A new power brick for the Commodere 64

or designing a switched mode power supply with discrete components

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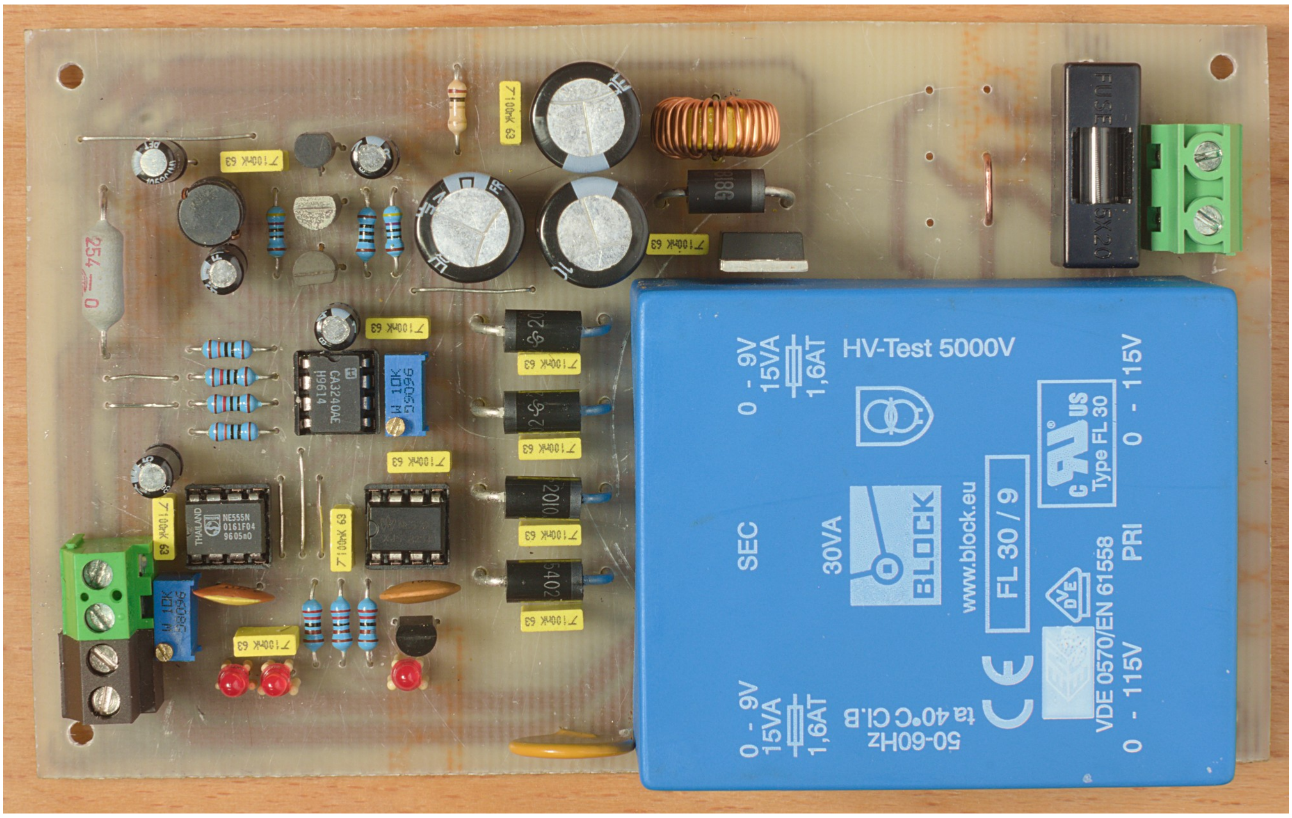


Abtract

When I purchased a Commodore 64 home computer, the power brick was slowly dying. Because of that, it was not save to power on the computer. Repairing it was not an option, as the power brick is sealed in epoxy resin. An other solution had to be found.
I like to do things the hard way, so I decided to design and build a new power supply out of discrete components. It had to be a switched mode power supply, of course. Because of safety reasons I did use a normal transformer to step down the mains voltage to 9 volts AC, but after that a buck converter regulates the voltage to 5 Volts DC.
And because I like the good old 555 timer IC, I used two of these in the regulator circuitry. Just because I could!

Original power supply

A common problem with the Commodore 64 power brick as that the 5 Volt output, in time, slowly drifts out of specification. And when it goes above 5.5 Volts the magic smoke could escape out of your computer. And you will not be able to put it back in, so be warned!
As the power supply which came with my computer is completely potted in epoxy resin, repairing it is not an option. The only option is to replace it with something else.

