The OPTOGLO II: An improved optically isolated high current switch

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AMA 345702

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The original article for the OPTOGLO optically isolated high current switch appeared in the December, '98 issue of Model Aviation magazine. That article, as it was published, documents a good design that will work very well in almost every R/C switching application. Since that time, however, I have revisited the design. Like a couple of commercially available glow switches, the first OPTOGLO used a bulky MOSFET transistor with a large heat sink tab and a separate optical isolator. I have replaced these components on the OPTOGLO II with a single small package, called a Power MOSFET Photovoltaic Relay, which has both the isolator as well as two MOSFETs built in. The small photovoltaic relays are much easier to handle and install than the previously used large power MOSFET transistors. The result is the most advanced, compact, and lightweight R/C switch design currently available, incorporating recently available, state-of-the-art electronic switching components.

Summary

A small and simple circuit, shown in Figure 1, has been designed as a general purpose electronic switch for radio control (plane, boat, car) applications. It is primarily intended to operate on-board glow systems for model engines but, with an operating voltage of up to 20V and a high current switching capacity, it can be used for on/off control of a wide variety of devices such as smoke pumps, lighting systems, or even electronic ignition systems for spark engines.

Complete optical isolation between the receiver and the switch circuit eliminates the possibility of interference from electrical noise generated by electric motors or metal to metal vibration in glow engines. Its straightforward design uses readily available electronic components making the OPTOGLO II a great project for any R/C modeler!

Onboard glow: a safer alternative

Many of the hazards that we face in R/C model aviation are centered on the process of starting and tuning our glow engines before each flight. It requires us to work in close proximity to the running engine and often to reach around the very dangerous spinning propeller. In particular, removing the glow plug power source once the engine is running often leads the modeler to reach over the top of the propeller disk. This single action is the cause of a large number of injuries sustained from propeller strikes. A solution, of course, is to securely tie down the airplane or have a companion hold the craft during starting. Once the engine is running, the modeler can then move around to a position behind the propeller arc and more safely remove the glow plug connector and make carburetor mixture adjustments. However, another significant increase in safety can be provided by an onboard glow ignition system. This system consists of a rechargeable 1.2V NiCd battery and a switch that can be remotely activated by the radio control system. The modeler is then never required to disconnect the glow power source from the running engine.

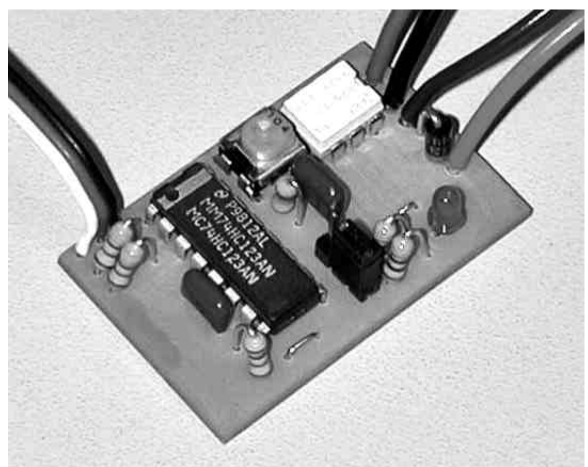

Figure 1 Photograph of the finished OPTOGLO II electronic switch. The circuit pictured is the single photovoltaic relay version for one glow plug or two plugs wired in series. It can be used for any switching application with up to 4.5A of current.

One motivation to use onboard glow systems has been four-stroke engines that sometimes benefit from applying current to the glow plug to

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provide a smoother and more reliable low speed idle. These glow systems are either mechanically or electronically coupled to the throttle control in such a way that the glow plug is ignited below a preset throttle setting. Onboard glow systems are also extensively used for multi-cylinder two and four-stroke engines for which it is impractical to make separate manual connections for each glow plug every time the engine is started. However, it should be recognized that the use of onboard glow systems can add safety and convenience to *any* model engine. Even in cases for which glow current is not required at idle, an electronic glow system can be connected to an unused radio channel, allowing the glow current to be switched on and off with just the flip of a switch on the transmitter. No more fiddling around with wires or glow batteries just inches away from a hungry spinning propeller!

An electronic glow switch has a number of advantages over mechanically actuated switches. The first, of course, is the ease with which the on/off set point can be adjusted. Another big advantage is the fact that the plug is automatically extinguished when the receiver is turned off, eliminating the possibility of accidentally discharging the glow battery between flights by leaving the throttle in the closed position.

