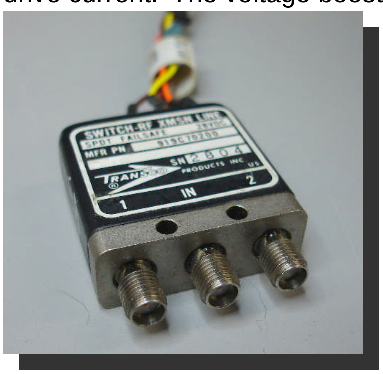
Switching Regulator Boost Converter Drives 24-28V RF Relays

Very good microwave single pole double throw relays can be found on the surplus market. Many relays with attractive prices tend to have 24 to 28 volt relay coils. A simple boost converter is presented here that can be used to drive these relays from a 12V battery supply. It has the following features.

- Wide input voltage range, from under 10 to 15V.
- Drives 24-28V relay coils requiring up to about 500mA.
- On-board flyback catch diode suppresses relay coil transients.
- Low standby current - under 150 µA, and typically 120 µA.
- High efficiency switching boost converter achieves about 90% efficiency.
- Relay control via local SPST switch or remote logic configurable to ground or Vin / 5V.
- Relay state output indicator using LED & 5V logic output.
- Small footprint PCB can be mounted directly on the relay.
- Low power option has the potential to reduce supply power by a factor of four.

Switching Circuit Description

The relay used for this application was a Transco (KC) 919C70200-8 SPDT 18 GHz SMA relay with indicating contacts, and of course a 28 Volt coil that requires about 100mA of drive current. The voltage boost circuit shown in the schematic is based on a Linear



Technology LT1372 integrated circuit. This device is a high efficiency buck boost converter in an 8 pin SO package and is capable of delivering up to about three quarters of an amp in this boost configuration. The input supply voltage is connected to the PCB Vin pad and adjacent GND pad. Vin must be between 10 and 15 Volts. C1 and C2 are input filter capacitors and L1, D1, C3 and C4 perform the switched output bias storage, rectification, and output supply filtering. C5, R12 and C6 provide loop stability for U1. . The output voltage is set by the ratio of R1 and R2. It's targeted at 26 Volts a mid-point that allows a single solution to be used to drive either 24 or 28V relays. Note that as the output voltage is defined by the ratio of R1 and R2 the converter can be set to provide any voltage between Vin and 30 volts the maximum specified for this IC. For example if R2 is 6.19k, the output voltage will be 24V with an R1 of 113k or 28 volts if R1 is 133k. The only critical components in this regulator are L1, D1, and C3 and C4. They were chosen for optimum cost, size, and reasonable performance. L1 is a Taiyo Yuden NRS4018T100M, a 10uH power inductor with 1.3A saturation current, a low 0.18 ohm series resistance, and a self resonance of 25MHz. C3 and C4 are Taiyo Yuden multi-layer ceramic capacitors part number GMK316BJ106KL-T. They were chosen for their low ESR at the converter switching frequency, 0.01 Ohms. D1 is a SS14 1A, 40V Schottky diode. Care was taken with the PCB layout to insure clean switching and low EMI by minimizing the track distances between U1, D1, C3, and C4, as these carry high frequency switching currents.

The relay is activated using the SwIn PCB I/O pad. The converter can be configured to turn on with a control input that is either 'active high', SwIn is taken high, or 'active low', SwIn is pulled low to ground. The configuration depends on whether R14 or R15 is populated during construction. The active high configuration can be used with standard five volt logic levels or high side switches such as open collector PNPs or open drain P-channel MOSFET switches. The active low configuration can be used with low side switches like open drain NPNs or N-channel MOSFETs. For an active high configuration, install R14 and do NOT install R15. This essentially disables Q5 and drives the enable input to U1 and the base of Q3 directly. R3 and R4 form a voltage divider to the enable pin of U1 and R11 and R16 form a voltage divider to the base of Q3. These voltage dividers help set the switching levels enabling good switching margins with most logic families. An open circuit