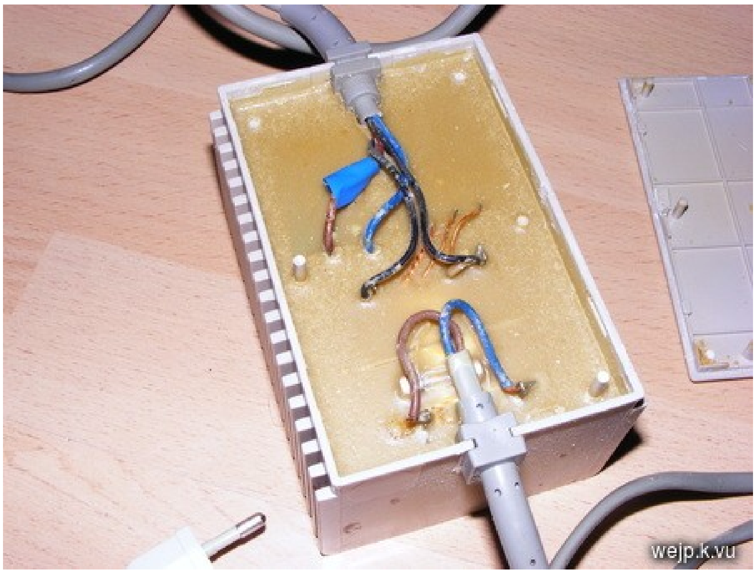


Image 1: inside an original power brick

New power supply

I could have bought one of the many aftermarket Commodore 64 power supplies available, but than would be too easy. So I decided to design a new power supply myself.
It had to be more or less authentic, meaning that, in theory at least, it could have been made in the 80s. It also had to be more efficient than the original power brick, which had a linear regulator heating up the epoxy resin. And it had to use at least one 555 timer, just because that’s cool!

The design constrains of the new power supply are modest:

- 9 Volt AC / 1 A
- 5 Volt DC / 1.7 A
- galvanically isolated from each other

The block diagram shows an overview of the new power supply. It is very simple as all the magic is in the AC/DC block.

The maximum current of 1.7 Ampere comes from the specifications of the power supply that came with my Commoder 64. This is slightly higher than the 1.5 Ampere shown in the original Commodore drawing.

