

Jaldi Charger Hardware Design

AirJaldi
2007

Table of Contents

1. Version.....	3
2. Terminology.....	4
3. Specification	5
3.1 Functionality	5
3.2 Modularity.....	5
3.3 Electrical requirements	5
3.4 Protection circuits	6
3.5 Physical parameters	6
4. Design	7
4.1 Block diagram.....	7
5. Detailed function description	8
5.1 Charger.....	8
5.2 LVD	9
5.3 POE + surge protection.....	10
6. Tuning and Testing	11
6.1. Charger unit tuning	11
6.2. LVD unit tuning.....	11
7. Schematics	12
7.1. Charger unit	12
7.2. LVD	12
7.3. POE + surge protection.....	13
8. PCB layout	14
9. Simulations	15
9.1. Simulated circuit (LVD)	15
9.2. Normal functionality.....	15
9.3. Reversed battery polarity	16
10. Notes	17
11. References.....	18

1.Version

<i>Version</i>	<i>Date(dd.mm.yyyy)</i>	<i>Author</i>	<i>Comments</i>
V.1.3	22.06.2007	Pauli Narhi	First documented version
V.1.3.1	25.06.2007	Pauli Narhi	Terminology, Schematics and PCB layout added
V.1.3.2	26.06.2007	Pauli Narhi	Chapters 6, 10 and 11 added, minor changes in chapters 4 and 5.
V.1.5	11.07.2007	Pauli Närhi	Changes on schematics: solderpads and power resistor added for fan. PCB made a few mms shorter.
V.1.6	12.07.2007	Pauli Närhi	Changes on schematics: screw terminal for remote temperature element added.
V.1.6.1	12.07.2007	Pauli Närhi	Minor changes in chapters 2, 3, 5 and 10. Added component types for Q1 and Q2, fixed C1 value.
V.1.6.2	23.07.2007	Pauli Närhi	Schematics updated and copied to chapter 5. Tuning manual added.
V.1.6.3	24.07.2007	Pauli Närhi	Added note about malfunctioning LVD- delay in chapter 10.

Table 1 Version

2. Terminology

2.1 LVD

- **Low Voltage Disconnect.** Circuit used to protect batteries from harmful deep discharging. Disconnects load from battery when battery gets empty (terminal voltage drops to about 11V for a 12V battery)

2.2 POE

- **Power Over Ethernet.** Technique used to deliver operating voltage (in our case 12-48Vdc) through Ethernet cable along with data. For new routers we are using **IEEE 802.3af standard using spare pairs** a.k.a **New Cisco Standard**. Note that most of our routers are still using old standard that uses totally reversed polarity.

2.3 PCB

- **Printed Circuit Board.** In electronics, printed circuit boards, or PCBs, are used to mechanically support and electrically connect electronic components using conductive pathways, or *traces*, etched from copper sheets laminated onto a non-conductive *substrate*. Source: Wikipedia. We are producing our own PCBs using Press-n-Peel technique. Nice guide on making PCBs this way: <http://max8888.orcon.net.nz/pcbs.htm> A detailed guide of making Jaldi Charger PCBs is under construction.

2.4 PSU

-
- **Power Supply Unit.** An external (so far) unit that produces operating voltage (17-18Vdc) for our charger. PSU takes its power from mains (100-220Vac)

2.5 C-rate

- The charge and discharge current of a battery is measured in C-rate. A discharge of 1C draws a current equal to the rated capacity. For example, a battery rated at 1000mAh provides 1000mA for one hour if discharged at 1C rate. The same battery discharged at 0.5C provides 500mA for two hours. At 2C, the same battery delivers 2000mA for 30 minutes. 1C is often referred to as a one-hour discharge; a 0.5C would be a two-hour, and a 0.1C a 10 hour discharge.
- Source: [Batteries In a Portable World](#)

3.Specification

3.1 Functionality

Jaldi Charger V.1.1 (and newer) provides four main functions as follows:

- 3.1.1 Battery charge control
 - Charge voltage regulation
 - Charge current limiting
 - Charge voltage negative temperature compensation
- 3.1.2 LVD
 - Low battery voltage limit (adjustable)
 - Delay on connecting and disconnecting load
 - Voltage hysteresis between load disconnection and reconnection.
- 3.1.3 POE injector
 - Screw terminal for feeding battery voltage over ethernet cable
- 3.1.4 Surge protection
 - Protection against surges coming through ethernet cable

3.2 Modularity

- All functions as mentioned above are modular, meaning that user can select to include one or more functions as needed easily by placing relevant components on pcb.

