OrcBoard are state packets, which can be nearly 64 bytes. As a quick, conservative rule of thumb, limiting traffic to two simultaneous transactions will prevent buffer overrun on the OrcBoard.

However, the buffers on the OrcBoard are not the limiting factor. The buffers on the host are often more easily overrun. If the host is a PC, the PC might be busy servicing other interrupts, and can starve the serial/USB driver. Most PC's serial UARTS have only a 16 byte receive buffer, making it easy to overrun them. The USB module has a 384 byte buffer, but is far more likely to be starved. Application writers must always be prepared to deal with lost packets.

4.2.3 Asynchronous Events

The OrcBoard sends some packets without a specific request to do so. These packets are primarily from the OrcPad, which provides asynchronous notification when a user interface element (the joystick or a push button) has changed state. This means that an application which is waiting for a user to push a button or move the joystick does not need to poll constantly; instead, these events will be sent out asynchronously.

The OrcPad is limited to sending asynchronous messages at a maximum rate of one every 9 ms. It will send a message at least every 250 ms.

Chapter 5
Request API

This chapter documents the low-level API, at the packet level, for the OrcBoard. Most users won't need this information, as they'll use a higher-level software library which abstracts away some of the implementation details.

In the sections that follow, we describe the length and contents of the request and response packets. For the sake of brevity, the header and checksum bytes are not repeated.

Please note that each chip numbers its pins in a way that is convenient within that chip, which does not always match the pin numbering used to label the ports on the board. For example, while port 3 is the master's pin 3, port 17 is the slave's pin 1.

Also, some transactions are very similar between chips. Both the master and slave implement identical digital I/O commands. These will be indicated by appropriate cross-references.

Lastly, multi-byte quantities are always sent in network byte order, i.e., MSB first, LSB last.

5.1 Pin Modes

Pins are configured by issuing a configuration command to the chip that implements that pin. This is done on a pin-by-pin basis, and configuration information reverts to "safe" values on reset.

Not all pins can be configured in every mode, see Table 1.1 for a list of supported configurations on a pin-by-pin basis.

Pins 0-15 are implemented by the master, while pins 16-19 are implemented by the slave.

Mode	Description
0	Digital In
1	Digital In (Pull-Up)
2	Digital In (Pull-Down)
3	Digital Out
4	Digital Out (Slow)
5	Servo
6	Sonar Ping
7	Sonar Echo
8	Analog In
9	Analog Out
10	Clock Generator Out
11	Quadrature Phase
12	Mono Phase

5.2 Simple Acknowledgments

Many requests are acknowledged very simply– with a one byte error/success code.

Response Code	Description
0	Success
1	Bad Port
2	Bad Parameter
3	Unknown command

You are not guaranteed to receive an acknowledgment for every command. Some errors (communication errors in particular) will result in a request being silently dropped.

5.3 Master Requests

The master implements ports 0-15 (except current sense on ports 0 and 1), as well as the I2C interface. The routing field of the flags byte should be set to 0b00 for transactions to the master.

5.3.1 State Request

The fastest way of retrieving the status of all sensors and actuators is to request a state update.

Request		
Offset	**Size**	**Description**
0	1	'*' (0x2A)

Reply		
Offset	**Size**	**Description**
3	1	'*' (0x2A)
4	2	Low 16 bits of 512Hz clock
6	2	Digital-in values (ports 0-15)
8	2	Servo 0 PWM (port 0)
10	2	Servo 1 PWM (port 1)
12	2	Servo 2 PWM (port 2)
14	2	Servo 3 PWM (port 3)
16	2	Analog In 0 (port 8)
18	2	Analog In 1 (port 9)
20	2	Analog In 2 (port 10)
22	2	Analog In 3 (port 11)
24	2	Analog In 4 (port 12)
26	2	Analog In 5 (port 13)
29	2	Analog In 6 (port 14)
30	2	Analog In 7 (port 15)
32	2	Analog In 8 (port 0)
34	2	Analog In 9 (port 3)
36	1	Analog LPF 0-1 (ports 8-9)
37	1	Analog LPF 2-3 (ports 10-11)
38	1	Analog LPF 4-5 (ports 12-13)
39	1	Analog LPF 6-7 (ports 14-15)
40	1	Analog LPF 8-9 (ports 0, 3)
41	1	Pin Modes 0-1 (ports 0-1)
42	1	Pin Modes 2-3 (ports 2-3)
43	1	Pin Modes 4-6 (ports 4-5)
44	1	Pin Modes 6-7 (ports 6-7)
45	1	Pin Modes 8-9 (ports 8-9)
46	1	Pin Modes 10-11 (ports 10-11)
47	1	Pin Modes 12-13 (ports 12-13)
48	1	Pin Modes 14-15 (ports 14-15)
49	2	Ultrasound Range 0 (port 5)
51	2	Ultrasound Range 1 (port 7)
53	1	Ultrasound Ping Count 0-1 (ports 5,7)
54	1	Clock Generator Source
55	1	Clock Generator Period
56	1	Clock Generator Width
57	1	DAC value
58	4	Gyro Integrator (port 15)

Servos are controlled by a 16bit PWM value, where 0xFFFF means 25% duty cycle. The PWM clock runs at 16MHz, so to generate a pulse of n ms, set the PWM to $n * 16000$. The maximum pulse width is therefore just over 4ms. A value of zero disables the PWM, effectively powering down the servo. Pulses are sent at 61Hz.

Analog Inputs are unsigned values, ranging from 0 (0V) to 65535 (5V).

Analog Low-Pass Filters (LPFs) are described by 4 bits; a value of zero disables the filter, with each successive value doubling the strength of the filter. The maximum value is 15, but above 8 is probably useless. The even channel LPF is in the low four bits, the odd channel in the upper four bits.

Pin Modes indicate the current mode of the pin, see Table 5.1. The even pin mode is in

the low four bits, the odd mode in the upper four bits.

Ultrasound ranges are measured in intervals of a 1MHz clock.

The Ultrasound Ping count is a a 4 bit rolling counter of how many times each ultrasound port has been pinged, with channel 0 in the low four bits, channel 1 in the high four bits.

The Gyro Integrator is a wrapping 32bit accumulator of the sum of the Analog In 7 (port 15) minus 32768, evaluated at 512Hz.

5.3.2 Analog Filter Set

Set the analog low-pass filter for a port.

Request		
Offset	**Size**	**Description**
3	1	'F' (0x46)
4	1	Filter value [0-15]

The response is a simple ack.

5.3.3 Configure Clock

Configure the programmable clock generator. Note: not implemented.

Request		
Offset	**Size**	**Description**
3	1	'K' (0x4B)
4	1	Source [0-15]
5	1	Period [0-255]
6	1	Width [0-255]

The response is a simple ack.

5.3.4 Configure Pin

Updates the digital out value for pins configured as a digital out.

Request		
Offset	**Size**	**Description**
3	1	'C' (0x43)
4	1	Digital pin number [0-15]
5	1	Value [0, 1]

The response is a simple ack.

5.3.5 Digital Out Set

Updates the digital out value for pins configured as a digital out.

Request		
Offset	**Size**	**Description**
3	1	'D' (0x44)
4	1	Digital pin number [0-15]
5	1	Value [0, 1]

The response is a simple ack.

5.3.6 I2C Read

Perform an I2C Read transaction. (Note: not implemented)

Request		
Offset	**Size**	**Description**
3	1	'i' (0x69)
4	1	I2C Address
5	1	*length* in bytes

Request		
Offset	**Size**	**Description**
3	1	Result code
4	*length*	Data

5.3.7 I2C Write

Perform an I2C Write transaction. (Note: not implemented)

Request		
Offset	**Size**	**Description**
3	1	'I' (0x49)
4	1	I2C Address
5	*length*	Data to write

The response is a simple ack.

5.3.8 Servo Set

Change the value of the servo PWM.

Request		
Offset	**Size**	**Description**
3	1	'S' (0x53)
4	1	Servo number [0-3]
5	2	PWM Value

The response is a simple ack.

5.3.9 Sonar Initiate

Send a pulse on the sonar channel's pulse pin, then begin measuring the pulse width that occurs on the channel's echo pin. For channel 0, the pulse port is 4, echo is port 5. For channel 1, the pulse port is 6, echo is port 7.

Request		
Offset	**Size**	**Description**
3	1	'R' (0x52)
4	1	Sonar channel [0-1]

The response is a simple ack.

5.4 Slave Requests

The slave device is responsible for ports 16-19, the motors, and all the current-sense capabilities on the board (including those on ports 0 and 1). The routing field of the flags byte should be set to 0b01 for transactions to the slave.

Motor directions come up in several transactions, and are encoded in two bits as follows:

Value	Description
0	Disabled (open circuit)
1	Forward
2	Reverse

Table 5.1: Motor Direction Constants

Braking can be accomplished by selecting either forward or reverse and selecting zero PWM.

5.4.1 State Request

The fastest way of retrieving the status of all sensors and actuators is to request a state update.

Request		
Offset	**Size**	**Description**
3	1	0x2A

Reply		
Offset	**Size**	**Description**
3	1	'*' (0x2A)
4	1	Pin Modes 0-1 (ports 16-17)
5	1	Pin Modes 2-3 (ports 18-19)
6	1	Digital-in values of (ports 16-19)
7	2	Quad/Mono-phase 0 (ports 16-17)
10	1	Quad/Mono-phase 0 error count
11	2	Quad/Mono-phase 1 (ports 18-19)
12	1	Quad/Mono-phase 1 error count
13	1	Motor 0 Goal PWM
14	1	Motor 0 Actual PWM
15	1	Motor 0 Slew
16	1	Motor 1 Goal PWM
17	1	Motor 1 Actual PWM
18	1	Motor 1 Slew
19	1	Motor 2 Goal PWM
20	1	Motor 2 Actual PWM
21	1	Motor 2 Slew
22	1	Motor 3 Goal PWM
23	1	Motor 3 Actual PWM
24	1	Motor 3 Slew
25	1	Motor Dir Goal/Actual 0-1
26	1	Motor Dir Goal/Actual 2-3
27	2	Analog In 0 (Motor Current 0)
29	2	Analog In 1 (Motor Current 1)
31	2	Analog In 2 (Motor Current 2)
33	2	Analog In 3 (Motor Current 3)
35	2	Analog In 4 (Port/Servo Current 0) (port 0)
37	2	Analog In 5 (Port/Servo Current 1) (port 1)
39	2	Analog In 6 (port 16)
41	2	Analog In 7 (port 19)
43	1	Analog In LPF 0-1
44	1	Analog In LPF 2-3
45	1	Analog In LPF 4-5
46	1	Analog In LPF 6-7

The formats for the pin modes and LPFs is identical to those on the master.

The motor direction bytes encode both the desired (goal) and actual directions of the motors. For the even-numbered channel, the goal direction is in the low two bits, and the actual direction is in bits 3 and 4. Data for the odd-channel is similarly stored in the high four bits.

5.4.2 All Stop

Stops all motors as quickly as the slew rate allows. This is the command that is internally called when the emergency stop button is pressed.

Request		
Offset	**Size**	**Description**
3	1	'X' (0x58)

The response is a simple ack.

5.4.3 Analog Filter Set

Identical to the master, except only channels [0,7] exist.

5.4.4 Configure Pin

Identical to the master, except only channels [0,3] exist.

5.4.5 Digital Out Set

Identical to the master, except only channels [0,7] exist.

5.4.6 Motor Set

Set the direction/speed motor.

Request		
Offset	**Size**	**Description**
3	1	'M' (0x4D)
4	1	Motor channel [0-3]
5	1	Direction
6	1	PWM

The response is a simple ack.

5.4.7 Motor Slew Set

Set the slew rate for a motor. The value is the maximum change in the PWM in 1/512 second.