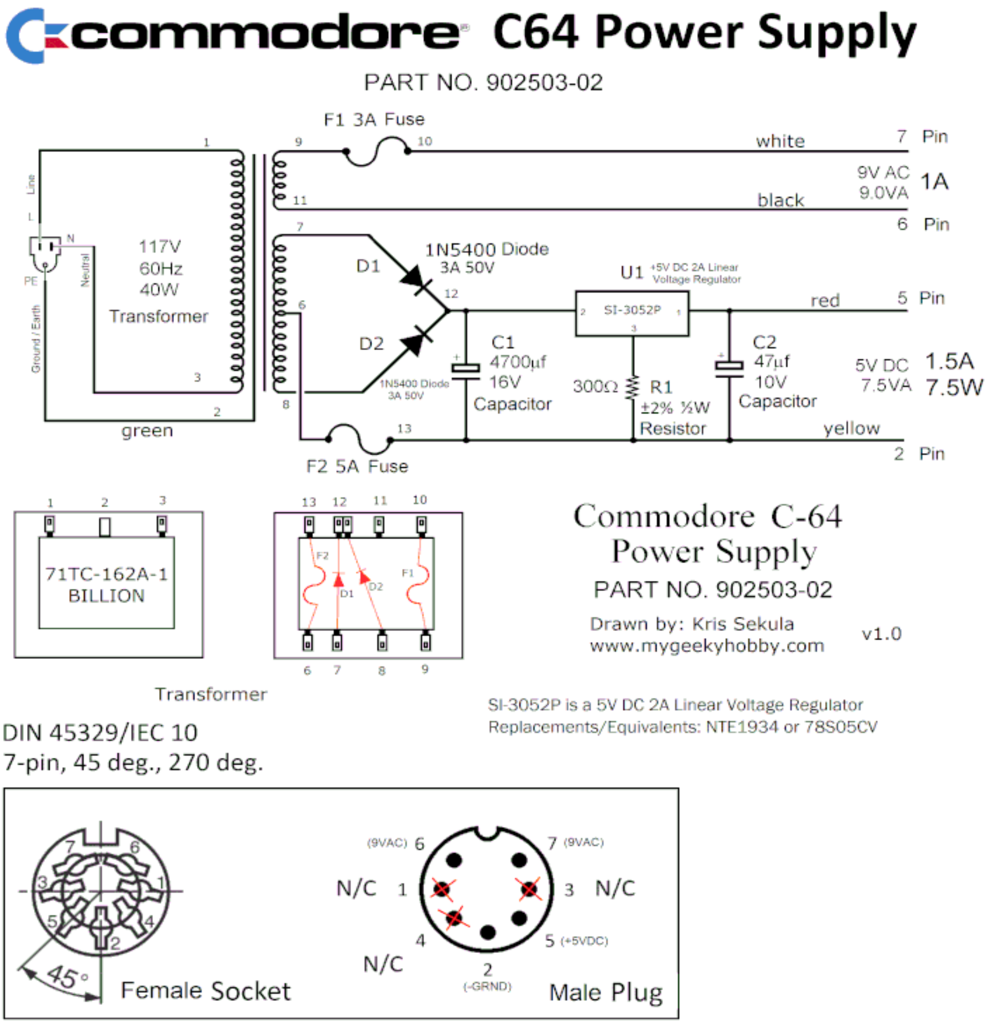


Image 2: Schematic of the original Commodore 64 power supply

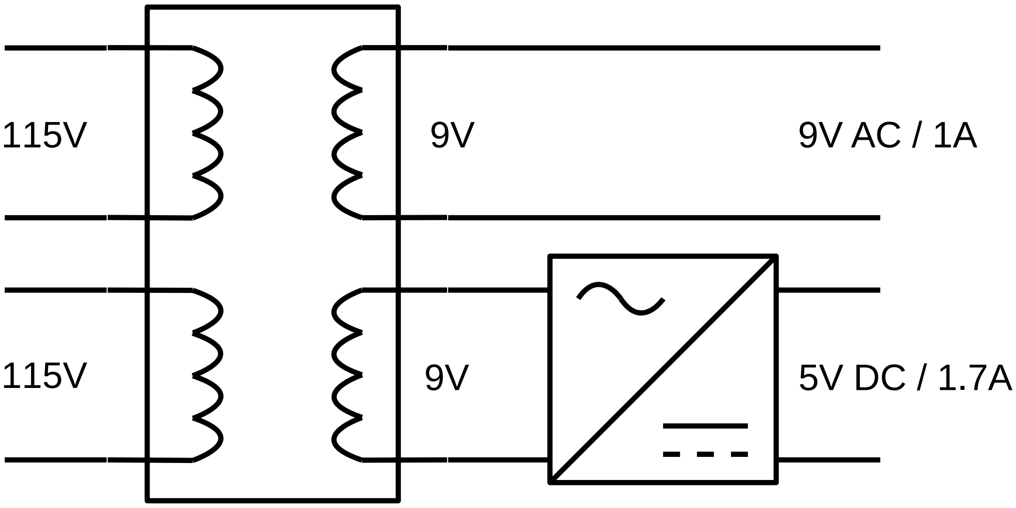


Image 3: Block diagram of power supply

The design

The heart of the power supply is the buck converter, consisting of a FET, a diode, a inductor and a capacitor.

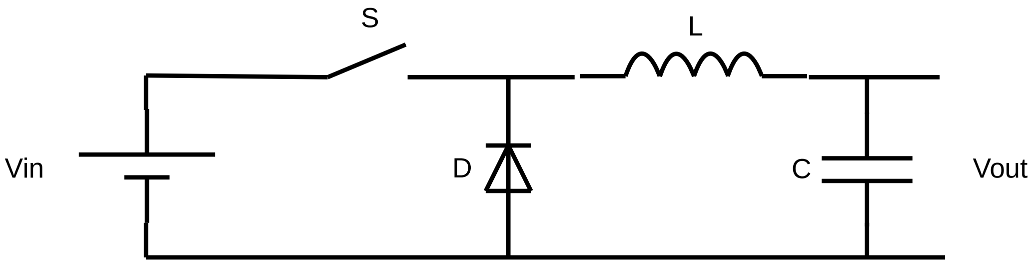


Image 4: Buck converter

When the switch closes, a current can flow through the inductor. This current increases linearly until the switch opens again. The current is interrupted, but the current in the inductor cannot stop instantly, and the current now flows through the diode while it decreases linearly until the switch closes again or the current becomes zero. In the latter case, the current remains zero until the switch closes again. Now, the cycle repeats. The capacitor smooths the voltage across the output.
The output voltage is equal to Vin * duty-cycle. With an input voltage of 12 Volt and a duty cycle of 40%, the output voltage is 12 * 0.4 ≈ 5 Volt.
This is only true when the buck converter is loaded such that the current trough the inductor never reaches zero. This is called continuous current mode.
Below a certain value of the load, the current through the inductor becomes zero for a portion of the clock cycle. This is called discontinuous current mode. In this mode the equation Vout = Vin * duty-cycle does not apply any more and the output voltage rises when the duty cycle stays the same. Therefore, the duty cycle has to change. An active regulator in the feedback loop can take care of this.