Theory of Operation

The common glow plug is designed to be energized by a single NiCd or dry cell battery. As I began to design the first OPTOGLO circuit, I was initially surprised to find out that the average current draw of a typical glow plug is about 3 amps at 1 volt. This means that the filament resistance is only about 0.3 ohms. For this reason, special care must be taken to design an electronic switch that adds very little resistance to the glow plug circuit. If the switch resistance is comparable to that of the glow plug, then a significant amount of battery power will be dissipated in the switch itself. This not only robs power from the plug, it results in heating in the electronic switch. For this design, I have chosen a power MOSFET photovoltaic relay with an on resistance of no more than 0.04 ohms. This results in around 10% of the power being dissipated in the transistor which is quite acceptable. Power MOSFETs with an on resistance of less than 0.01 ohm are available but the slight improvement in performance over the one used here does not justify the significant increase in price and lowered availability.

My first glow switch design did not incorporate optical isolation. The voltage to drive the gate on the MOSFET derived from the 4.8V receiver pack therefore it was necessary to tie together the negative terminal of the flight battery and the glow battery. The result was that the body of the glow engine was electrically connected to the negative terminal of the flight battery. The first indication that this was not a great idea came when I sometimes noticed small servo twitches when the receiver was turned on and I would tap the engine with a metal object such as a screwdriver. This illustrated the potential interference that could result due to metal to metal vibration when the engine was running. Although a number of commercially available glow switches are configured this way, I abandoned this first design at the rough prototype stage. An ideal solution is one in which there is absolutely no electrical connection between the receiver electronics and the glow battery circuit. This can be accomplished with optical isolation. The challenge with optical isolation in the case of switching glow power is that the battery voltage on the switch side of the circuit is only 1.2V, much less than the required 5-15V gate voltage of a MOSFET transistor. For this reason, a special optical isolator is used which is called a photovoltaic isolator. This isolator consists of a light emitting diode (LED) and a photovoltaic array, more commonly referred to as a solar cell array. Current is supplied to the LED which generates light that is then collected on the solar cells and is converted into a voltage on the other side of the isolator. The PVN012 power MOSFET photovoltaic relay used in the OPTOGLO II contains one of these optical isolators and two MOSFET transistors, all in one small 6 pin package. The only communication between the half of the OPTOGLO II circuit connected to the radio receiver and the half connected to the glow plug circuit is through photons of light. That means that the OPTOGLO II can be used as an on/off switch for not just glow plugs but a wide variety of devices including electric motors, pumps, buzzers, etc. with no fear of direct interference into the radio receiver.

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It is worth pointing out that although the PVN012 is called a photovoltaic "relay," it is not a relay in the conventional sense. It has no mechanical moving parts and switch closure is accomplished using two high current MOSFET transistors that are built into the package. Each relay is capable of handling up to 4.5 amps of continuous current at voltages up to 20V. The current capacity of the OPTOGLO II can be doubled to 9 amps by adding a second photovoltaic relay as shown in Figures 2 and 6(b).

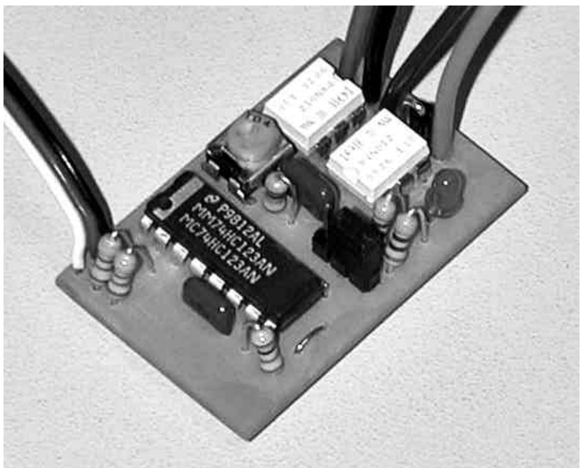

Figure 2 Dual photovoltaic relay version of the OPTOGLO II required for 2 or 3 plugs wired in parallel or other switching applications with >4.5A of current.

Remember that the signal from the receiver that is sent to control each servo is a train of pulses ranging from about 1 to 2 milliseconds in duration and occurring at about 60 per second. A pulse width of 1ms sends the servo output to the limit of rotation in one direction and 2ms to the limit in the other. For example, the pulse width supplied to a servo near the center position is approximately 1.5 ms. There are three wires connecting each servo to the receiver. The first two supply the plus and minus voltage from the battery pack and are often red and black, respectively (see Table 3). The third wire carries pulses which direct the motion of the servo. The OPTOGLO II has its own onboard adjustable reference pulse generator. When the input pulses from the receiver are longer than the onboard reference pulses, the electronic switch closes (turns on). When the input pulses are shorter, it switch opens (turns off). A jumper on the OPTOGLO II allows the direction of operation to be reversed so that it is open for long pulses and closed for short pulses. The jumper therefore functions in a way similar to a servo reversing switch.