or a voltage at the SWin pin below 1.5V will keep the converter off. Any voltage above 2.5V up to Vin will pull turn the converter on. The input impedance is about 40 kΩ, determined primarily by the series combination of R3 and R4. Note that input voltages over about 1.5V will turn on Q3 and provide a DC path from Vin to Vout. If this happens the relay may attempt to switch so avoid SW In voltages between 1.5 and 2.5 volts.
Installing R15 and NOT R14 changes the input to one that can be pulled low from Vin using an NPN transistor in an open collector configuration or an open drain N-channel transistor. In this configuration the input resistance is about 47kΩ, so the switching device must be capable of sinking about 0.5mA to ground. When SwIn is pulled low inverter transistor Q5 turns on turning on U1 and Q3 in the same fashion as with the active high configuration.
Turning on Q3 turns on Q4. Q4 provides a low on resistance path between the converter output and the boost converter. R9 and R10 form a voltage divider to insure the maximum gate to source voltage specified for Q2 isn't exceeded. The converter output pad is marked 'Vout' and is connected to the relay coil. Note that some relay coils are polarity sensitive, so investigate the relay before using the converter to determine which coil connection should be positive. The other coil connection should go to the 'GND' pad adjacent to the Vout pad. In some instances a transient suppression diode will be connected across the relay coil. It can be removed, but if it isn't insure that the anode side of the diode connects to the converter's positive output. Otherwise there may simply be a forward biased diode to ground at the converter's output. It will act as essentially as a short to ground. Note that boost converters are not protected against short circuit loads. The full current available from the input supply will flow though the L1, D1, and the output switch Q4 to ground most likely destroying one of those components.

Relay State Indicator Output

An indication of the relay state is available at the sense output, SOut pad. Q1 and the relay sense contacts perform this state indication function. The sense common pad SCom is wired to the relay's sense common contact and the relay's normally open sense contact is wired to the sense normally open, S_NO pad on the PCB. A voltage divider from the Sense NO pad comprising R5 and R6 sets the base voltage on Q1. When the relay is not powered, the sense contacts are open so the voltages at Q1's base, emitter, and SOut pad are all 0V. When the relay is energized the sense contacts close and the base voltage becomes approximately 5.3 Volts with a nominal 13.8 Volts at Vin. This produces about 4.7 Volts at the emitter to provide the SOut logic drive. The combination of the emitter voltage at Q1 and the value of R7 determine Q1's emitter current. It's dependent on Vin but typically ranges between 4 and 5mA. The drive impedance is determined by the dynamic output impedance of Q1, typically around 30 ohms when the relay is on. But when the relay is off the output impedance is determined by R7. Note that SOut can't sink current. It has an off resistance of R7. Additionally it should not drive more than a couple milliamps. into an external load when high. Most any CMOS input will behave quite adequately, but make sure that if there is an internal input 'pull-up' the that the pull-up current is low enough to maintain a logic level low across R6. Also note that for 5V logic applications the voltage at the SOut pin changes with Vin. It will go slightly above 5V to about 5.1V when Vin is at its maximum, 15V, and decreases to 3.2V when Vin is at its 10.0V minimum.

State Indicator LED

A state indicator LED can be wired to the LED+ (anode) and LED- (cathode) pads. Alternatively there is space on the PCB for a miniature LED, D3. Use one or the other but not both. The current through the LED is, like Q1's emitter current, between 4 and 5 mA. For lowest power consumption, consider using high efficiency LED's like the OSRAM LW PS4G. These LED's have a higher forward threshold voltage, up to 3.8V, but that's just fine for this application. They produce a very usable light output at currents under 1mA. LED current can be managed by changing the value of R6 to between 470 Ω (10mA) and 10kΩ (0.5mA). This range will not impact the SOut logic function but do keep in mind the current required by the circuitry attached to the SOut pad as it will modify the LED current. If you choose not to use a LED, short the LED+ to LED- leads on the PCB.

Feedback Option for Relays without Sense Contacts

If your relay doesn't have sense contacts you can still use the indicator LED and / or the Sense Out to indicate that the converter is providing a 26 volt output. To do this connect a 22kΩ resistor between the 24V output pad and sense normally open, S_NO pad. This resistor will provide a voltage at SOut of 5V with a 28V output. It also insures there is the sufficient collector current through Q1 to drive a LED. Do NOT install the low power option described in the next section. The low power option should only be used with relays that have sense contacts. If both the low power option and the 22k resistor are installed voltage from the Vout pad through the 22k resistor will turn on Q1 and then Q2 disabling the switching converter before most relays can activate.

