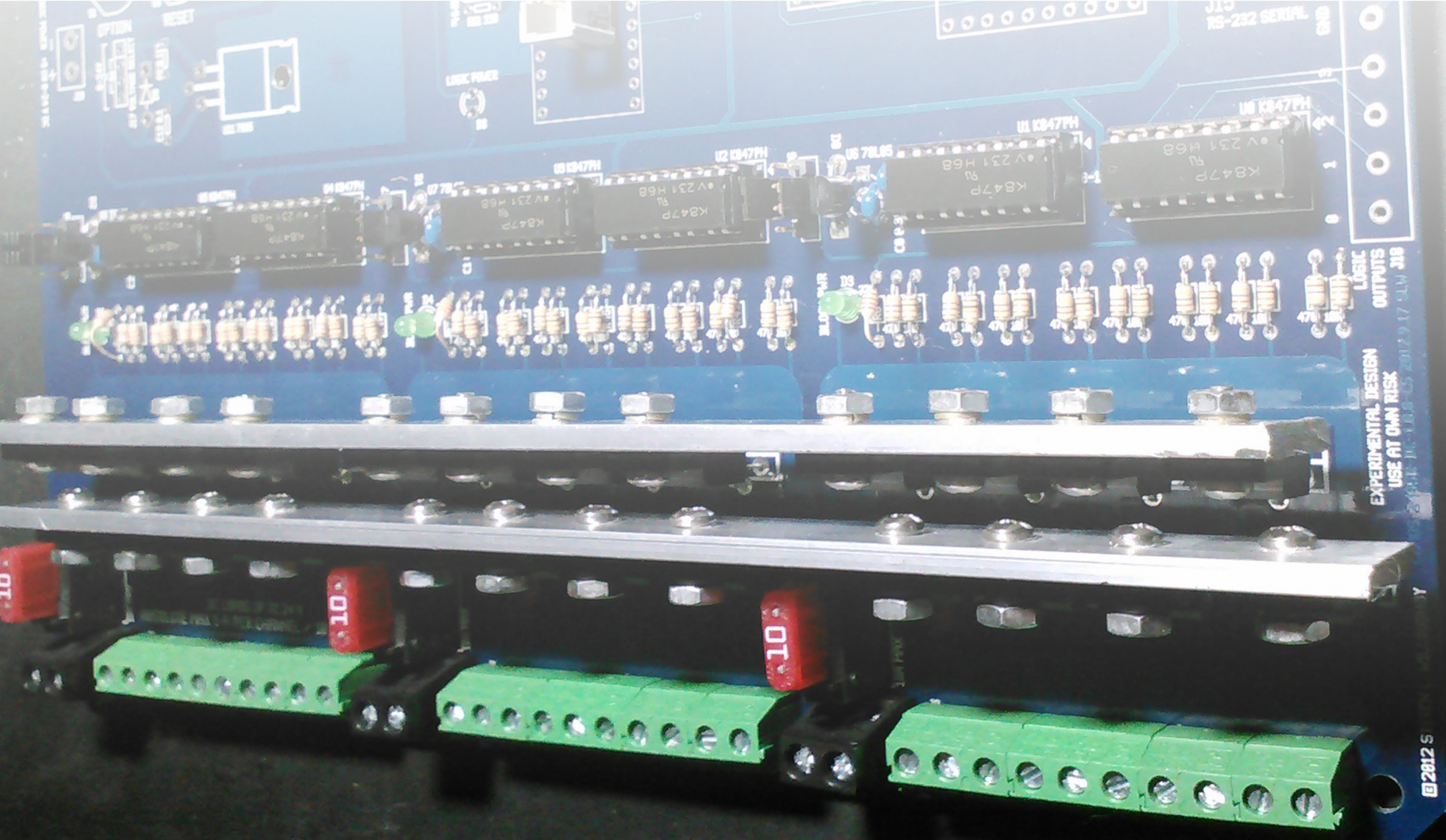
Assembling the Lumos™ 24-Channel DC SSR Controller



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 24-Channel DC Controller circuit version 1.0.8.

Contents

Contents iii

List of Figures v

List of Tables v

1 Introduction 1
- 1.1 Intended Audience . . . 1
- 1.2 Limitation of Warranty . . . 2
- 1.3 How to Use this Manual . . . 2
- 1.4 The Name of the Game . . . 2
- 1.5 Getting Additional Help . . . 2

2 Safety Information 3
- 2.1 Hazardous Materials . . . 3
- 2.2 Small Part Danger . . . 3
- 2.3 Hazardous Voltage . . . 4
- 2.4 Physical Hazards . . . 4
- 2.5 Electrostatic Discharge (ESD) Warning . . . 4
- 2.6 Circuit Loading . . . 4

3 Before You Begin 5
- 3.1 The Common "Base" Relay Configuration . . . 5
- 3.2 The "CPU" Option (Intelligent Controller) . . . 5
- 3.3 Communications Options . . . 6
- 3.4 The Sensor-In Option . . . 7
- 3.5 The Logic-Out Option . . . 7
- 3.6 Valid Option Combinations . . . 7

4 What You Will Need 9
- 4.1 Bill of Materials . . . 10
- 4.2 Heat Sinks HS0–HS1 . . . 10

5 Assembling the PC Board 15
- 5.1 Building the Relay Section . . . 16
- 5.2 Making a Relay-Only Lumos Board . . . 21

6 Assembling the CPU Option **23**

7 Assembling the Communications Options **27**
7.1 RS-485 Full Duplex / DMX512 27
7.2 RS-485 Half Duplex 28
7.3 RS-485 Terminator Construction 29
7.4 RS-232 32

8 Assembling the Sensor Input Option **33**
8.1 What If I Want to Keep All My LEDs? 34
8.2 Installing the Option Hardware 34

9 Assembling the Logic Output Option **37**

10 Using a Front Panel **39**

11 Going On From Here **41**

Ordering Information **43**
Components 43

Errata **45**

Connector Pinouts **47**
RS-485 Connection (8p8c Female Modular Jacks) 47
RS-485 Terminator (8p8c Male Plug) 48
RS-232 Serial Connection (9-pin Female DE-9 Jack) 48
Sensor Input Terminals (J16) 49
Logic Output Terminals (J18) 49
ICSP Header (J11) 49
Voltage Select Headers (J6–J8, J17) 50
Relay Control Connection (26-pin Male IDC Header) 51

Schematics **53**

Glossary **59**

Acknowledgements **61**

Index **63**

Colophon **65**

List of Figures

4.1 Drill Locations for Heat Sinks HS0–HS1 12

5.1 Lumos Board Parts Placement Diagram 17
5.2 Lumos Board Parts Placement (Reverse Side) 18
5.3 Bending the Pins of the MOSFETs 20

7.1 Terminator PCB 30
7.2 Fully Wired Terminator (Colors Vary from Text) 31

8.1 Sensor Input Circuit 34
8.2 Sensor Input Circuit with LED Present 35

10.1 Example of a Front Panel Circuit for a Lumos Board 40

A.1 Duty Cycles of Channel Logic Drive Outputs 50

List of Tables

3.1 Hardware Configuration Option Combinations 7

4.1 Lumos Bill of Materials (Components) 11
4.2 Lumos Bill of Materials (Sockets and Hardware) 13

8.1 Mapping of Diagnostic LEDs to Input Sensors 34

A.1 Component Ordering Information (accessories) 43
A.2 Component Ordering Information (electronics) 44

A.3 Typical Wiring Arrangement to Adapt DMX to Lumos 48

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™ 24-Channel DC Controller board places 24 such devices under the control of your computer. These outputs are arranged into three blocks of eight channels. Each block is electrically isolated from the logic control circuit and from each other, so each block may be separately powered at different voltages if desired.

If Lumos boards are configured with the RS-485 network option, up to sixteen Lumos boards may be "daisy chained" together (a total of 384 channels) 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 (Q0–Q23), voltage regulators (U6–U8 and U11), diodes (D0–D11), and integrated circuits (U0–U5, U9–U10, and U12–U13).

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.

Each block of eight controlled loads may not exceed 10 A total for the block. 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 24 output relays, so our assembly instructions will begin with the step-by-step instructions for building this portion of the board (the entire lower half of the PCB). In the bill of materials in Chapter 4, this is listed as the "base" set of materials all Lumos boards require.

You may choose to stop there, creating a remote-controllable DC relay board. If you go this route, you need some other circuit to provide the control (e.g., the Lumos 48-channel control board, which can control two of these so-called "dumb" relays). The control interface between them is the 26-pin connector J14, which carries +5 V DC power to the Lumos relay board and 24 TTL-level active-low logic inputs to drive the relays.

3.2 The "CPU" Option (Intelligent Controller)

If a simple "dumb" relay board is not what you need, then regardless of any other options selected, you will need to include the "CPU" option. This includes all the control logic—including a programmed microcontroller chip—required to make the Lumos controller an intelligent device capable of responding to commands from a host PC or even able to act independently.

3.3 Communications Options

An intelligent board needs to have some way to communicate with the outside world. At a minimum, it needs to be able to receive configuration and programming commands from a host PC. Usually, it will be fed a live stream of commands from a PC telling it when to turn on or off various output chanels.

There are three options available for the Lumos boards:

RS-485, Full Duplex

RS-485 (also known as TIA/EIA-485) is a communications standard using differential serial data signals in a multi-drop bus arrangement. An RS-485 data cable may support up to 16 Lumos boards and may have a maximum length of 1,200 m (4,000 ft). The cable used is unshielded twisted pair (usually CAT3, CAT5, or CAT6).

In order to use RS-485, the host PC will need some kind of USB or RS-232 to RS-485 adapter.

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.

RS-485, Half Duplex

This 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.

Either RS-485 option is suitable for DMX512 communications.

RS-232

RS-232 (also known as TIA/EIA-232) is the standard serial communications scheme used by PCs, modems, terminals, and similar devices (although most of those functions have now been moved to USB in recent years). Since the host PC will likely either already have an RS-232 port, or can be supplied with a USB-to-serial adapter for less than $15, this is the simplest and least expensive option.

However, that simplicity comes at a price. Only one device may be plugged in to an RS-232 line at a time, and the cable should be a high-quality, shielded cable 25 ft or shorter to avoid interference which can disrupt communications.

3.4 The Sensor-In Option

Sensor inputs may be added to an intelligent 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 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.

3.5 The Logic-Out Option

The Lumos board provides four TTL-logic-level outputs for the first four output channels. These may be used for experimentation, diagnosis of the board, or possibly to have one Lumos board's logic-level outputs fed into another Lumos board's sensor inputs to coordinate their actions.

3.6 Valid Option Combinations

You need to choose one of these combinations of options to make a complete unit:

Base	CPU	FDX-485	HDX-485	RS-232	Sensor-In	Logic-Out	Description
✓						?	"Dumb" relay-only board
✓	✓	✓			?	?	Full-Duplex RS-485
✓	✓		✓		?	?	Half-Duplex RS-485
✓	✓			✓	?	?	RS-232 Serial

Table 3.1: Hardware Configuration Option Combinations

"✓" denotes a required option for a given configuration; "?" indicates an optional selection.

Note that the **Sensor-In** and **Logic-Out** options may be added to any of the other basic configurations (except that **Sensor-In** can't be used with relay-only boards). If you don't know which option to choose, the most likely set to be useful to begin with would either be **Base+CPU+RS-232** if you want a single Lumos board connected to a PC via standard serial port, or **Base+CPU+FDX-485** if you want to use RS-485 communications (including DMX512) over long distances or with multiple units connected together.

