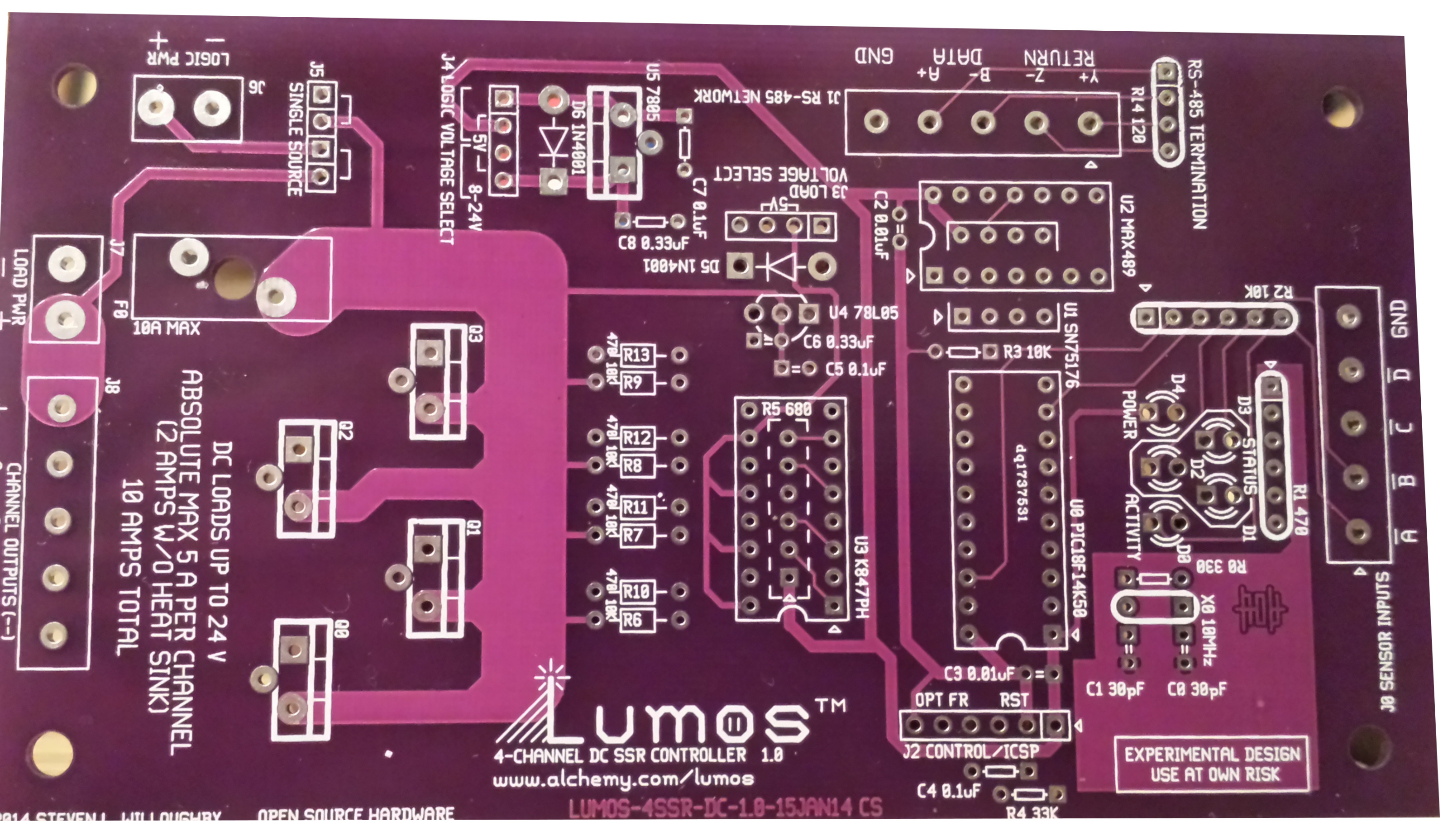
Assembling the Lumos™ 4-Channel DC SSR Controller



RISK OF FIRE, ELECTROCUTION, SERIOUS INJURY OR DEATH!

This circuit design, including but not limited to any associated plans, schematics, designs, board layouts, documentation, and/or components, is EXPERIMENTAL and for EDUCATIONAL purposes only. It is not a finished consumer-grade product. It is assumed that you have the necessary understanding and skill to assemble and/or use electronic circuits.

Proceed ONLY if you know exactly what you are doing, understand the proper procedures for working with the high voltage present on the components and PC boards, and understand that you do so ENTIRELY AT YOUR OWN RISK.

The author makes NO representation as to suitability or fitness for any purpose whatsoever, and disclaims any and all liability or warranty to the full extent permitted by applicable law.

Edition 1.0, for Lumos 4-Channel DC Controller circuit version 1.0.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Congratulations on joining the many computer-controlled Christmas light enthusiasts, theatrical lighting technicians, electronics hobbyists, and home automation innovators who are experimenting with new ways to have computers control lights and other electronic devices.

The Lumos™ 4-Channel DC Controller board places four such devices under the control of your computer. These outputs are electrically isolated from the logic control circuit (although the option exists to use a common power source if the application warrants it and that isolation is not needed).

Since these boards use RS-485 for communication, up to sixteen Lumos boards may be “daisy chained” together and controlled from the same PC serial port. By plugging DC-powered Christmas lights into the Lumos controller, your PC can orchestrate a dazzling display of lights synchronized to music.

This manual details the process of assembling a Lumos controller from a bare printed circuit board and set of components, and also shows the various optional configurations which may be used during construction.

1.1 Intended Audience

This is an “advanced” level do-it-yourself electronic circuit project. It is not an off-the-shelf consumer-ready product. It is only designed for educational and experimental use by experienced hobbyists and professionals who possess the skill to construct electronic circuits, to understand how they function, troubleshoot problems with them, and to use them safely.

1.2 Limitation of Warranty

Since this is a do-it-yourself project, the quality of the final product, and whether it functions as intended, is largely a result of your own efforts in building it. As such, we cannot offer to troubleshoot, repair, or replace a board we did not assemble for you. Accordingly, these instructions, and all accompanying plans, schematics, software, hardware, and other project materials are provided to you "AS-IS" at no cost, as a courtesy between DIY hobbyists with NO WARRANTY of any kind expressed or implied. If you proceed to build and/or use this unit, you do so ENTIRELY AT YOUR OWN RISK.

If you purchased hardware materials from us (such as a PC board or programmed controller chip), we will—at our sole discretion—replace, repair, or refund the cost of those materials if they were defective in manufacture as shipped to you, up to 90 days from the date they were shipped to you, but are not liable for damage caused by your handling or assembly of the unit. Otherwise, we make no representation of suitability or fitness for any particular purpose and disclaim all other warranty or liability of any kind to the full extent permitted by law.

1.3 How to Use this Manual

Please begin by reviewing the safety information in Chapter 2.

When you are ready to begin assembling your Lumos controller, gather the required tools and materials as explained in Chapter 4.

Then read carefully the *entire* set of instructions in the following chapters before beginning any actual work. Begin assembly *only* if you understand all the steps you will need to carry out.

Once your controller is complete and ready to use, refer to the separate manual, *Using the Lumos SSR Controllers* for full instructions on how to program and use your controller.

1.4 The Name of the Game

The name "Lumos" is a combination of *lumen*, the Latin word for "light," and the initial letters of "Orchestration System." Hence, "Light Orchestration System" which is the most common application for which the Lumos hardware and software are used—running computerized lighting displays.

1.5 Getting Additional Help

The product website at `www.alchemy.com/lumos` contains additional documentation, pointers, hints, and tips to assist you further. If that doesn't answer all your questions, there is an online forum where you may submit questions for help.

CHAPTER 2

SAFETY INFORMATION

BEFORE YOU BEGIN BUILDING your Lumos controller, please take the time to carefully read the following safety precautions. Failure to follow this advice could result in death or serious injury, damage to the Lumos controller unit, and/or damage to the other devices plugged into the controller.

2.1 Hazardous Materials

While assembling this unit you may come in contact with hazardous chemicals. The Lumos product contains no hazardous parts *per se* but if you choose to assemble it using lead-based solder, you may expose yourself to risk of lead poisoning. The main cause of lead poisoning due to soldering is by ingesting lead particles left on your hands or work surface. To avoid this, keep food away from your work area, and thoroughly wash your hands and work surfaces before handling food.