Low Power Option

The architecture of boost switching converters is such that there is always a DC path from the input supply to the output, in this case through L1, D1, and Q4. Q4 and its control switch Q3 are used to isolate the output load from the converter output when the converter is off. Otherwise the DC path from Vin would maintain the output near Vin with the converter switched off. For battery operation where minimum supply current draw is a factor consider populating Q2 and R8, the low power option. These components cut relay power use by about three quarters by turning the switching converter off after the relay has switched. Most relays have a coil hold-in voltage is much lower than the initiation voltage required to switch it on. Many relays will hold their state until the coil voltage falls below about eight volts. It's imperative you check the relay first to make sure it stays on with some margin below the lowest possible 'Vin' voltage. But if it does, consider populating Q2 and R8. These parts will shut down the converter after the relay sense contacts indicate the relay has switched while leaving Q4 on. This will provide a voltage to the relay coil of Vin minus the drop across L1, D1, and Q4 to keep the relay held-in for as long as SwIn remains active.

Ok so you installed Q2 and R8 without testing the relay and now it's chattering when activated (shame on you for not testing it first). To disable the low power feature after Q2 and R8 are soldered in place add a jumper shorting the base to the emitter of Q2.

Using several relays with one sense output

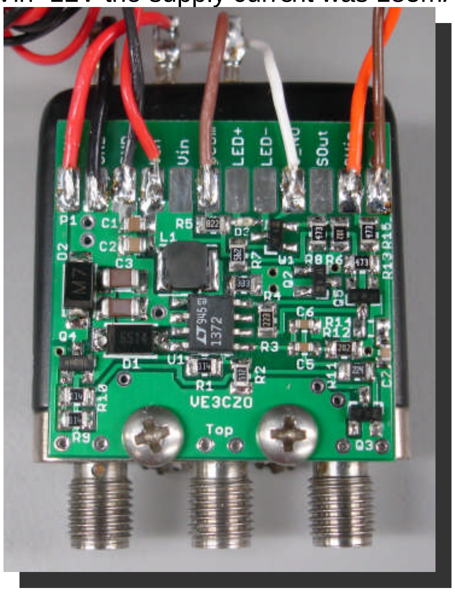
To minimize the number of feedback sense inputs to a controller, several relays with boost converters can be wired in a configuration providing a single sense output that indicates all relays have successfully changed state. To create this wired AND configuration, connect the normally open sense contact of the first relay to the common sense contact of the second relay. Do not connect the common sense contact of the second relay to the boost controller board. If a third relay is used connect the normally open contact of the second relay to the common sense contact of the third relay. Again do not connect the common sense contact of the relay to the boost controller board. Similarly wire subsequent relays in the chain. Use the sense output 'SOut' on the last boost controller board in the chain to provide feedback to the controller. If there is a relay failure in this type of series connected configuration it's a bit more challenging to pinpoint the fault. It likely lies with the device after the last one in the chain that has a valid LED indicator or SOut voltage.

Printed Circuit Board

A 30 mm x 30 mm (1.2" x 1.2") PCB mounts all parts on the top side. The layout has 11.2 mm on center holes that line up with holes in many SMA relays. There are no components or tracks on the bottom side so that the board can be mounted directly on the relay.

Performance Measurements

The converter tested was built with a target output voltage of 26V. The output voltage remains constant at about 25.6V for Vin voltages ranging from below 9V to 15V. With Vin=12V the supply current was 185mA (2.2Watts). At 25.6V the coil current was 78mA (1.96W) yielding a total efficiency of about 90%. With Q2 (the low power option) installed the supply current drops to 40mA (0.48W) reducing the power to about ¼ that needed by an unmodified relay. The low power option works down to under 9V with this relay, and the voltage on the relay coil with Vin=12V was 11.65V, representing a drop of 0.35V across the FET switch, inductor, and Schottky diode. The off state idle current is approximately 0.13mA.



RFI from the inverter appears minimal. Although I'm not set up to do field emission measurements, I did run the inverter with a two meter all mode rig set to CW and attached a quarter wave whip to the rig's antenna input then moved the relay about. When the relay was moved within about 30cm of the antenna some increase in the noise floor was noticed. The 'S Meter' indication increased to about S5 with the relay touching the antenna. There were no tonal artifacts, but rather a general increase in the overall noise floor. There was no noticeable interference with the radio connected to a coax cable leading to an external antenna. With the low power option installed, the inverter runs only momentarily, about 20 to 30 ms. until the relay is switched so there is minimal RFI in this mode.

Switching Boost Regulator Assembly Instructions

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Version

This document is to be used with version 0.7d of the printed circuit board.