Request		
Offset	**Size**	**Description**
3	1	'W' (0x57)
4	1	Motor channel [0-3]
5	1	Slew rate [1-255]

The response is a simple ack.

5.5 Pad Requests

The pad handles all LCD drawing/writing/reading functions, as well as reading the status of the joystick and buttons. The routing field of the flags byte should be set to 0b10 for transactions to the OrcPad.

Two different types of text drawing are supported. One allows text to be arbitrarily positioned on the screen, while the other implements "console"-type behavior, including automatic scrolling.

Note that text as actually limited to be vertically aligned on 8 pixel boundaries. I.e., text can only be drawn on the y values 0, 8, 16, ..., 56.

A number of fonts are available for drawing in. The are all (at most) 8 pixels high, but have different widths.

LCD requests tend to be dramatically slower than most other type of requests. The interface to the LCD is quite slow, and drawing operations can require a large number of operations.

Font Code	Description
A (0x41)	Smallest font
a (0x61)	Smallest font, white on black
B (0x42)	Small font
b (0x62)	Small font, white on black
C (0x43)	Medium font
c (0x63	Medium font, white on black
D (0x44)	Large font
d (0x64)	Large font, white on black

Table 5.2: Font Codes for use in Text Drawing

The state of the buttons on the OrcPad can be queried. The button state is the logical or of the button flags listed below.

Mask	Description
0x01	Stick Button
0x02	Menu Button
0x04	Stop Button

Table 5.3: Button Masks

5.5.1 State Request

Pad status packets are special, in that they are sent asynchronously (without having been requested) when the joystick or buttons change state. This is to eliminate the need for constantly polling for user interface activity. These asynchronous updates are sent at a minimum rate of 4Hz.

There is no reason to explicitly request a state request, since the changes are asynchronously broadcasted.

Request		
Offset	**Size**	**Description**
3	1	'*' (0x2A)

Reply		
Offset	**Size**	**Description**
3	1	'*' (0x2A)
4	1	Joystick X position (0=left, 255=right)
5	1	Joystick Y position (0=up, 255=down)
6	1	Button state (logical OR of button codes)
7	1	Move up counter, Move down counter
8	1	Move left counter, Move right counter
9	2	Battery voltage, in hundredths of a volt

The move counters are continuously wrapping 4 bit counters of "synthetic" key events. If the joystick is held up for a short while, it generates an "up" event. This is analogous to a conventional keyboard's auto-repeat. The OrcPad interprets all joystick movements as possible up/down/left/right movements to simplify those users who desire that sort of interface, while simultaneously giving all applications the same "feel". You can detect if a button has been pressed by testing if the counter has changed value.

The move up and move down counters are stored in one byte, with "up" stored in the low 4 bits, and "down" in the upper four bits. Similarly, "left" is stored in the low 4 bits and "right" in the upper 4 bits.

5.5.2 Clear Display

Clear the display.

Request		
Offset	**Size**	**Description**
3	1	'C' (0x43)

The response is a simple ack.

5.5.3 Console Goto Cursor

Clear the console and home the cursor.

Request		
Offset	**Size**	**Description**
3	1	'G' (0x47)
4	1	x position [0, 26]
5	1	y position [0, 7]

The response is a simple ack.

5.5.4 Console Home Cursor

Clear the console and home the cursor.

Request		
Offset	**Size**	**Description**
3	1	'H' (0x48)

The response is a simple ack.

5.5.5 Console Set Size

Set the size of the console "window". Dimensions are in "characters".

Request		
Offset	**Size**	**Description**
3	1	'S' (0x53)
4	1	top
5	1	height
6	1	left
7	1	width

The response is a simple ack.

5.5.6 Console Write

Draw text at the current console position, wrapping and scrolling as necessary.

Request		
Offset	**Size**	**Description**
3	1	'W' (0x57)
4	(≤ 32)	String

The response is a simple ack.

5.5.7 Draw Mode Set

Set the draw mode

Request		
Offset	**Size**	**Description**
3	1	'M' (0x4D)
4	1	The mode, 0=clear, 1=set, 2=xor

The response is a simple ack.

5.5.8 Draw Lines

Plot one or more lines in the current drawing mode. Lines are drawn from (xa, ya) to (xb, yb).

Request		
Offset	**Size**	**Description**
3	1	'L' (0x4C)
4	1	xa_0
5	1	ya_0
6	1	xb_0
7	1	yb_0
...	...	...
$4 + 4n + 0$	1	xa_n
$4 + 4n + 1$	1	ya_n
$4 + 4n + 2$	1	xb_n
$4 + 4n + 3$	1	yb_n

The response is a simple ack.

5.5.9 Draw text

Draw text at a random location in a user-definable font.

Request		
Offset	**Size**	**Description**
3	1	'T' (0x54)
4	1	x
5	1	y
6	1	font code
7	(≤ 32)	String

5.5.10 Draw top text

Draw text on the top line.

Request		
Offset	**Size**	**Description**
3	1	't' (0x74)
4	1	x
5	($\leq$ 32)	String

The response is a simple ack.

5.5.11 Draw Pixels

Plot one or more pixels in the current drawing mode.

Request		
Offset	**Size**	**Description**
3	1	'P' (0x50)
4	1	x_0
5	1	y_0
...	...	...
$4 + 2n + 0$	1	x_n
$4 + 2n + 1$	1	y_n

The response is a simple ack.

5.5.12 Fill Display

Fill the display with a pattern, x=even columns, y=odd columns. For example, to fill with a checkerboard pattern, use x=0x55, y=0xAA. To fill with vertical stripes, x=0xFF, y=0x00. To fill with horizontal stripes, x=0x55, y=0x55.

Request		
Offset	**Size**	**Description**
3	1	'F' (0x46)
4	1	even column value
5	1	odd column value

The response is a simple ack.

5.5.13 Raw read

Read the LCD's frame buffer in a horizontal swath, 8 columns high. See Appendix B for more information.

Request		
Offset	**Size**	**Description**
3	1	'r' (0x72)
4	1	x
5	1	y
6	1	$length \leq 32$

Reply		
Offset	**Size**	**Description**
3	1	result code
4	*length*	data

5.5.14 Raw write

Write the LCD's frame buffer in a horizontal swath, 8 columns high. See Appendix B for more information.

Request		
Offset	**Size**	**Description**
3	1	'R' (0x52)
4	1	x
5	1	y
6	($\leq$ 32)	data

The response is a simple ack.

Appendix A
Soldering and PCB Assembly

To a beginner, soldering can seem very simple: melt some metal "glue" to join two other metal bits together. However, glue is *not* glue. Creating a good solder joint–one which is both electrically and mechanically reliable– is a function of chemistry and technique.

A.1 Chemistry and Metallurgy of Soldering

In a piece of metal, the metal atoms form metallic bonds. In this state, an electron is not associated with any particular atom, but is free to move around the metal. This freedom of mobility is what gives metals such good electrical and thermal conductivity.

When building circuits, we often want to join together two smaller bits of metal, making a good thermal/electrical/mechanical connection. In other words, we want to make the two pieces of metal act as though they were a single piece.

There are two main enemies of a good metal joint. The first is oxidation: instead of forming metallic bonds, the metal atoms form ionic bonds with oxygen atoms. In these molecules, electrons are tightly bound to their molecule. Electrons can't move, and poor conductivity results.

The second enemy of a good metal joint is a poor mechanical linkage. Not only should the two metals be as physically close as possible, but there should be no sudden changes in the composition/properties of the material when moving from one piece of metal to the next piece. When the interface between two different materials occurs over a very small distance, a poor mechanical linkage results. These interfaces act like cracks in a crystal.

One approach to joining bits of metal is to melt the two bits and let them cool together. This makes a terrific joint. But the melting point of copper is 1084 degrees Celsius, making this an impractical approach.

The goal of soldering is to join bits of metal by using an intermediary metal that has a low melting point. For example, typical tin/lead solder melts at around 350 degrees Celsius. Of course the solder will fill gaps and spaces between the two pieces. More importantly, however, when the bits of metal are heated as well, the solder will diffuse into the bits of metal. When it does this, it forms an alloy where the concentration of the bit of metal and solder gradually changes. The result is a stronger mechanical connection.

The metals used in electronics oxidize in the presence of oxygen, forming a "skin" layer which has poor conductivity. When soldering, this layer must be removed. The solution is *flux*, an acid which reduces the metallic oxides to metallic salts and water which then flow away from the joint.

Most solder comes with flux mixed in. Flux can be any of a number of chemicals, but is often an organic carboxylic (R-COOH) acid. The "smoke" you see when soldering is

actually a result of the flux burning, and contains very little metal. The burning of the flux also helps to remove oxygen immediately around the joint, which helps to prevent oxidation in the joint itself.

Fluxes which use organic acids leave residue on the PCB which, depending on the severity, may need to be removed using a solvent. "No-clean" fluxes are available which typically perform quite poorly, but they do not require cleaning.

Key points:

- Both the solder and the metal it is being applied to must be heated, in order for an alloy to form. "Cold joints" can be difficult to detect visually, so they must be prevented through good technique.
- The joint must be free of oxidation. Oxidation is often easy to spot; it results in a dull, lumpy, or "rusty" appearance. A good joint should always appear clean and lustrous.

A.2 Soldering Tools

Achieving high quality soldering results requires a number of tools. Good quality tools can very quickly pay for themselves by making it possible to work much more quickly and efficiently.

A basic set of tools consists of:

- A high-quality soldering iron. If the iron costs less than $40, it is almost certaily garbage. Good irons typically cost at least $100. If that sounds like a lot, consider the value of your time and that making a joint with a lousy iron– if possible at all– can easily take many times longer. Weller's WESD-51D and WLC-100 are both fine irons.
- Several sizes of rosin-core flux. For fine electronics work (e.g., SMT devices), use thin solder (0.015-0.025 inch diameter): it gives you a great amount of control over how much solder is being applied. On larger soldering jobs (such as rows of DIPs or power connectors), thicker solder (0.050 inch diameter) is less tedious to apply. The solder must have flux; I prefer solders with a greater amount of flux (3.3%). Additional flux makes the solder flow better, but the additional residue left on the board can require cleaning in order to get a "professional" look.
- Solder removing device(s). There are two basic types: solder suckers and solder braid, each preferred by different folks. I vastly prefer solder suckers. With both devices, the trick to removing solder is that you often need to *add* solder first, so that there's enough thermal conductivity to melt the entire chunk of solder at once.
- Tweezers, preferrably normally-closed. When working on two-terminal SMD devices, tweezers are a must. Tweezers which are normally-closed will be much less tiring to use.
- Flux pen. Particularly when working on fine-pitch components, adding a little flux can make the solder flow much better. Or, when solder has been overworked and is beginning to oxidize, it is helpful to be able to add a bit more flux.
- A "helping hand" unit, basically two alligator clips on positionable arms, can be very helpful when making cables.

- An anti-static mat and wrist-band. After assembling a board, it'd be unfortunate it if got zapped before you even got a chance to use it!
- Fume extractor. Flux fumes can irritate the respiratory tract, so if doing a lot of soldering, using a fume extractor is a good idea. Inexpensive units, consisting of little more than a fan to suck the exhaust with an activated carbon filter, are available for under $30.