CHAPTER 4

What You Will Need

Assembling this project requires soldering approximately 140 components onto a PC board.[1] Before beginning construction, be sure you have the following tools and materials on hand:

- A Lumos 24-Channel DC Controller PC board. These instructions are intended for version 1.0 of this board, which includes boards numbrered "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.

[1]The actual number will vary depending on the options selected.

- A few ounces of thermal (heat sink) grease.

If you need to make any RS-485 terminators, you will also need the materials listed in Section 7.3 (p. 29). Those materials are *not* included in this bill of materials here.

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 Tables 4.1 and 4.2.

Note that all resistors and capacitors are miniature-size. Check the dimensions of the parts you order to ensure they will fit properly on the board and will go through the holes.

IC sockets XU0–XU5 need to be open-frame type so they don't interfere with the pins of resistor arrays R0–R5.

4.2 Heat Sinks HS0–HS1

We recommend mounting the MOSFETs to a heat sink when assembling the board. These will need to be custom built. The bill of materials refers to these as HS0 and HS1. If you don't install a heat sink, the Lumos board will not be able to provide as much current to the output channels before the MOSFET parts overheat. (In our testing, we found that the transistors ran comfortably cool up to about 1 A, and warm to the touch with a load up to about 2 A. However, after the current load increased into the 2–3 A range, the transistors got too hot to touch.)

To construct these two heat sinks, you will need two $8\frac{1}{2} \times \frac{3}{4} \times \frac{1}{8}''$ thick ($\approx 25.5 \times 2 \times 0.3$ cm thick) aluminum bars (we found these to be readily available at home improvement and hardware stores). Drill twelve $\frac{1}{8}''$ holes into each bar at the locations shown in Figure 4.1.

Base	CPU	FDX-485	HDX-485	RS-232	Sensor-In	Logic-Out	Number	Description
3	1						C0–2, 11	Capacitors, 0.33 μF
3	2						C3–5, 8, 12	Capacitors, 0.1 μF
	2						C6–7	Capacitors, 33 pF ceramic
	1	1	1				C9, 10	Capacitor, 0.01 μF
				1			C13	Capacitor, 1 μF, electrolytic
3	1						D0–2, 6	Diodes, 1N4004
4	1				$-x$*		D3–5, 7, 8	LED, green, 3 mm
	2				$-x$*		D9, 11	LED, yellow, 3 mm
	1				$-x$*		D10	LED, red, 3 mm
3							F0–2	Fuse, 10 A, Littelfuse 0297010.WXNV or equiv.
		1	1				F3	Fuse, 800 mA, Cooper Bussmann SR-5F-800MA-AP or equiv.
2							HS0, 1	Heat sinks, aluminum (see text)
	1						HS2	Heat sink, TO-220, for U11
3							J0–2	Terminal block, 10-position, Altech MBE-1510
3	2				−1		J3–5, 9, 10	Terminal block, 2-position, Altech MBE-152
3	1						J6–8, 17	Jumper block header, 4-position
	1						J11	Jumper block header, 5-position
		2	2				J12, J13	Modular jack, 8p8c
1	−1						J14	Ribbon cable box header, 26-position
				1			J15	Connector, D-sub-miniature DE-9, female
					1	1	J16, 18	Terminal block, 5-position, Altech MBE-155
24							Q0–23	Transistor, MOSFET, FQPF13N06L
6							R0–5	Resistor network, 680 $\Omega\times$5
4	−1						R6–8	Resistor, 220 Ω, ¼ W
24							R9–32	Resistor, 470 Ω, ¼ W
24	1	1	1		−1		R33–56, 58, 62	Resistor, 10 K, ¼ W
		1	1				R63	Resistor, 100 Ω, ¼ W
	1						R57	Resistor, 33 K, ¼ W
					1		R59	Resistor network, 10 K$\times$5; *replaces R58*
	1						R60	Resistor network, 220 $\Omega\times$5, ¼ W
	1						R61	Resistor, 330 Ω, ¼ W
	1						S0	Push-button, red, "reset"
	1						S1	Push-button, green, "option"
6							U0–5	K847PH quad opto-isolator, NPN transistor output
3							U6–8	LM78L05 +5 V DC regulator, 100 mA
	1						U9	PIC18F4685 microcontroller, Lumos programmed
			1				U10	SN75176 half-duplex RS-485 driver/receiver
	1						U11	LM7805 +5 V DC regulator, 1.5 A
				1			U12	MAX233A RS-232 driver/receiver
		1					U13	MAX489 full-duplex RS-485 driver/receiver
	1						X0	Crystal, 10 MHz

*Some of these are not used to make room for sensor input lines.

Table 4.1: Lumos Bill of Materials (Components)

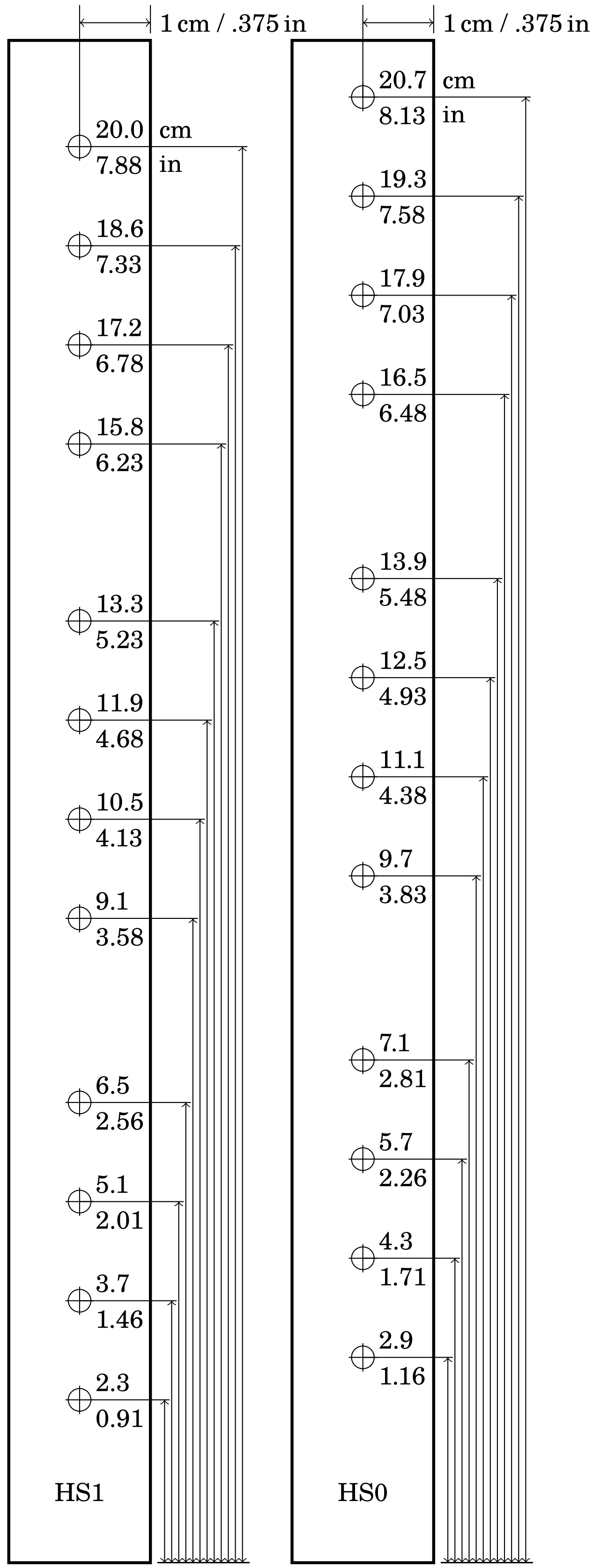


Figure 4.1: Drill Locations for Heat Sinks HS0–HS1

Base	CPU	FDX-485	HDX-485	RS-232	Sensor-In	Logic-Out	Number	Description
3							XF0–2	Fuse holders, Littelfuse 01530008Z, for F0–2
		1	1				XF3	Fuse holder, Cooper Bussmann 504-PCS, for F3
6	2						XJ0–7	Jumper, 2-pos, 0.1″ pitch
6							XU0–5	DIP socket, 16-pin, for U0–5
	1						XU9	DIP socket, 40-pin, for U9
			1				XU10	DIP socket, 8-pin, for U10
				1			XU12	DIP socket, 20-pin, for U12
		1					XU13	DIP socket, 14-pin, for U13
24							XX0–XX23	#4 bolts, ⅜″ long, with lock washers and nuts

Table 4.2: Lumos Bill of Materials (Sockets and Hardware)

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.).**

5.1 Building the Relay Section

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 (3) 220 Ω resistors in positions R6–R8 as marked on the PCB and Figure 5.1. These have the color bands "red-red-brown" marking them. Push them all the way until flush with the PCB.

2. solder their leads on the bottom side of the board.

3. Trim the excess leads with diagonal cutters.

4. Repeat steps 1–3 to install (24) 470 Ω resistors ("yellow-violet-brown") at R9–R32.

5. Repeat steps 1–3 to install (24) 10 K resistors ("brown-black-orange") at R33–R56.

6. In the same fashion, install and solder (3) 0.33 μF capacitors into positions marked C0–C2.

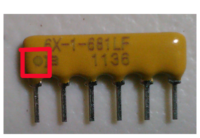
7. Install and solder (3) 0.1 μF capacitors into positions C3–C5. **NOTE: Capacitor C3 is located nearest to C0 on the PCB. On board versions through 1.0.8, this is mis-labeled as "C1."**

8. Install (3) 1N4004 diodes at D0–D2. **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.

9. Install (3) green LEDs at D3–D5. **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.

10. Note the location of U0–U5 and R0–R5 (located *inside* the borders of chips U0–U5).

11. Flip the board over to the bottom (solder) side. Be sure you still see where R0–R5 are located.



12. Install (1) 680 Ω resistor network *on the bottom (solder) side* of the board at R0 (the row of six holes *inside* U0). **Note the correct position of R0.** The square hole on the PCB marks where pin 1 of R0 should be inserted. Pin 1 is marked with a dot on R0 itself. See Figure 5.2.