3.3 Electrical requirements

Jaldi Charger V.1.1 (and newer) has following electrical requirements:

- 3.3.1 Input voltage
 - 17-25Vdc (17-18Vdc for best efficiency)
- 3.3.2 Input current (required min.)
 - 2.5A (can be adjusted to be smaller if small battery and load used)
- 3.3.3 Output voltage
 - 13.5-14Vdc

- 3.3.4 Output current (max.)
 - 2.25A (can be adjusted to be smaller if small battery and load used)
- 3.3.5 Battery type to be used
 - Lead acid, capacity 7-120Ah

3.4 Protection circuits

- 3.3.1 Reversed battery polarity protection
 - Charger unit protected by diode and fuse that burns if reversed polarity occurs
 - LVD and POE protected by P-type MOS-FET, no burning fuses
- 3.3.2 Over current and short circuit protection
 - Charger unit protected by 5A fuse
 - LVD and POE units protected by 2A fuse

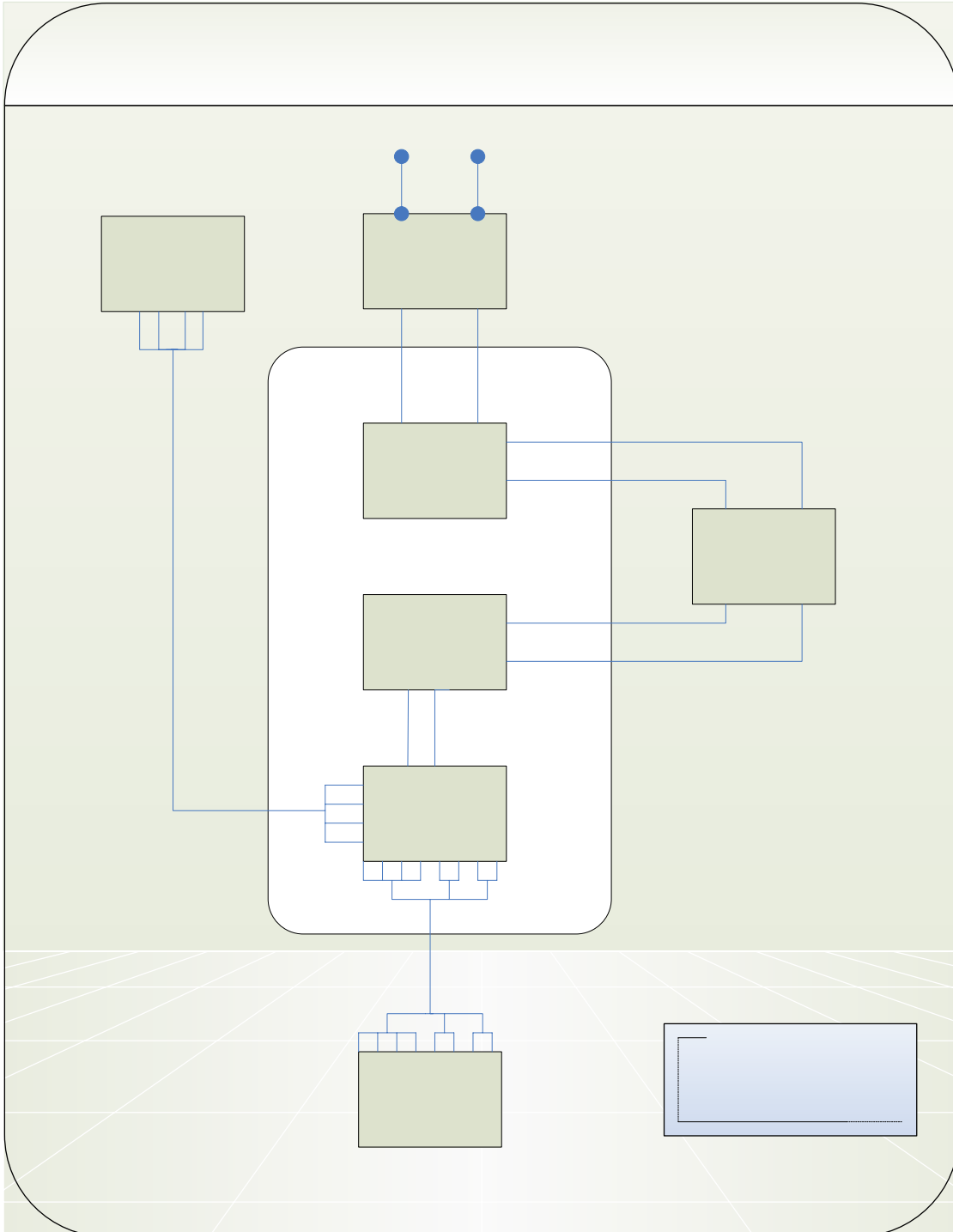
3.5 Physical parameters

- 1.3.1 PCB dimensions
 - 127mm * 87mm

4.Design

Jaldi Charger functionality is clearly divided into three functional blocks that are connected to each other and to their environment as shown in following diagram.