Equipment you'll need

- Surface Mount Device (SMD) soldering kit
  - Temperature controlled soldering iron with fine tip. Insure the tip is grounded!
  - A length of fine solder suitable for SMD work
  - Small vise to hold the PCB
  - Liquid no clean solder flux
  - SMD Tweezers – 2 pair
  - Isopropanol 99%
  - Cotton swabs
  - Solder wick and solder sucker
- Electrostatic Discharge (ESD) protection - mat - wrist strap
- Larger diameter solder 1mm or so, for attaching the leads
- Needle nose pliers
- Wire cutters
- Wire strippers
- Variable regulated power supply with a range of 10v to 15V capable of delivering 0.5A or a 12V battery.
- Single pole single throw normally open pushbutton for initial relay testing
- Wire to connect the Boost Converter board to the relay, supply and temporary push button switch
- Screwdriver with Philips tip
- Voltmeter with leads capable of probing the Relay Boost Converters I/O pads.

Before You Begin

- Check the contents of the kit against the parts list to make sure that none of the parts are missing.
- As an aid to assembly, print out the circuit schematic, and the PCB component layout sections of this document.
- Pay attention to the component sizes. Most resistors are 0805, and most capacitors 0603, however there are size variances for the same value part so be sure to use the correct size.
- Resistor tolerances are mostly 1%. Resistors are identified by their value and a multiplier. The multiplier R is one; K is one thousand and M one million. So 3k3 would mean 3,300 Ohms, 100R, is 100 Ohms; and 2M0 two mega Ohms. One percent resistors are often designated with a third digit for example 1k91 is 1910 ohms.

Assembly Tips

1. Use two pair of tweezers, one for pulling up the hold down tape on the parts sheet and opening the SMD parts carrier, and the other for mounting components on the PCB. This prevents the tape glue residue from getting on the tweezers used for SMD mounting work.
2. If adhesive does get onto the tweezers' tips parts will stick to them. If this happens wet a cotton swab with isopropyl alcohol. Spread the tweezer tips to clamp around the swab and draw them across the swab to clean the tips.

3. If there is more that one part of a value, remove the part from the strip then return the remaining parts to the parts sheet in their original location and cover them with the strip of tape. The tape used to hold the components to the sheet is special Scotch removable tape so that the parts can be returned to the strip and tacked down or repositioned several times.
4. Orient all resistors in the same direction on the PCB so that they can more easily be read and identified after installation. Use the same orientation as is used on the PCB silk screen.
5. As you go through each assembly section check off components in the square box beside the component identifier as you install devices.
6. All components are mounted on the PCB's top side.

1. Install components on the top side of the PCB in the following order.

- ☐ L1 10uH
- ☐ U1 LT1372
- ☐ C4 10uF 35V (1206)
- ☐ C3 10uF 35V (1206)
- ☐ C2 10uF 25V
- ☐ C1 10uF 25V
- ☐ D1 SS14 (observe polarity)
- ☐ D2 1N4001 (observe polarity)
- ☐ Q4 SQ2361
- ☐ R10 110k
- ☐ R9 110k
- ☐ R1 124k
- ☐ R2 6K19
- ☐ R4 33k
- ☐ D3 LWL883 LED – install only if no external LED is used
- ☐ Q1 BC847
- ☐ R5 8k2
- ☐ R6 5k6
- ☐ R7 1K0
- ☐ R8 47k – install only for low power option
- ☐ Q2 BC847 - install only for low power option
- ☐ R15 47k – install for active low then do NOT install R14
- ☐ R13 47k
- ☐ Q5 BC857
- ☐ R14 0R – install for active high then do NOT install R15
- ☐ R3 9k1
- ☐ C6 4.7nF
- ☐ C5 47nF
- ☐ R12 2k0
- ☐ R11 220k
- ☐ C7 1nF
- ☐ Q3 BC847
- ☐ R16 33k (0603) tuck between Q3's base & emitter leads & solder. There is no silk screen identification for this part.

Carefully check the PCB for shorts or poor solder joints. Either R14 or R15 should be missing. R8 and Q1 should not be populated unless the low power option is installed.

2. *Wire the PCB I/O to the relay and external components*

- Mount the PCB onto the relay

Measure and record the relay coil resistance

- Relay coil resistance __________ Ohms.