A.3 Assembly Strategy

Planning your assembly process in advance, and staying organized, will greatly assist assembly. Here are some basic tips:

- Start with the shortest/smallest components first. This will help the board lay flat, making it easier to keep components in position while assembling them.
- Add through-hole devices in batches. Gently bending the leads on electroylitic capacitors will prevent them from falling out. Then you can solder them all at once. It's often helpful to "tack" each capacitor in position with just one lead; then the tacked pin can be reflowed and the capacitor pushed flush to the board.
- Keep the iron tip clean with a sponge or tip cleaner. The tip should be smooth and lustrous. It should also be "primed" with a small amount of solder; this will aid thermal conduction to joints. If the tip is severely soiled, adding flux will often help. *Never* sharpen or slice off oxidation from the tip; it will ruin the tip!
- Use moderate iron temperatures. High temperatures can damage components. For most board work, a temperature of 650 degrees should be sufficient.
- Somewhat paradoxically, the best soldering results come from work that is performed quickly (i.e., where the length of time that solder is liquefied is minimized.) Painstakingly applying and "working" solder is doomed to produce heavily oxidized joints. Of course, it takes some practice to learn how to move quickly.

When your soldering technique is developed, you'll find that solder acts like a liquid with pretty high surface tension. This surface tension does most of the work for you– if you put solder near a joint, it will flow onto the joint and cover it.

A.4 Making Cables

A surprisingly difficult problem in practical electrical enginnering is how to connect two devices. There are several features which someone might look at when selecting a cable/connector system:

- Mechanical Robustness. The connectors stay connected, and the connector/cable will not fatigue and break.
- Polarization. The connector can only be inserted one way, eliminating the risk of damaging equipment.
- Inexpensive.

- Physical Size. Depending on the application, an easily manipulatable (large) connector might be preferrable, or density might be an issue, where fitting the maximum number of connectors per unit area is critical.

- Electrical Properties. Current carrying capacity, parasitic inductance, capacitance, resistance, can all be important in some situations. Motor connectors, for example, should be able to carry more power than a simple push button.

The OrcBoard has a lot of sensor connectors, so an inexpensive and physically small connector are used predominantly. These connectors are constructed from 0.100" male and female header. These connectors are not polarized (though the distinctive pattern of Pin-Pin-Blank-Pin is intended to make it easy to discern the correct polarization.)

It takes a fair amount of practice to produce reliable cables using 0.100" header, and several steps are required (see Fig. A.4). Of critical importance is the use of stranded, rather than solid wire. Solid wire fatigues very rapidly with mechanical stress, whereas stranded wire is much more robust.

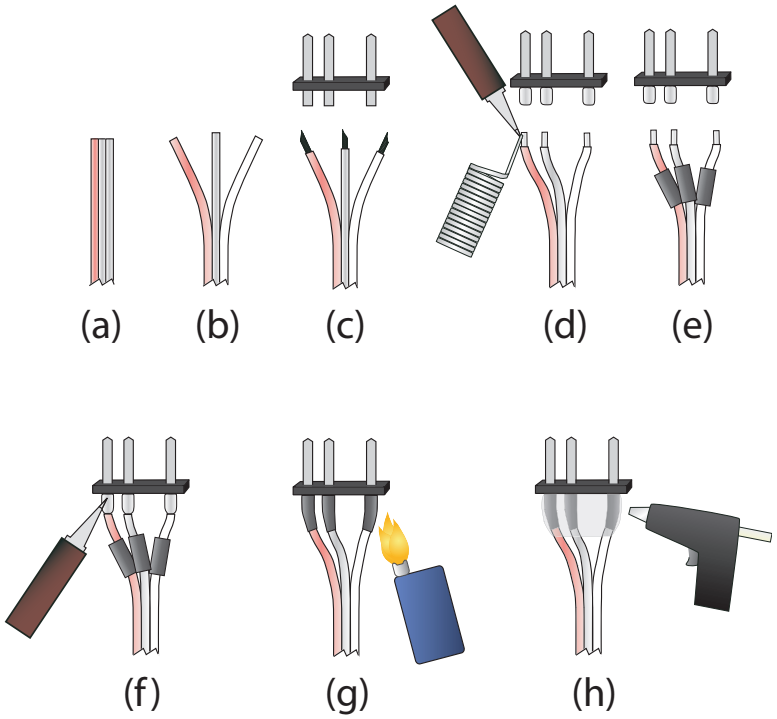


Figure A.1: Making Cables. Beginning with stranded ribbon cable (a), separate the leads about 1" (b). Strip about 0.25" from each lead and lightly twist together the stranded wires (c). Tin the ends of the wire and the connector (d), then slip on 0.3" lengths of heatshrink tubing onto each wire (e). Join the wires and the header (f), adding more solder if necessary. Position the heatshrink tubing and heat it (g). For added structural strength, apply hot glue to the connector (h).

Notice that virtually every connector on the OrcBoard has "ground" on the *outside* of the board. The convention of OrcBoard cables is to call the ground wire "pin 1", and to color that wire to designate it as such. The color coding thus provides a polarization cue: the colored wire should be on the outside of the board.

An option to those who loathe assembling cables as described in this section is to use female crimp connectors. The sensors connectors (now female) are then attached to the OrcBoard (also female) by using a coupler created from wire-wrap male header.

A.5 Assembling through-hole devices

The OrcBoard contains a substantial number of through-hole components, mostly in an attempt to maximize the number of parts which are socketed (and can be easily replaced if they fail.)

The steps for assembling a through-hole part are shown in Fig. A.5. Making sure that the part is flush with the board is important for both cosmetic and signal integrity reasons. The best way to mount components so that they are flush is to tack down one pin, then reflow that pin while pushing the part flush to the board. Then, tack down the other pins.

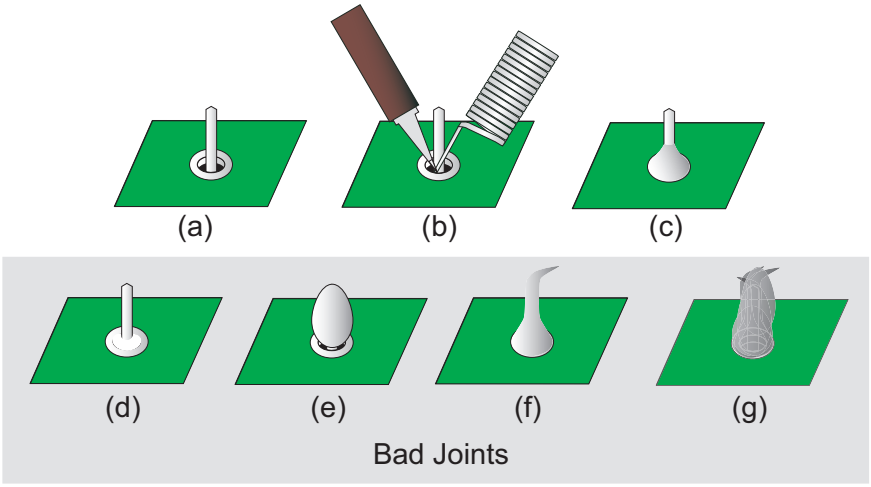


Figure A.2: Through-hole Soldering. Beginning with an unsoldered connection (a), add solder while heating both the pin and the pad (b). When finished, the joint should be conical and lustrous (c). Joint (d) doesn't have enough solder; often only a thin membrane of solder is in place, and the joint is very weak. A common result of heating the pin but not the pad is (e), known as a "lollipop joint". These joints can be difficult to spot, since the solder on the pin conceals the missing connection to the pad. Joint (f) shows signs of oxidation: the solder has become sticky and is too thick; it also shows a little "tail". These joints are usually functional, if unattractive. Joint (g) is grotesquely oxidized; the solder has become sludgy and is on far too thick. Adding additional flux and reflowing might fix the joint, but removing the solder and starting over can be necessary.

Be especially aware of "lollipop joints", a joint where solder has only adhered to the pin and not to the pad. It is caused by not heating the pad with the iron. These joints can be hard to see when they do occur, because the solder attached to the pin makes it hard to see whether there is a connection to the pad.

A.6 Assembling SMT devices

Two-terminal SMT devices, including capacitors and resistors, are easy to assemble and

take up little board space. In the case of resistors, it is also easier to read the value of the resistor (which is printed in ordinary numerals on the package): the last digit is typically the power of 10, so "1202" means $120 * 10^2$, or 12k.

Two-terminal devices can be easily assembled by amateurs with ordinary equipment. There's a little trick (see Fig. A.6). In short, put a dab of solder on one pad, then slide the part into position while melting that dab. Then (and only then!) add solder to the second terminal.

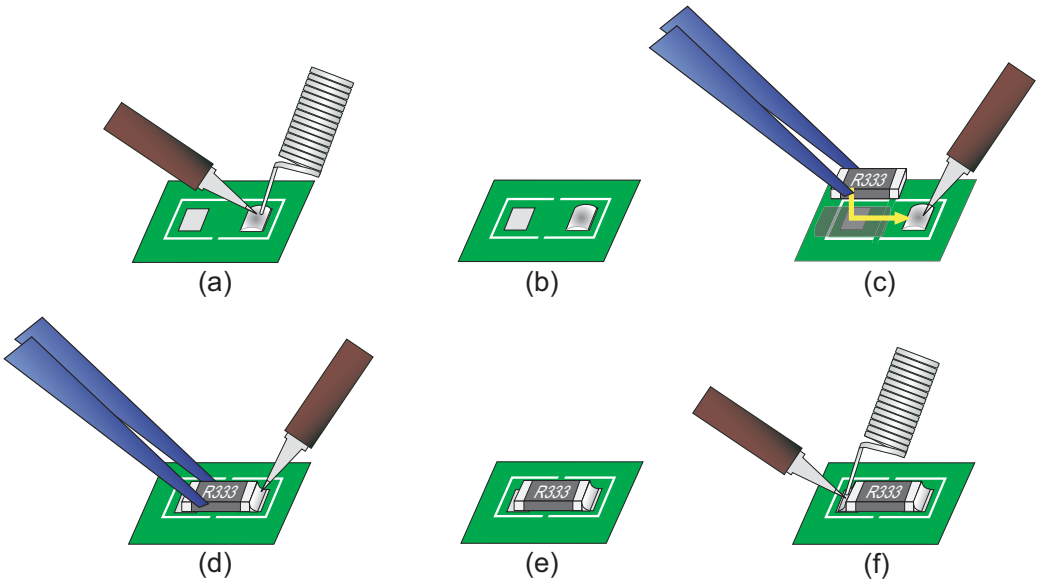


Figure A.3: SMT Soldering. When soldering two-terminal SMT devices such as capacitors and resistors, begin by adding solder to just one pad (a, b). Then reflow the solder and slide the component into place (c, d, e). Finally, add solder to the other terminal (f).

Let's discuss for a moment the challenge of assembling high-density SMT devices, such as those in TQFP packages. There are a number of approaches suggested by hobbyists. They all start with carefully aligning the package and tacking down the part, usually by carefully soldering two pins on opposite sides of the part.

Many approaches involve using solder paste (balls of solder in a flux suspension). You can sparingly "paint" an area with cold paste, then run the iron over the paste and pins. For the most part, the solder will melt, and, thanks to surface tension, spread out over the pins and pads without any manual effort. I don't like this approach; it's hard to regulate how much paste to put down, hard to put it where you want it, and impossible to get rid of solder balls that escaped the heat of the iron. These lonely, unmelted solder balls can cause problems later, migrating around and potentially shorting pins.

My favored approach is brute force, using an iron with a tiny tip and a spool of super-thin solder (0.015 inch). At first, position the solder at the point where the end of the pin touches the pad, then lightly touch both the pin and the pad with the iron. Proceed pin by pin.

After a little practice, you learn how to keep just the right "buffer" of melted solder on your iron, dragging the iron along the pins, very slowly adding more solder to the iron/pins. In this way, it is possible to solder a couple pins per second.

The finer the pitch on SMT components is, the more likely it is that the solder will form a bridge connecting two adjacent pins. It can be very hard to remove bridges. I rely first

and foremost on a flux pen (to keep the solder flowing easily) and a solder sucker. But in cases where you've really made a mess, a dental pick to scrape molten solder from the pins can be a help.