13. Holding R0 in place, carefully flip the board over.

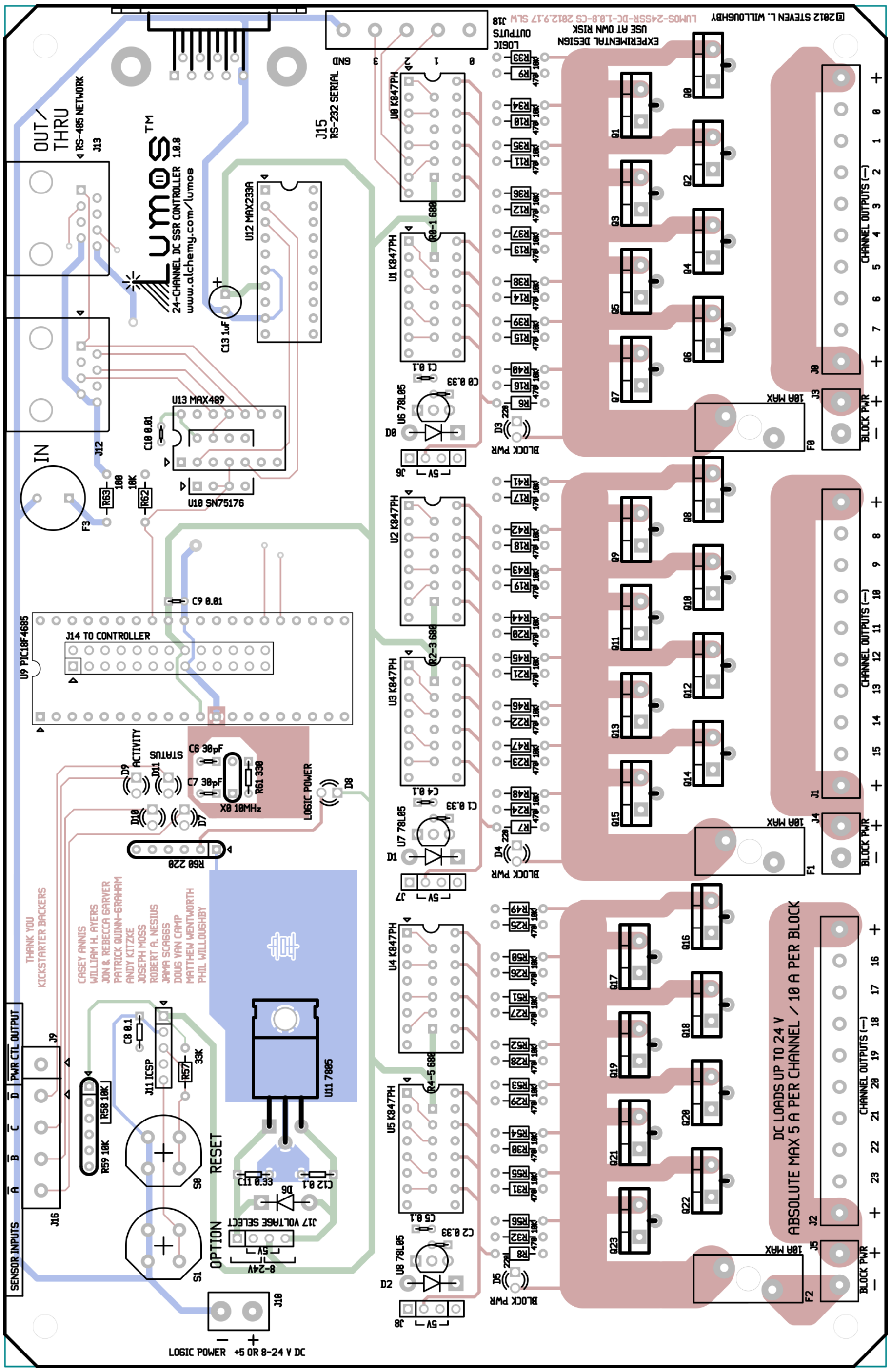


Figure 5.1: Lumos Board Parts Placement Diagram

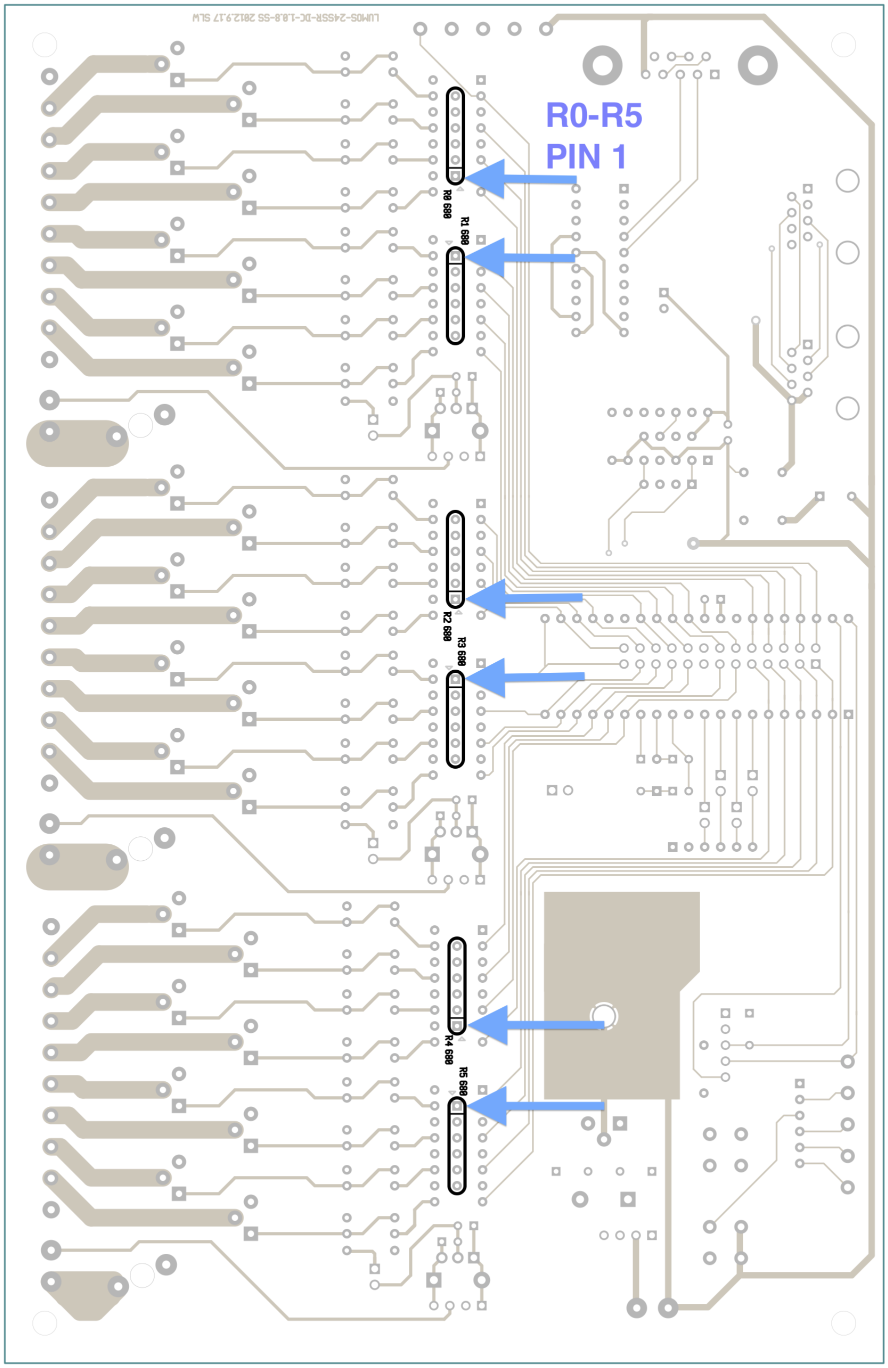


Figure 5.2: Lumos Board Parts Placement (Reverse Side)

14. Keeping R0 straight, solder into place (soldering on the component side of the PCB).

15. Repeat steps 12–14 to install R1 on the bottom side of the PCB, inside U1's space. **Caution:** Pin 1 of R1 still goes in the square hole, but beware—this location is the mirror image of where it was for R0. In other words, pin 1 of R0 and R1 are next to one another.

16. Repeat steps 12–15 to install (4) more resistor networks at R2–R5.

17. Flip the board back over to the component side. **Caution:** From this point forward, don't forget those resistors are on the other side of the board. If you press down on the board (e.g., when installing chips into sockets), you will bend the resistors and may break them.

18. Install (6) 16-pin DIP sockets XU0–XU5 in positions marked U0–U5. Note that they need to fit easily over the soldered leads from R0–R5. If they don't, select a different style of socket or carefully trim down the resistor leads.

19. Solder sockets XU0–XU5.

20. Install (3) 4-position jumper block headers at J6–J8. Solder.

21. Install (3) LM78L05 voltage regulators at U6–U8. **These parts 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.

22. Install (3) fuse holders at F0–F2. Due to the wide PCB traces here, this may require extra soldering time, but be careful not to overheat the parts. The same will be true for steps 23–24.

23. Install (3) 10-position terminal blocks at J0–J2.

24. Install (3) 2-position terminal blocks at J3–J5.

25. Using ESD protection, lay out (12) MOSFETs on your workbench.

26. 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 5.3 and should fit easily into the holes at Q0 on the PCB.

27. Apply a *small* dab of heat sink grease on the back side of the transistor.

28. Bolt the transistor onto heat sink HS0, with the washer and nut on

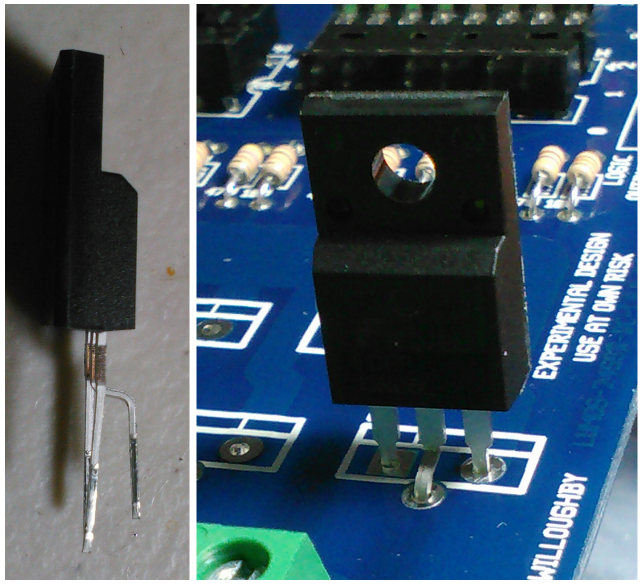


Figure 5.3: Bending the Pins of the MOSFETs

the transistor side, making sure to smear the heat sink grease in a thin layer between the heat sink and the transistor. Make the part snug but not over-tight, and approximately 90° perpendicular to the heat sink bar.

29. Repeat steps 25–28 for the remaining transistors until you have a row of 12 bolted to the heat sink.

30. Position the heat sink over all the even-numbered positions Q0–Q22 on the PCB, carefully adjusting the position of each part until all 36 pins slide into their holes. Push the entire set very carefully into place until all transistors are seated as far as they will go. **Note:** Due to irregularities in hole placement on the heat sink, it's possible the transistors won't all be *perfectly* straight, but they should be as close as possible. You may need to loosen the bolts slightly to position the transistors, then tighten again when they are in place.

31. Using appropriate heat protection and/or limiting soldering time to 4 seconds or less per pin, solder the leads of the 12 transistors into place.

32. Trim the excess leads.

33. Repeat steps 25–32 for another 12 transistors, except:

    - Bolt them to the heat sink HS1 with the nut and washer on the side opposite the transistor.

- Insert them into the odd-numbered locations Q1–Q23.
- When finished, there should be a slight air gap between the two rows of transistors.

34. Insert (6) K847PH opto-isolator chips into their sockets at U0–U5. **Note:** pin 1 of each chip is marked with a small triangle on the PCB and a square hole.

35. Insert (3) 10 A fuses into the fuse holders.

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

Skip ahead to Chapter 6 if you are making a normal ("intelligent") Lumos controller.

Continue to the rest of this chapter if you are making a "dumb" relay-only board instead.

5.2 Making a Relay-Only Lumos Board

If you only want relays with no intelligent logic on-board, perform the following additional steps to allow the board to accept external control signals from another circuit. **Do not do the following if you will be adding the intelligent on-board controller ("CPU" option)!**

1. Install a 26-pin male header at J14 (inside the boundaries of the 40-pin chip U9, which will not be installed on this board). Note the location of pin 1, as marked by a triangle on the PCB. Align this with pin 1 on the header part, usually marked by a triangle or arrow engraved on the plastic. There is also usually a key in the center of the side where pin 1 is located. Solder into place.

2. Install a 220 Ω resistor ("red-red-brown") into the bottom two holes (this is the square hole and the immediately adjacent round hole) of R60 (see Figure **??**). Solder into place.

3. Install a green LED at D8. As before, note that **this 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.

Your relay-only board is now complete and ready to plug into the controlling circuit which will be driving it. For details on how to plug it in, see the connector pinout diagrams in the appendices, and the theory of operation section of *Using the Lumos SSR Controllers* as it applies to the way signals are sent to the relays, since your controlling circuit will need to do this directly via its connection at J14.