In addition, if you choose to use other chemical agents (e.g., to clean excess flux from your soldered board), be sure to read and follow their precautions and instructions carefully.

2.2 Small Part Danger

This board contains small parts which could pose a choking hazard to small children. This product is not a toy and is not intended for use by children in any circumstance. The small parts on the product can be swallowed by children under 4 years of age. Keep out of reach of children.

2.3 Hazardous Voltage

Exercise care when working with any electrical system, including one such as the Lumos DC controllers (even though in theory they deal with low voltages). The power supplies of the loads plugged into the Lumos controller, and even the power loads being controlled, may present a shock hazard if not wired and handled using standard safety protocols. Never touch or work with live circuits. Always disconnect the power source before working on your Lumos controller.

When working with loads outdoors, be sure all supplies are plugged into GFIC-protected circuits.

2.4 Physical Hazards

While assembling the unit, always wear ANSI-approved eye protection gear. When soldering, always be aware of—and in control of—the location of your soldering iron (it will be 300°F–500°F—any slight mistake can be costly, painful, or dangerous)! Bits of molten metal or flux can spatter onto your skin or in your eyes during soldering. When cutting leads, sharp metal wires may be launched into the air, and could hit your eyes.

2.5 Electrostatic Discharge (ESD) Warning

Many of the components used in this project are sensitive to static electricity. Always use a proper ESD-safe work environment when handling them, or these parts may be permanently damaged. If a part is damaged in this way, it is impossible to tell by looking at the part, and you won't necessarily feel the static discharge which caused the damage. Never take the risk of handling sensitive components without ESD protection in place.

These parts include all transistors, voltage regulators, diodes (D0–D11), and integrated circuits.

2.6 Circuit Loading

Always respect the maximum voltage and current capacity of the board and your wiring. Overloading any of these may result serious injury, death, fire, and/or severe damage to any or all of the devices in use.

The four output channels combined may not exceed 10 A total. Each single output channel may not exceed 5 A. These should be considered *absolute maximum* tolerances. The board was designed to operate at sustained levels below those limits.

CHAPTER 3

BEFORE YOU BEGIN

THE LUMOS CONTROLLER board may be built in a variety of different configurations depending on how it will be used. In order to know how to proceed from this point, you must first decide what varition of Lumos board you wish to build.

3.1 The Common "Base" Relay Configuration

All boards will contain a microcontroller and four output relays, so our assembly instructions will begin with the step-by-step instructions for building this portion of the board. In the bill of materials in Chapter 4, this is listed as the "base" set of materials all Lumos boards require.

3.2 Communications Options

You will need to decide whether to use full- or half-duplex RS-485 communications, since the parts installed to support either option will be different.

With the full duplex option, there are two independent data channels. One is used for the host PC to send commands to the Lumos board(s). The other is used for the Lumos board(s) to respond back to the host PC if asked to send status information about their configuration.

The half-duplex option uses RS-485 as indicated above, but only a single data channel is used. Most of the time, the host PC keeps control of the wire and sends a stream of commands to the Lumos board(s) connected to the wire. However, if it asks one of them for a response, it must relinquish control of the line and allow the Lumos board to assert control, transmit its response, then release control again.

With half-duplex operation, the PC needs to be able to control whether it asserts or releases control of the serial data line. The Lumos software assumes this is accomplished by switching the DTR line on when the PC is to transmit, and switching it off to release control and allow another device to transmit.

Normally, we'd recommend full-duplex unless your specific needs dictate otherwise.

3.3 The Sensor-In Option

Sensor inputs may be added to a Lumos board to allow for external sensors to trigger pre-programmed relay actions. The host PC may also monitor the sensors.

At the present time, pre-programmed actions are not yet implemented. The host PC may query the Lumos board to see the status of its sensors, then command the board to do something in response.

A Lumos board may accommodate up to four such sensor inputs. These are TTL-level inputs which may be active low or high (although the Lumos board provides 10 K pull-up resistors on the sensor input lines). These inputs take the place of the four diagnostic LED indicators, so if this route is taken those will no longer be available to assist with using the board.

CHAPTER 4

What You Will Need

Assembling this project requires soldering over 50 components onto a PC board. Before beginning construction, be sure you have the following tools and materials on hand:

- A Lumos 4-Channel DC Controller PC board. These instructions are intended for version 1.0 of this board, which includes boards numbrered "1.0" and "1.0.x" where x is any number. If your board has a different version number printed on it, you need an instruction manual which was written for that board type. DO NOT proceed to use these instructions for that board!
- All the electronic components required for the board. These are listed in the following table.
- A soldering iron with thin "pencil" tip.
- Rosin-core solder.
- Diagonal wire cutters.
- ESD protection gear such as an anti-static grounding strap.
- IC chip insertion tools.
- Needle-nose pliers.
- A heat sink which can be clipped onto component leads while soldering.
- A few ounces of thermal (heat sink) grease.

4.1 Bill of Materials

Referring back to the set of options you selected in Chapter 3, add up the quantity of parts needed for each option in the bill of materials in Table 4.1. Note that the board is designed for miniature-size resistors and capacitors. See the ordering information in Chapter 10 (p. 31) for example part numbers of components known to work with this board.

Base	FDX-485	HDX-485	Sensor-In	Number	Description
2				C0–1	Capacitors, 30 pF or 33 pF ceramic
2				C2–3	Capacitors, 0.01 μF
3				C4,5,7	Capacitors, 0.1 μF
2				C6,8	Capacitors, 0.33 μF
2			$-x$	D0,2	LEDs, yellow, 3 mm*
2				D1,4	LEDs, green, 3 mm
1			$-x$	D3	LED, red, 3 mm*
2				D5,6	Diodes, 1N4004
1				F0	Fuse, 10 A, Littelfuse 0297010.WXNV or equiv.
5				HS0–4	Heat sinks, TO-220, if needed
2			1	J0,1,8	Terminal blocks, 5-position, Altech MBE-155
1				J2	Jumper block header, 6-position
3				J3–5	Jumper block headers, 4-position
2				J6,7	Terminal blocks, 2-position, Altech MBE-152
4				Q0–3	Transistors, MOSFET, FQPF13N06L
1				R0	Resistor, 330 Ω, ¼ W
1				R1	Resistor network, 470 Ω×5, bussed type
			1	R2	Resistor network, 10 K×5, bussed type
5				R3,6–9	Resistors, 10 K, ¼ W
1				R4	Resistor, 33 K, ¼ W
1				R5	Resistor network, 680 Ω×5, bussed type
4				R10–13	Resistors, 470 Ω, ¼ W
1				R14	Resistor network, 120 Ω×2, isolated type
1				U0	PIC18F14K50 microcontroller, Lumos programmed
		1		U1	SN75176 half-duplex RS-485 driver/receiver
	1			U2	MAX489 full-duplex RS-485 driver/receiver
1				U3	K847PH quad opto-isolator, NPN transistor output
1				U4	LM78L05 +5 V DC regulator, 100 mA
1				U5	LM7805 +5 V DC regulator, 1.5 A
1				X0	Crystal, 10 MHz
1				XF0	Fuse holder, Littelfuse 01530008Z, for F0
6				XJ0–5	Jumpers, 2-pos, 0.1″ pitch
1				XR14	SIP socket, 4-pin, for R14
1				XU0	DIP socket, 20-pin, for U0
		1		XU1	DIP socket, 8-pin, for U1
	1			XU2	DIP socket, 14-pin, for U2
1				XU3	DIP socket, 16-pin, for U3

*Some of these are omitted in order to make room for sensor input lines.

Table 4.1: Lumos Bill of Materials

CHAPTER 5

Assembling the PC Board

With all the parts and tools at hand as described in the previous chapter, you are now ready to begin assembly of the Lumos controller PC board. The order of installation presented here is intended to make assembly as convenient as possible. Generally this means progressing from the shortest to the tallest components, allowing the board to be laid flat face-down on the work surface while soldering the component leads.

☞ **Note: Take care to make good, solid solder connections when installing components. Hold your soldering iron to the part's lead *and* the annular ring of the PCB until both are hot, then apply just enough solder to cover the ring, withdraw the solder, then remove the heat. Good solder connections should be shiny and smooth.**

☞ **Note: The board layout is quite compact, with many components in a small space. Take care when soldering that you don't accidentally heat the wrong component or form solder bridges between nearby contact points.**

☞ **Note: We will point out a few places where ESD protection is needed, but that is intended to call attention to the issue at some key points, not to be a comprehensive list of *every* case where it is needed. You are expected to use appropriate handling protocols for all parts, which includes the use of ESD protection when working with semiconductors (e.g., all chips, voltage regulators, transistors, etc.).**

Refer to Figure 5.1 throughout these instructions to see where the components are located on the PCB. The locations are also labeled on the PCB itself.