I consider a stereo microscope essential with parts finer than TQFP44, and I generally consider TQFP144s the upper-limit of what can/should be assembled without specialized equipment.

Appendix B
LCD Memory Map

When drawing large or complicated images to the LCD, it is often faster and more efficient to access the frame buffer directly, rather than through the various draw functions. Two raw functions are available, Raw Read and Raw Write. To use these, however, requires understanding the memory map of the LCD frame buffer.

The LCD is composed of 128x64 pixels. Each pixel is stored in a single bit. The entire frame buffer is $128 * 64/8 = 1024$ bytes in size.

Each byte in the frame buffer corresponds to a column of eight adjacent pixels. The low bits correspond to pixels closer to the top of the screen. Consecutive bytes move in rows.

In other words, writing a block of N bytes to the frame buffer has the effect of rewriting a region 8 pixels high and N bytes wide. The first eight rows of pixels are stored in 0x000-0x07F, and the second row in 0x080-0x0FF, and so on.

To modify a single pixel, the old frame buffer value must be read, then modified, then rewritten to the frame buffer. Drawing a line causes many of these operations to be performed. To minimize the number of transactions required to perform simple drawing functions, these functions are implemented in the firmware.

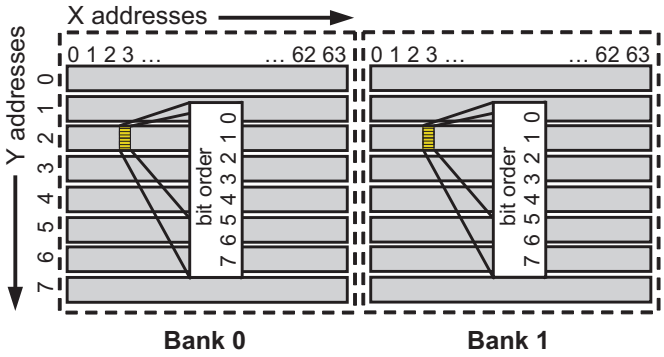


Figure B.1: LCD Memory Map.

This memory layout accounts for some of the limitations of the built-in firmware, namely that text can only be drawn at rows that are a multiple of eight, and that all the built-in fonts are 8 pixels high. These limitations greatly simplified the implementation of the drawing routines, since text drawing never involves read-modify-write operations. In fact, the built-in fonts are laid-out in memory in rows of pixels 8 columns high, allowing font characters to be rapidly blitted to the screen.

The availability of the raw read/write commands allows any arbitrary drawing to be

performed. Despite the fact that the display is monochrome, video can be displayed in a reasonably intelligent way, provided that the frame is redrawn fast enough (8 Hz) to achieve some "temporal dithering."

In truth, the frame buffer is somewhat more complicated; the left half of the screen is addressed independently of the right half of the screen, and there are in fact two distinct frame buffers. However, this complexity is handled by the OrcPad firmware.

Appendix C
The OrcPad as a Prototyping Board

The OrcPad can be used as a standalone prototyping board. It contains a DB-9 connector and a RS-232 charge pump that, when populated, allow the OrcPad to be directly connected to a host without an OrcBoard.

The OrcPad can use either the 128x64 pixel LCD, or a character LCD module, such as the CFAH1602B. The graphical LCD panel uses a large number of pins; using a character module frees up some of those pins, allowing them to be used to implement other features. Note that the character module and graphical module cannot be used at the same time, and also that they require separate contrast adjustment potentiometers.

Ordinarily, the OrcPad receives its power from the OrcBoard. In a standalone application, the OrcPad can receive its power from a wall adapter (a power jack is provided) and a 5V linear regulator. If a regulated 5VDC wall adapter is used, then the 5V regulator is unnecessary; simply short pins 1 and 3 with a short piece of wire.

Appendix D
Orcd, The Orc Communications Manager

In simple applications, a single application will connect to the OrcBoard (see Fig. D). These applications have exclusive access to the OrcBoard.

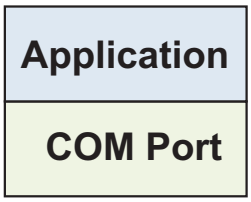


Figure D.1: System without Orcd. In simple systems, a single application communicates directly with the OrcBoard.

In many applications, it is convenient for many applications to access the same OrcBoard. Orcd allows multiple applications to share an OrcBoard. Applications access orcd via TCP sockets. Orcd implements the following features:

- Allows multiple applications to connect and issue transactions to the OrcBoard. Responses generated by other applications are automatically filtered out.
- Assigns new transaction IDs to all requests (and their responses) so that requests from multiple applications do not collide. Each packet is transparently rewritten, so that the response packet's transaction ID received by an application matches the transaction ID used in the application's request.
- Provides a simple synchronous interface for requests/responses. Each connection to *command port* (TCP port 7320) allows a single outstanding request, and is guaranteed to send either the Orc's response or a timeout error packet. An application can support multiple simultaneous transactions by connecting more than once. This makes writing an application much easier.
- Automatically polls the master and slave for state update requests, and publishes the results to the *asynchronous event port* (TCP port 7321). A client can enter a simple infinite read loop to receive these packets. Use of this feature conserves OrcBoard bandwidth since all applications can share the same state update information.

It is important to note that orcd does *not* perform any resource allocation. For example, if two applications try to set a motor port to different values, both transactions will be processed.

A system using orcd is diagrammed in Fig. D.

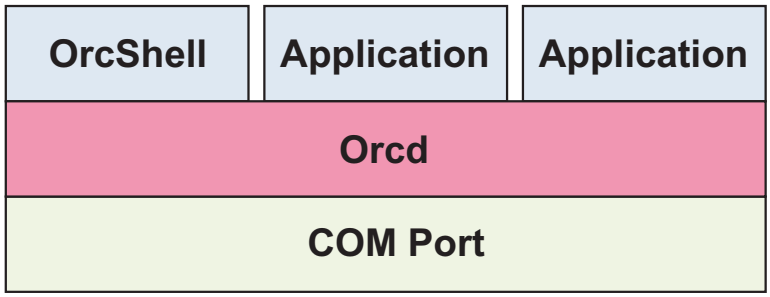


Figure D.2: System with Orcd. More complex systems might have multiple applications which communicate (simultaneously) with the OrcBoard. Orcd moderates these transactions, ensuring that each can issue transactions without confusing each other.

Appendix E
Firmware Overview

The firmware used on the OrcBoard and OrcPad is available under the GPL license. It is available under other licenses by contacting the copyright owner (Edwin Olson, eolson@mit.edu). The firmware is a mix of PSoC/M8C assembly and C.

By modifying the firmware, not only can you fix bugs, but you can add new features. The "basic" firmware that ships with the OrcBoard tries to be a "Swiss Army Knife", providing a bit of everything. But many specialized robots will need more specialized functionality. For example, the firmware could be changed to support a dozen servos, at the expense of some of the other built-in features.

When implementing new commands,keep in mind the nature of the packet-based messaging system. Packets may be lost, so commands and responses which are idempotent are desirable whenever possible. For example, rather than implementing "Increase Motor Speed", implement "Set Motor Speed". If an acknowledgment is not received by the user after sending an "increase" command, there's no way of knowing whether the request was received, whether it was executed, or whether the acknowledgment was lost. If it retransmits, it might effectively increase the motor speed *twice*. Clearly, a "set" function does not have this problem.

This chapter will describe some of the common design patterns in the firmware, as well as explaining a few of the "tricks" that were used. A basic familiarity with PSoCs will be assumed.

E.1 Pin Reconfiguration

Many pins on the OrcBoard have multiple functions. This is accomplished in a straightforward way in the firmware. In almost every case, any given pin can only be in one of three modes: a digital in/out pin, an analog in/out pin, or a single "special" function. The special modes change for each pin, but include all those modes which use a digital block: servos, sonar echo, PWM, etc.

Using the PSoC's internal routing, the digital blocks which implement each pin's special function are statically routed to their pin. When switching the mode of a pin to the special function, only a single configuration bit needs to be changed.

E.2 Interrupts and Performance

The firmware is written for high performance, low latency, and maximum throughput. Serial read and write operations are all performed via interrupt-driven queues. This way,

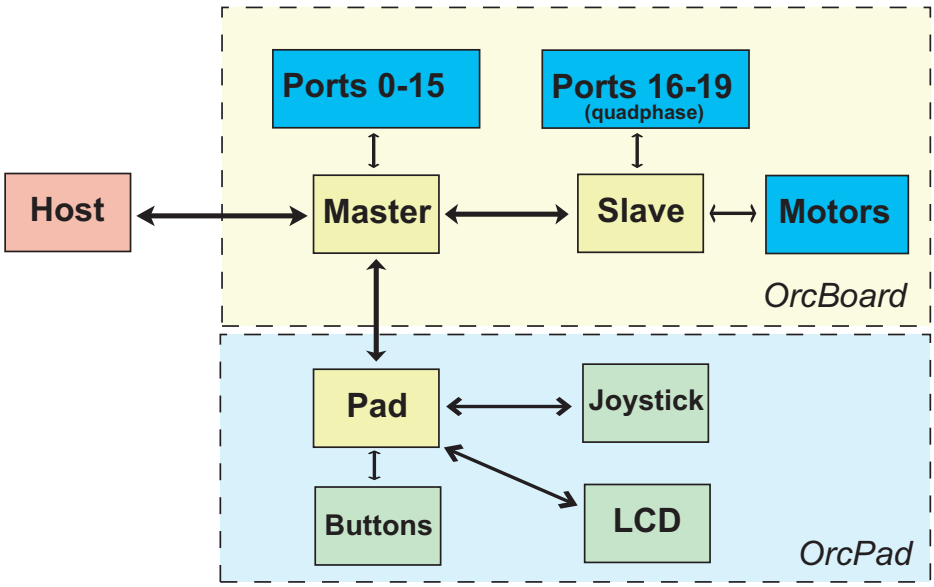


Figure E.1: Internal Block Diagram. The Host, Slave, and Pad are connected to the Master via high-speed serial connections. The master can route packets between any two devices.

the host can perform other tasks while waiting for slow I/O operations to complete.

Each PSoC's firmware is structured about the same way; after initialization, they enter an infinite "idle" loop. The idle loop checks for new data on the serial port(s), processing packets when they have been fully received. Other tasks are also performed during the idle loop, such as updating the A/D converter (and updating the LPF values), or performing other house keeping.

It is critical to minimize the maximum ISR latency. The PSoC's serial receive buffer is only one byte in size; if two bytes are received before the receive ISR can be called, data will be lost. This problem is especially acute on the master, where data can be received on three ports at the same time.

Each chip also uses the PSoC's hardware sleep timer as a system clock. Often, tasks need to be completed periodically, and the sleep timer helps to control the rate of these tasks. But rather than executing these tasks in the Interrupt Service Routine (ISR), the idle loop polls the value of the clock, comparing it to the last sampled value. If the value has changed, then the doSleepInterval() function is called. This mechanisms moves much more code into non-interrupt mode, ensuring that tasks can be interrupted by important activities (such as the serial RX ISR.)

Interrupts are used for transmission as well. If the transmit buffer is full, then the putChar() function will block. Note that Cypress' provided code for writing to the serial ports should not be used, since they do not call the correct putChar() function.

E.3 Master

Packets are routed on a store-and-forward basis: a packet is fully received (and checksum verified) before it is enqueued for transmission on an outgoing port. This is suboptimal for minimizing latency compared to wormhole routing, where the forwarding of a packet can begin before the packet is fully received. However, wormhole routing would significantly

complicate the firmware.