Figure 3 shows the electronic schematic for the OPTOGLO II. The set point for on/off is changed by adjusting potentiometer R4. R4, resistor R5, and capacitor C2 determine the reference pulse duration. The outputs from pin 5 and from pin 12 of the integrated circuit IC1 have reversed polarity. Moving jumper J2 applies the output from either pin 5 or pin 12 to the photovoltaic relay IC2 (and optional IC3). Notice that the only link between the power switch side of the circuit and the side connected to the receiver is through the optical isolator. The red LED D1 lights to indicate that voltage is being applied to the photovoltaic relay, closing the MOSFET switch inside the relay. D2 is a catch diode placed across the device that is being powered by the OPTOGLO II switch. When inductive loads such as a mechanical relay or motor windings are de-energized, they produce a voltage spike which can cause erratic shut-off characteristics. The catch diode suppresses the possible spike. Finally, note that the schematic illustrates the connections for a glow plug and glow battery. The glow battery can be replaced with any DC voltage source of up to 20V and the glow plug can be any of a wide range of electrically powered devices.

Construction

Table 1 is a complete parts list for the OPTOGLO II with catalog part numbers from Digi-Key Electronics.[1] Figure 4 is a 2X scaled pattern for the printed circuit board. It should be reduced to 1/2 size when it is reproduced. The best way, I believe, of making this board is with a product called "Press-n-Peel."[2] It is a blue plastic film which can be run through a conventional photocopy machine or printed onto directly with a laser printer. Following the instructions supplied with the film, the image in Figure 4 should be copied onto the dull side. It is then ironed onto a copper clad board (such as Radio Shack 276-1499) using a household iron or your airplane film sealing iron. When experimenting with the best temperature, I find it useful to securely tape the film to the board along one edge. I can then carefully peel back a

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small portion to test the adhesion of the pattern to the board. If the transfer was incomplete, the film is let back down and additional pressure at a higher temperature used.

After successful image transfer, the board is etched in a solution of ferric chloride (Radio Shack 276-1535) for 30-60 minutes or until all of the unwanted copper is gone. Note that this particular blank board is two-sided so the copper will be completely removed from the back side. After etching, the mounting holes should be drilled with a #65 drill bit. This is easily accomplished since the copper surrounding each hole location accurately guides the drilling. Slightly larger holes will be required for the glow plug and battery wires. The smallest possible holes should be drilled in each case. Those modelers interested in building a circuit but who do not want to manufacture a PC board may contact the author. Alternatively, a complete unassembled kit, minus the wiring harnesses, can be obtained.[3]

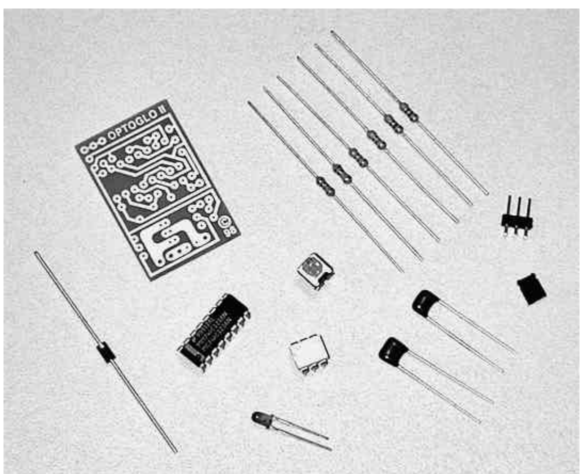

Figure 5 - Photograph of the required electronic components to build the OPTOGLO II.

Figure 5 is a photograph of the complete set of electronic components and Figure 6 shows a schematic of the installation of these components onto the board. They should be inserted from the side opposite from the copper circuit pattern. Table 2 is a list of the components with their required values. All of the resistors should be mounted vertically as shown in the photographs in Figures 1 and 2. Jumper J1 is simply made from a left over piece of resistor lead. Notice that if the single photovoltaic relay version is built, a second jumper J3, made the same way as J1, should be installed. Pay special attention to IC1, IC2, optional IC3, D1, and D2 since the direction they are installed is very important. Notice that the LED D1 has a small flat spot which should be oriented as shown in Figure 6. This indicator LED can also be placed on extension wires to locate it in an easily visible location on the airplane such as in the cockpit area. Diode D2 should be installed with the striped end facing down. For high current applications (4.5-9A), an optional photovoltaic relay IC3 can be installed in the second board position.

Carefully solder the installed components to the copper circuit pattern, taking care to avoid solder bridges across gaps between the traces. It is *extremely* important to use a good quality resin core electronics-grade solder and to brighten the copper traces with fine steel wool or a scotch-brite pad before starting. Advice and/or instruction from a fellow modeler with circuit assembly experience could be useful here. The excess resin left from soldering should be removed with a solvent such as lacquer thinner (I use K&B Superpoxy thinner since that's what I have in my shop) and an epoxy brush with the bristles cut back to 1/4". A receiver lead compatible with your radio system can be purchased at your local hobby shop or you could use the wiring harness from a worn out or damaged servo. Table 3 summarizes the wire color codes typically used for some common radio systems. Using Figure 6, carefully attach the leads according to this chart. Airtronics users should be cautioned that the V+ and V- wires are reversed in the servo harness from those for Futaba, JR, and RCD radio systems. Since the Airtronics harness has two wires of the same color (black), carefully note which one is denoted as the center wire in Table 3.