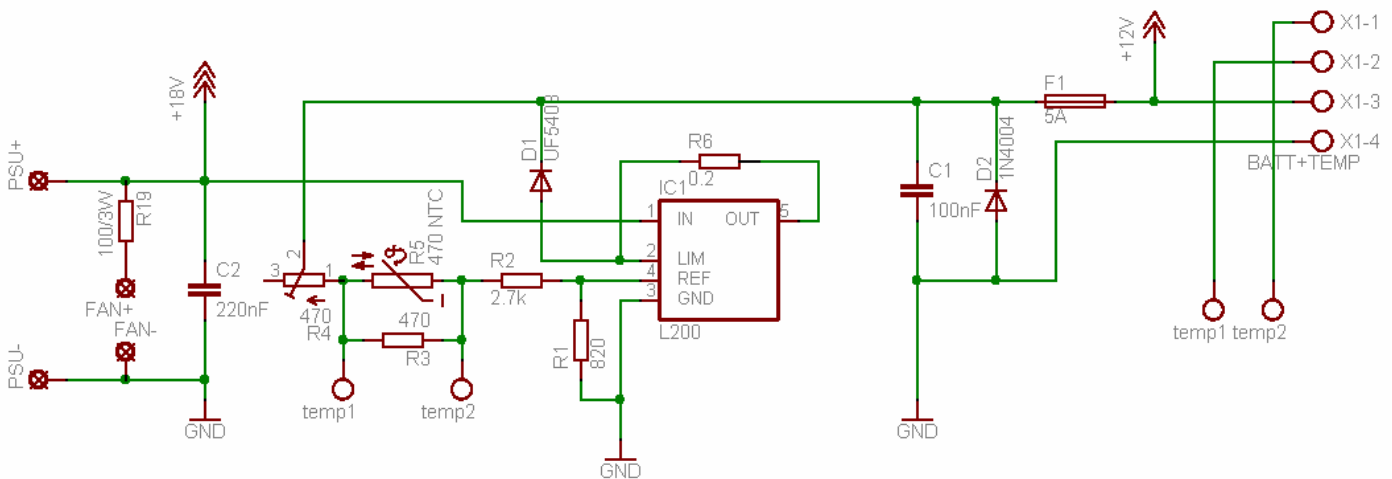
4.1 Block diagram



5. Detailed function description

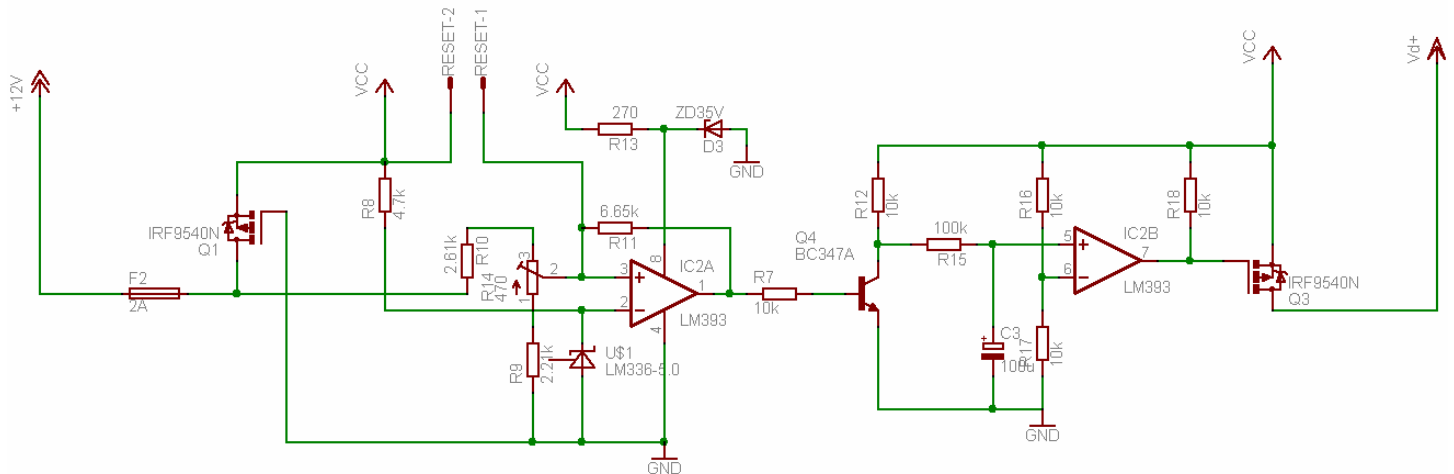
5.1 Charger

Charger unit is based on simple "Programmable Voltage Regulator with Current Limiting"- circuit found on L200 datasheet (<http://www.ortodoxism.ro/datasheets/stmicroelectronics/1318.pdf>) on page 2 (Figure 1.) The only modifications made are additional diode D1, diode D2, fuse F1 and resistor network R2-R5. Diode D1 prevents charger from drawing current from battery when PSU fails (during power failure). Diode D2 and fuse F1 provides reversed battery polarity protection causing short circuit through the fuse and burning it off when battery is connected in the wrong way. Resistor network R2-R5 forms voltage divider with resistor R2, providing output voltage selection (12.6V-14.2V@25°C) by adjusting trimmer R4 and negative temperature compensation of about -10mV/°C by NTC (Negative Temperature Coefficient) resistor R5. Output current $I_o(\max)$ is limited by resistor R6 (0.2Ω/1W) to 2.25A max. Capacitors C1 and C2 stands for reducing ripple on input and output lines and preventing regulator from oscillation caused by ripple in feedback loop. More info about L200 circuit operation can be found on "A designer's guide to the L200 voltage regulator" (http://bwir.de/downloads/L200_english.pdf)