E.4 Slave

The slave's most interesting feature is the quadrature phase decoder ISR. Configured to run whenever the General Purpose I/O (GPIO) pins change state, they implement a state machine. The state is the last sampled value of the two quadrature phase pins, and the input is the new value of the two pins. A lookup table is used to branch to an appropriate routine, which increments/decrements the counter, or increments the error counter if an illegal transition was detected. This process is repeated for both quadrature phase channels.

The ports are reconfigured to perform simple (monophase) decoding by simply using a different lookup table.

The slave is also responsible for implementing the PWM slewing function. When the system timer (implemented by the sleep counter) changes, the PWM values of each motor channel are updated. (Actually, the system clock runs at 512Hz, and PWM are only updated every fourth time yielding an update rate of 64Hz.)

Implementing the motor PWM modules required exploiting the PSoC's digital Look-Up-Tables (LUTs). Each motor is controlled by three pins: an enable pin, and two control pins (call them A and B). To drive forward or backward, the enable pin must be set. Driving forward is accomplished by setting A=PWM and B=0, while driving backwards is accomplished by setting A=0 and B=PWM. Each motor's PWM signal is routed to two LUTs. These LUTs can then be set to follow the PWM signal or to be the constant value 0. Changing the LUTs allows the direction to be changed.

E.5 Pad

The Pad's chief responsibility is managing the LCD and updating measurements of the two analog joystick axes and the three binary push buttons.

In addition, it monitors the battery voltage so it can be displayed on the LCD. This is done on the Pad instead of the OrcBoard in order to avoid the need for the pad to query the master/slave for the voltage, and also because the pad's PSoC had an extra pin left over, whereas pins were very scarce on the master and slave.

A powerful feature of the pad is its ability to generate synthetic cursor events. The joystick is monitored for movement up, down, left, and right; when enough movement has occurred, a discrete "key press" is generated. If the joystick is held in a particular direction, additional discrete key presses are generated, much like a keyboard's auto-repeat function. This feature is implemented by integrating the joystick's deviation in the X and Y direction, and comparing the integrated value to particular thresholds. This feature simplifies the design of other applications which are more easily described in terms of key presses than joystick movement, while giving all such applications the same "feel."

Uniquely, the pad will send state update messages without having been requested to do so. When the discrete buttons change state, or the joystick state changes by a threshold, a new packet is scheduled for transmission (the needUpdate flag is set.) However, the rate at which these unsolicited packets are sent is limited to about 110 Hz, in order to prevent them from consuming an excessive amount of bandwidth.

The unsolicited messages are designed so that applications do not need to rapidly poll the pad for user input; the applications can simply go to sleep and wait for the pad to announce that an event has occurred.

Appendix F
Schematics

The schematics are available in electronic format for Mentor Graphics PADs PowerLogic and PowerPCB.

F.1 Design Notes

F.1.1 Conventions

A general goal was to reduce component count in order to make assembly easier. Components with integrated passives are used whenever available. For example, the RS-232 charge pump is the more expensive MAX233E, which includes the passive capacitors. LEDs, please note, are always LEDs with built-in current limiting resistors; do not substitute a conventional LED!

F.1.2 Power Supply

The switching power supply was obtained by using National's online "Web Bench" application. The supply is rated for 5A. The high switching frequency is important for rapidly dealing with transients. An earlier version of the OrcBoard with a slower switching supply suffered from brownouts with load transients.

F.1.3 Motor Drivers

The two motor drivers share a single charge pump circuit, as described by the L6205N application note.

F.1.4 Cut Header

To populate an OrcBoard and OrcPad, the following header will need to be cut:

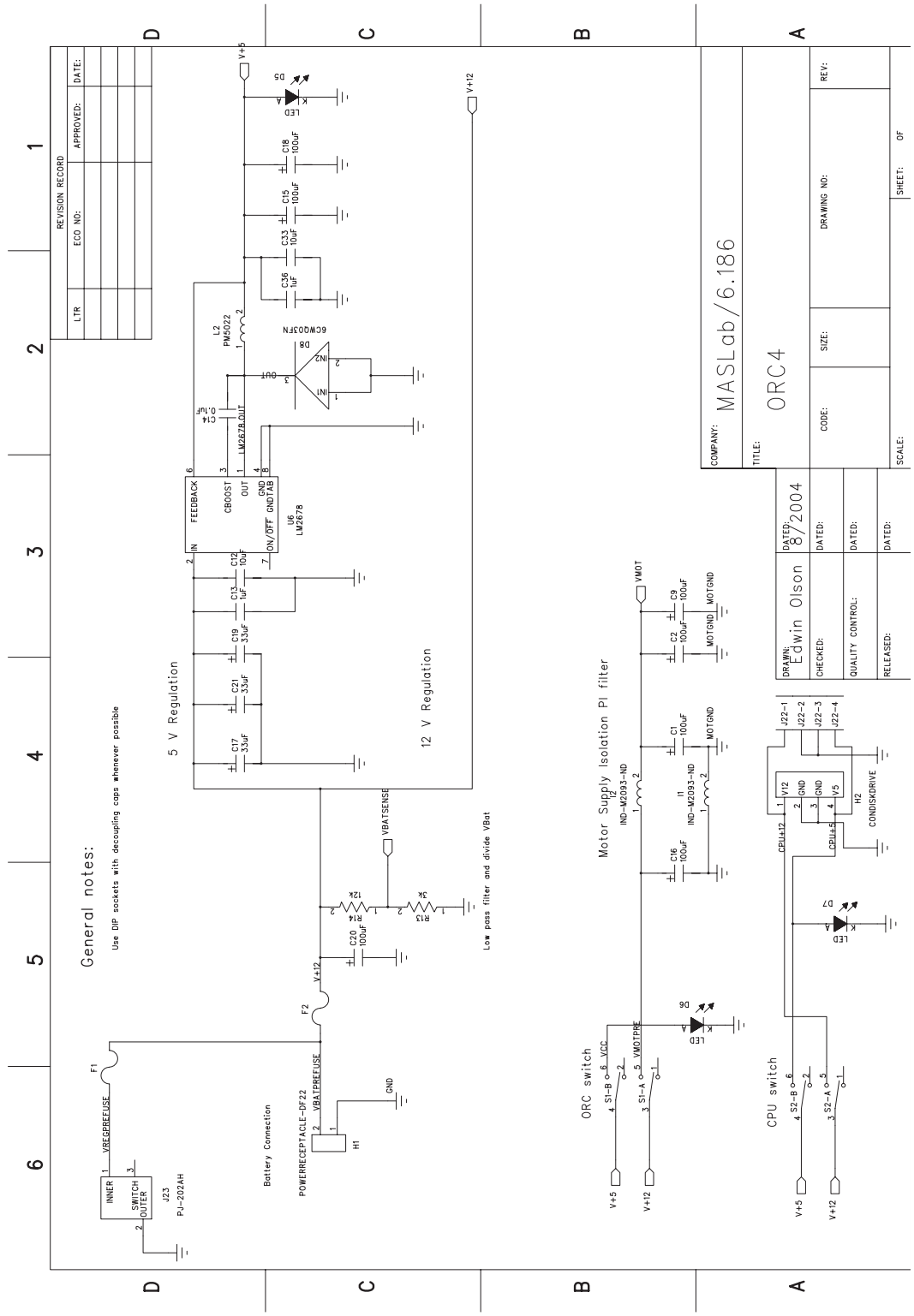
Type	Size	Qty per kit
Right-angle Male	5 x 2	2
Male	20 x 1	1
Female	20 x 1	1
Female	8 x 1	1
Female	5 x 1	2
Female	8 x 2	3
Female	4 x 2	3

F.1.5 Communications

The USBMOD3, manufactured by Elexol, can be mounted in the DIP32 (0.6") landing on the OrcBoard, providing a USB interface to the OrcBoard. There is only enough room for either the DB-9 and RS-232 chargepump *or* the USBMOD3, so only one can be used at once.

When using RS-232, a TX and RX LED are available. These are powered directly from the TX and RX signals themselves, so the sources of these signals must be strong enough to drive an LED while maintaining adequate rise/fall times. The PSoC can drive the TX pin adequately, and the MAX233 charge pump can drive the RX pin adequately. However, the USBMOD3 cannot drive the RX pin, so the RX LED must not be used with the USBMOD3. A dedicated LED is available for the USBMOD3; it should be used instead.