Installation of the OPTOGLO II

Figure 8 shows a completed OPTOGLO onboard glow system, including the 1.2V NiCd battery and glow plug connector. The finished circuit weighs only about 1/2oz. The complete onboard system with wiring and a sub-C battery weighs 4oz. In the set up shown, the battery and glow plug in-line connectors are gold plated Ultra Plugs made by W.S. Dean and available through most hobby retailers (Tower Hobbies,

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part #WSDM3001). The stainless steel glow plug connector is manufactured by McDaniel R/C (McDaniel R/C #448). The small circular lug should be attached to the engine case. This can be conveniently accomplished by placing it under one of the engine's mounting ear screws. Notice that an extra electrical lead is installed on the sub-C battery for charging and is terminated with a Deans 2-pin connector (Tower Hobbies, part #WSDM3002).

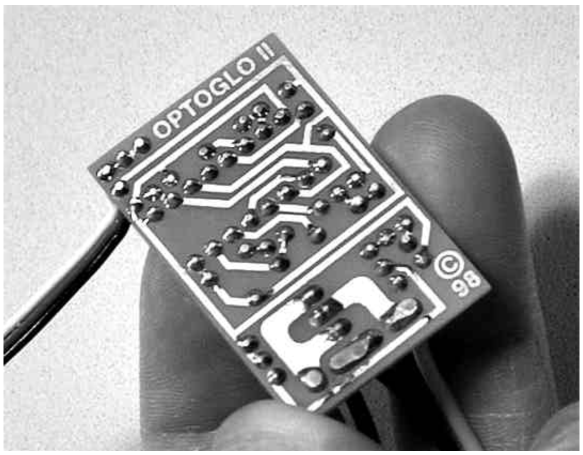

Figure 7 - Completed OPTOGLO II as viewed from the trace side of the board.

When installing the in-line connectors, be sure to place the female half of the connector on the battery side of the battery wiring harness and on the circuit side of the glow plug wiring harness. This reduces the risk of a short circuit when the plugs are not connected. Great care should be taken when hooking up the battery since installing it backwards will quickly damage the MOSFET switch in the photovoltaic relay or the catch diode D2. A simplified wiring schematic for a single glow plug system is shown in Figure 9(a).

Care should be taken in choosing the wire size used to connect the glow battery and the glow plug connector to the OPTOGLO II circuit. 20 gauge copper wire has a resistance of .00085 ohms/inch therefore up to 24 total inches of wire can be included in both harnesses before the resistance of the wire will have an resistance comparable to that of the MOSFET switch. The total length of both wiring harnesses should be kept as short as possible. If more than 24 inches of wire are required, 18 gauge (smaller number means bigger wire) should be used to avoid undesirable voltage drop in the harnesses.

When using the OPTOGLO II to power the two glow plugs on a twin cylinder engine, there are two possible connection schemes, as shown in Figures 9(b) and (c). For the parallel scheme in Figure 9(b), the negative wire is attached to the engine case and the positive lead is attached to both glow plugs. The two plugs in parallel draw twice the current of a single plug therefore it is recommended that two batteries in parallel be used as a power source. In this case, the optional photovoltaic relay IC3 should be installed. Figure 9(c) shows the alternate series connection scheme. In this case, the positive wire is attached to one glow plug and the negative wire to the other glow plug. The electrical current through the OPTOGLO II for series wiring is the same as for a single glow plug but twice the voltage is required, therefore two batteries in series are used. Since the current is not increased, only one photovoltaic relay is required for the series connection scheme.

Figure 8 - A completed onboard glow system including the 1.2V NiCd battery and glow plug connector. This setup is illustrated with the original OPTOGLO design using a discrete MOSFET transistor.

Which method for twin cylinder hook up is right for you? There are good arguments in favor of both wiring methods and I will summarize these. The advantage of the parallel wiring scheme is

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increased reliability since, if one plug fails in flight, the other plug will still light, providing the best chance of keeping the motor running at idle. However, some prefer the series wiring scheme since if one plug does fail, neither plug will light, preventing the modeler from inadvertently starting the engine on the ground on only one cylinder. The two glow plugs in series draw the same current as a single plug meaning that the same power is dissipated as heat in the MOSFET switch (meaning that IC3 is not required). However, if the plugs are not well matched in resistance, the power delivered to each plug may not be equal when they are wired in series. In fact, since the plug resistance increases as the filament heats, the power imbalance between the plugs could increase with the hotter plug getting hotter and the cooler plug getting cooler. Therefore, for series wiring, the two plugs should be as well matched as possible. The parallel wiring scheme, however, results in good heat balance between the plugs even in a case of mismatched resistances. A final consideration is the charging of the glow battery. Since it is generally not advisable to charge two NiCd cells in parallel, they should theoretically be removed from the circuit for recharging. In the series scheme, the batteries can simply be charged in place. Surveying posts to the internet newsgroup REC.MODELS.RC.AIR will find modelers who prefer and successfully employ both series and parallel wiring schemes. Even so, I believe that the series scheme may offer a few more advantages and an easier wiring job overall.