Connect the PCB pads as follows

- 24V pad connects to the relay coil positive
- GND pad connects to the relay coil negative
- The second GND connects to wires leading to the battery or supply ground
- Vin connects to wires leading to the battery or supply positive terminal

The second Vin can be used for an active high push button switch connection described in the next section

- SCom is wired to the relay sense contacts common terminal
- LED+ is connected to an external LED anode if used
- LED- is connected to an external LED cathode if used
- If neither an external nor internal LED is used solder a short jumper wire between LED+ to LED-.
- S_NO pad is wired to the relay sense contact normally open terminal
- SOut is wired to a system relay state sensor input

SWin connects to a normally high or low driver to energize the relay. In the next section it will be used to temporarily connect to a push button switch for testing. The ground adjacent to SWin can be used by an active low switch.

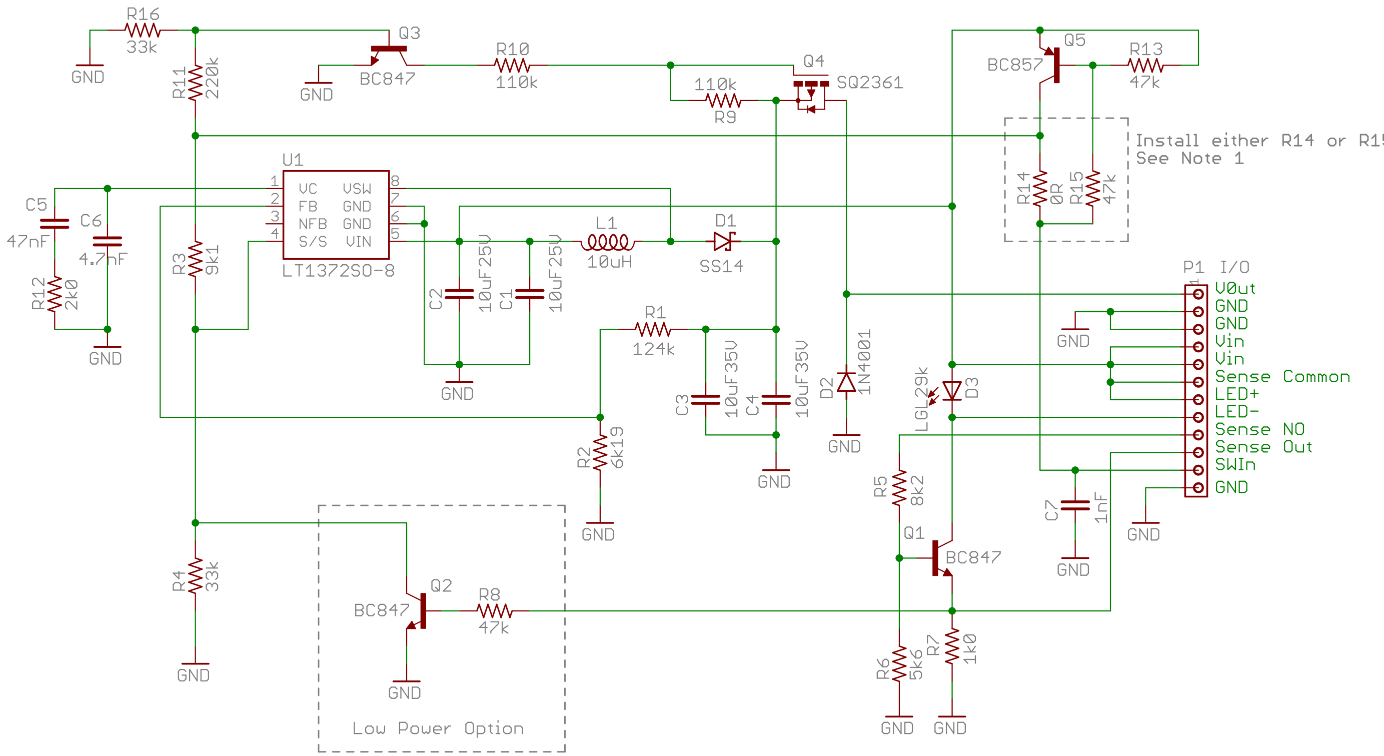
3. *Test the boost converter*

This test verifies the boost converter functionality with local control.