If you also want to install the logic output option, skip to Chapter 9 now. Otherwise, you are finished. **No other options may be installed on this board.** They all require an intelligent controller on-board.

Stop.

CHAPTER 6

ASSEMBLING THE CPU OPTION

WITH THE BASIC RELAY CIRCUITS in place, the next step in Lumos controller construction is to add the control logic. You will be adding the microcontroller "brain" of the Lumos board which turns the relays on and off according to the commands and programs it receives.

Follow these steps to add the CPU to your Lumos board:

1. Install a 33 K resistor ("orange-orange-orange") at position R57. Solder into place.
2. Install a 330 Ω resistor ("orange-orange-brown") at position R61. Solder into place.
3. Install a 40-pin DIP socket at U9. Solder into place.
4. Install (2) 33 pF capacitors at positions C6 and C7. Solder into place.
5. Install a 0.1 μF (100 nF) capacitor at C8 and C12. Solder into place.
6. Install a 0.01 μF (10 nF) capacitor at C9. Solder into place.
7. Install a 0.33 μF (330 nF) capacitor at C11. Solder into place.
8. Install a 220 Ω×5 resistor network at R60. Ensure the dot on the resistor package (pin 1) goes into the square hole (marked by a triangle). Solder into place.
9. Install a 1N4004 diode at D6. **This part will not function if not oriented correctly.** Be sure the stripe printed on the diode is on the side inserted into the square hole, and marked with a straignt line,

while the other, unmarked lead goes in the round hole marked with a large triangle. Solder into place.

10. Install a five-pin header at J11. Keep the pins straight and perpendicular to the board while soldering into place.
11. Repeat Step 10 for the four-pin header at J17.
12. Install a two-position terminal block at J10. Solder into place.
13. **Using proper static protection,** prepare U11 for insertion by bending its leads 90° back toward the back of the part, with the center pin about 0.1″ longer before the bend. Bend the pins to the right locations so that the pins easily slip into the holes at U11 with the large tab mounting hole aligned with the corresponding hole in the PCB.
14. Place a TO-220 heat sink on the board at U11, with its hole aligned with the hole in the PCB at U11.
15. Place a small dab of thermal grease on the back of U11, then slip its pins through the holes at U11 on the board, laying it down on the heat sink. Secure U11 by installing a #6 bolt through U11, through the heat sink, all the way through the PCB, terminated by a nut on the opposite side. Tighten but don't over-tighten. Solder the three leads into place.
16. Install a 10 MHz crystal at X0. Solder into place.
17. Install a red push-button at S0 ("reset"). **This part will not function if not oriented correctly.** Be sure to line up the indentations on one side of the button with the silk screened image. The button should be oriented so that the top two pins short to the bottom to pins when the button is pressed. Ensure the button is straight and solder into place.
18. Repeat step 17 to install a green push-button at S1.
19. Install the pre-programmed PIC18F4685 microcontroller chip into its socket at U9. **This part will not function if not oriented correctly.** Pin 1 is marked by the indentation on the chip body outline on the board. Pin 1 is also marked by a triangle.

The following instructions depend on which other options you selected for your board. Perform each in the order shown here.

IF you will be installing any sensor inputs **OR** you wish to attach front-panel LEDs for diagnostic output rather than the on-board LEDs,

THEN do the following:

1. Review all of Chapter 8 to determine which, if any, LEDs you will install on the board, and which will be omitted.

2. Install a 10 K$\times$5 resistor network at R59. Ensure the dot on the resistor package (pin 1) goes into the square hole (marked by a triangle). Solder into place.
3. Install a 5-position terminal block at J16 (this will also occupy J9). Solder into place.
4. Install a green LED at D8. **This part will not function if not correctly oriented.** Insert the longer lead (anode) into the square hole on the board. The shorter lead (cathode) goes into the round hole. Solder into place.
5. Repeat Step 4 to install the LEDs you didn't decide to exchange for sensor inputs (if any) into positions D7 (red), D9 (yellow), D10 (green), and D11 (yellow). Solder into place. **Omit this step** if you are moving the LEDs to the front panel.

OTHERWISE do the following:

1. Install a 10 K resistor at R58. Note that it goes into the square hole (marked with a triangle on the board) and the second hole to the left of it (there will be one empty hole under the resistor, between the leads). See Figure **??** for details. Solder into place.
2. Install a 2-position terminal block at J9. This will go into the two right-most holes (the ones marked with triangles). Solder into place.
3. Install a red LED at D7. **This part will not function if not correctly oriented.** Insert the longer lead (anode) into the square hole on the board. The shorter lead (cathode) goes into the round hole. Solder into place.
4. Repeat Step 3 to install (2) green LEDs at D8 and D10.
5. Repeat Step 3 to install (2) yellow LEDs at D9 and D11.

This completes the installation of the CPU option.

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

Chapter 7

Assembling the Communications Options

An intelligent controller board needs some way to receive commands from the outside world. Three different options are available: RS-485 full duplex, RS-485 half duplex, and RS-232 (standard serial). (If you will be using the Lumos controller with DMX512, build the board with one of the RS-485 options. The DMX512 mode of operations will only accept commands and never transmit data back, so it will not take advantage of the full duplex capability, but you may wish to have full duplex for Lumos mode operations or for programming and configuring the board.

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

7.1 RS-485 Full Duplex / DMX512

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

1. Install a 10 K resistor ("brown-black-orange") at R62. Solder into place.
2. Install a 14-pin DIP socket at U13. 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.
3. Install a 0.01 μF (10 nF) capacitor at C10. Solder into place.
4. Install a fuse holder at F3. Solder into place. This is optional (you could solder a fuse directly onto the board, but the holder is recom-

mended. It makes it far easier to replace the fuse if it should ever blow.

5. Install an 800 mA fuse at F3. Clip the leads to the appropriate length so it will rest all the way down into the socket.

6. Install (2) 8p8c modular jacks at J12 and J13, noting the position of pin 1 as indicated by square pads and silk-screened triangles. Solder into place.

7. If the other devices you will plug together share a common notion of "ground" a wire jumper may be installed in place of R63. Otherwise, if you need to protect against ground loops, install a 100 Ω resistor ("brown-black-brown") at R63. Solder into place.

8. Install a MAX489 driver/receiver chip into its socket at U13, noting the marked location of pin 1 (see Step 2). Press carefully down into place.

Skip to the section on RS-485 terminators below.

7.2 RS-485 Half Duplex

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

1. Install a 10 K resistor ("brown-black-orange") at R62. Solder into place.

2. Install an 8-pin DIP socket at U10. 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.

3. Install a 0.01 μF (10 nF) capacitor at C10. Solder into place.

4. Install a fuse holder at F3. Solder into place. This is optional (you could solder a fuse directly onto the board), but the holder is recommended. It makes it far easier to replace the fuse if it should ever blow.

5. Install an 800 mA fuse at F3. Clip the leads to the appropriate length so it will rest all the way down into the socket.

6. Install (2) 8p8c modular jacks at J12 and J13, noting the position of pin 1 as indicated by square pads and silk-screened triangles. Solder into place.

7. If the other devices you will plug together share a common notion of "ground" a wire jumper may be installed in place of R63. Otherwise, if you need to protect against ground loops, install a 100 Ω resistor ("brown-black-brown") at R63. Solder into place.

8. Install an SN75176 driver/receiver chip into its socket at U10, noting the marked location of pin 1 (see Step 2). Press carefully down into place.

Continue to the section on RS-485 terminators below.

7.3 RS-485 Terminator Construction

Each end of an RS-485 communications line must be terminated, or it won't work. The schematic for this is on page 48 in the appendices. To build one yourself, you'll need:

- (2) 120 Ω resistors.
- Lumos RS-485 terminator PCB.
- A short length of CAT5 cable.
- An 8p8c male modular plug with detachable boot.
- A modular plug crimping tool.

Perform the following steps:

1. Cut the following lengths of CAT5 cable:
   a) (2) 2″ (5 cm) lengths of orange wire.
   b) (2) 2″ (5 cm) lengths of blue wire.
   c) (1) 2″ (5 cm) length of green wire.
2. Strip ¼″ (4 mm) of insulation from *one* end of the orange and blue wires.
3. Refer to the diagram in Figure 7.1. Solder an orange wire to hole #2.
4. Solder another orange wire to hole #4.
5. Solder a blue wire to hole #6.
6. Solder another blue wire to hole #8.
7. Install a 120 Ω resistor ("brown-red-brown") between holes #1 and #3. Solder into place.
8. Install a 120 Ω resistor ("brown-red-brown") between holes #5 and #7. Solder into place.
9. The board should now look like Figure 7.2.
10. Arrange all the wires in a row so they are straight and parallel, with the colors in the following order:

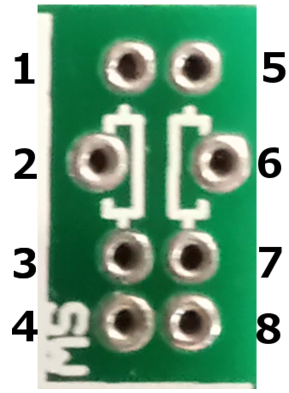


Figure 7.1: Terminator PCB

- orange
- orange
- green
- blue
- blue
- green

Note that there is only one green wire. One end will be at position 3 in the set of wires, the wire will loop around and the other end appears at position 6. Allow enough of the green wire to loop around the board without interfering with it, leaving the excess wire with the bundle of other wires you're arranging.

11. Carefully, so as not to disturb the order of the wires, trim the excess wire so the wires extend about 1″ (25 mm) from the end of the PCB. Be sure to make the cut so you leave a clean, straight edge to the flat bundle of wires.

12. Carefully, so as not to disturb the order of the wires, insert them into an 8p8c male plug shell, with the first orange wire at pin 1 of the plug and the last green wire at pin 6. Note that pins 7 and 8 will have no connection. Push the wires all the way to the end so they are snug against the end of the plug.

13. While applying gentle but firm pressure to hold the wires all the way in position, insert the plug into a modular jack crimping tool. Crimp the plug onto the wires.