Using a single photovoltaic relay, the OPTOGLO II will easily handle the 3 amp current requirements for a single plug or the series connection scheme of dual plugs. For three cylinders or more, the parallel arrangement is the only possible wiring scheme since each plug is connected to the common engine case. Two photovoltaic relays are required for both the 2 and 3 plug parallel connection scheme. More than three glow plug connection is not recommended with the OPTOGLO II.

Using the OPTOGLO II

There are two ways to connect the OPTOGLO II circuit to the radio control receiver. The first is to connect the circuit to the throttle servo channel using a Y-harness. The jumper J2 should be placed in the position that lights the glow plug when the throttle position is below the set point, near idle. The potentiometer R4 should be adjusted so that the glow plug comes on at the desired throttle setting by observing the indicator LED. Remember that the LED shows that the electronic switch is closed, not necessarily that the plug is glowing. The indicator will light whether or not the glow battery is properly charged or the plug is burned out. A second hook up option is to connect the OPTOGLO II to a separate receiver channel. Electronic mixing on the receiver can then be used to slave that channel to the throttle servo channel. This is my preferred set up since, with a computer radio, the mixing can be deactivated if desired and the glow power can be applied when needed with the flip of a switch for the glow channel.

Figure 10 - Photograph of author's Pica 1/6 scale Cessna 182 with onboard glow connector in place.

Sliding the finished circuit into a short length of 1.25" diameter heat shrinkable tubing, as pictured in Figure 8, provides protection for the OPTOGLO II circuit. Be careful not to overheat the circuit when shrinking. A set of access holes can be cut through the covering to allow set point adjustments and to move the reversing jumper J2. If the circuit is connected to a separate receiver channel as described earlier, access to these adjustments may not be necessary since this can be accomplished by receiver programming. I like to wrap the finished circuit in a layer of 1/4" latex foam held with a

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couple of rubber bands to shield it against engine vibration.

Controlling other on board devices

As I described in the introduction to this article, the OPTOGLO II can be used as an on/off switch for a variety of devices operating with battery voltages of up to 20V. Among the possible applications are the control of smoke pumps, lighting systems, buzzers, and electronic ignition systems for spark engines. The OPTOGLO II can easily handle 4.5 amps of current with a single photovoltaic relay installed with no heat sinking required. This current handling can be doubled to 9 amps by adding the additional optional photovoltaic relay IC3. It should be noted that devices such as lighting systems and smoke pumps typically draw much less current than a single glow plug! Consult the documentation supplied with these devices to determine the actual requirements. Remember, as long as the battery voltage is less than 20V, only the current (in amps) determines how much power is dissipated in the power MOSFETs inside the photovoltaic relays.

The original OPTOGLO could also be used as a small and inexpensive switch for the increasingly popular Speed 400 and similar electric motors. In theory, the current draw required for these motors could just be handled by the OPTOGLO II using two photovoltaic relays. However, it is very near the design limit and I do not recommend that the OPTOGLO II be used for Speed 400 on/off control. There are now a number of very compact, lightweight proportional speed controllers for these motors available commercially and I highly recommend one of these.

The author

Brent Dane has been an AMA member and an R/C model pilot since 1990. He is a member of both the Livermore Flying Electrons and the East Bay Radio Controllers, two AMA chartered clubs which have flying fields near Livermore, CA. Brent is a physicist in the laser program at Lawrence Livermore National Laboratory. For answers to questions or for additional information about the OPTOGLO II, Brent can be contacted on the internet at email address cbdane@pacbell.net. Additional information on other R/C electronic projects can be found at http://www.cliftech.com/.

End notes

1. Digi-Key Corporation, 701 Brooks Ave. South, Thief River Falls, MN 56701-0677, (800) 344-4539.

2. Press-n-Peel is manufactured by Techniks and can be ordered from All Electronics Corp., Van Nuys, CA 91411, (818) 997-1806.

3. To receive an etched printed circuit board, send a check or money order for $10.00 per board to Brent Dane, 678 Crane Ave, Livermore, CA 94550. A complete unassembled kit, *without* wiring harnesses or battery, can be obtained for $25.00 (includes postage and handling). Add an additional $5.00 for a second photovoltaic relay for applications requiring >4.5 amps (but not more than 9 amps) of current.