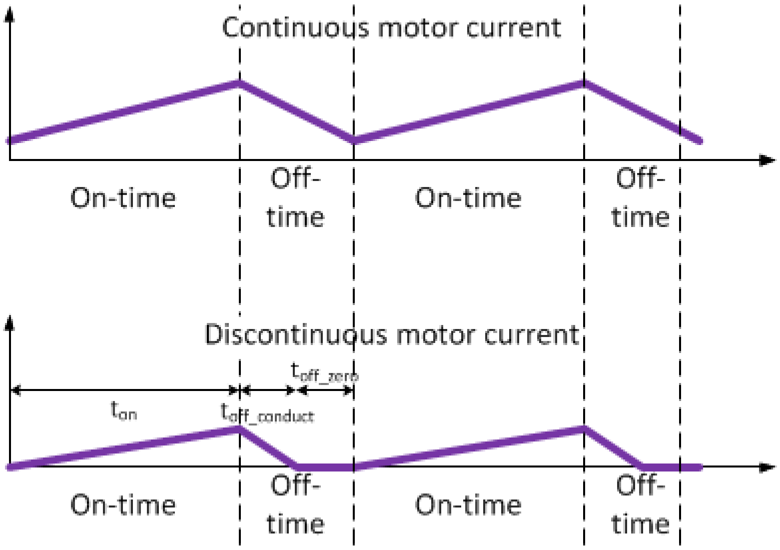


Image 5: Continuous and discontinuous current modes in a buck converter (motor current = inductor current)

The image shows the current trough the inductor (here called motor) in both continuous and discontinuous current modes.

The block diagram shows the circuit I designed. The clock signal is a saw tooth. The comparator compares the value of the saw tooth with a reference voltage and generates a RESET signal for the flip-flop when the saw tooth is higher than the reference voltage. Every period of the clock, a RESET signal is generated. The used flip-flop only resets when no SET-signal is present: an important detail of this solution.

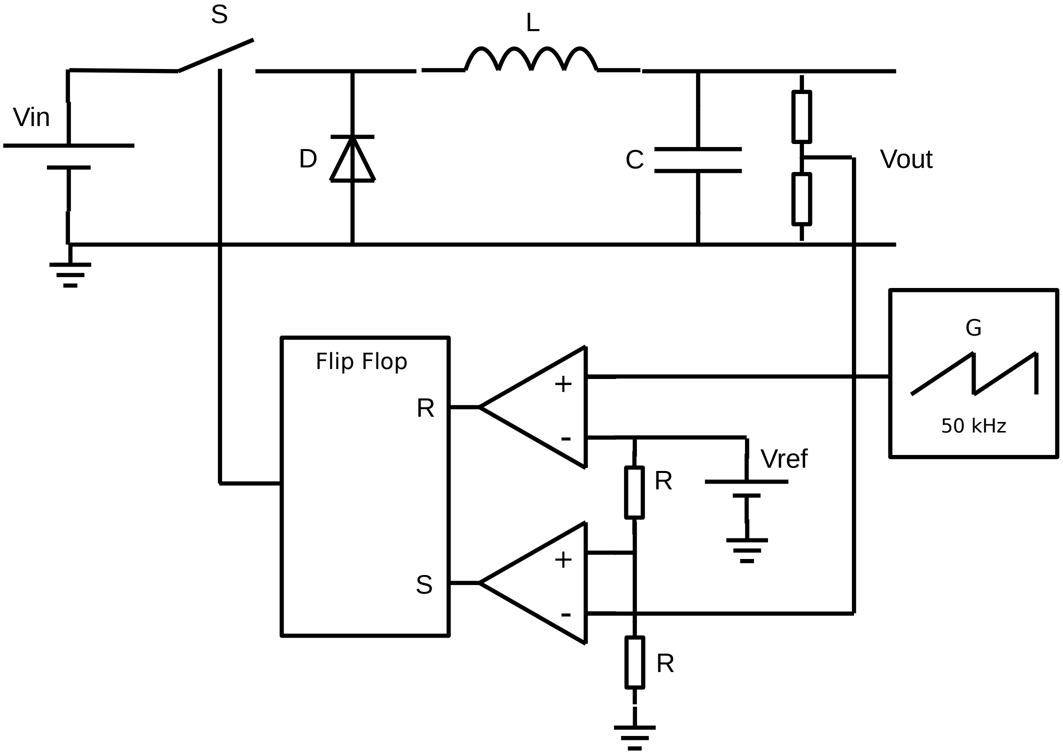


Image 1: Feedback regulator

An other comparator compares the output voltage of the power supply with half the reference voltage. When the output voltage drops below this value, the flip-flop is SET.