14. Cover the end with a plastic boot or other suitable protection.

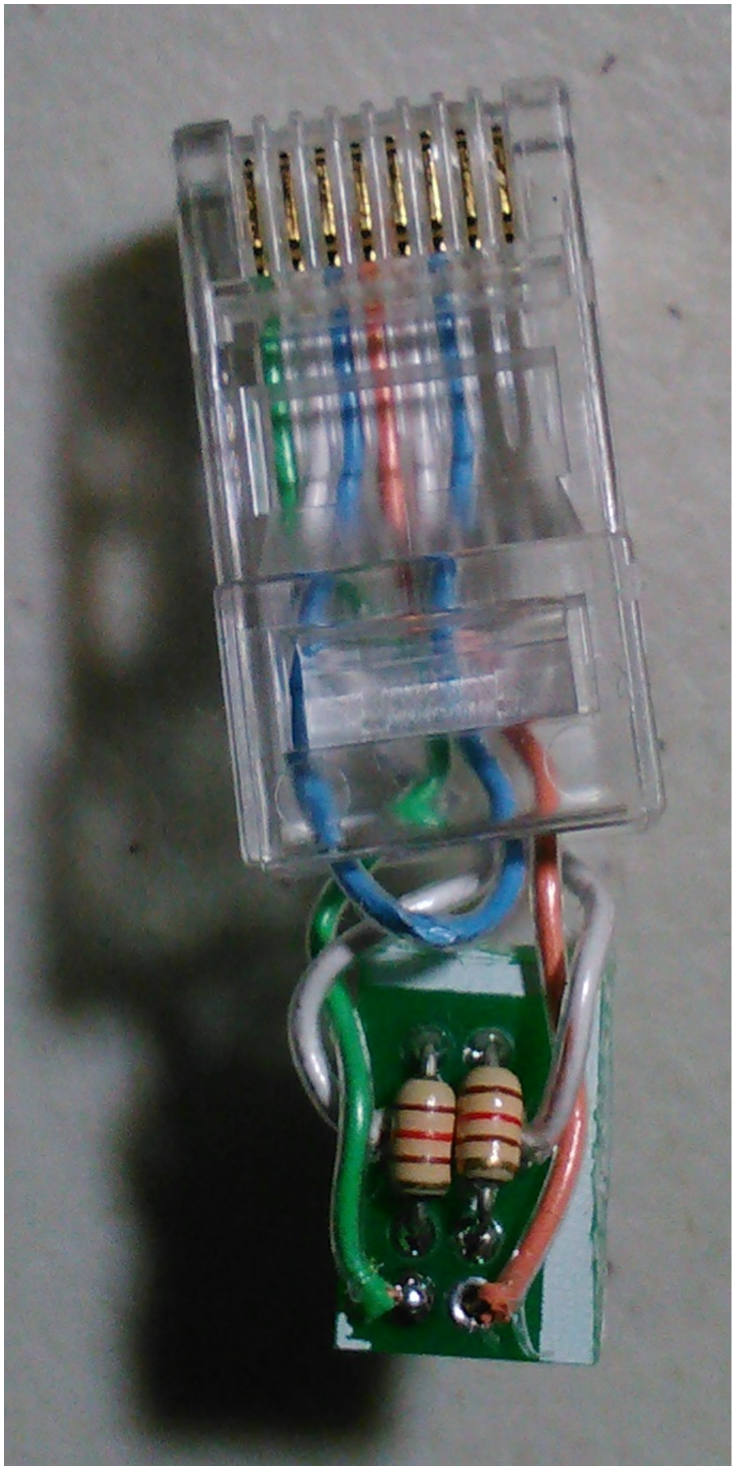


Figure 7.2: Fully Wired Terminator (Colors Vary from Text)

This completes the assembly of an RS-485 full-duplex terminator with cable-check pins, suitable for use with full-duplex or half-duplex Lumos boards. It may nor may not be compatible with other RS-485 gear.

Skip to the next chapter to install more options, if desired.

7.4 RS-232

If you will be using a standard RS-232 serial port to communicate with your Lumos board, perform the following steps to add this capability to the basic CPU circuit:

1. Install a 20-pin DIP socket at U12. 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 a 1 μF electrolytic capacitor at C13. **This component will not function unless installed in the correct orientation.** Note the positive lead is indicated on the PCB with a square hole and a silk-screened "+" mark; however, it is typical for electrolytic capacitors to mark the *negative* lead in some way (usually with an arrow and "$-$" sign printed on the package). Solder into place.
3. Install a female DE-9 (9-pin D-subminiature serial) jack at J15, noting the position of pin 1 as indicated by a square pad. Solder into place.
4. Install a MAX232A driver/receiver chip into its socket at U12, noting the marked location of pin 1 (see Step 1). Press carefully down into place.

This completes the installation of the RS-232 serial option.

Continue to the next chapter to install more options, if desired.

CHAPTER 8

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 8.1.

These are named as active-low inputs (i.e., "$\overline{\text{A}}$" 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 Lumos board.

Sensor	Diagnostic LED	
$\overline{A}$	D7	“Status” (red)
$\overline{B}$	D10	“Status” (green)
$\overline{C}$	D9	“Activity” (yellow)
$\overline{D}$	D11	“Status” (yellow)

Table 8.1: Mapping of Diagnostic LEDs to Input Sensors

8.1 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 8.1. However, if the LED is physically present on the board at the same time, the effective circuit becomes the one shown in Figure 8.2. 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.

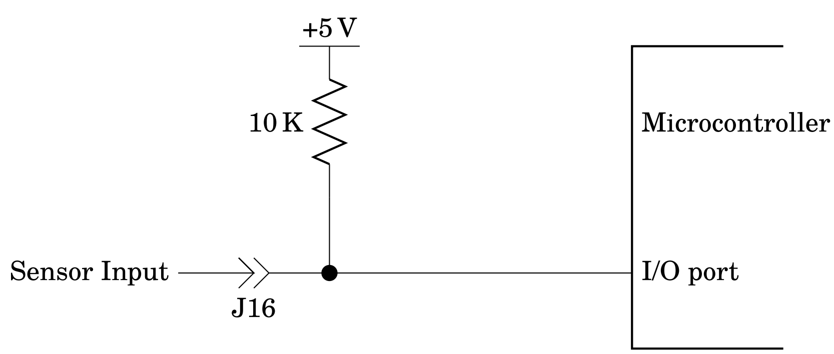


Figure 8.1: Sensor Input Circuit

8.2 Installing the Option Hardware

To install this option, do the following:

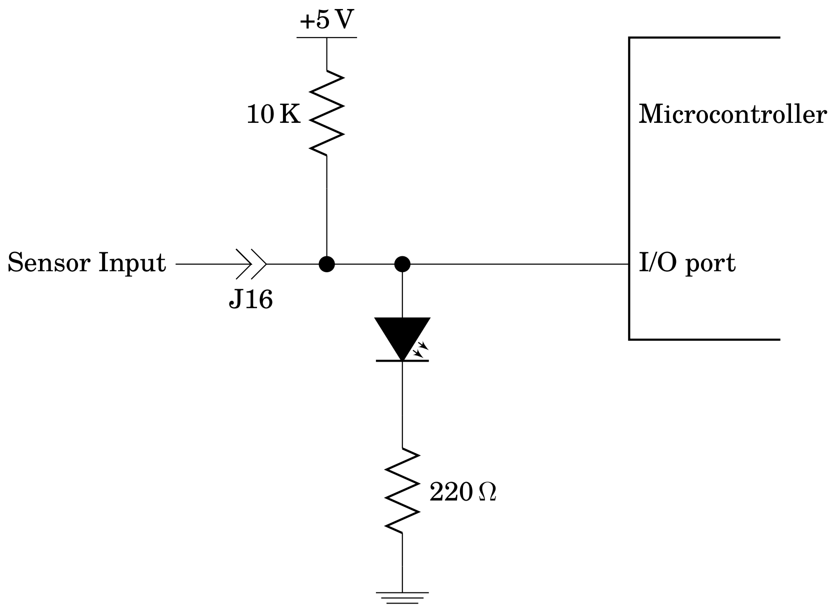


Figure 8.2: Sensor Input Circuit with LED Present

1. Install a 10 K×5 resistor network at R59. **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. Note that R59 takes the place of R58 on the Lumos board. If you're adding this option to an existing Lumos board which was built without this option originally, you will need to remove R58 first. Keeping the pins straight, solder R59 into place.

2. Install a five-position terminal strip at J16. Note that this takes the place of J9. If you're adding this option to an existing Lumos board which was originally completed without inputs, you will need to remove J9 first. Solder J16 into place.

☞ **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.

Continue to the next chapter to add more options if desired.

Chapter 9

Assembling the Logic Output Option

If you need to control 1–4 TTL-level outputs from the Lumos board, this can be accomplished by adding the Logic Output Option to the basic unit. This can be added to any Lumos board, even “dumb” relay-only boards.

To provide this option, simply install a five-position terminal strip at J18 and solder it into place.

Having done that, the raw logic-level outputs for channels 0–3 from the controlling circuit (either external or the on-board microcontroller) are present on J18, along with a ground reference.

☞ **N.B.:** These outputs are straight from the logic circuitry which drives the Lumos relays. They are *not* isolated like all the other power outputs are. Care should be exercised when attaching these outputs to other devices.

Continue to the next chapter to install more options, if desired.

CHAPTER 10

USING A FRONT PANEL

MANY CONTROLLERS ARE INSTALLED into a weather-resistant enclosure which allows access to the circuit board to make connections and to access the buttons and LEDs. If the Lumos board will be installed in a closed box 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 50 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 J12 and J13 or J15.

If external LEDs are needed, the easiest approach is to install a terminal strip at J16. The terminals A–D on that terminal carry the same signals that run the on-board LEDs. See the schematic in Figure 10.1 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 D7, D9, D10, and D11 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 J16.

The Option and Reset buttons can be external buttons which are wired to a 5-pin connector plugged in to J11. An example front panel circuit is shown in Figure 10.1.

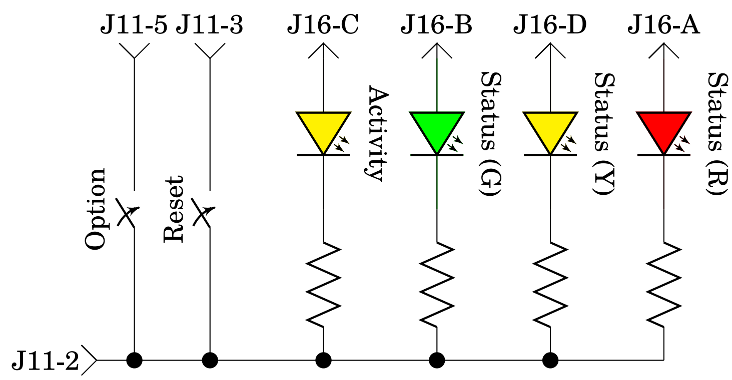


Figure 10.1: Example of a Front Panel Circuit for a Lumos Board

Chapter 11

Going On From Here

Now that your lumos controller board is assembled, go on to read the manual *Installing the Lumos 24-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)**
HS2	532-507302B00	Heat sink, TO-220, horizontal	$0.25
XF0–2	576-01530008Z	Fuse holder, Littelfuse 01530008Z or equiv.	2.45
XF3	504-PCS	Fuse holder, Cooper Bussman 504-PCS or equiv.	.89
XJ0–7	571-8815452	Jumper, 2-pos., 0.1 in pitch	.12
XU0–5	517-4816-3004-CP	IC socket, DIP, 16-pin	.29
XU9	517-4840-6000-CP	IC socket, DIP, 40-pin	.54
XU10	517-4808-3000-CP	IC socket, DIP, 8-pin	.28
XU12	517-4820-3004-CP	IC socket, DIP, 20-pin	.42
XU13	517-4814-3004-CP	IC socket, DIP, 14-pin	.36

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

Table A.1: Component Ordering Information (accessories)