1. Install a 330 Ω resistor in position R0 as marked on the PCB and Figure 5.1. This is marked with the color bands "orange-orange-brown." Push it all the way until flush with the PCB.
2. solder the resistor leads on the bottom side of the board.
3. Trim the excess leads with diagonal cutters.
4. Repeat steps 1–3 to install (5) 10 K resistors ("brown-black-orange") at R3 and R6–R9.
5. Repeat steps 1–3 to install (4) 470 Ω resistors ("yellow-violet-brown") at R10–R13.
6. Continue in the same way to install and solder the remaining discrete resistor, 33 K at position R4.
7. **If you will *not* be installing sensor inputs,** you will not install the 10 K resistor network at R2. However, you will instead install a single 10 K resistor between pins 1 and 2 of R2. See Figure 5.3 for a photo of what this looks like.
8. In the same fashion, install and solder (2) 30 pF or 33 pF capacitors into positions marked C0–C1.
9. Install and solder (2) 0.01 μF capacitors into positions C2–C3.
10. Install and solder (3) 0.1 μF capacitors into positions C4, C5, and C7.
11. Install and solder (2) 0.33 μF capacitors into positions C6 and C8.
12. Install (2) 1N4004 diodes at D5 and D6. **Note: These parts will not function if inserted the wrong direction.** Each diode has a stripe on one end. This end is inserted into the hole marked by the straight line (cathode) drawn on the PCB. The unmarked end goes into the hole marked by the triangle (anode). Solder into place.
13. Install (2) green LEDs at D1 and D4. **Note: These must be inserted in the correct orientation.** The longer lead (anode) goes into the square hole, while the shorter lead (cathode) goes into the round hole. Solder into place.
14. Install (2) yellow LEDs at D0 and D2, noting the cautions from the previous step. **Note: if you will be using sensor inputs, you may wish to omit D0 and/or D2. See Chapter 7 for details before installing these parts.** Solder into place.