5.2 LVD

LVD unit is based on LM393 Voltage Dual Comparator (datasheet: <http://www.national.com/ds/cgi/LM/LM193.pdf>) connected as Comparator With Hysteresis a.k.a. Schmitt Trigger (http://en.wikipedia.org/wiki/Schmitt_trigger). Stable 5.0V reference voltage is provided to comparator A inverting(-) input by LM336-5.0 Reference Diode and resistor R8. Voltage divider R9,R10,R14 is connected across battery voltage providing comparator A non-inverting(+) input comparison voltage level depending on battery state. Cut off voltage (10.4V-12.6V) can be selected by adjusting trimmer R14. Resistor R11 stands for positive feedback causing hysteresis(about 1.5V) for the comparator A. Output A drives switch transistor Q4 causing capacitor C3 to either charge or discharge through resistor R15. This slowly rising or dropping voltage connected to comparator B non-inverting(+) input is compared to voltage provided by voltage divider R16,R17 (half of supply voltage) causing delay (about 5 sec.) on state-change-situation. This delay prevents quick turn-on-turn-off situations caused by unstable mains-power. About the same LVD functionality could have been achieved by using only one comparator with capacitors at non-inverting input, but the leakage current of these capacitors would have had effect on switching states of the LVD. This is prevented by driving another comparator through transistor that "isolates" these two comparator stages from each other. Output B drives FET-transistor Q3 connecting/disconnecting voltage Vd+ (load supply voltage) to load. P-type MOSFET is used for switching instead of relay because it doesn't draw driving current. Transistor Q1 works as reversed polarity protection. Transistors Q1 and Q3 on-resistance Rds(on) is 0.20Ω causing maximum voltage drop of 0.6V (@max. load-current = 1.5A) across the LVD.



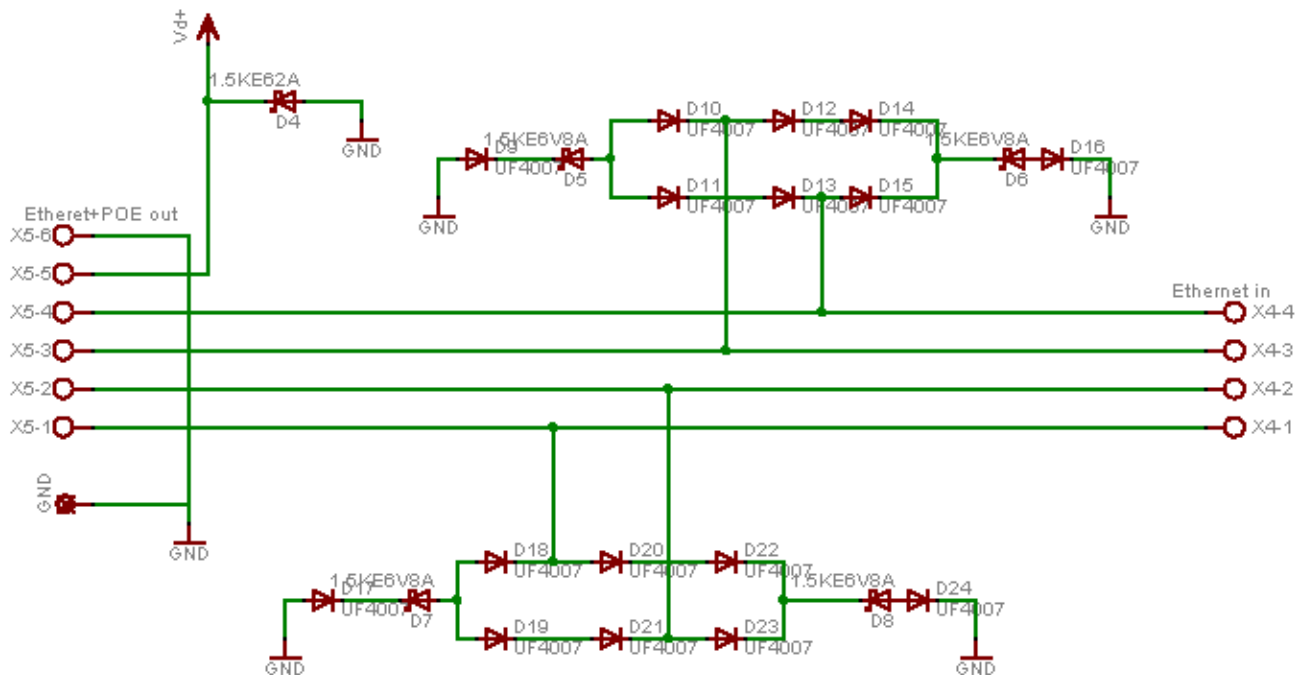
Following modifications needs to be done to LVD unit in order to use it in 12V, 24V, 36V or 48V configurations (NOTE: charger unit currently supports only 12V configuration!)

- **12V version:** replace R13 with jumper (piece of wire) and leave D26 off.