F.2 OrcBoard Schematics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LTR
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APPROVED:
DATE:
General notes:
Use DIP sockets with decoupling caps whenever possible
5 V Regulation
12 V Regulation
Motor Supply Isolation PI filter
ORC switch
CPU switch
Battery Connection
Low pass filter and divide VBat
COMPANY: MASLab/6.186
TITLE: ORC4
DRAWN: Edwin Olson
DATED: 8/7/2004
CHECKED:
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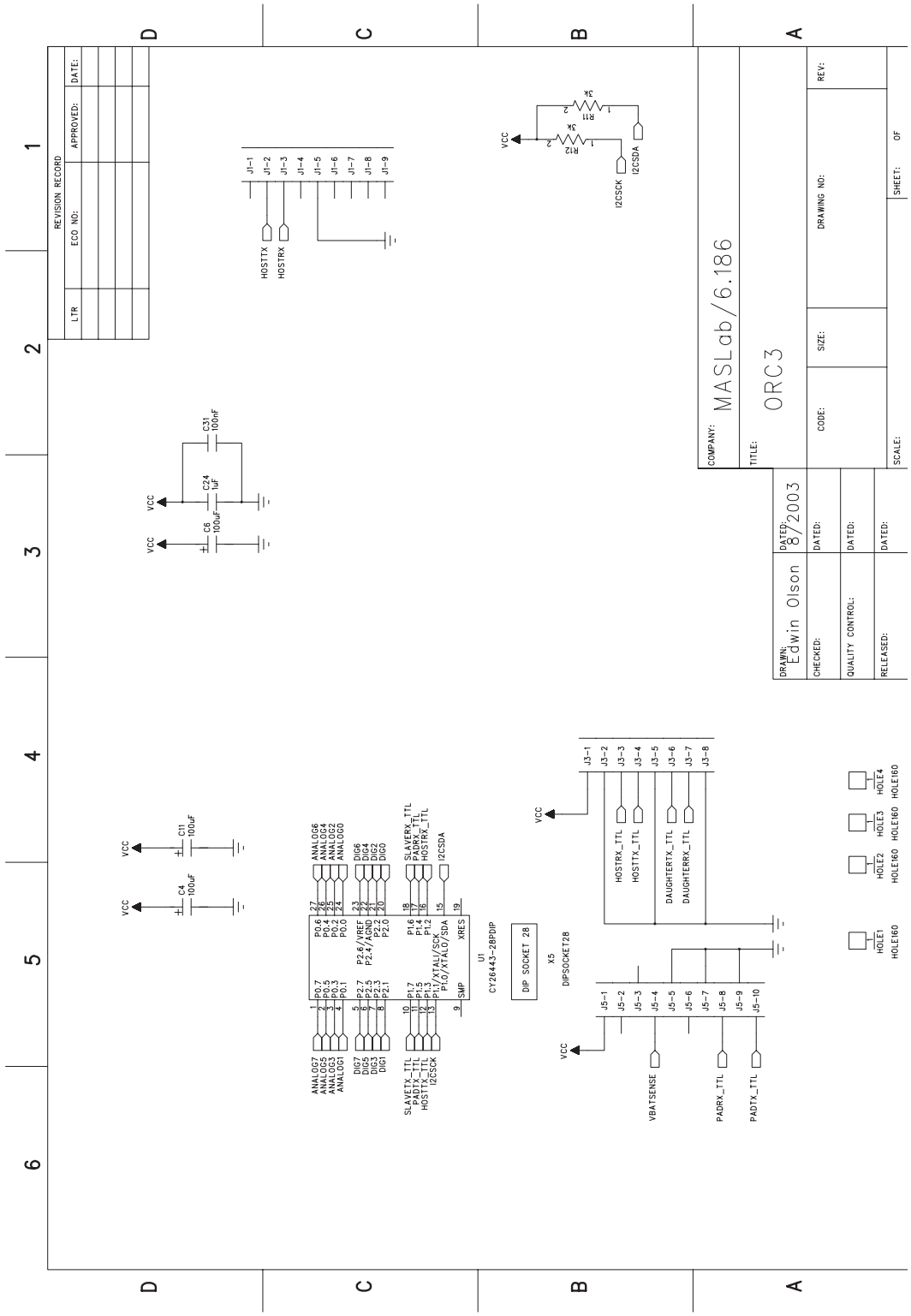
CODE:
SIZE:
DRAWING NO:
REV:
SCALE:
SHEET: 0F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CODE:
SIZE:
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REV:
SCALE:
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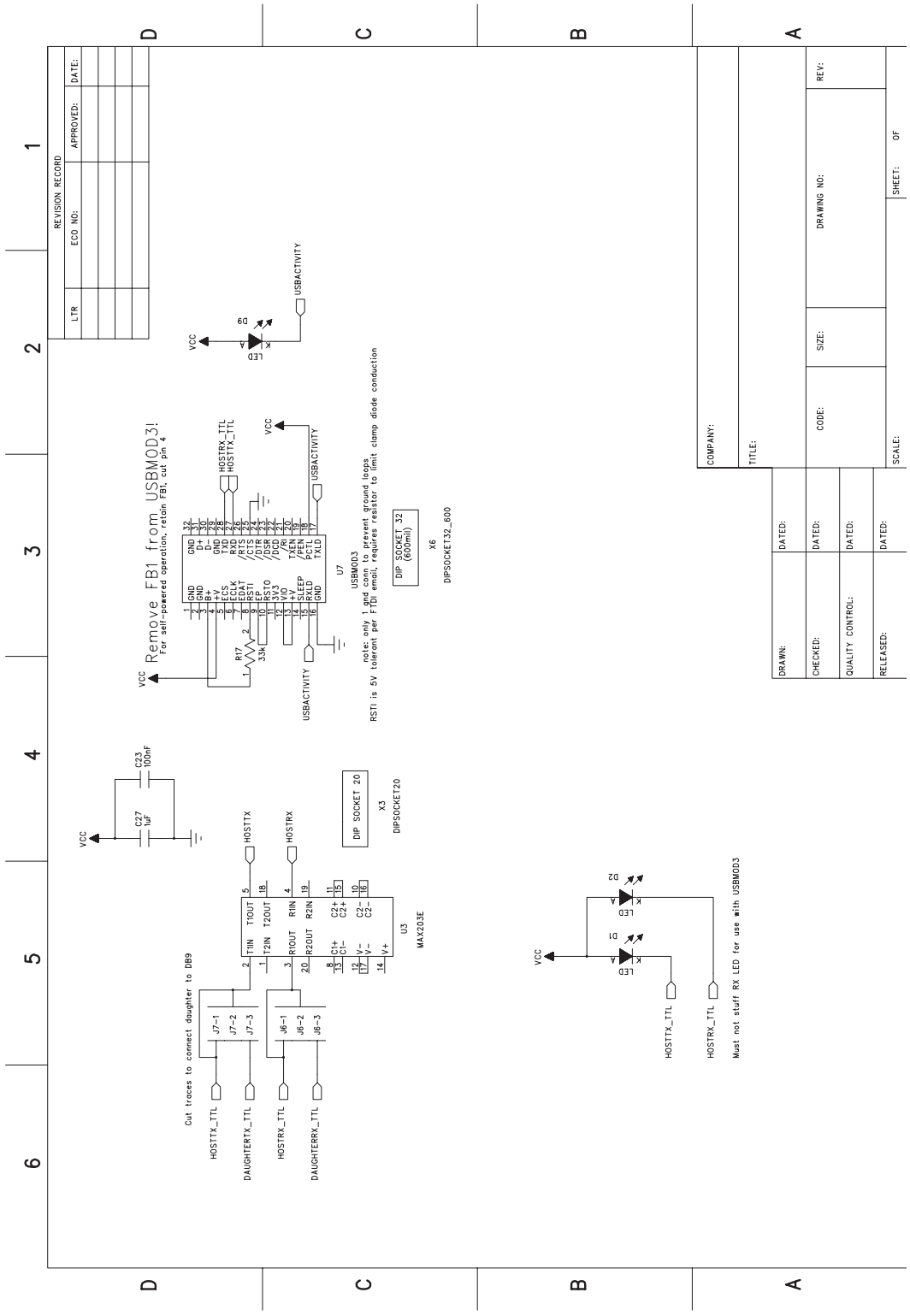
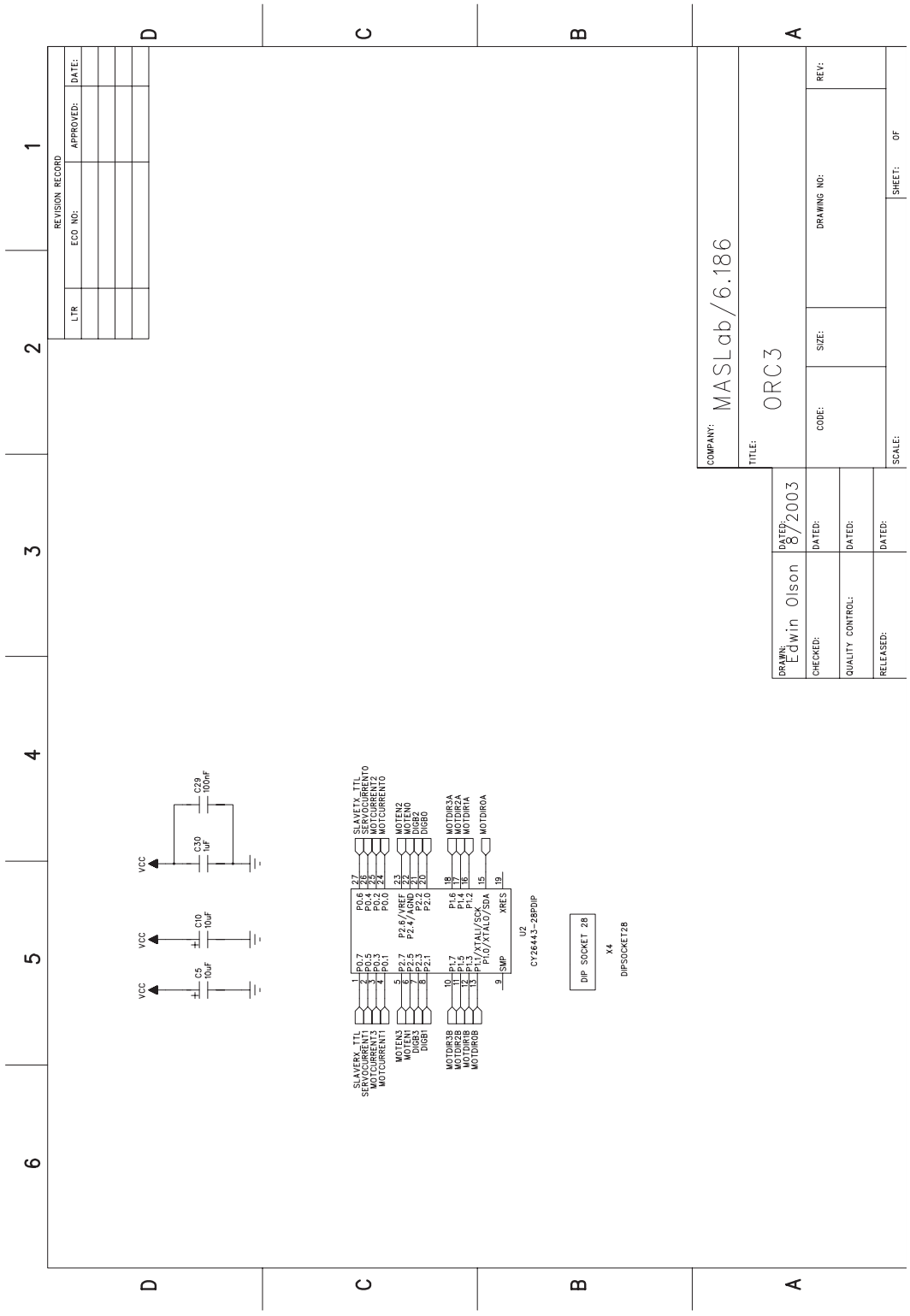
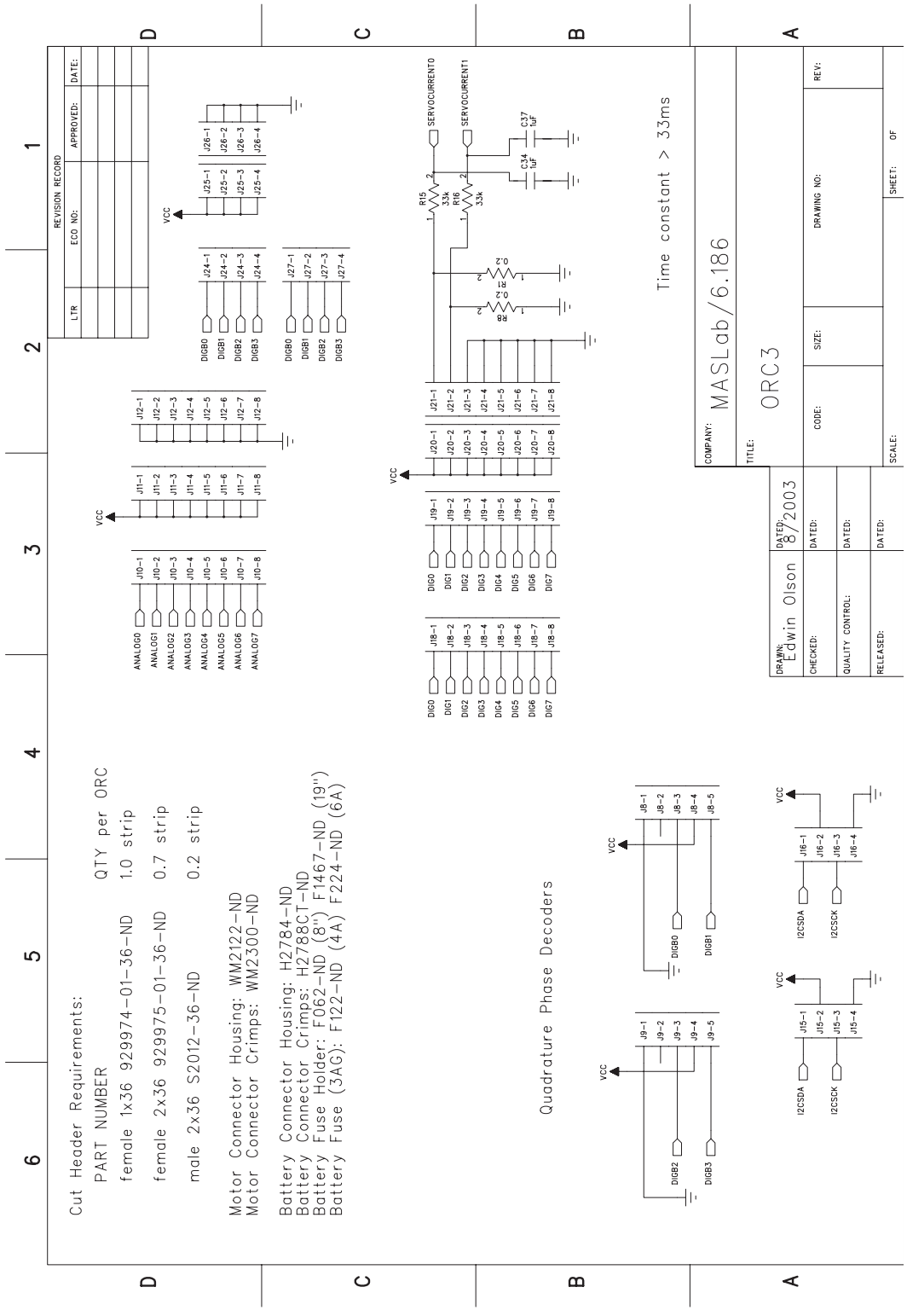
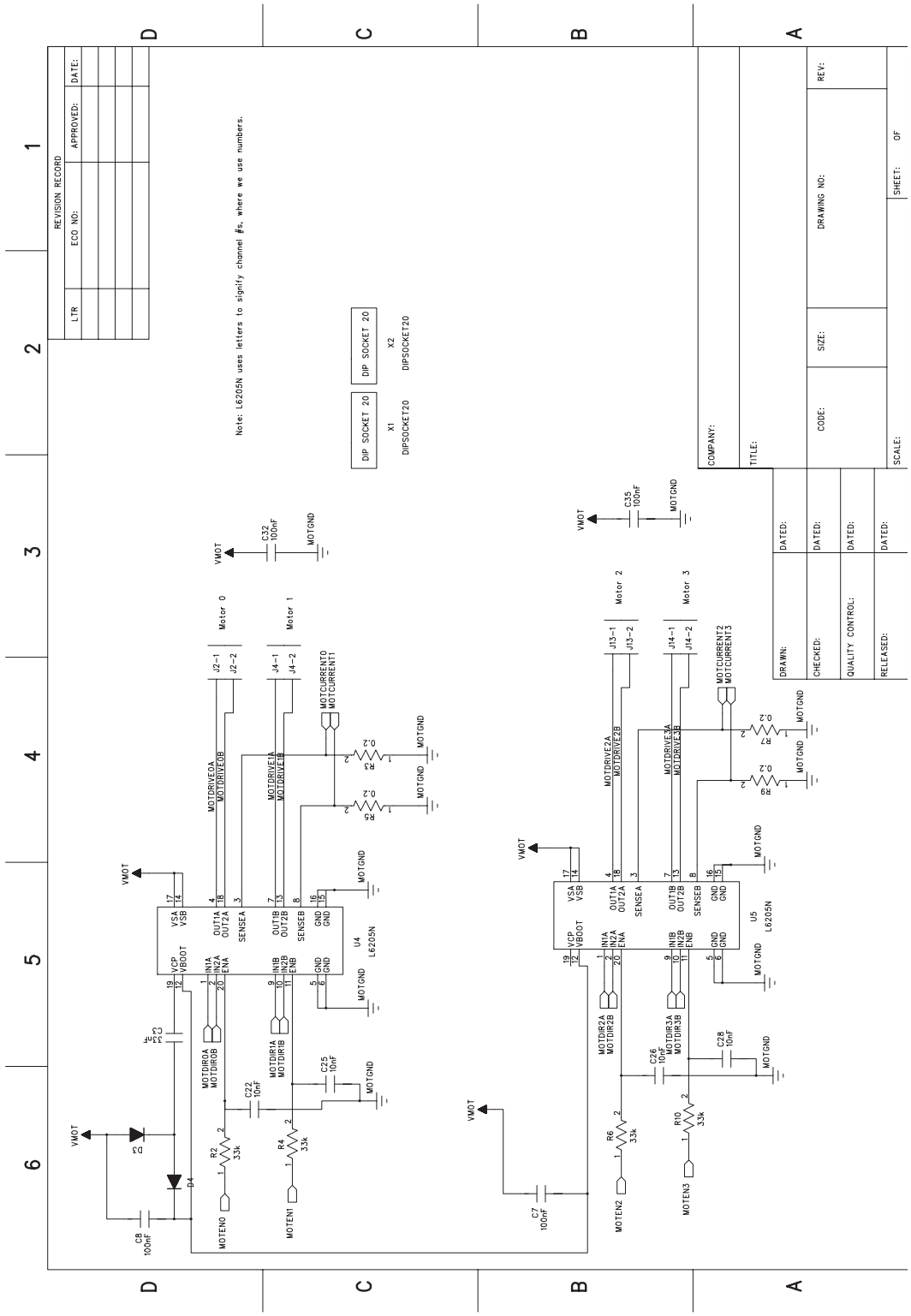
X5
DIPSOCKET28
DIP SOCKET 28
C4 100uF
C11 100uF
C6 100uF
C24 1uF
C31 100nF
R11 3k
R12 3k
VCC
HOSTTX
HOSTRX
I2CSCK
I2CSDA
VBATSENSE
PADRX_TTL
PADTX_TTL
HOSTRX_TTL
HOSTTX_TTL
DAUGHTERTX_TTL
DAUGHTERRX_TTL
HOLE1 HOLE160
HOLE2 HOLE160
HOLE3 HOLE160
HOLE4 HOLE160