Lets analyze the circuit from the moment it is switched on and lets assume it is working in continuous current mode.

The output voltage is zero and therefore lower than half the reference voltage. The SET-input of the flip-flop is HIGH and the switch closes. The output of the buck converter rises until it becomes higher than half the reference voltage. The SET-input goes LOW, but the flip-flop remains in the SET position. Within one period of the clock signal, the flip-flop receives a RESET from the upper most comparator. The switch opens again.

Now, the output voltage lowers until it becomes lower than halve the reference voltage and the flip-flop gets a SET-signal again. The switch closes and the cycle repeats.

In Continuous Current Mode the duty-cycle will stabilize to the value given by the equation Vout/Vin.

The maximum duty cycle is 100% and the minimum duty cycle is a function of the slope of the saw tooth signal and half the reference voltage, which is the difference between the reference of the upper and the lower comparator.

The duty cycle can not go below this value. In stead, the controller will skip pulses because the output voltage stays above half the reference voltage for longer than the period of the clock signal. This is called: 'pulse skipping'.

I choose to use two 555 timers for the voltage regulation. Not just because I like the good old 555, but also because these integrated circuits are perfect for the job.

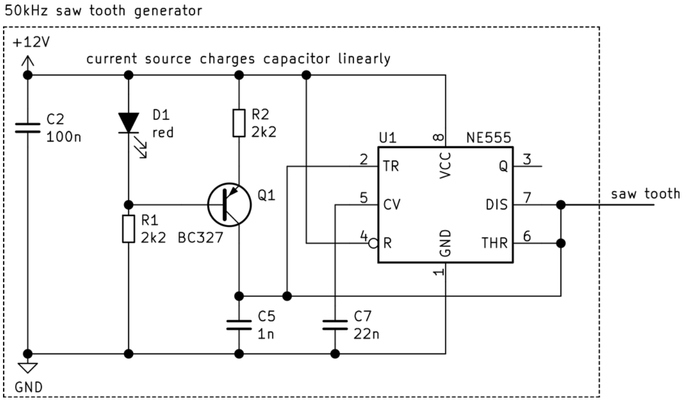


Image 6: Saw tooth generator build with a 555 timer

A circuit with a 555 generates the saw tooth signal. Capacitor C5 is charged via a current source (Q1, D1 and R2). This way, the voltage rises linearly. When the voltage comes above a certain threshold, the 555 discharges the capacitor in a very short time. The capacitor charges again via the current source and a saw tooth signal is present across the capacitor. This signal is fed to the next stage of the regulator.

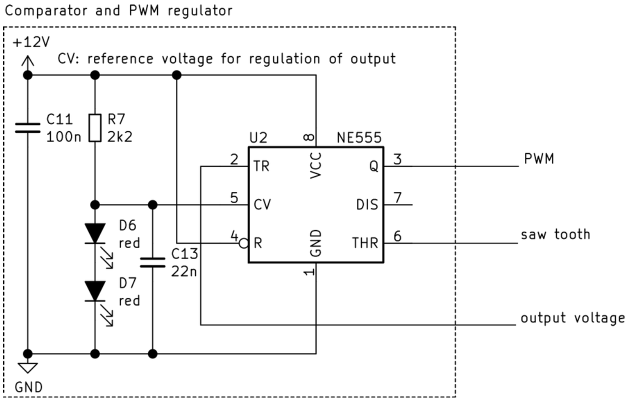


Image 7: Voltage regulator

The regulator is also build with a 555, but in a more complex configuration: the 555 has two comparators and a flip-flop inside. Just like shown in the block diagram above.

A reference voltage, generated by two LEDs in series is present at the CV-input. I could have uses a zener diode, but my junk box is full of LEDs, so I choose to use these.

The saw tooth is present at the threshold-input and a part of the output voltage of the buck converter is fed to the trigger input via a potentiometer. The PWM signal is present on the output of the 555. This signal goes to the switching FET.