1. Solder temporary wires to a SPST NO push button from the PCB I/O pads as follows
   - For an active low configuration solder wires to the SWin and adjacent GND pad.
   - For an active high configuration solder wires to the SWin and unused Vin pad.
2. Adjust a variable regulated supply to 13.8V. Current limit it to 0.5A if possible then switch it off.
3. Measure the relay coil resistance now that it’s connected to the PCB. It should be in the 300 Ohm range and should not be different from the readings taken in step 2. If it’s under 30 Ohms (1 Amp at 28 Volts) or a short find out what’s wrong before applying power or you may damage the converter board.
4. Connect the leads going to the PCB Vin and GND pads to the power supply and turn it on. The relay should NOT energize.
5. Close the push button. The relay should energize and the LED if installed should light. Release the push button. The relay should return to the off state.
6. With the relay energized measure the voltage from the SOut pad to ground. It should be between 4.5 and 4.7 Volts.
   - Voltage at SOut __________ Volts.
7. Test the relay function over its input supply voltage by varying the power supply voltage from 10 to 15 volts and then activate the relay.
8. Disconnect the relay from the supply and remove the temporary push button connections.

Switching Boost Regulator Parts List

Qty	Value	Device	Part ID	Source	Part No.
Resistors					
1	0R	RESISTOR 0805	R14	Digikey	311-0.0ARCT-ND
1	1k0	RESISTOR 0805	R7	Digikey	311-1.10KCRCT-ND
1	2k0	RESISTOR 0805	R12	Digikey	311-2.00KCRCT-ND
1	5k6	RESISTOR 0805	R6	Digikey	311-5.60KCRCT-ND
1	6k19	RESISTOR 0805	R2	Digikey	311-6.19KCRCT-ND
1	8k2	RESISTOR 0805	R5	Digikey	311-8.20KCRCT-ND
1	9k1	RESISTOR 0805	R3	Digikey	311-9.10KCRCT-ND
1	33k	RESISTOR 0805	R4	Digikey	311-6.19KCRCT-ND
1	33k	RESISTOR 0603	R16	Digikey	311-33.0KHRCT-ND
3	47k	RESISTOR 0805	R8,R13,R15	Digikey	311-47.0KCRCT-ND
2	110k	RESISTOR 0805	R9,R10	Digikey	311-110KCRCT-ND
1	124k	RESISTOR 0805	R1	Digikey	311-124KCRCT-ND
1	220k	RESISTOR 0805	R11	Digikey	311-220KCRCT-ND
16	***Resistors***				
Capacitors					
1	1nF	CAP_NONPOLARIZED 0603	C7	Digikey	490-1494-1-ND
1	4.7nF	CAP_NONPOLARIZED 0603	C6	Digikey	490-3192-1-ND
1	47nF	CAP_NONPOLARIZED 0603	C5	Digikey	445-1313-1-ND
2	10uF25V	CAP_NONPOLARIZED 0805	C1,C2	Digikey	490-5523-1-ND
2	10uF35V	CAP_NONPOLARIZED 1206	C3,C4	Digikey	587-2484-1-ND
7	***Capacitors***				
Inductors					
1	10uH NR40	INDUCTOR_Taiyo Yuden_NRS4018T100M	L1	Digikey	587-2886-1-ND
1	***Inductor***				
Diodes & Transistors					
3	BC847	NPN SOT23-3	Q1,Q2,Q3	Digikey	568-4867-1-ND
1	SQ2361	PCH MOSFET SOT2-3	Q4	Digikey	SQ2361EES-T1-GE3CT-ND
1	BC857	PNP SOT23-3	Q5	Digikey	568-6082-1-ND
1	SS14	DIODE SCHOTTKY SMA	D1	eBay	Ele-Parts
1	1N4001	DIODE SMA	D2	eBay	ICMarket2009
1	LGL29k Grn	Smart LED Green 0603	D4	Digikey	475-2709-1-ND
8	***Devices***				
IC's					
1	LT1372	LT1372CS8#PBF SW REG SO-8	U1	Digikey	LT1372CS8#PBF-ND
1	***IC***				
Hardware					
2	4-40	3/4" Screws			
2	4-40	Nuts			
2	4-40	Lock Washers			
1	PCB	30x30mm 2 layer plate through holes			
7	***Pieces***				



Notes

1 SwIn can be active low or high depending on which resistor is installed
   Active high install R14 and do not install R15
   Active low install R15 do not install R14
2 LED D3 can be installed either on board or off but not both
3 L1 is a Taiyo Uden NRS4018 series inductor
4 Do not install Low Power Option Q2 & R8 before verifying relay suitability