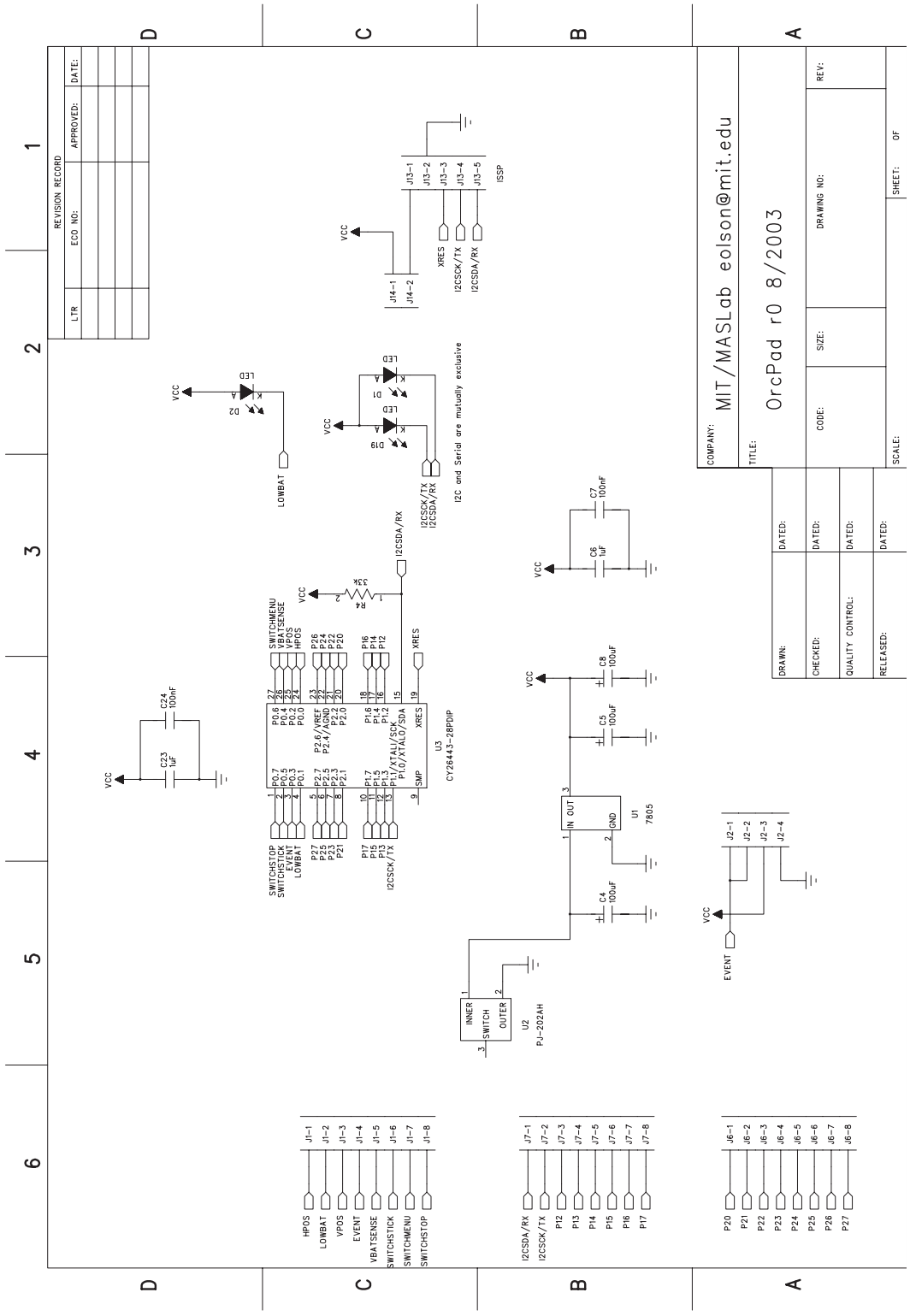

REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
USBACTIVITY
D9
LED
VCC
Remove FB1 from USBMOD3!
For self-powered operation, retain FB1, cut pin 4
HOSTRX_TTL
HOSTTX_TTL
R17
3.3K
U7
USBMOD3
note: only 1 gnd conn to prevent ground loops
RSTI is 5V tolerant per FTDI email, requires resistor to limit clamp diode conduction
DIP SOCKET 32 (600mil)
X6
DIPSOCKET32_600
C23
100nF
C27
1uF
HOSTTX
HOSTRX
DIP SOCKET 20
X3
DIPSOCKET20
U3
MAX203E
Cut traces to connect daughter to DB9
J7-1
J7-2
J7-3
J6-1
J6-2
J6-3
HOSTTX_TTL
DAUGHTERTX_TTL
HOSTRX_TTL
DAUGHTERRX_TTL
D2
D1
HOSTTX_TTL
HOSTRX_TTL
Must not stuff RX LED for use with USBMOD3
COMPANY:
TITLE:
DRAWN:
DATED:
CHECKED:
QUALITY CONTROL:
RELEASED:
CODE:
SIZE:
DRAWING NO:
REV:
SCALE:
SHEET: OF