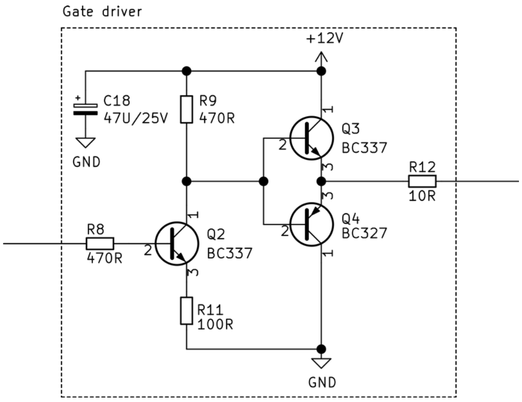
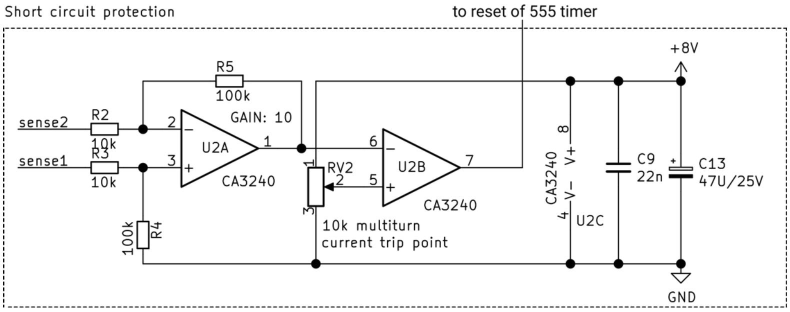


Image 8: FET driver

As the gate of the FET has a high input capacitance, a lot of current is needed to switch it on and off. A special FET-driver takes the relative weak control signal from the 555 timer as an input and amplifies it to a strong signal for the FET.



Afbeelding 9: Short circuit protection

Because the Commodore 64 uses an external power supply, it is important that this power supply has an overload protection. When for some reason, the output of the power supply is short circuited, the power supply, or worse, the Commodore 64 can be damaged.

I designed a simple, but effective overload protection for the buck converter.

A shunt resister is placed in series with the output of the power supply. A differential amplifier (U2A) measures the voltage across this sense resistor and amplifies it 10 times. This signal is fed into a comparator (U2B) and compared against a reference set by RV2. When the voltage (and therefore the output current) comes above a certain value, the output of the comparator switches from high to low and the voltage regulator gets a reset signal. When the over current condition disappears, the reset signal to the voltage regulator disappears. Because this current limiter is part of the feedback loop, the current is now limited to a preset value. In other words, the power supply acts as a constant voltage source below the maximum current set by RV2 and as a constant current source above the maximum current set by RV2.

Adjusting

The power supply must be adjusted before it can be used.

With no load at the output, adjust RV1 so that the output of the power supply is 5.00 Volt.

Next, short the output with a current meter and adjust RV2 so that the output current is 2 Ampere.

Bill of material C64 power supply Rev. 2

Date: 2020-10-21

Quantity	References	Value	Description	Manufacturer	Ordering #	Conrad #	Note
1	C5	1n	Ceramic capacitor	Kemet	R82EC1100AA50K	1235242	
3	C10 C11 C16	2200U/25V	Electrolytic capacitor	Panasonic	EEU-FR1E222L	1476100	
14	C2 C3 C4 C6 C7 C8 C9 C12 C14 C15 C19 C20 C21 C22	22n	Ceramic capacitor	Kemet	R82EC2220AA50K	1235248	
5	C1 C13 C17 C18 C23	47U/25V	Electrolytic capacitor	Panasonic	EEUFR1E470H	792077	
4	D2 D3 D4 D5	1N5403	Diode	Vishay	1N5402-E3/54	564862	
1	D8	SB540	Schottky diode	Vishay	SB540-E3/54	164089	
3	D1 D6 D7	red	Light emitting diode	Vishay	TLUR4400	1125485	
1	F2	0.5AT	Fuse holder	ESKA	503500	533866	Also place protection cap (Conrad #535184) and fuse (0.5AT 5x20mm)
1	F1	1.5A	Resettable fuse	Bourns	FRX160-60F	524898	
1	J1	MAINS	Screw terminal	Degson	DG129-7.5-02P-14-00AH	1327240	
1	J2	POWER OUT	Screw terminal	PTR	50350040001F	732129	
1	L1	3.3UH	Inductor	Tru Components	1589086	1589086	
1	L2	47UH/4A	Inductor	Tru Components	1381109	1568957	
2	Q1 Q4	BC327	Transistor PNP	Diotec	BC327-40BK	140535	
2	Q2 Q3	BC337	Transistor NPN	Diotec	BC337-40	140536	
1	Q5	IRF9540N	HEXFET P-Channel MOSFET	Infineon	IRF9540NPBF	162537	
1	R10	0R1/1W	Resistor	VitrOhm	CR254-05T 0R1	458060	
1	R11	100R	Resistor	Generic	100R 1% 0.6W	1557059	
2	R4 R5	100k	Resistor	Generic	100k 1% 0.6W	1557185	
1	R12	10R	Resistor	Generic	10R 1% 0.6W	1557481	
2	R2 R3	10k	Resistor	Generic	10k 1% 0.6W	1557185	
3	R1 R6 R7	2k2	Resistor	Generic	2k2 1% 0.6W	1557513	
2	R8 R9	470R	Resistor	Generic	470R 1% 0.6W	1557322	
2	RV1 RV2	10k multiturn	Potentiometer	Bourns	3296W-1-103LF	447277	
1	SW1	SW_DPDT_x2	Switch, dual pole double throw	Marquardt	4021.4620	704503	
1	TR1	9V/30VA	Transformer	Block	FL 30/9	710586	
1	U2	CA3240	Opamp	Generic	CA3240AE		
2	U1 U3	NE555	Timer	Generic	NE555P	152184	