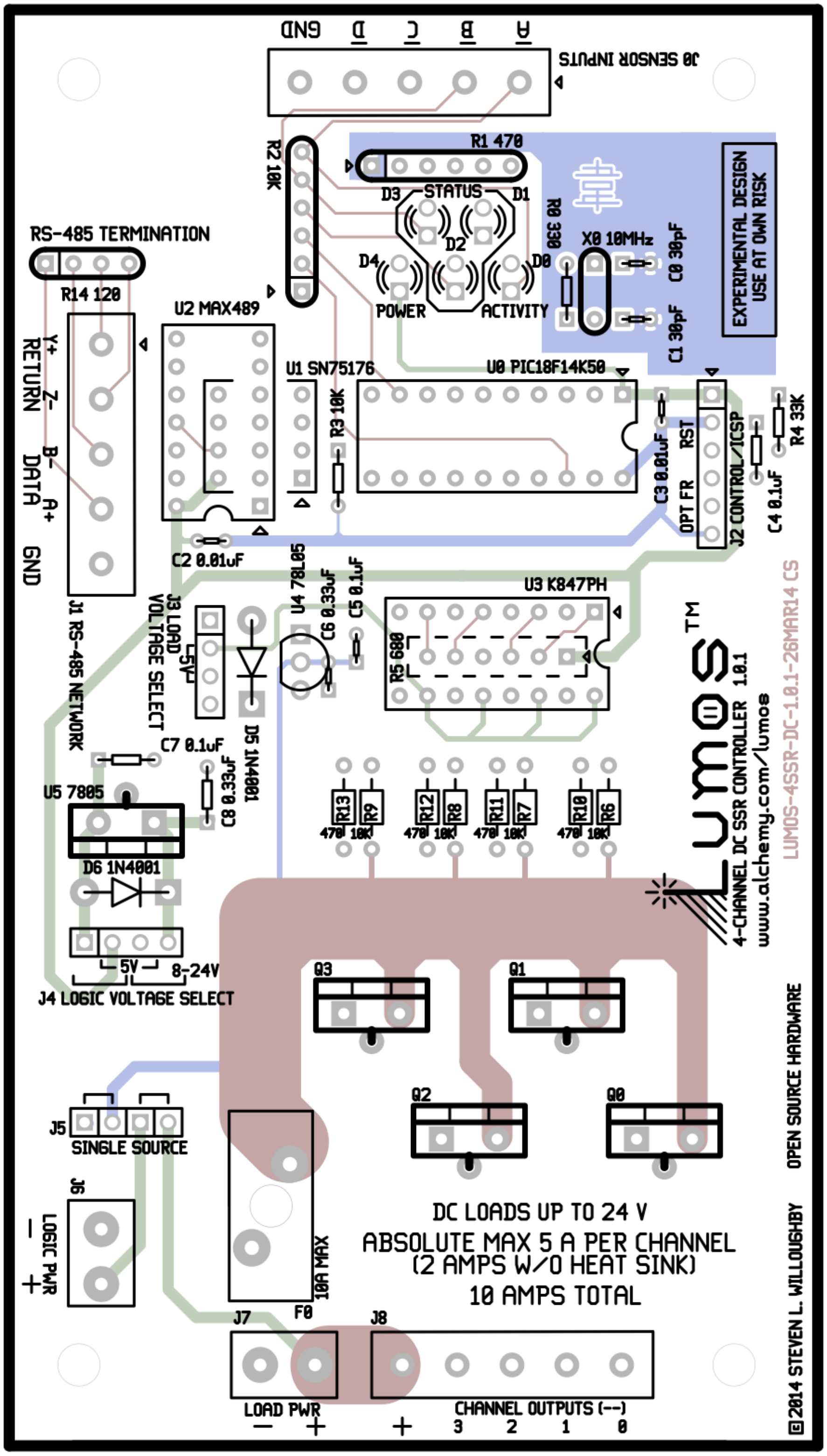


Figure 5.1: Lumos Board Parts Placement Diagram

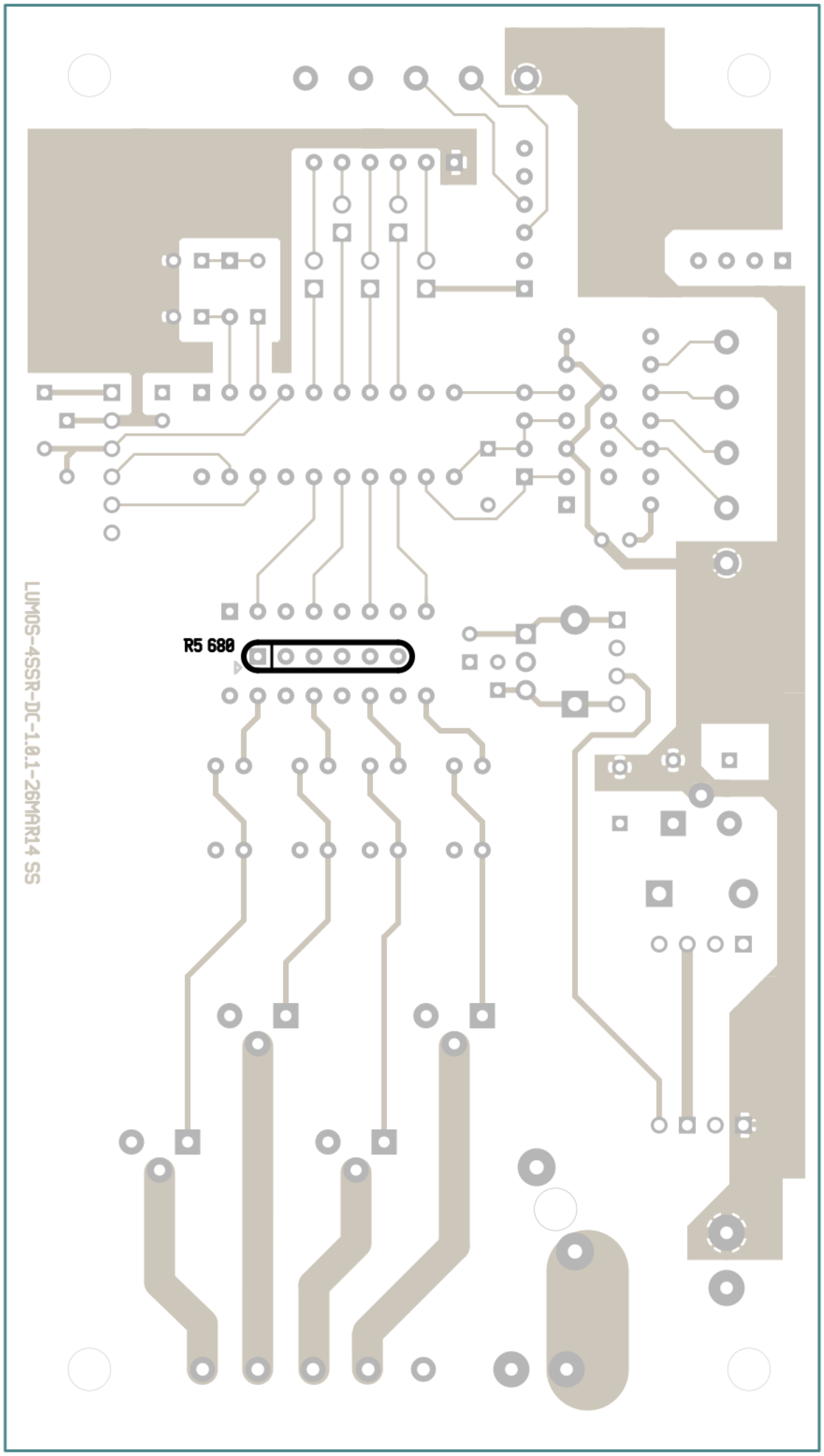


Figure 5.2: Lumos Board Parts Placement (Reverse Side)

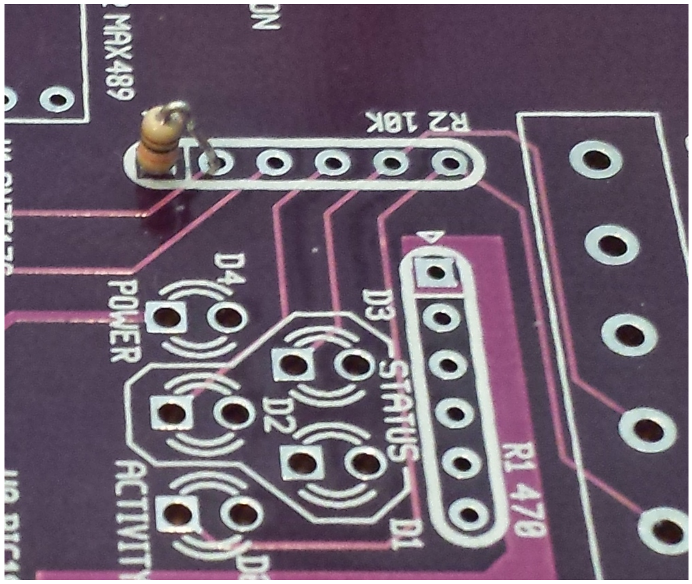


Figure 5.3: Discrete R2 Resistor If No Sensor Inputs Are Used

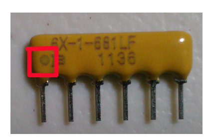
15. Install a red LED at D3 as described in the previous two steps. **Note: if you will be using sensor inputs, you may wish to omit D3. See Chapter 7 for details before installing this part.** Solder into place.

16. Install a 20-pin DIP socket XU0 at position U0. Solder.

17. Note the location of U3 and R5 (located *inside* the borders of chip U3).

18. Flip the board over to the bottom (solder) side. Be sure you still see where R5 is located.

19. Install a 680 Ω resistor network *on the bottom (solder) side* of the board at R5 (the row of six holes *inside* U3). **Note the correct position of R5.** The square hole on the PCB marks where pin 1 of R5 should be inserted. Pin 1 is marked with a dot on R5 itself. See Figure 5.2.



20. Holding R5 in place, carefully flip the board over.

21. Keeping R5 straight, solder into place (soldering on the component side of the PCB).

22. Flip the board back over to the component side. **Caution:** From this point forward, don't forget that resistor is on the other side of the board. If you press down on the board (e.g., when installing chips into sockets), you will bend R5 and may damage it.

23. Install a 16-pin DIP socket XU3 in the position marked U3. Note that it needs to fit easily over the soldered leads from R5. If not, select a different style of socket or carefully trim down the resistor leads.

24. Solder socket XU3.

25. Install a 6-position jumper block header at J2. Solder.

26. Install (3) 4-position jumper block headers at J3–J5. Solder.

27. Install an LM78L05 voltage regulator at U4. **This part will not function unless oriented correctly.** Note the flat side on the component case. This aligns with the flat side drawn on the circuit board. Apply heat protection while soldering in place, and/or limit soldering time to 4 seconds or less. Use ESD protection.

28. Install a fuse holders XF0 at position F0. Due to the wide PCB traces here, this may require extra soldering time, but be careful not to overheat the parts.

29. Install (2) 5-position terminal blocks at J1 and J8.

30. Install (2) 2-position terminal blocks at J6 and J7.

31. Using ESD protection, lay out (4) MOSFETs on your workbench.

32. Prepare each MOSFET by bending the middle lead 90° up toward the front of the transistor body, then move your pliers down the lead another 0.1″ and bend it 90° back again, parallel to the other pins again. It should now look like the photo in Figure 5.4 and should fit easily into the holes at Q0 on the PCB.

33. If using a heat sink, apply a *small* dab of heat sink grease on the back side of the transistor and attach the heat sink.

34. Using appropriate heat protection and/or limiting soldering time to 4 seconds or less per pin, install and solder transistors Q0–Q3 onto the board.

35. Trim the excess leads.

36. Follow the same process as outlined in steps 31–35 to install voltage regulator U5 on the board.

37. Install resistor network R1 onto the board, noting that pin 1 (marked with a dot on the resistor as was the case with R5) goes into the square hole marked with an arrow on the board. Solder into place.

38. Install and solder socket XR14 at position R14.

39. Install fuse F0 into its socket.

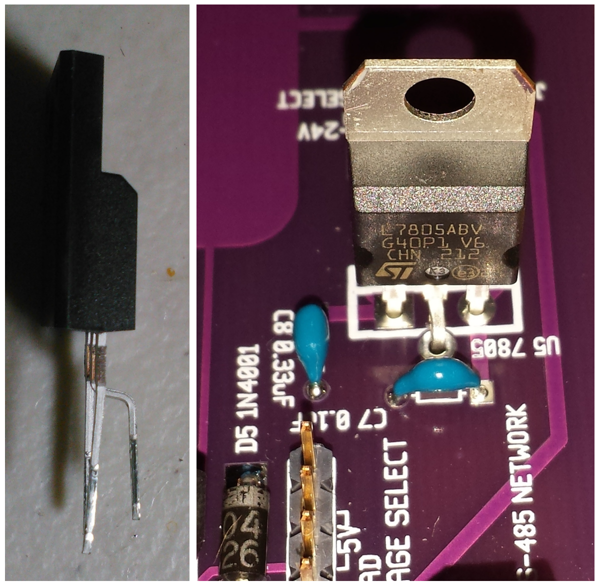


Figure 5.4: Bending the Pins of the MOSFETs and 7805

40. Install crystal X0 onto the board without allowing it to short against any other component leads. It is fine if the crystal is not flush against the board. Solder into place.

41. Using ESD protection, install microcontroller chip U0 into its socket. Note the location of pin 1 of the chip, marked with a small arrow or triangle on the board.

42. Using ESD protection, install optoisolator chip U3 into its socket. Note the location of pin 1 of the chip, marked with a small arrow or triangle on the board.

This completes the assembly of the main portion of the Lumos board, common to all configurations.

Continue to the following sections to install the other options you selected.

CHAPTER 6

Assembling the Communications Options

An intelligent controller board needs some way to receive commands from the outside world. The Lumos 4-channel DC controller uses RS-485 for this functionality, allowing for two different options for how that is configured: full duplex and half duplex.

Skip to the section below which describes the communication option you have selected. You must do exactly **one** of these.