- **24V version:** replace resistor R11 with 8.2k Ω , resistor R10 with 7.15k Ω and capacitor C3 with 100uF/50V
- **36V version:** add R13 (1.5k Ω) and D26 (24V/0.4W zener), replace resistor R11 with 12.1k Ω , resistor R10 with 10k Ω and capacitor C3 with 100uF/50V
- **48V version:** add R13 (4.53k Ω) and D26 (30V/0.4W zener), replace resistor R11 with 18.2k Ω , resistor R10 with 10k Ω and capacitor C3 with 100uF/100V

5.3 POE + surge protection

POE injector consists of a 4-pin screw terminal to connect incoming ethernet (Ethernet switch) to, and 6-pin screw terminal to connect outgoing ethernet + poe (wifi-router) to. Pins number 1-4 are used for data, pin number 5 for positive POE-voltage and pin number 6 for negative POE-voltage/ground. Data lines are protected by Transient Voltage Suppressor Diodes D5-D24. Positive POE-voltage line is protected by diode D4. Negative POE-voltage line must be well grounded.



6. Tuning and Testing

6.1. Charger unit tuning

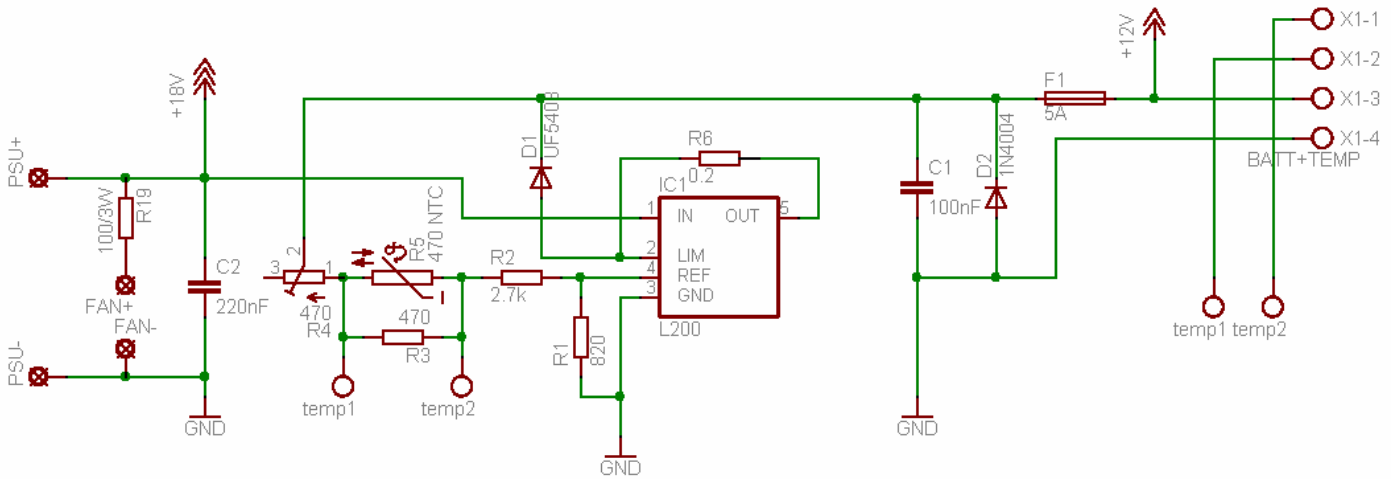
- Connect NTC resistor (thermistor) to *BATT + TEMP* connectors pins 1 and 2 if not soldered on board.
- Set up temperature measurement device to measure ambient temperature.
- Set variable voltage power supply to about 18V and connect it to PSU+ and PSU- pads on Jaldi Charger pcb.
- Measure voltage between *BATT + TEMP* connectors pins 3 and 4 and turn trimmer resistor R4 to set voltage according to following table. If there is no voltage between these pins, check fuse F1 and that all parts are connected properly and there is no unwanted shorts on the pcb.