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Table 1

# parts	Description	Digi-Key part number
2	1/4W resistor 470Ω	470QBK-ND
2	1/4W resistor 47k	47KQBK-ND
1	1/4W resistor 100k	100kQBK-ND
1	1/4W resistor 1M	1.0MQBK-ND
1	100k rotary potentiometer	D4AA15-ND
1	polyester film capacitor 0.010µF	P4513-ND
1	polyester film capacitor 0.056µF	P4522-ND
1	red LED with diffuse lens	P363-ND
1	600V silicon diode	1N4005CT-ND
1	dual retriggerable monostable multivibrator	MM74HC123AN-ND
1 (2)	power MOSFET photovoltaic relay	PVN012-ND
1	3 pin square header	S1011-03-ND
1	shorting jumper	S9002-ND

Table 2

Resistors

R1	47k	yellow, purple, orange *
R2	47k	yellow, purple, orange
R3	1M	brown, black, green
R4	100k	rotary trim potentiometer 104
R5	100k	brown, black, yellow
R6	470	yellow, purple, brown
R7	470	yellow, purple, brown

Capacitors

C1	0.056µF **
C2	0.010µF ***

Diodes

D1	red LED
D2	1N4005

Integrated circuits

IC1	MM74HC123****	Dual resetable monostable multivibrator
IC2	PVN012	Power MOSFET photovoltaic relay
IC3	PVN012	Power MOSFET photovoltaic relay (optional)

NOTE: The optional relay IC3 is needed for 2 or 3 glow plugs wired in parallel or for applications with current draw of >4.5A. A single glow plug or dual plugs wired in series do not require IC3.

* The last resistor color band is gold for ±5% resistors.
** 0.056µF capacitor is labeled 563.
*** 0.010µF capacitor is labeled 103.
**** The MM74HC123 works differently than other 74HC123 and 74HCT123 ICs. If you don't use the MM74HC123 then change C1 to 0.1µF (104) and C2 to 0.022µF (223).

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Table 3

Manufacturer	Negative voltage (A)	Positive voltage (B)	Signal (C)
Airtronics / Sanwa	black (center wire)	black with red stripe	black
Futaba	black	red (center wire)	white
Hitec / RCD	black	red (center wire)	yellow
JR	brown	red (center wire)	orange
KO Propo	black	red (center wire)	blue
Kyosho / Pulsar	black	red (center wire)	yellow
Tower Hobbies	black	red (center wire)	white

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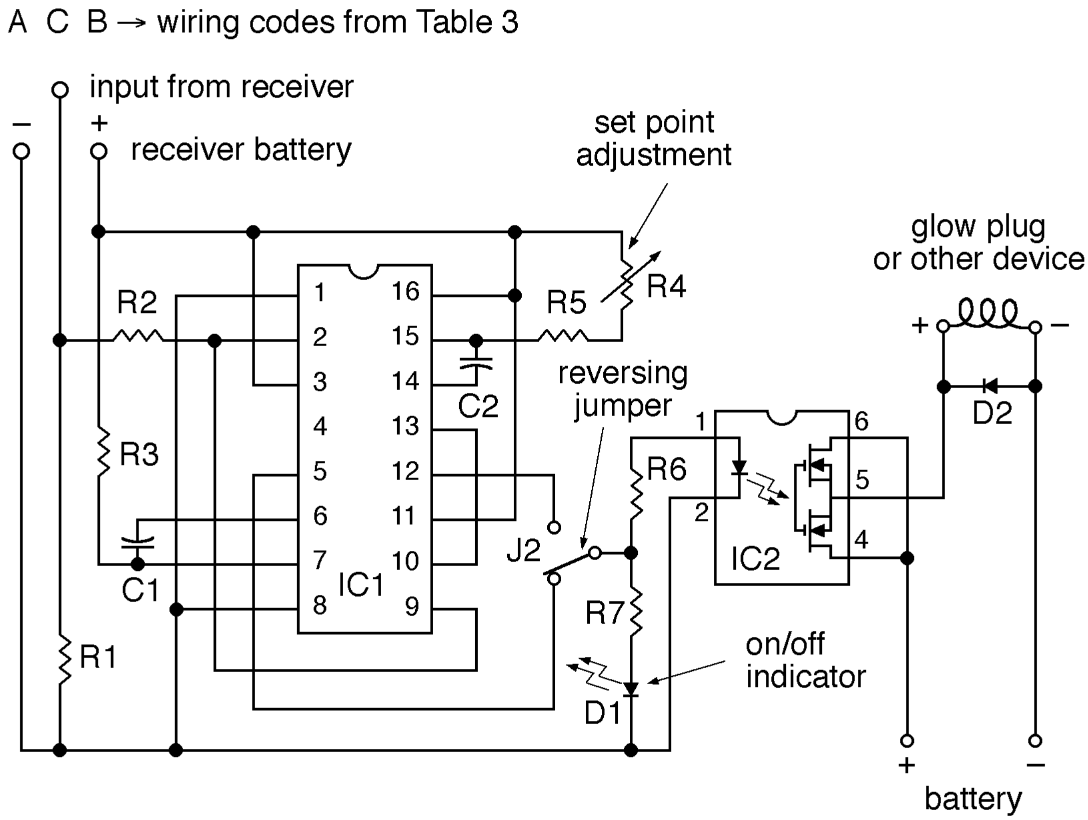


Figure 3 - Electronic schematic of the OPTOGLO II switch.