6.1 RS-485 Full Duplex

Perform the following steps to add **full-duplex** RS-485 capability:

1. Install a 14-pin DIP socket XU2 at position U2. Note the position of pin 1 (indicated a square pad and silk-screened triangle). If your socket also indicates pin 1, align it to match the PCB. Solder into place.
2. Install a MAX489 driver/receiver chip into its socket at U2, noting the marked location of pin 1. Press carefully down into place.

Skip to the next chapter.

6.2 RS-485 Half Duplex

Perform the following steps to add **half-duplex** RS-485 capability:

1. Install an 8-pin DIP socket XU1 at position U1. Note the position of pin 1 (indicated by a square pad and silk-screened triangle). If your socket also indicates pin 1, align it to match the PCB. Solder into place.
2. Install an SN75176 driver/receiver chip into its socket at U1, noting the marked location of pin 1. Press carefully down into place.

Skip to the next chapter.

CHAPTER 7

ASSEMBLING THE SENSOR INPUT OPTION

LUMOS BOARDS SUPPORT THE OPTION of attaching up to four simple TTL-level logic inputs. The host PC can query the Lumos board to find out the current state of these inputs.

These inputs may come from sensors (e.g., light sensors or motion sensors) which produce a compatible output signal. They may even come from the logic outputs of another Lumos board.

The trade-off here, however, is that the signal lines used by the sensors are also used to drive the diagnostic LEDs. Any given line may only be a sensor input *or* an LED output at any given point in time, but never both.

It is generally recommended that you decide in advance how many sensor inputs you will need, then look at the table of diagnostic codes in *Using the Lumos SSR Controllers* to determine which specific LEDs you're willing to live without. Those LEDs should then be omitted from the construction of the board's CPU option, so they won't interfere with the inputs coming in on the same pins of the microcontroller.

The correspondence of LEDs to inputs is shown in Table 7.1. Note that sensor input $\overline{\mathrm{D}}$ is available without the need to remove any LEDs from the board.

These are named as active-low inputs (i.e., "$\overline{\mathrm{A}}$" instead of "A") because that is a common model and is compatible with the Lumos logic output lines which are active-low signals. As such, the Lumos board includes a 10 K pull-up resistor connected to each of the input lines so they will default high unless explicitly pulled low by the input. It may be actively driven low or high by the sensor. The Lumos board may, however, be programmed to respond to the inputs as if they were active-high or active-low. There shouldn't therefore be a need to invert an active-high input for use with a

Sensor	Diagnostic LED	
$\overline{A}$	D0	“Activity” (yellow)
$\overline{B}$	D3	“Status” (red)
$\overline{C}$	D2	“Status” (yellow)

Table 7.1: Mapping of Diagnostic LEDs to Input Sensors

Lumos board.

7.1 What If I Want to Keep All My LEDs?

A natural question to ask here is, “Can I keep the LEDs installed *and* have sensor inputs, deciding at different times to configure the Lumos board to treat them as inputs or LEDs as needed at that moment?”

The answer is “maybe.” It depends on what you plug into the sensor inputs and how much current it can supply, since it would have to power the LEDs too.

Normally, the sensor inputs have the effective circuit shown in Figure 7.1. However, if the LED is physically present on the board at the same time, the effective circuit becomes the one shown in Figure 7.2. Consider whether your input source can tolerate that circuit configuration before proceeding. If it can’t, you need to remove the LED(s) corresponding to the input lines you’ll use.

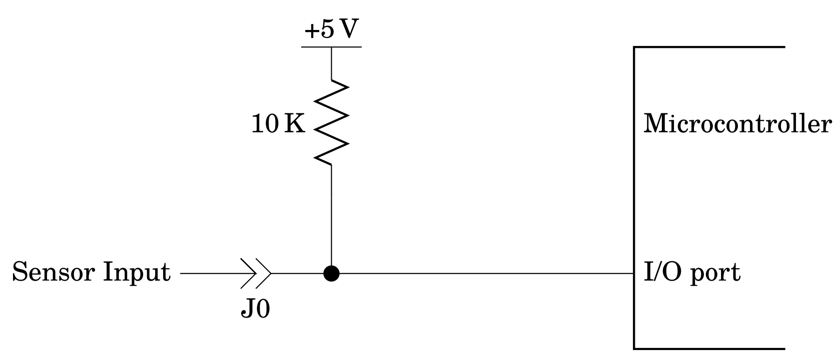


Figure 7.1: Sensor Input Circuit

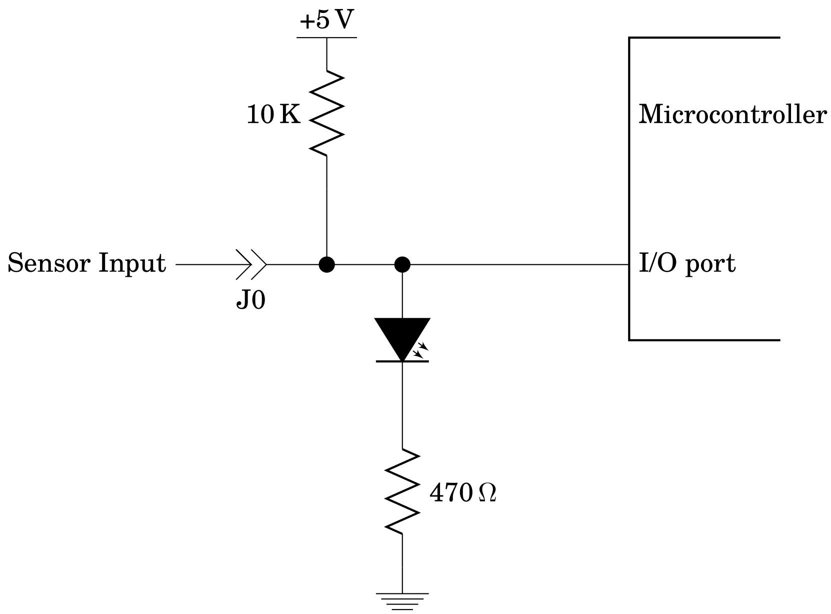


Figure 7.2: Sensor Input Circuit with LED Present

7.2 Installing the Option Hardware

To install this option, do the following:

1. Install a 10 K×5 resistor network at R2. **This component will not function if not oriented correctly.** Pin 1 (the common pin) is marked with a dot on the resistor itself. This goes into the hole marked with a square pad and silk-screened triangle. Keep the pins straight and solder R2 into place.

2. Install a five-position terminal strip at J0. Solder.

☞ **Note:** Before any inputs will be recognized, the Lumos board must be configured in software to change those specific lines from LED outputs to logic inputs. See *Using the Lumos SSR Controllers* for programming and configuration details. **Never attach sensors to the terminal block at any time the Lumos board is software-configured to drive those lines as LEDs.**

☞ **Note: Always configure those as inputs before attaching the sensor hardware.** Otherwise, the Lumos board will try to drive those LEDs, which the sensors may not tolerate well. If the sensor is also driving the line at the same time, you may short out those input pins on the microcontroller, causing damage.

This completes the construction of the sensor input option.

CHAPTER 8

Using a Front Panel

YOU MAY WISH TO INSTALL your Lumos board into a weather-resistant enclosure which allows access to the circuit board to make connections and to access the jumper blocks and LEDs. It may be desirable to bring the LEDs, buttons, and other connections to panel-mount components.

For power connections, there are a variety of panel-mount connectors which may be employed and wired back to the terminal strips on the Lumos board. Select those which work for your application. Since the power connections need jumpers to select the input voltage, you may need to bring those selectors out to a front or back panel as well. You can easily connect a DPDT switch to a 4-position connector which attaches to the jumper blocks. The wiring arrangement for this is shown on page 34 in the appendices.

Similarly, network connections may be brought to the outside of the box by installing modular jacks on the outside, wiring them back to J1. In this case, *both* input and output jacks should be wired back to the terminal block.

If external LEDs are needed, the easiest approach is to install a terminal strip at J0. The terminals A–C on that terminal carry the same signals that run the on-board LEDs. (Unfortunately, the green status LED is not available in this manner.) See the schematic in Figure 8.1 to find which terminal carries which LED power. To avoid overloading the microcontroller's I/O port power capacity, it would be better to remove the on-board LEDs in the cluster D0–D4 if external LEDs will be used in this manner. Note that the external LEDs require appropriate current-limiting resistors installed for them. This is not provided at J0.