6.2. LVD unit tuning

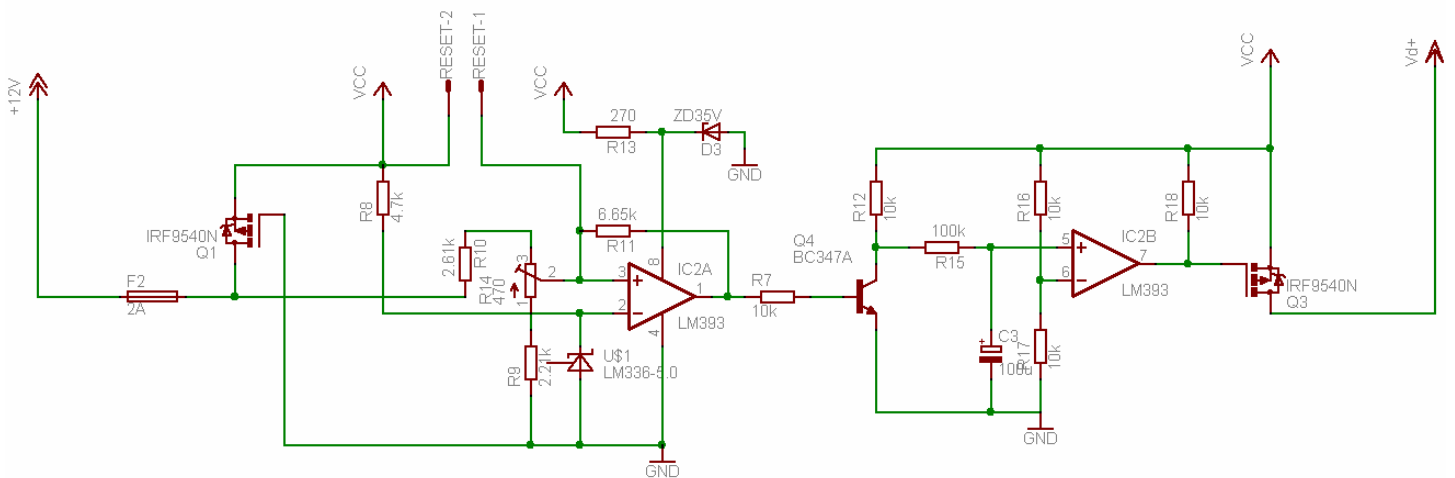
- Connect dummy load to *Ethernet + POE out* connectors pins 5 and 6.
- Set variable voltage power supply to about 15V and connect it to *BATT + TEMP* connectors pins 3 and 4.
- Dummy load should now be powered, if not, check fuse F2 and that all parts are connected properly and there is no unwanted shorts on the pcb.
- While measuring voltage between *BATT + TEMP* connectors pins 3 and 4, slowly decrease voltage using ADJUST- potentiometer on variable voltage power supply until dummy load is switched off.
- If switch-off voltage isn't close to 11V, turn trimmer resistor R14, raise variable voltage power supply voltage up until dummy load is powered again and repeat last stage.
- When switch-off voltage gets close to 11V start using FINE TUNE- trimmer on variable voltage power supply to set switch-off voltage to precisely 11 volts. Remember to turn FINE TUNE- trimmer back after every iteration to avoid it running to one end or another.