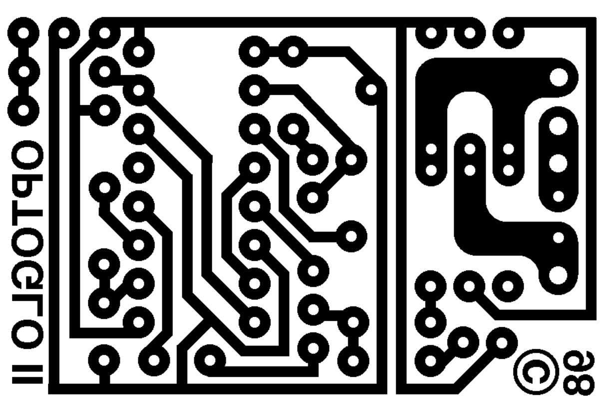
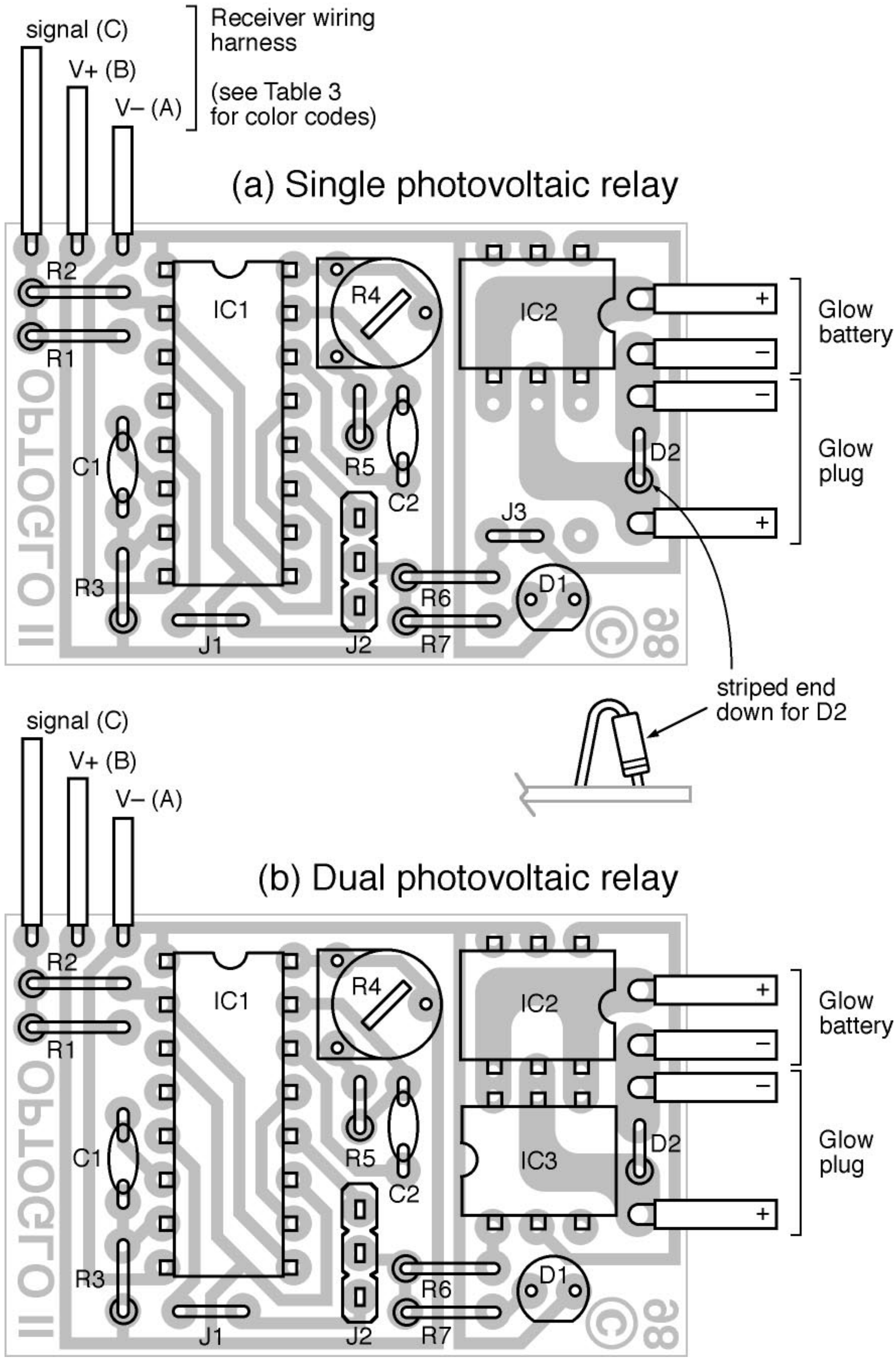
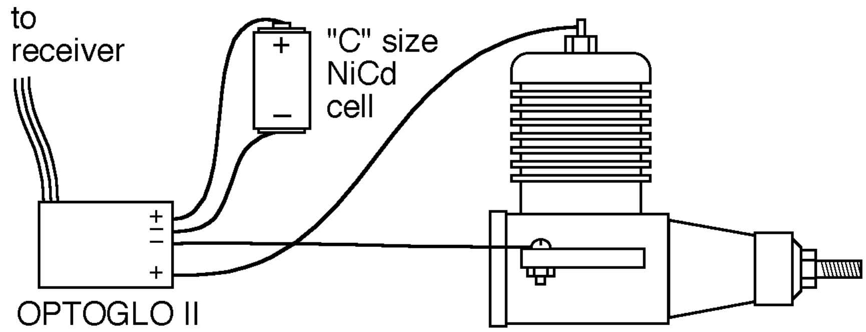