The Option and Reset buttons (not normally provided in any other way for the 4-channel board) can be external buttons which are wired to a 6-

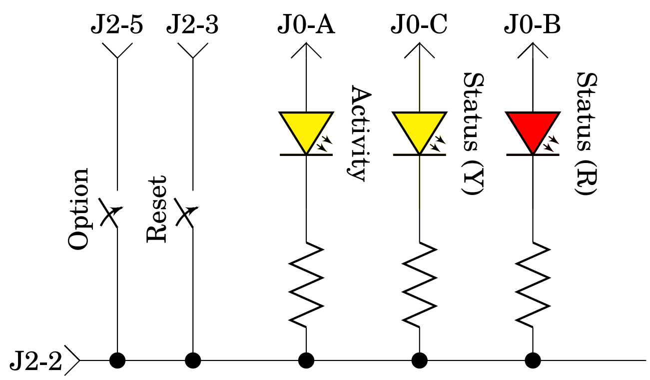


Figure 8.1: Example of a Front Panel Circuit for a Lumos Board

pin connector plugged in to J2. An example front panel circuit is shown in Figure 8.1.

CHAPTER 9

Assembling a Relay-Only Controller

Although not explicitly supported by the design, the Lumos 4-Channel DC controller may be modified to be a simple four-channel DC solid-state relay unit with on on-board intelligent controller. This would then require an external TTL-level logic input to drive each relay output.

To do this, omit everything between U3 and J0. Install four jumper wires across the holes where the following pins of U0 would have gone:

U0 pin 9—13
U0 pin 8—14
U0 pin 7—15
U0 pin 5—16

This connects the SSR inputs directly to the pins at terminal strip J0. The inputs are listed in Table 9.1.

Additionally, you'll need to provide a positive 5 V supply along with the logic inputs. This can be done by completing the voltage regulator circuit

Input	**Channel**
$\overline{\mathrm{A}}$	0
$\overline{\mathrm{B}}$	2
$\overline{\mathrm{C}}$	1
$\overline{\mathrm{D}}$	3

Table 9.1: Relay-Only Logic-level Inputs

around U5, or omitting that regulator ciruit (U5, D6, C7, C8, J4, J5, and J6) and instead attaching a 5 V lead at J2 pin 1.

Chapter 10

Going On From Here

Now that your Lumos controller board is assembled, go on to read the manual *Installing the Lumos 4-Channel DC Controller* for help in setting up your controller for use (including cabling and connector pinout information), and *Using the Lumos SSR Controllers* to learn how to control and program it using software.

Ordering Information

Components

The components used on the Lumos board are all commonly available from retail electronics suppliers. As an example, Tables A.1 and A.2 list the part numbers we used when building the prototypes, ordered from Mouser (an on-line electronics retailer). These specific parts are known to work with the board and are the correct sizes to fit through all the holes. Any equivalent parts from any supplier should work as well.

Lumos Part #	Mouser Part #	Description	Price* (2012)
HS0–4	532-507302B00	Heat sink, TO-220, horizontal	$0.25
XF0	576-01530008Z	Fuse holder, Littelfuse 01530008Z or equiv.	2.45
XJ0–5	571-8815452	Jumper, 2-pos., 0.1 in pitch	.12
XR14	Jameco 6100-1-4†	SIP socket, 4-pos., 0.1 in pitch	.75
XU0	517-4820-3004-CP	IC socket, DIP, 20-pin	.42
XU1	517-4808-3000-CP	IC socket, DIP, 8-pin	.28
XU2	517-4814-3004-CP	IC socket, DIP, 14-pin	.36
XU3	517-4816-3004-CP	IC socket, DIP, 16-pin	.29

*This is not a price quote and we do not represent Mouser.com in any way. This is simply the price *we* found when we looked in 2012 and 2014, offered for general budgetary reference. The prices shown were for each unit, but may reflect quantity discounts we were given.
†This part was found at Jameco, another online electronics outlet.

Table A.1: Component Ordering Information (accessories)

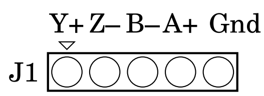
Lumos Part #	Mouser Part #	Description	Price* (2012)
C0–1	80-C315C300J1G	Capacitor, ceramic, 30 pF, ±5%	$0.70
C2–3	810-FK18C0G1H103J	Capacitor, ceramic, 0.01 μF, 50 V, ±5%	.21
C4,5,7	810-FK18X7R1H104K	Capacitor, ceramic, 0.1 μF, 50 V, ±10%	.10
C6,8	810-FK14X7R1H334K	Capacitor, ceramic, 0.33 μF, 50 V, ±10%	.186
D0,2	604-WP132XYD	LED, yellow	.06
D1,4	604-WP132XGD	LED, green	.07
D3	604-WP132XID	LED, red	.07
D5,6	512-1N4004	Diode, 1N4004	.079
F0	576-0297010.WXNV	Fuse, 32 V, 10 A, fast-acting	.526
J0,1,8	845-MBE-155	Terminal block, 5-pos., 5 mm pitch	.80
J2	649-68001-106HLF	Header, 6-pos., 0.1 in pitch	.28
J3–5	649-68001-104HLF	Header, 4-pos., 0.1 in pitch	.202
J6,7	845-MBE-152	Terminal block, 2-pos., 5 mm pitch	.35
Q0–3	512-FQPF13N06L	Transistor, MOSFET, N-Channel, 60 V	.524
R0	660-CFS1/4C331J	Resistor, 330 Ω, ¼ W, mini, ±5%	.15
R1	652-4606X-1LF-470	Resistor network, 6-pin, 470 Ω, bussed	.13
R2	652-4606X-1LF-10K	Resistor network, 6-pin, 10 K, bussed	.13
R3,6–9	660-CFS1/4C103J	Resistor, 10K, ¼ W, mini, ±5%	.05
R4	660-CFS1/4C333J	Resistor, 33K, ¼ W, mini, ±5%	.15
R5	652-6406X-1LF-680	Resistor network, 6-pin, 680 Ω, bussed	.16
R10–13	660-CFS1/4C471J	Resistor, 470 Ω, ¼ W, mini, ±5%	.05
R14	652-4604X-2LF-120	Resistor network, 4-pin, 120 Ω, isolated	.25
U0	579-PIC18F14K50-I/P	PIC18F46K50 microcontroller	2.87
U1	595-SN75176BP	SN75176 RS-485 transceiver, half-duplex	.88
U2	700-MAX489EPD	MAX489 RS-485 transceiver, full-duplex	4.11
U3	782-K847PH	K847PH quad optocoupler, phototransistor output	.827
U4	512-LM78L05ACZXA	LM78L05 linear +5 V regulator, 0.1 A	.216
U5	511-L7805ABV	L7805 linear +5 V regulator, 1.0 A	.46
X0	774-MP101	Crystal, 10 MHz, 30 pF	.60

*This is not a price quote and we do not represent Mouser.com in any way. This is simply the price *we* found when we looked in 2012 and 2014, offered for general budgetary reference. The prices shown were for each unit, but may reflect quantity discounts we were given.

Table A.2: Component Ordering Information (electronics)

Connector Pinouts

RS-485 Connection (terminal block J1)

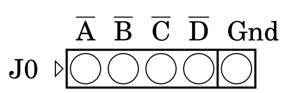


Note that RS-485 works best if the signal bus is a single line from one end to the other, with very short "taps" in the line for each Lumos board. In other words, if this is one unit in a chain, both the input and output lines should be tied to the terminal block. Do not "tap in" to the communication line and run a single jumper out to the Lumos board.

If this is the last device in the chain, install a terminator at R14.

The main data line carrying PC commands to the Lumos boards connects at "A+" and "B–" (the positive and negative signals respectively). The return channel (for full-duplex networks) is on "Y+" and "Z–".

Sensor Input Terminals (J0)

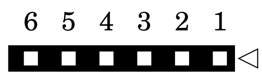


If the Lumos controller is built to accommodate one or more sensor inputs, a set of terminals will be installed at J0.

It is important to note that the board's circuitry must be configured for certain inputs to be enabled at the time the board is built, and that the board must be configured (using software) to recognize those inputs, before they will be usable.

Each input accepts a TTL-level signal. The lines are pulled up to +5 V internally. The board can be configured in software to react to the inputs as active-high or active-low.