7. Schematics

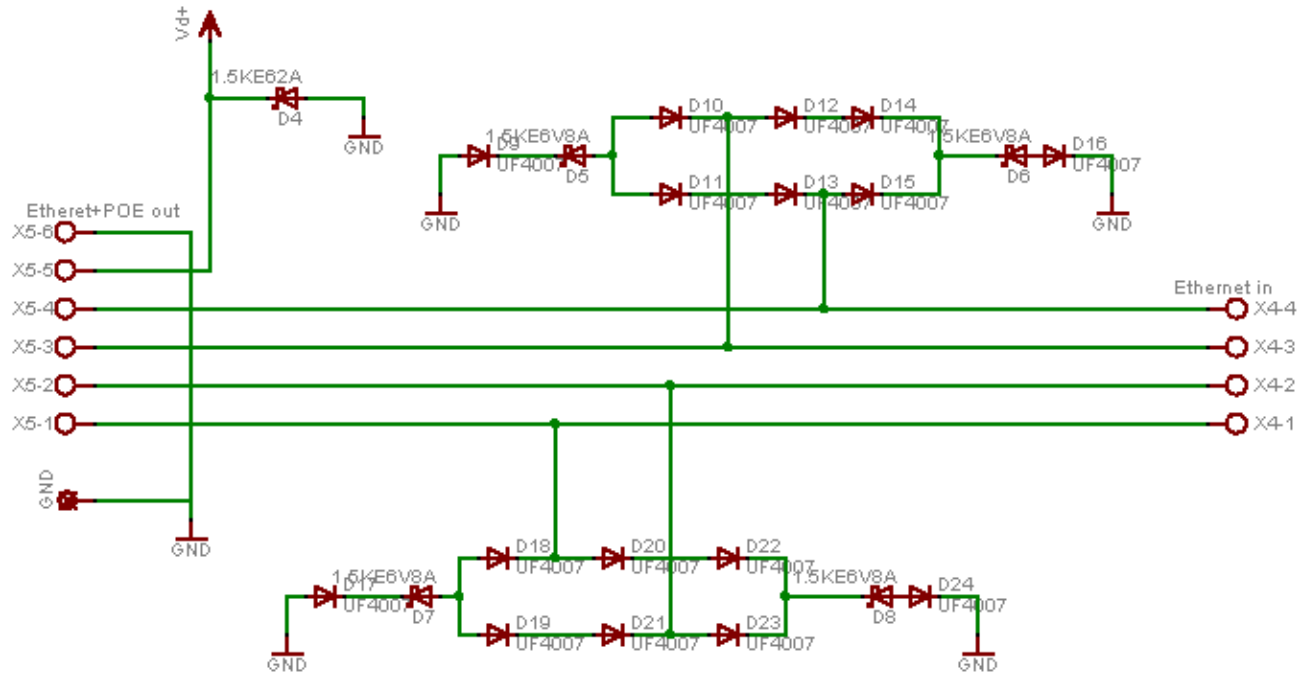
7.1. Charger unit



7.2. LVD



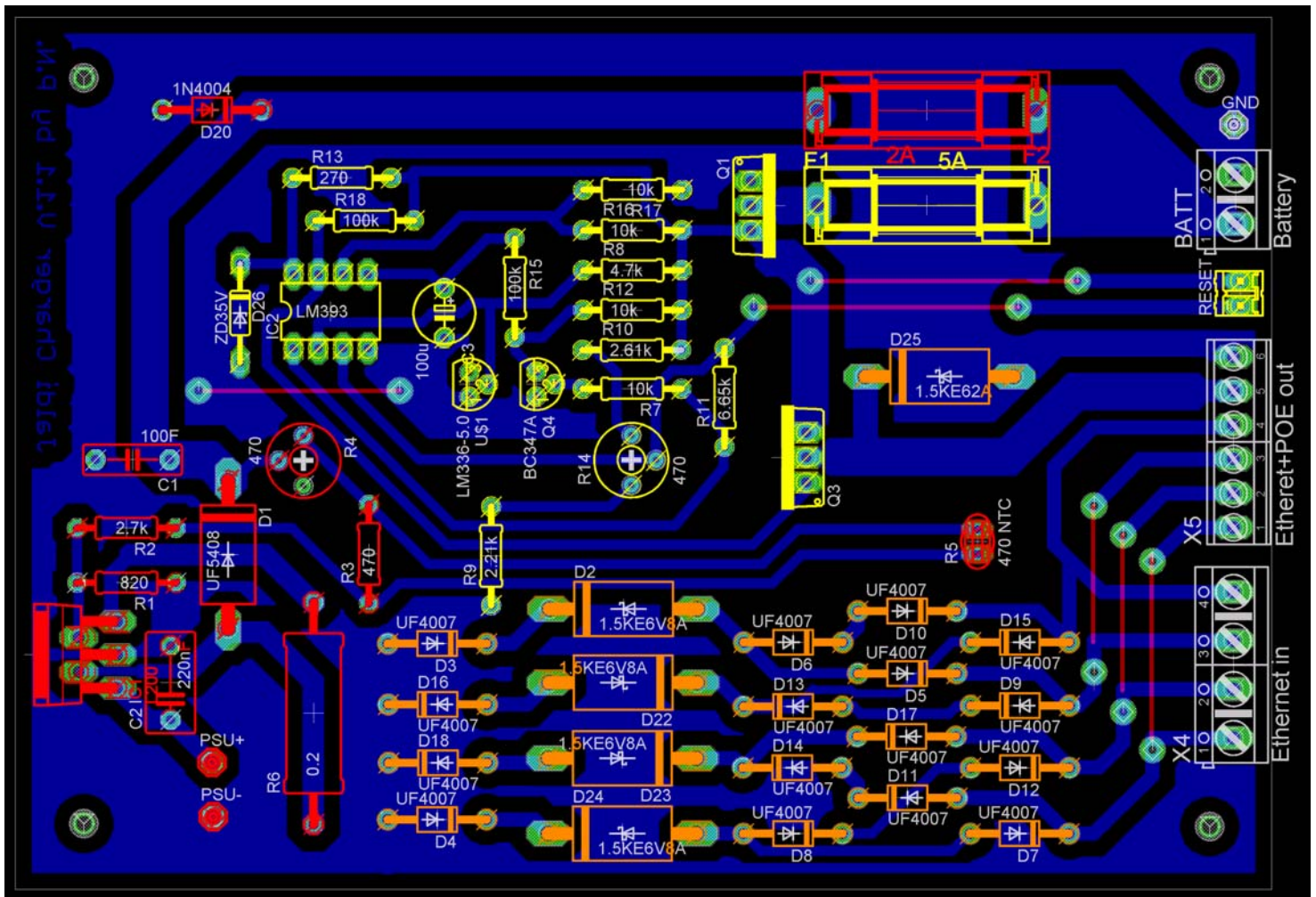
7.3. POE + surge protection



8. PCB layout

Color coding

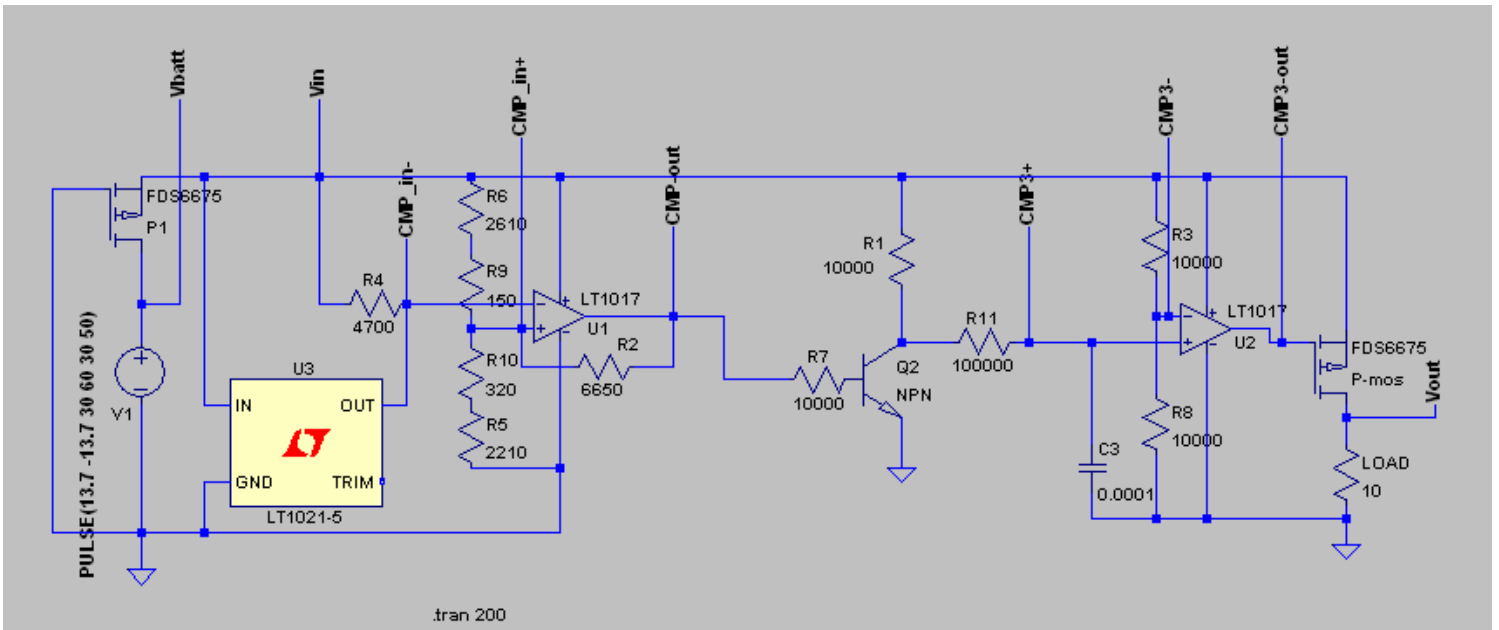