Lumos Part #	Mouser Part #	Description	Price* (2012)
C0–2, 11	810-FK14X7R1H334K	Capacitor, ceramic, 0.33 μF, 50 V, $\pm$10%	$0.186
C3–5, 8, 12	810-FK18X7R1H104K	Capacitor, ceramic, 0.1 μF, 50 V, $\pm$10%	.10
C6–7	80-C315C300J1G	Capacitor, ceramic, 30 pF, $\pm$5%	.70
C9–10	810-FK18C0G1H103J	Capacitor, ceramic, 0.01 μF, 50 V, $\pm$5%	.21
C13	667-EEA-GA1H1R0H	Capacitor, electrolytic, aluminum, 1 μF, 50 V	.32
D0–2, 6	512-1N4004	Diode, 1N4004	.079
D3–5, 7, 8	604-WP132XGD	LED, green	.07
D9, 11	604-WP132XYD	LED, yellow	.06
D10	604-WP132XID	LED, red	.07
F0–2	576-0297010.WXNV	Fuse, 32 V, 10 A, fast-acting	.526
F3	504-SR-5F-800MA-AP	Fuse, 250 V, 800 mA, SR-5F	1.17
J0–2	845-MBE-1510	Terminal block, 10-pos., 5 mm pitch	1.47
J3–5,9,10	845-MBE-152	Terminal block, 2-pos., 5 mm pitch	.35
J6–8,17	649-68001-104HLF	Header, 4-pos., 0.1 in pitch	.202
J11	649-68001-105HLF	Header, 5-pos., 0.1 in pitch	.39
J12–13	649-69255-001LF	Modular jack, 8p8c, vertical PCB mount	1.25
J14	571-5103309-6	Header, IDC-type, 26-pos.	1.47
J15	617-09-66-152-6612	Socket, D-subminiature, 9-pin, female, PCB	4.44
J16, 18	845-MBE-155	Terminal block, 5-pos., 5 mm pitch	.80
Q0–23	512-FQPF13N06L	Transistor, MOSFET, N-Channel, 60 V	.524
R0–5	652-6406X-1LF-680	Resistor network, 6-pin, 680 Ω, bussed	.16
R6–8	660-CFS1/4CVTR221J	Resistor, 220 Ω, ¼ W, mini, $\pm$5%	.34
R9–32	660-CFS1/4C471J	Resistor, 470 Ω, ¼ W, mini, $\pm$5%	.05
R33–56, 58, 62	660-CFS1/4C103J	Resistor, 10K, ¼ W, mini, $\pm$5%	.05
R57	660-CFS1/4C333J	Resistor, 33K, ¼ W, mini, $\pm$5%	.15
R59	652-4606X-1LF-10K	Resistor network, 6-pin, 10K, bussed	.13
R60	652-4606X-1LF-220	Resistor network, 6-pin, 220 Ω, bussed	.25
R61	660-CFS1/4C331J	Resistor, 330 Ω, ¼ W, mini, $\pm$5%	.15
R63	660-CFS1/4C101J	Resistor, 100 Ω, ¼ W, mini, $\pm$5%	.15
Terminators	660-CFS1/4CT52R121J	Resistor, 120 Ω, ¼ W, mini, $\pm$5%	.15
S0	611-D6R40F1LFS	Switch, tactile key, N.O., SPDT, 0.01 A, red	1.00
S1	611-D6R50F1LFS	Switch, tactile key, N.O., SPDT, 0.01 A, green	.90
U0–5	782-K847PH	K847PH quad optocoupler, phototransistor output	.827
U6–8	512-LM78L05ACZXA	LM78L05 linear +5 V regulator, 0.1 A	.216
U9	579-PIC18F4685-I/P	PIC18F4685 microcontroller	10.15
U10	595-SN75176BP	SN75176 RS-485 transceiver, half-duplex	.88
U11	511-L7805ABV	L7805 linear +5 V regulator, 1.0 A	.46
U12	700-MAX233ACPPG36	MAX233ACPP RS-232 driver/receiver	12.46
U13	700-MAX489EPD	MAX489 RS-485 transceiver, full-duplex	4.11
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* paid in 2012, offered for general budgetary reference. The prices shown were for each unit, but may reflect quantity discounts we were given.

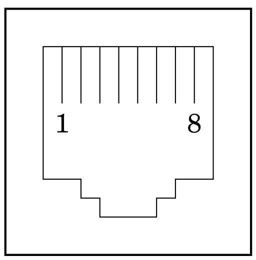
Table A.2: Component Ordering Information (electronics)

Errata

On PCB version 1.0.8, one of the parts is mis-labeled on the white silk-screened legend. There are two capacitors labeled “C1.” The true C1 is a 0.33 μF capacitor next to C4 near the center of the PCB. The 0.1 μF capacitor next to C0 should have been marked “C3.”

Connector Pinouts

RS-485 Connection (8p8c Female Modular Jacks)



1 Return Data (+); *[Full-duplex models only]*
2 Return Data (−); *[Full-duplex models only]*
3 Cable Check
4 Data (−)
5 Data (+)
6 Cable Check
7 Data Ground
8 Return Data Ground

Note that the jacks are labeled "IN" and "OUT/THRU" on the board. This is intended to remind the user that these are daisy-chained connections with a signal coming "in" to the board on one wire, and on "through" to the next board in the circuit.These names also mirror the naming conventions used with DMX equipment.

Electrically, however, the RS-485 serial "network" is a single bus running from the host PC to the last Lumos controller. Each controller "taps" into the line as it goes by. This means that, labeling notwithstanding, the "IN" and "OUT/THRU" jacks are in fact completely identical and interchangeable.

The "cable check" lines are simply passed through the Lumos board from input to output, with the expectation that the terminator will connect them together. These lines are not used by Lumos boards at all. They are provided as a convenient way for the host PC interface to verify cable continuity by sending a voltage down one pin all the way to the terminator and back on the other pin. This helps warn the user if a cable becomes disconnected. The Lumos front panel circuit board is one example of a circuit which makes use of this feature.

The two grounds on pins 7 and 8 are actually shorted together and connected to the common signal ground on the Lumos board.

If connecting a Lumos board to a DMX controller, an adapter cable is needed to connect the DMX DIN plug to the 8-pin modular plug used on the Lumos board. A typical adapter is wired as shown in Table A.3, but check your equipment in case it is different.

Signal	DMX DIN Connector	Lumos Modular Connector
Ground	1	7, 8
Data (−)	2	4
Data (+)	3	5

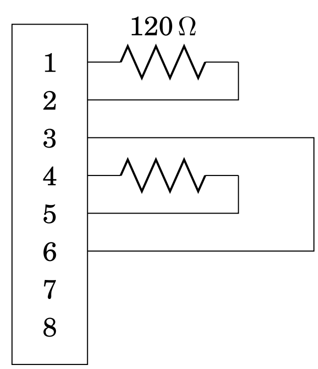
Table A.3: Typical Wiring Arrangement to Adapt DMX to Lumos

RS-485 Terminator (8p8c Male Plug)

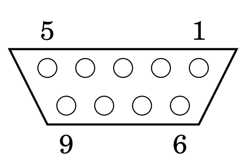
The terminator plug consists of a pair of 120 Ω resistors. One is connected across pins 1–2, and the other across pins 4–5. This provides the proper line termination at the end of the RS-485 chain. A terminator must be plugged in to each end of the chain (but note that often the PC's RS-485 adaptor contains a built-in terminator).

To enable the cable check feature to work, pins 3 and 6 must also be shorted together.

The schematic diagram for the terminator is included below. Often, the resistors are mounted to a small circuit board which fits inside the modular plug, making a self-contained terminator plug.



RS-232 Serial Connection (9-pin Female DE-9 Jack)



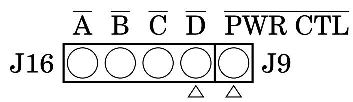
2 Receive Data
3 Transmit Data
4 Data Terminal Ready
5 Signal Ground
6 Data Set Ready
7 Request to Send
8 Clear to Send

For Lumos boards configured to use RS-232 serial connections to a host PC, a standard 9-pin connector is used, with the Lumos board wired as a DCE device.

On the Lumos board, Data Terminal Ready (DTR) and Data Set Ready (DSR) on pins 4 and 6 are shorted together, as are Request to Send (RTS) and Clear to Send (CTS) on pins 7 and 8. This should satisfy most communications software which expects to see these signals present, although the Lumos board itself does not perform any hardware or software handshaking.

Receive Data (RxD) and Transmit Data (TxD) are named from the point of view of the DTE (host PC), so TxD is the wire which carries data from the host PC to the Lumos board.

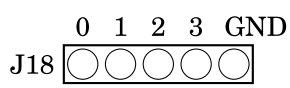
Sensor Input Terminals (J16)



If the Lumos controller is built to accommodate one or more sensor inputs, a set of terminals will be installed at J16, next to the $\overline{\text{PWR CTL}}$ output at J9. These are labeled from left to right (as the board is viewed right-side-up from the front) as $\overline{A}$, $\overline{B}$, $\overline{C}$, and $\overline{D}$. 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.

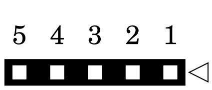
Each input accepts a TTL-level signal. The lines are pulled up to +5 V internally. The board can be configured in software to react to the inputs as active-high or active-low.

Logic Output Terminals (J18)



For experimental use, TTL-level outputs for the first four channels are available on J18. These are active-low outputs, where a "low" (0) state indicates that the output should be on, and a "high" (1) state means that the output should be off. Note that if an output is at a dimmer level other than fully on or fully off, the signal will pulse with a duty cycle corresponding to the dimmer level as illustrated in Figure A.1.

ICSP Header (J11)



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/$\overline{\text{OPTION}}$

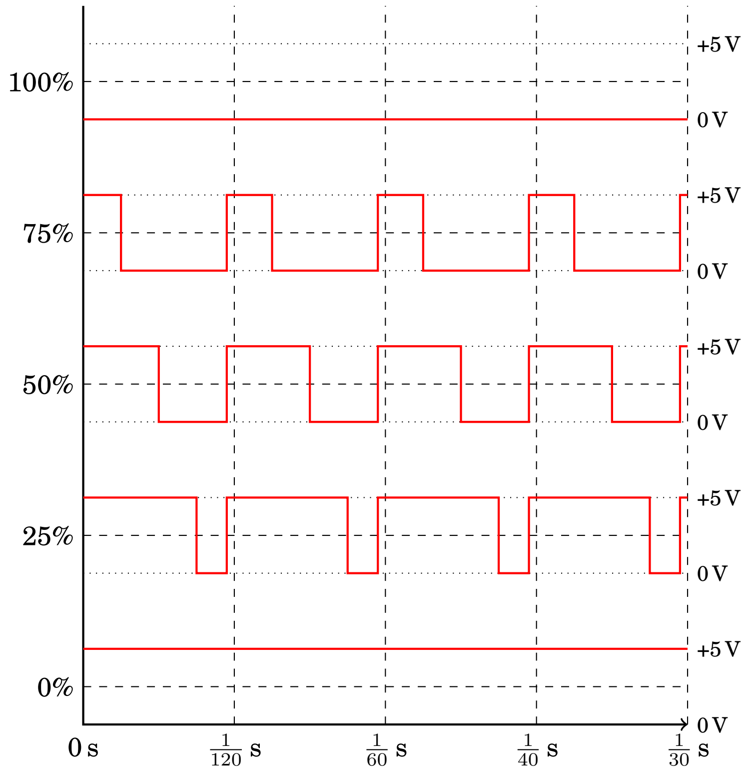
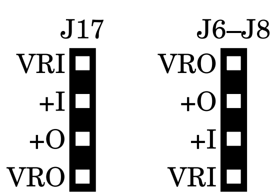


Figure A.1: Duty Cycles of Channel Logic Drive Outputs

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 also present on pin 4 of J11 in addition to its normal terminal at J9.

Voltage Select Headers (J6–J8, J17)

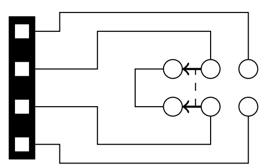


+I: Positive voltage in from power supply
+O: Positive voltage out to circuit
VRI: Input to voltage regulator
VRO: Output from voltage regulator

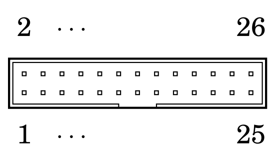
J6–J8 are used to select the input voltage supplied to the power control blocks for channels 0–7, 8–15, and 16–23 respectively. Likewise, J17 selects the input voltage supplied to the logic portion of the board. Although the pinouts are mirrored between J17 and the others, their operation is the same. 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.