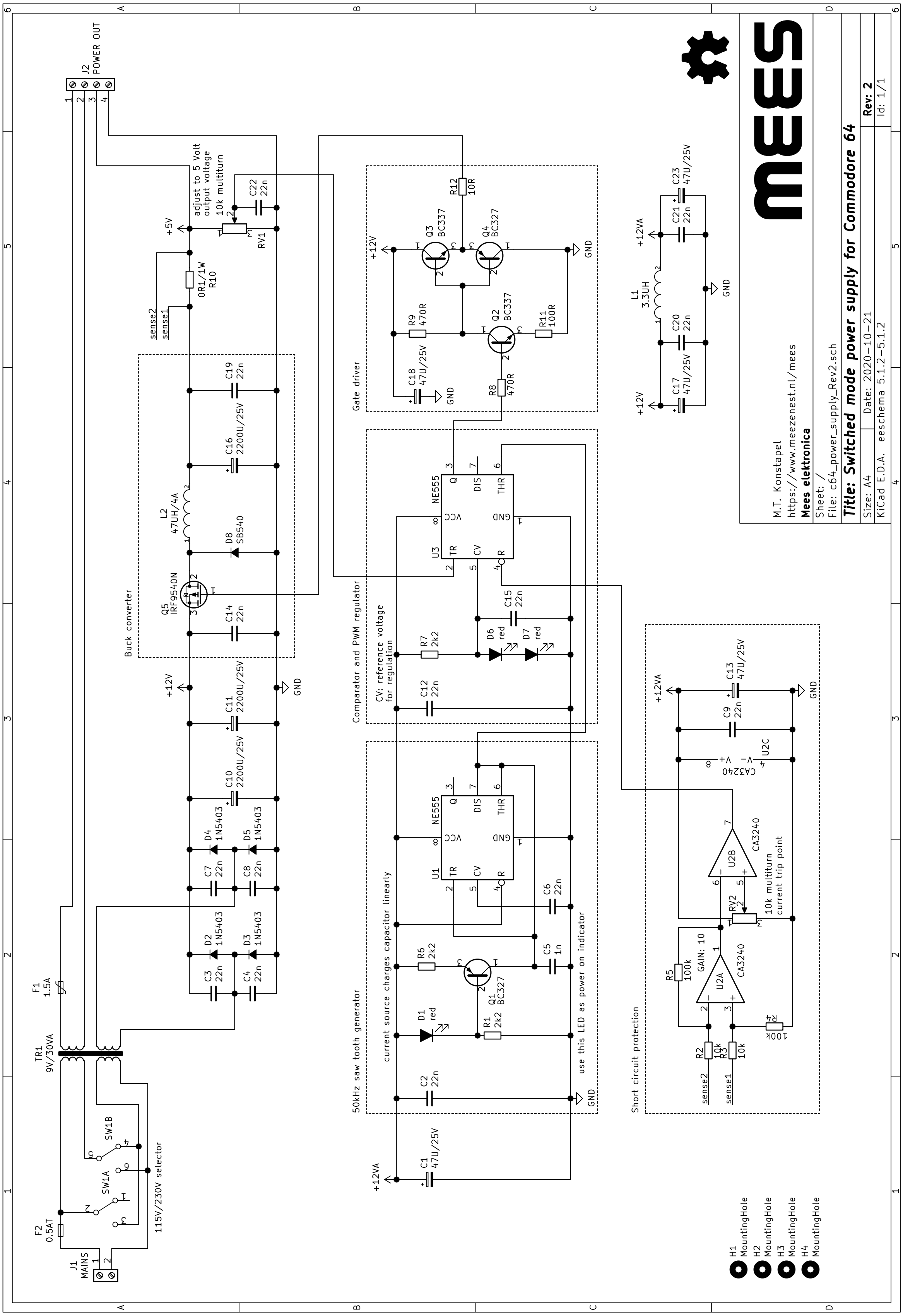


Image 10: Full schematic

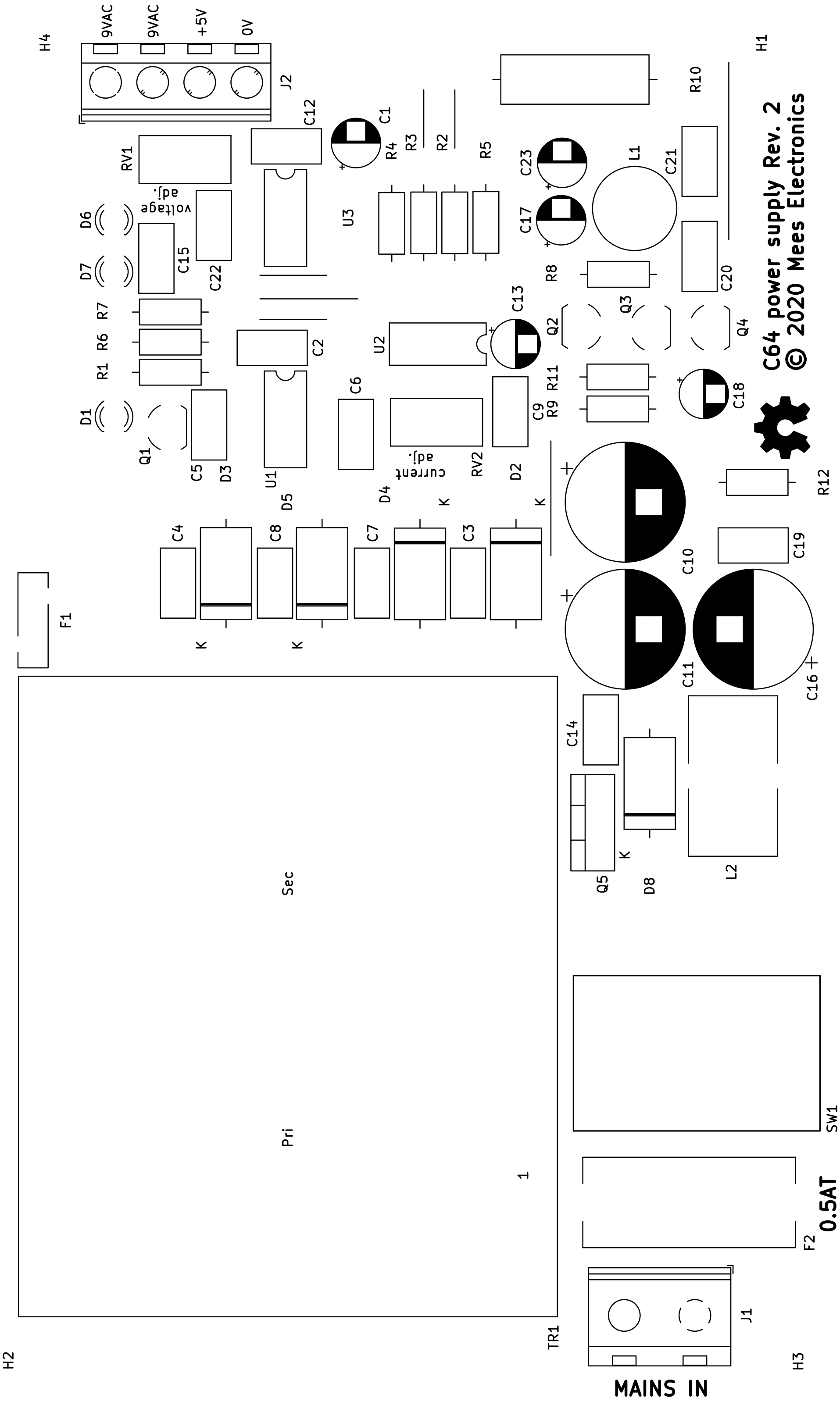


Image 11: Component placement

Do not forget to place 7 wire bridges on the PCB.