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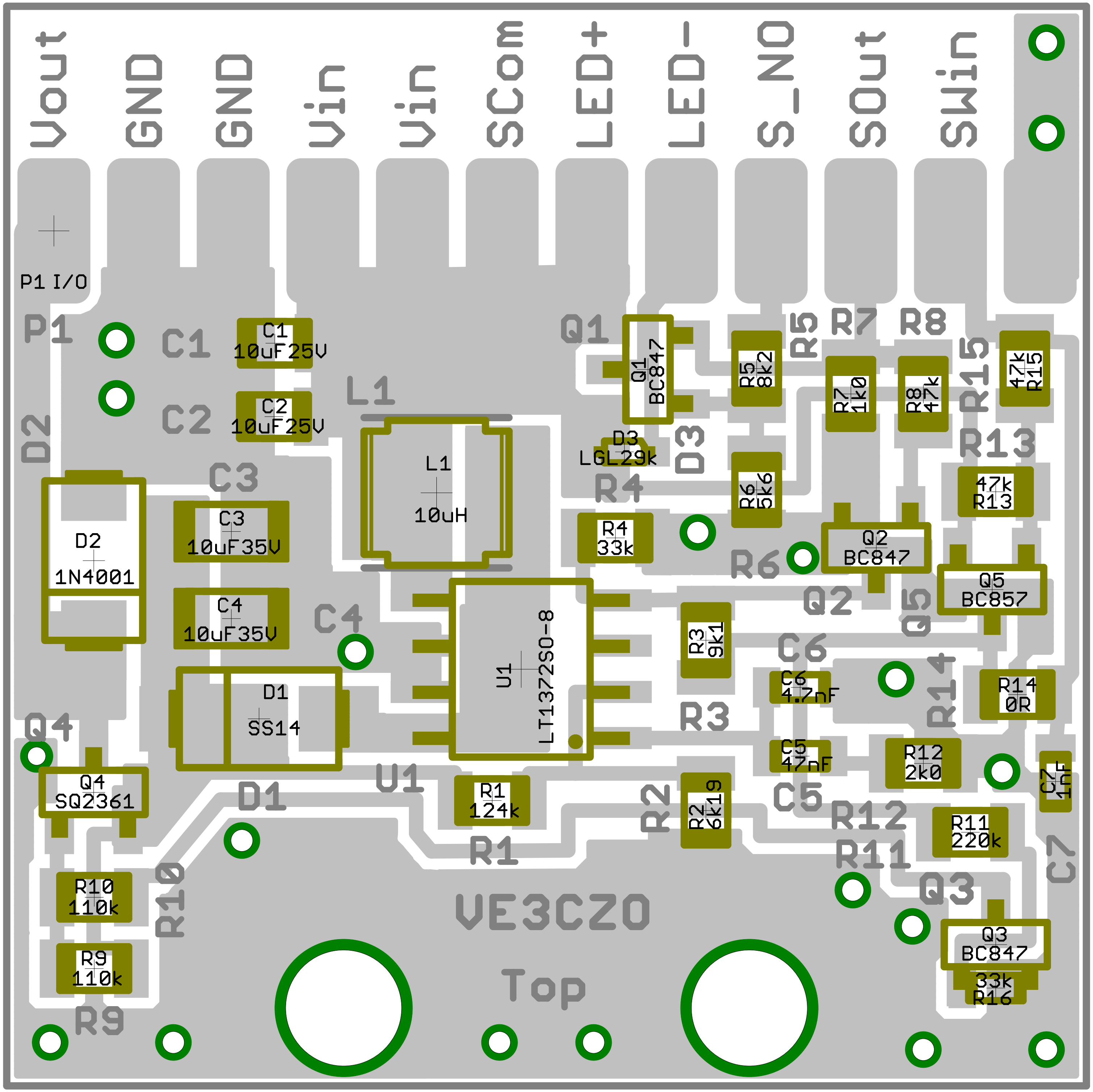
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GND
GND
Vin
Vin
SCom
LED+
LED-
S_NO
SOut
SWin
P1 I/O
P1
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C2 10uF25V
C3 10uF35V
C4 10uF35V
L1 10uH
D2 1N4001
D1 SS14
D3 LGL29k
Q1 BC847
Q2 BC847
Q3 BC847
Q4 SQ2361
Q5 BC857
U1 LT1372SO-8
R1 124k
R2 6k19
R3 9k1