If it is necessary to move this selection to a front panel switch, this can be accomplished simply by attaching a DPDT switch to each jumper block header like this:



Relay Control Connection (26-pin Male IDC Header)

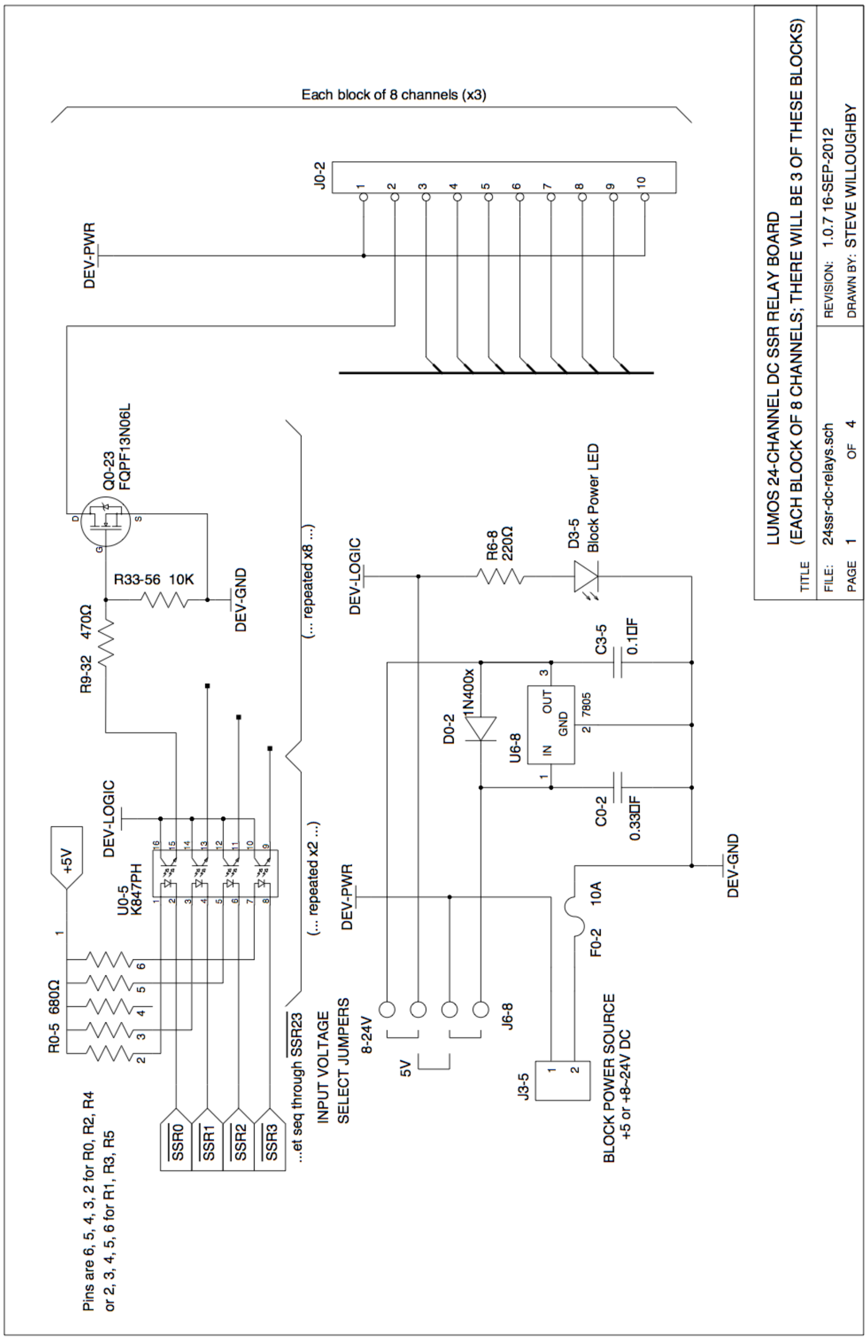


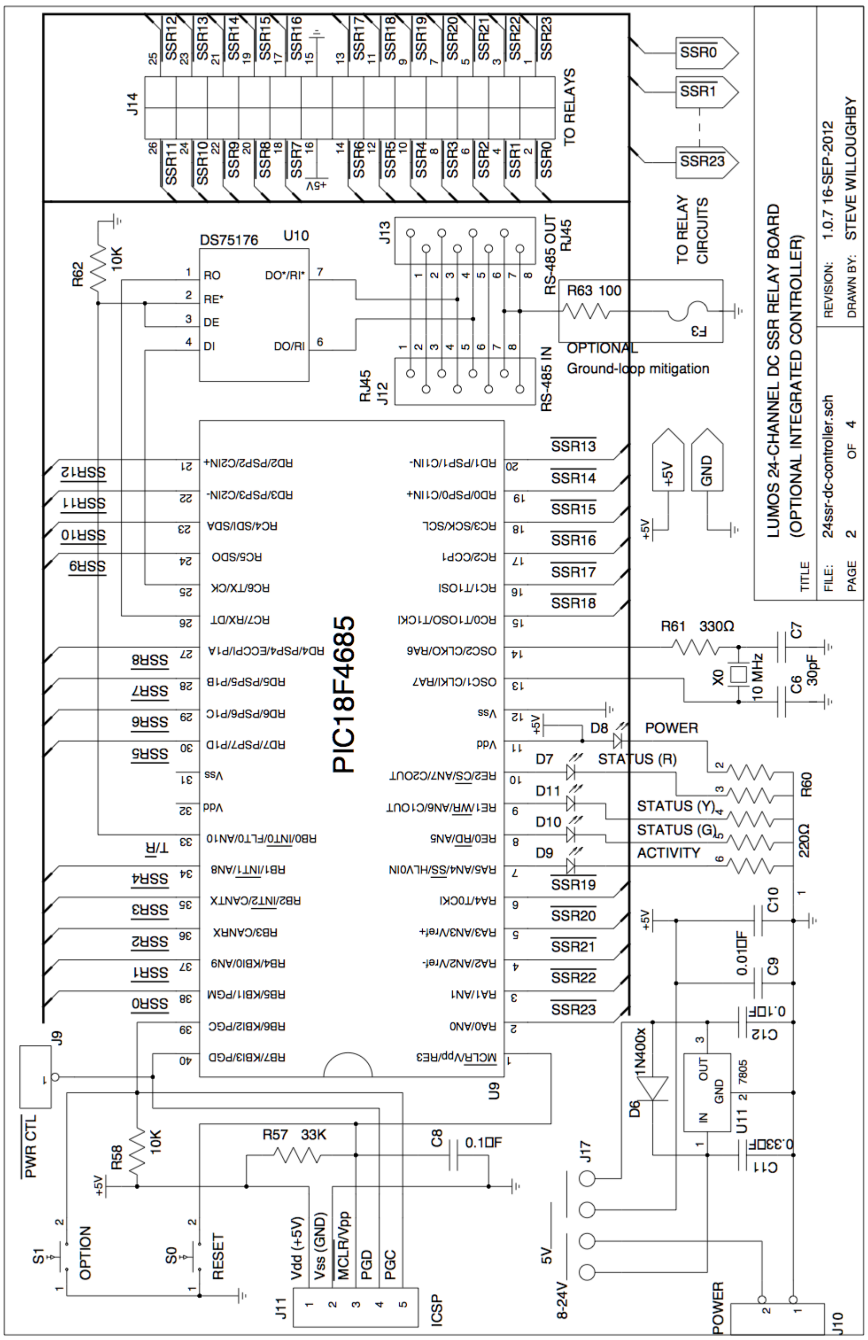
For Lumos controllers built as "dumb" relay boards with no built-in logic control of their own, a 26-pin IDC ribbon cable header is installed at J14. This is used to connect the relays to the controlling circuit (e.g., a Lumos 48-channel controller). The pinout of this header is:

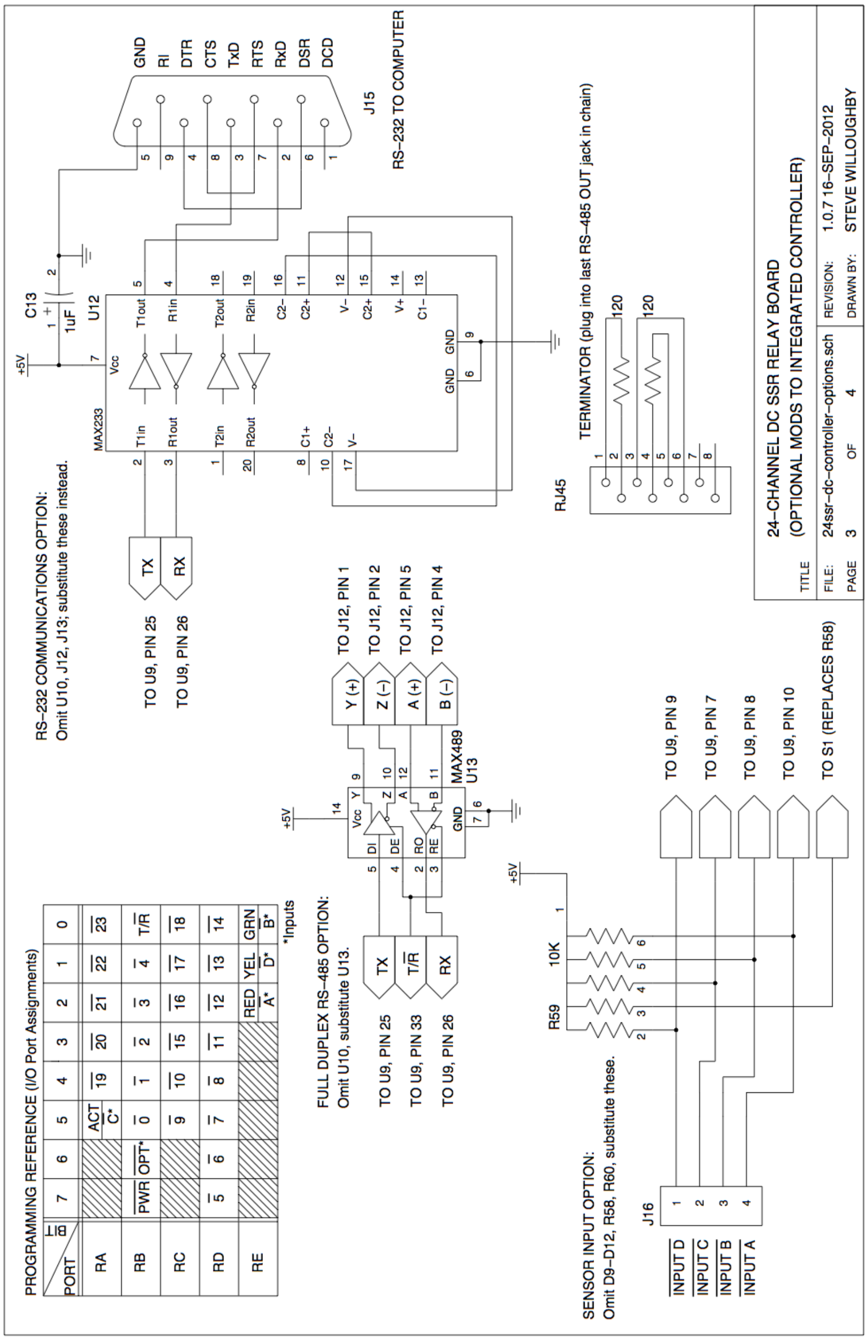
1	$\overline{\text{SSR23}}$	8	$\overline{\text{SSR3}}$	15	Gnd	22	$\overline{\text{SSR9}}$
2	$\overline{\text{SSR0}}$	9	$\overline{\text{SSR19}}$	16	+5 V	23	$\overline{\text{SSR13}}$
3	$\overline{\text{SSR22}}$	10	$\overline{\text{SSR4}}$	17	$\overline{\text{SSR16}}$	24	$\overline{\text{SSR10}}$
4	$\overline{\text{SSR1}}$	11	$\overline{\text{SSR18}}$	18	$\overline{\text{SSR7}}$	25	$\overline{\text{SSR12}}$
5	$\overline{\text{SSR21}}$	12	$\overline{\text{SSR5}}$	19	$\overline{\text{SSR15}}$	26	$\overline{\text{SSR11}}$
6	$\overline{\text{SSR2}}$	13	$\overline{\text{SSR17}}$	20	$\overline{\text{SSR8}}$		
7	$\overline{\text{SSR20}}$	14	$\overline{\text{SSR6}}$	21	$\overline{\text{SSR14}}$		

Schematics

The following pages contain the schematic diagrams for all the various options that can comprise a Lumos 24-channel DC controller.