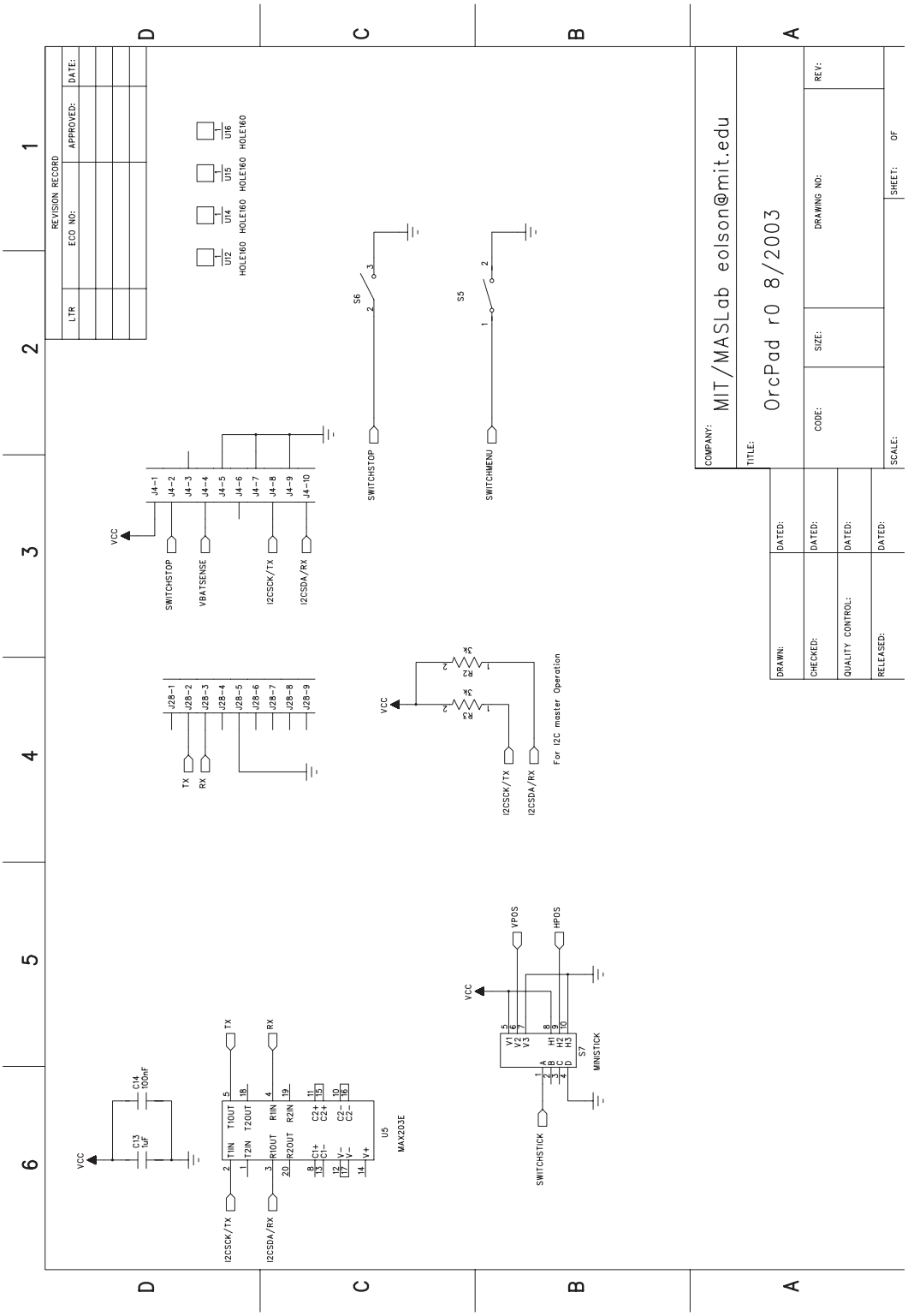

REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
COMPANY: MASLab/6.186
TITLE: ORC3
DRAWN: Edwin Olson
DATED: 8/2003
CHECKED:
QUALITY CONTROL:
RELEASED:
CODE:
SIZE:
DRAWING NO:
REV:
SCALE:
SHEET: OF
VCC
C5 10uF
C10 10uF
C30 1uF
C29 100nF
U2
CY26443-28PDIP
X4
DIPSOCKET28
DIP SOCKET 28

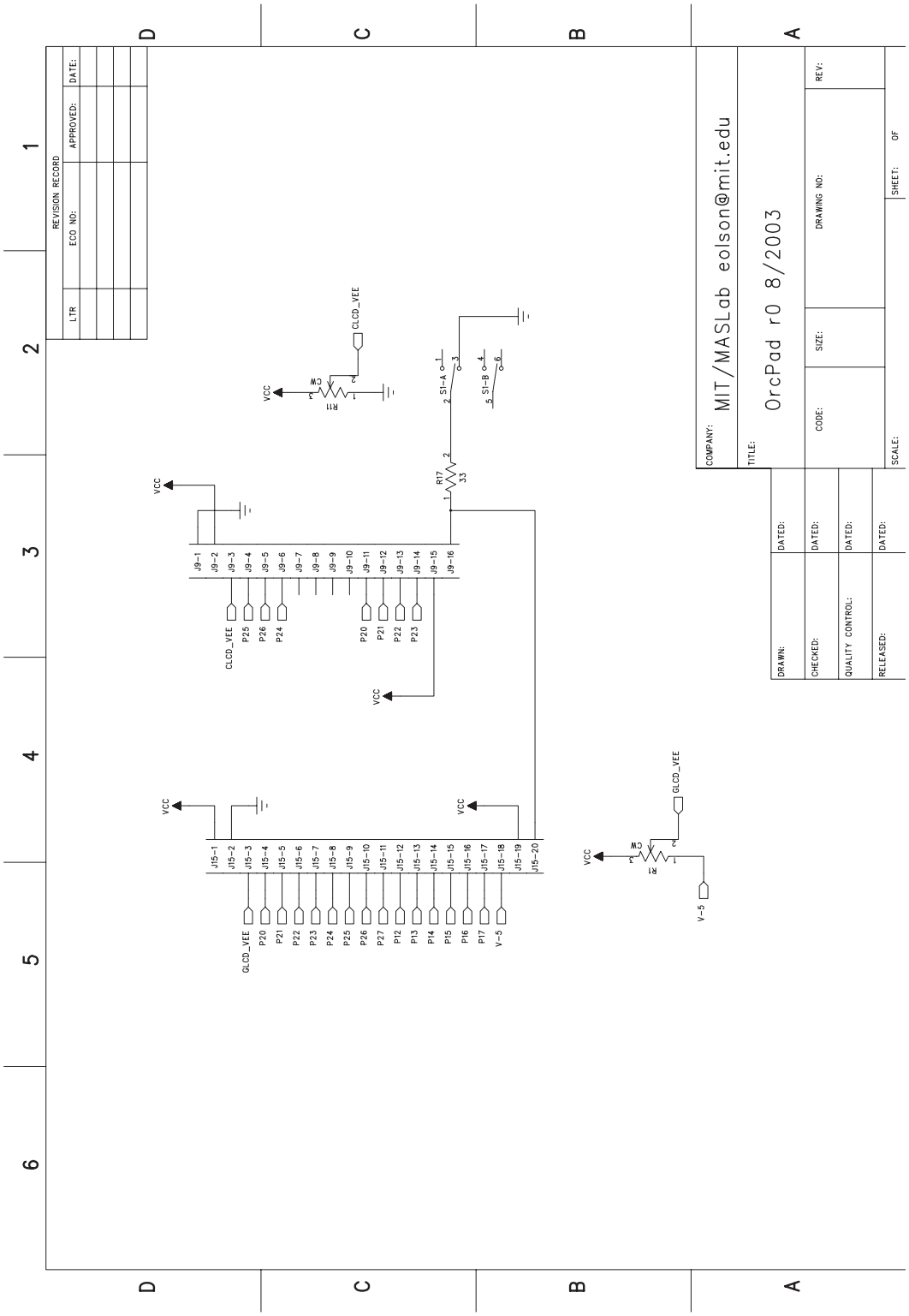

Cut Header Requirements:
PART NUMBER QTY per ORC
female 1x36 929974-01-36-ND 1.0 strip
female 2x36 929975-01-36-ND 0.7 strip
male 2x36 S2012-36-ND 0.2 strip
Motor Connector Housing: WM2122-ND
Motor Connector Crimps: WM2300-ND
Battery Connector Housing: H2784-ND
Battery Connector Crimps: H2788CT-ND
Battery Fuse Holder: F062-ND (8") F1467-ND (19")
Battery Fuse (3AG): F122-ND (4A) F224-ND (6A)
REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
Quadrature Phase Decoders
Time constant > 33ms
SERVOCURRENT0
SERVOCURRENT1
COMPANY: MASLab/6.186
TITLE: ORC3
DRAWN: Edwin Olson
DATED: 8/2003
CHECKED:
QUALITY CONTROL:
RELEASED:
CODE:
SIZE:
DRAWING NO:
REV:
SCALE:
SHEET: 0F


REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
Note: L6205N uses letters to signify channel #s, where we use numbers.
DIP SOCKET 20
X1
DIPSOCKET20
DIP SOCKET 20
X2
DIPSOCKET20
COMPANY:
TITLE:
DRAWN:
DATED:
CHECKED:
CODE:
SIZE:
DRAWING NO:
REV:
QUALITY CONTROL:
RELEASED:
SCALE:
SHEET: OF
Motor 0
Motor 1
Motor 2
Motor 3
U4 L6205N
U5 L6205N
VMOT
MOTGND
MOTEN0
MOTEN1
MOTEN2
MOTEN3
MOTDIR0A
MOTDIR0B
MOTDIR1A
MOTDIR1B
MOTDIR2A
MOTDIR2B
MOTDIR3A
MOTDIR3B
MOTDRIVE0A
MOTDRIVE0B
MOTDRIVE1A
MOTDRIVE1B
MOTDRIVE2A
MOTDRIVE2B
MOTDRIVE3A
MOTDRIVE3B
MOTCURRENT0
MOTCURRENT1
MOTCURRENT2
MOTCURRENT3
R2 33k
R4 33k
R6 33k
R10 33k
R5 0.2
R7 0.2
R9 0.2
C8 100nF
C7 100nF
C32 100nF
C35 100nF
C22 10nF
C25 10nF
C26 10nF
C28 10nF
D3
D4

F.3 OrcPad Schematics


REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
COMPANY: MIT/MASLab eolson@mit.edu
TITLE: OrcPad r0 8/2003
CODE:
SIZE:
DRAWING NO:
REV:
SHEET: OF
SCALE:
DRAWN:
CHECKED:
QUALITY CONTROL:
RELEASED:
DATED:
U3 CY26443-28PDIP
U2 PJ-202AH
U1 7805
I2C and Serial are mutually exclusive
SWITCHSTOP
SWITCHSTICK
EVENT
LOWBAT
SWITCHMENU
VBATSENSE
VPOS
HPOS
I2CSCK/TX
I2CSDA/RX
XRES
ISSP
LED
VCC
LOWBAT
EVENT
INNER SWITCH OUTER
IN OUT GND


REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
HOLE160
U12
U14
U15
U16
S6
S5
SWITCHSTOP
SWITCHMENU
J4-1
J4-2
J4-3
J4-4
J4-5
J4-6
J4-7
J4-8
J4-9
J4-10
VCC
SWITCHSTOP
VBATSENSE
I2CSCK/TX
I2CSDA/RX
J28-1
J28-2
J28-3
J28-4
J28-5
J28-6
J28-7
J28-8
J28-9
TX
RX
3K
R2
R3
For I2C master Operation
C14
100nF
C13
1uF
T1IN
T2IN
R1OUT
R2OUT
T1OUT
T2OUT
R1IN
R2IN
C1+
C1-
C2+
C2-
V-
V+
U5
MAX203E
VPOS
HPOS
V1
V2
V3
H1
H2
H3
S7
MINISTICK
SWITCHSTICK
COMPANY:
MIT/MASLab eolson@mit.edu
TITLE:
OrcPad r0 8/2003
DRAWN:
CHECKED:
QUALITY CONTROL:
RELEASED:
DATED:
CODE:
SIZE:
DRAWING NO:
REV:
SCALE:
SHEET: OF


REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
COMPANY: MIT/MASLab eolson@mit.edu
TITLE: OrcPad r0 8/2003
CODE:
SIZE:
DRAWING NO:
REV:
SCALE:
SHEET: OF
DRAWN: DATED:
CHECKED: DATED:
QUALITY CONTROL: DATED:
RELEASED: DATED:
VCC
GLCD_VEE
R1
CW
R17
33
S1-A
S1-B
J9-1 J9-2 J9-3 J9-4 J9-5 J9-6 J9-7 J9-8 J9-9 J9-10 J9-11 J9-12 J9-13 J9-14 J9-15 J9-16
CLCD_VEE P25 P26 P24 P20 P21 P22 P23
J15-1 J15-2 J15-3 J15-4 J15-5 J15-6 J15-7 J15-8 J15-9 J15-10 J15-11 J15-12 J15-13 J15-14 J15-15 J15-16 J15-17 J15-18 J15-19 J15-20
GLCD_VEE P20 P21 P22 P23 P24 P25 P26 P27 P12 P13 P14 P15 P16 P17 V-5
R2
V-5