R4 33k
R5 8k2
R6 5k6
R7 1k0
R8 47k
R9 110k
R10 110k
R11 220k
R12 2k0
R13 47k
R14 0R
R15 47k
R16 33k
C5 47nF
C6 4.7nF
C7 1nF
VE3CZO
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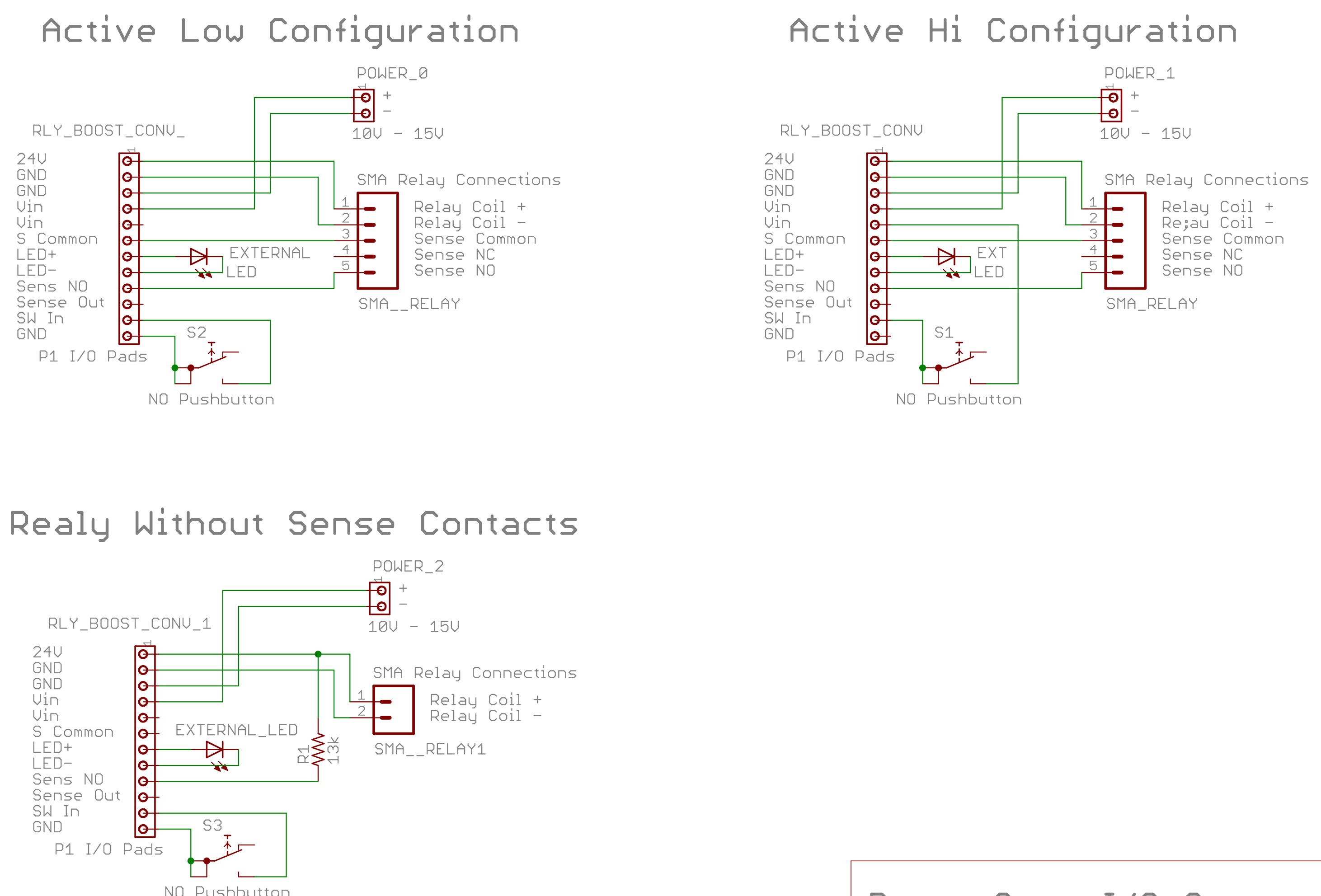

Notes
1 S3 shown wired for active lo but the controller can be configured for either active hi or low

Boost Conv I/O Connections	
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