Control/ICSP Header (J2)

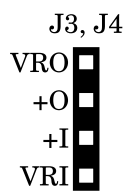


1 V_{DD} (+5 V)
2 V_{SS} (Ground)
3 $V_{PP}/\overline{\text{MCLR}}/\overline{\text{RESET}}$
4 PGD/$\overline{\text{PWR CTL}}$
5 PGC/$\overline{\text{OPTION}}$
6 Ground

This header is used for reprogramming a new firmware image onto the microcontroller chip. Be sure to check the pinout used by your programmer before connecting it to this port. It may be different!

During normal operations, this header may also be used to connect off-board buttons for the reset and option functions. These buttons should be normally open, but connect their respective pins to ground when pushed. Note that the $\overline{\text{PWR CTL}}$ output is only available on this header. If the board is to be used with a controlled power supply, a connector will need to be used to obtain this signal from J2.

Voltage Select Headers (J3, J4)



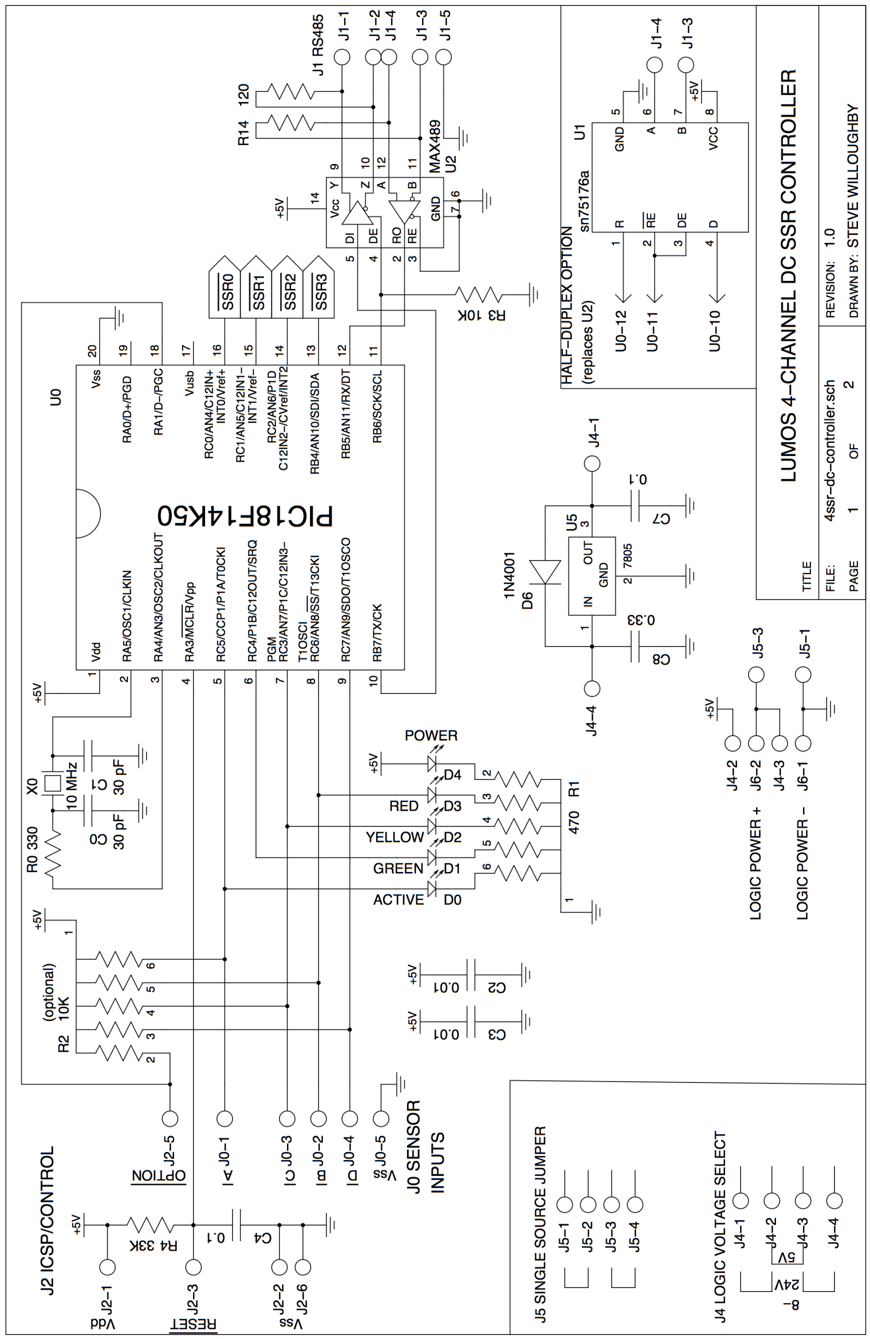
+I: Positive voltage in from power supply
+O: Positive voltage out to circuit
VRI: Input to voltage regulator
VRO: Output from voltage regulator

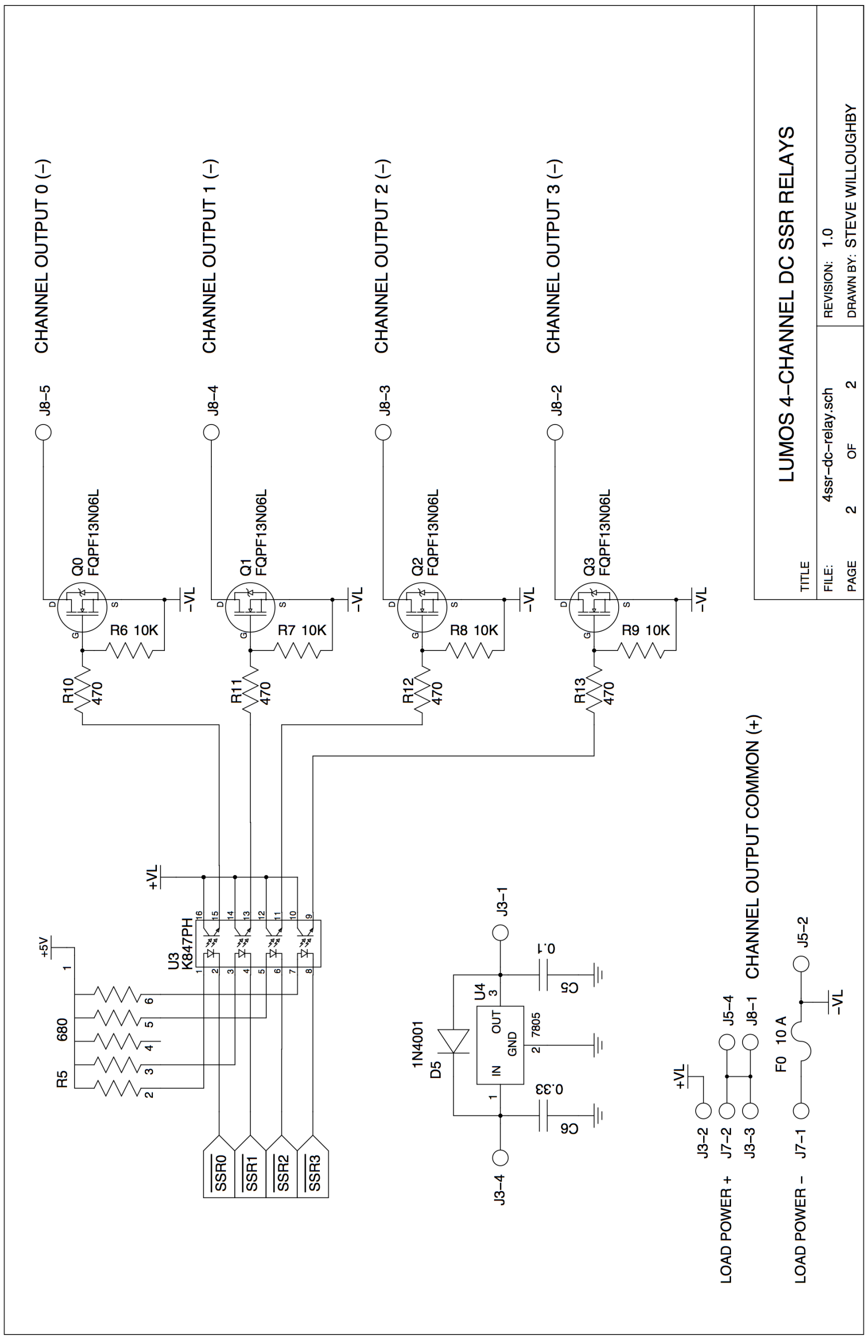
J3 and J4 are used to select the input voltage supplied to the load power control and the logic portion of the board. The square pin on the board corresponds to the VCO pin in the diagram above. If a regulated +5 V supply is employed, there is no need for the on-board regulator (and in fact it can't function properly unless its input is at least +8 V), so a jumper is placed across the middle two pins (connecting +I and +O), bypassing the voltage regulator entirely. *In this case, it is critically important that the input voltage be a clean, regulated +5 V supply. If this voltage is exceeded, permanent damage to the Lumos board will result!*

If +8 V to +24 V is attached to an input, the corresponding jumper block needs jumpers installed into the outer two pins, connecting +I to VRI and +O to VRO. This routes the incoming power through the voltage regulator.