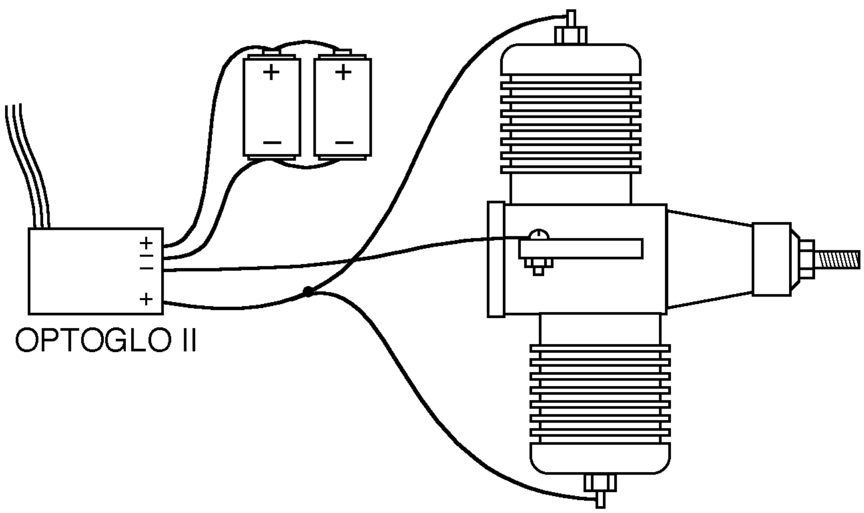
Figure 4 - 2X magnified printed circuit board pattern for the OPTOGLO II.


signal (C)
V+ (B)
V– (A)
Receiver wiring harness
(see Table 3 for color codes)
(a) Single photovoltaic relay
R2
R1
IC1
R4
IC2
C1
R5
C2
R3
J1
J2
R6
R7
J3
D1
D2
Glow battery
Glow plug
striped end down for D2
(b) Dual photovoltaic relay
IC3

a) Single cylinder wiring schematic



b) Twin cylinder "parallel" wiring schematic (IC3 required)



c) Twin cylinder "series" wiring schematic (IC3 not required)

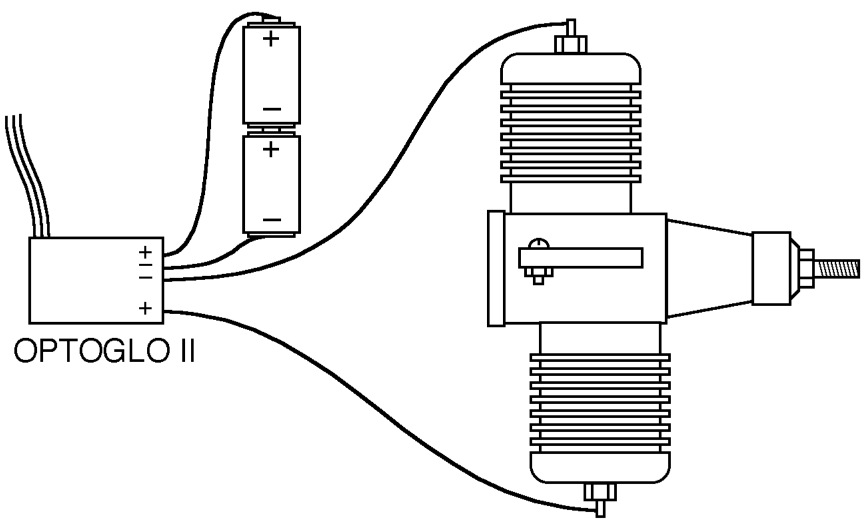


Figure 9 - Schematic wiring diagrams for single and twin cylinder configurations.