LUMOS 24-CHANNEL DC SSR RELAY BOARD
(EACH BLOCK OF 8 CHANNELS; THERE WILL BE 3 OF THESE BLOCKS)
TITLE
FILE: 24ssr-dc-relays.sch
PAGE 1 OF 4
REVISION: 1.0.7 16-SEP-2012
DRAWN BY: STEVE WILLOUGHBY
Each block of 8 channels (x3)
J0-2
DEV-PWR
Q0-23
FQPF13N06L
R33-56 10K
R9-32 470Ω
DEV-GND
(... repeated x8 ...)
DEV-LOGIC
R6-8
220Ω
D3-5
Block Power LED
C3-5
0.1□F
D0-2
1N400x
U6-8
IN
OUT
GND
7805
C0-2
0.33□F
DEV-GND
+5V
U0-5
K847PH
(... repeated x2 ...)
DEV-PWR
F0-2 10A
R0-5 680Ω
INPUT VOLTAGE
SELECT JUMPERS
8-24V
5V
J6-8
J3-5
BLOCK POWER SOURCE
+5 or +8~24V DC
SSR0
SSR1
SSR2
SSR3
...et seq through SSR23
Pins are 6, 5, 4, 3, 2 for R0, R2, R4
or 2, 3, 4, 5, 6 for R1, R3, R5

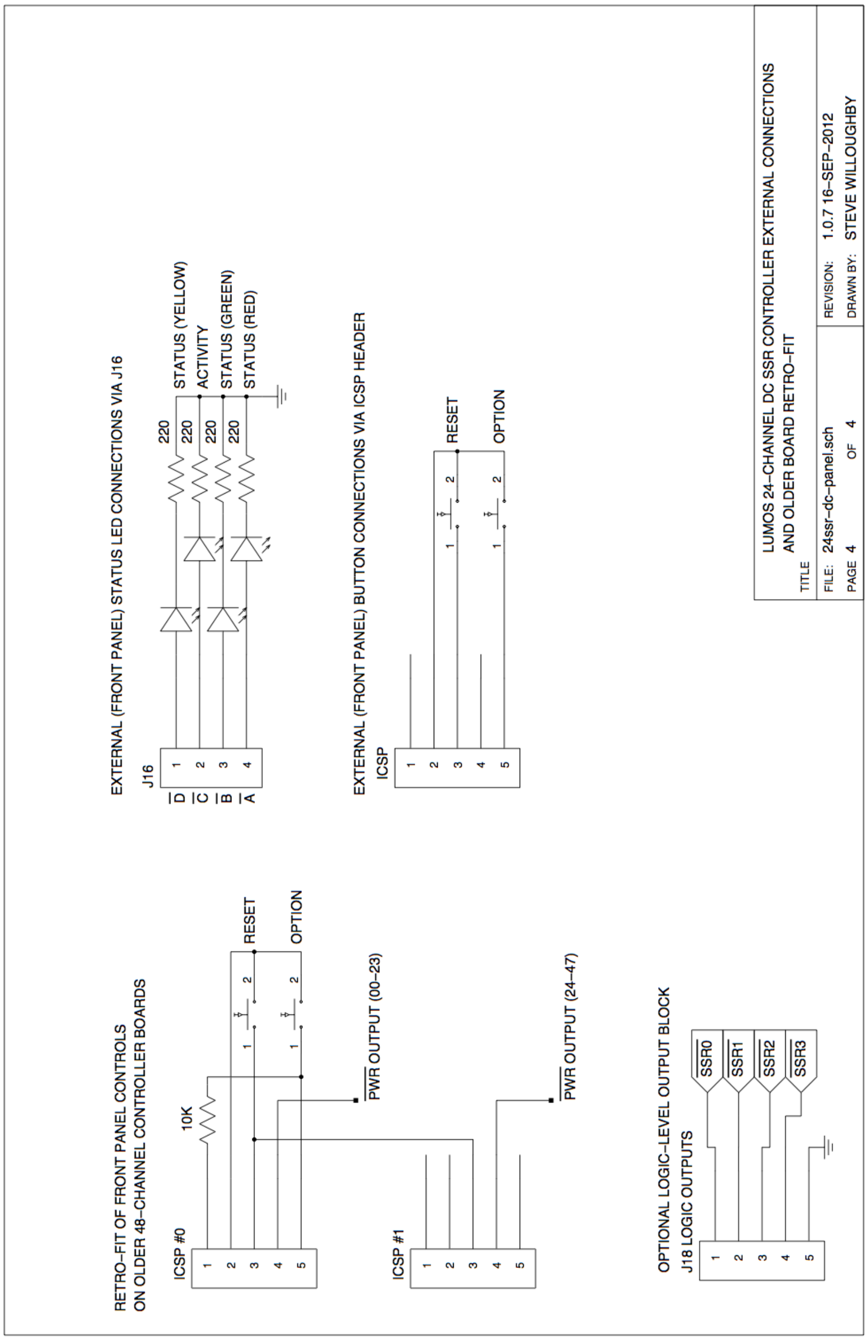

LUMOS 24-CHANNEL DC SSR RELAY BOARD
(OPTIONAL INTEGRATED CONTROLLER)
TITLE
FILE: 24ssr-dc-controller.sch
PAGE 2 OF 4
REVISION: 1.0.7 16-SEP-2012
DRAWN BY: STEVE WILLOUGHBY
PIC18F4685
U9
DS75176
U10
J14
TO RELAYS
TO RELAY CIRCUITS
RS-485 OUT
RS-485 IN
RJ45
J13
J12
R63 100
OPTIONAL
Ground-loop mitigation
F3
R62
10K
R61 330Ω
X0
10 MHz
C6
30pF
C7
POWER
STATUS (R)
STATUS (Y)
STATUS (G)
ACTIVITY
R60
220Ω
D7
D8
D9
D10
D11
C10
C9
0.01µF
C12
0.1µF
7805
U11
C11
0.33µF
D6
1N400x
J17
5V
8-24V
POWER
J10
J11
ICSP
Vdd (+5V)
Vss (GND)
MCLR/Vpp
PGD
PGC
R57 33K
C8
0.1µF
R58
10K
S0
RESET
S1
OPTION
PWR CTL
J9
+5V
GND



PROGRAMMING REFERENCE (I/O Port Assignments)

PORT \ BIT	7	6	5	4	3	2	1	0
RA			ACT / $\overline{C^*}$	$\overline{19}$	$\overline{20}$	$\overline{21}$	$\overline{22}$	$\overline{23}$
RB	$\overline{PWR}$	$\overline{OPT^*}$	$\overline{0}$	$\overline{1}$	$\overline{2}$	$\overline{3}$	$\overline{4}$	$T/\overline{R}$
RC			$\overline{9}$	$\overline{10}$	$\overline{15}$	$\overline{16}$	$\overline{17}$	$\overline{18}$
RD	$\overline{5}$	$\overline{6}$	$\overline{7}$	$\overline{8}$	$\overline{11}$	$\overline{12}$	$\overline{13}$	$\overline{14}$
RE						$\overline{RED}$ / $\overline{A^*}$	$\overline{YEL}$ / $\overline{D^*}$	$\overline{GRN}$ / $\overline{B^*}$

*Inputs


RETRO–FIT OF FRONT PANEL CONTROLS
ON OLDER 48–CHANNEL CONTROLLER BOARDS
ICSP #0
10K
RESET
OPTION
PWR OUTPUT (00–23)
ICSP #1
PWR OUTPUT (24–47)
OPTIONAL LOGIC–LEVEL OUTPUT BLOCK
J18 LOGIC OUTPUTS
SSR0
SSR1
SSR2
SSR3
EXTERNAL (FRONT PANEL) STATUS LED CONNECTIONS VIA J16
J16
D
C
B
A
220
STATUS (YELLOW)
ACTIVITY
STATUS (GREEN)
STATUS (RED)
EXTERNAL (FRONT PANEL) BUTTON CONNECTIONS VIA ICSP HEADER
ICSP
RESET
OPTION
TITLE
LUMOS 24–CHANNEL DC SSR CONTROLLER EXTERNAL CONNECTIONS
AND OLDER BOARD RETRO–FIT
FILE: 24ssr–dc–panel.sch
REVISION: 1.0.7 16–SEP–2012
PAGE 4 OF 4
DRAWN BY: STEVE WILLOUGHBY

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

Backer Level

DC

Silver Level

David Johnston	Melf

Gold Level

Rob Beasley	Phil Willoughby

Patron Level

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

annular ring, 15
ANSI, 4

blocks, 1

capacitors, 16
CAT3, 6
CAT5, 6, 29
CAT6, 6
channels, 1
chip insertion tools, 9
choking hazard, 3
Christmas lights, 1
components, 9
CPU, iii, 5, 21, 23, 25, 32, 33
CTS, 49

danger warnings, ii, 2–4
DCE, 48
DE-9, 32
diagonal cutters, 16
DIN, 47, 48
diodes, 16
DIP, 19, 23, 27, 28, 32, 43, 59
DIY, 2, 59, 61
DMX, v, 47, 48
DMX512, 6, 8, 27
DPDT, 39, 51
DSR, 49
DTE, 49
DTR, 6, 49

EDA, 65
ESD, 4, 15, 19, 59
eye protection, 4

fuse holders, 19
fuses, 21

GFIC, 4
grounding strap, 9
GUST, 65

hazardous chemicals, 3
heat protection, 19
heat sink, 19

IDC, 44, 51

jumper block, 19

lead poisoning, 3
LED, v, 7, 16, 21, 24, 25, 33–35, 39, 59
logic-level outputs, 7

MAX232A, 32
maximum limits, 4
MOSFET, 10, 11, 19, 44, 59, 62

online forum, 2
opto-isolator chips, 21
overloaded circuits, 4

PC board, 9
    versions, 9
PCB, v, 5, 15, 16, 19–21, 24, 27–30, 32, 44, 45, 59, 60, 65
PDF, 65
pliers, 9
product website, 2

resistor network, 16
resistors, 16

RS-232, 6, 7, 27, 32, 44
RS-485, 1, 6, 8, 10, 27–29, 32, 44, 60
RTS, 49
RxD, 49

safety precautions, 3
sensors, 7
shock hazard, 4
solder, 9
solder connections, 15
soldering iron, 9
static discharge, 4

theatrical lighting, 1
TIA/EIA-232, 6
TIA/EIA-485, 6
TO-220, 43
TRIAC, 62
TTL, 5, 7, 33, 37, 49, 60
TxD, 49

USB, 6

warnings, ii, 2–4
warranty, limitation of, ii, 2
website, 2
wire cutters, 9

Colophon

This manual was composed and typeset by the author using LaTeX with Memoir layout macros, augmented by wrapfig, lettrine, bytefield, wallpaper, Ti*k*Z, 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.

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