Schematics

The following pages contain the schematic diagrams for all the various options that can comprise a Lumos 4-channel DC controller.


LUMOS 4–CHANNEL DC SSR CONTROLLER
TITLE
FILE: 4ssr–dc–controller.sch
PAGE 1 OF 2
REVISION: 1.0
DRAWN BY: STEVE WILLOUGHBY
PIC18F14K50
U0
MAX489
U2
J1 RS485
R14 120
R3 10K
SSR0
SSR1
SSR2
SSR3
HALF–DUPLEX OPTION
(replaces U2)
sn75176a
U1
1N4001
D6
U5
7805
C7 0.1
C8 0.33
POWER
RED
YELLOW
GREEN
ACTIVE
R1 470
R0 330
X0 10 MHz
C0 30 pF
C1 30 pF
R2 10K (optional)
C2 0.01
C3 0.01
C4 0.1
R4 33K
J2 ICSP/CONTROL
J0 SENSOR INPUTS
LOGIC POWER +
LOGIC POWER –
J5 SINGLE SOURCE JUMPER
J4 LOGIC VOLTAGE SELECT


LUMOS 4−CHANNEL DC SSR RELAYS
TITLE
FILE: 4ssr−dc−relay.sch
REVISION: 1.0
PAGE 2 OF 2
DRAWN BY: STEVE WILLOUGHBY
CHANNEL OUTPUT 0 (−)
CHANNEL OUTPUT 1 (−)
CHANNEL OUTPUT 2 (−)
CHANNEL OUTPUT 3 (−)
J8−5
J8−4
J8−3
J8−2
Q0 FQPF13N06L
Q1 FQPF13N06L
Q2 FQPF13N06L
Q3 FQPF13N06L
R6 10K
R7 10K
R8 10K
R9 10K
R10 470
R11 470
R12 470
R13 470
−VL
+VL
+5V
R5 680
U3 K847PH
SSR0
SSR1
SSR2
SSR3
CHANNEL OUTPUT COMMON (+)
J3−1
J3−4
U4 7805
IN
OUT
GND
C5 0.1
C6 0.33
D5 1N4001
J3−2
J7−2
J3−3
J5−4
J8−1
F0 10 A
J5−2
J7−1
LOAD POWER +
LOAD POWER −

Glossary

Active High: A logic signal which is considered "on" when the signal is "high" (binary 1 or +5 V), and "off" when the signal is "low" (binary 0 or 0 V). Lumos relay circuits are triggered with active-low signals.

Active Low: A logic signal which is considered "on" and "off" at the opposite signal levels to an "active high" signal (q.v.).

Annular Ring: The exposed ring of metal around a hole in a PCB where a component is to be mounted. The solder will flow across the component lead and onto the annular ring.

DIP (Dual In-line Package): The style of chip where the pins are laid out in two parallel rows.

DIY: "Do-It-Yourself."

Duplex: a feature of a serial line. On a full-duplex connection, separate data wires are present to carry data in both directions, so one device can send and receive data at the same time. On a half-duplex connection, only a single set of data wires is present, so devices must take turns transmitting over them.

ESD (Electro-Static Discharge): static electricity which builds on your skin and is then discharged into sensitive components when you touch them. Invisible to the eye, this can punch microscopic holes in the inside of the components, severely damaging them.

Heat Protection: A temporary heat sink applied to a component when soldering that component onto the PCB. Typically used for heat-sensitive components such as transistors and integrated circuit chips.

Jumper Block: A series of pins mounted to the PCB. Different options are configured for the circuit by placing a jumper over certain pairs of pins, shorting them together.

LED (Light Emitting Diode): A special kind of diode which emits light when current passes from its anode to its cathode.

MOSFET: The type of transistor which forms the major part of a Lumos DC relay channel. The name is an acronym for Metal Oxide Semiconductor Field Effect Transistor.

PCB (Printed Circuit Board): The board where electronic components are mounted to form a complete circuit. Metal traces are "printed" (actually etched) onto the surface of the board itself to make the connections between components.

RS-232: A standard hardware protocol for sending serial data between two devices (such as a computer and a modem or a single Lumos board). Shielded cable should be used for best results, and the cable length should not exceed 25 ft.

RS-485: A standard hardware protocol for sending serial data between multiple devices on a single cable length (electrically it is a single cable which each device "taps into" along the line; physically it is typically a "daisy chain" arrangement where a short cable connects one device to the next, another cable to the next, and so on). Unshielded twisted-pair cable is used (like Ethernet cable), and the cable lengths should not exceed a total of 4,000 ft (1,200 m).

Terminator Plug: An RS-485 network requires a terminator at each end. This is a small plug which plugs into the last unit in the daisy chain.

TTL (Transistor-Transistor Logic): One of the ways digital logic circuits can be constructed. For our purposes here, we consider a "TTL-level" signal to be a logic input or output where a voltage near +5 V is "high" (binary 1 or "true") and a voltage near 0 V is "low" (binary 0 or "false"). The inputs should never be above +5 nor below 0 volts.

Acknowledgements

Kickstarter Project

We launched a Kickstarter project to build a test network of Lumos DC boards for final testing and debugging before releasing the final designs and firmware as an open source DIY project.

Thank you to all our Kickstarter backers who made the final testing of the Lumos DC controllers possible!

Fan Level

Amanda Allen

Supporter Level

Casey Adams
Sue Allen
Andrej Čibej
Betsy Fernley
Beth Gordon
Sara Jacobson
Tanya Spackman

Backer Level

DC

Silver Level

David Johnston
Melf

Gold Level

Rob Beasley
Phil Willoughby

Patron Level

Casey A.
William H. Ayers
Jon and Rebecca Garver
Andy Kitzke
Joseph Moss
Robert A. Nesius
Patrick Quinn-Graham
Jama Scaggs
Doug Van Camp
Matthew Wentworth

We also wish to thank Darren Bliss who has been a great supporter of the Lumos project since the very first prototype was being experimented with, and the other Kickstarter backers and friends who offered moral support, other contributions, or who wished to contribute anonymously.

Technical Legacy

The do-it-yourself computerized Christmas light hobby thrives as a community of enthusiasts who contribute their ideas and designs for others to build, enjoy, and improve upon with new designs of their own. This journey began for me years ago with the discovery of Hill Robertson's Computer Christmas website (`www.computerchristmas.com`). It continues on sites such as Chuck Smith's Planet Christmas (`www.planetchristmas.com`), `doityourselfchristmas.com`, and many others.

Over the years the users of these forums have produced some great designs which have become *de facto* standards as others adopt them and refine them in their own designs. The Lumos boards' TRIAC and MOSFET relay circuits (the final few components at the controlled outputs) are a continuation of the standard circuits used by those communities, inspired most by Robert Stark's TRIAC design and the DC MOSFET circuits by John Wilson (from Computer Christmas and Do It Yourself Christmas, respectively). I am pleased to contribute my own innovations on these common design themes back to the same community (the remainder of the Lumos circuits other than the TRIAC and MOSFET output sections are entirely my own original design).

Index

Colophon

This manual was composed and typeset by the author using LaTeX with Memoir layout macros, augmented by wrapfig, lettrine, bytefield, wallpaper, TikZ, and a host of miscellaneous behind-the-scenes working packages.

It was set 10/12 pt using the TeX Gyre Schola font family created by GUST, the Polish TeX User Group. This typeface is based on URW Century Schoolbook L, originally designed by Morris Fuller Benton in 1919, for the American Type Founders.

Schematics were generated using the gEDA tool `gschem`. The PCB layout illustrations were created by `pcb` on Linux. All of the above are free and open-source tools.

Published electronically in PDF format for ease of viewing on any platform.