- Red: Charger unit
- Yellow: LVD
- Orange: POE + surge protection



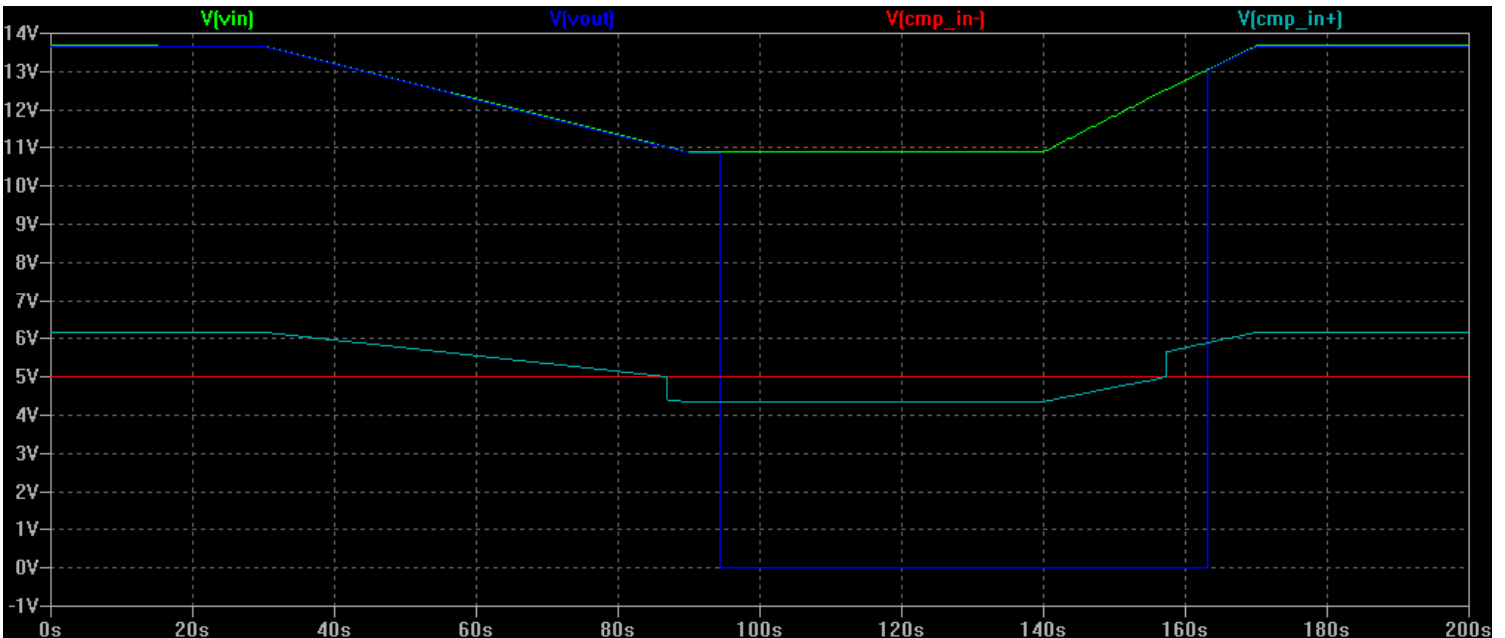
9. Simulations

All simulations were run on Linear Technology LTspice/SwitcherCAD III Version 2.20d

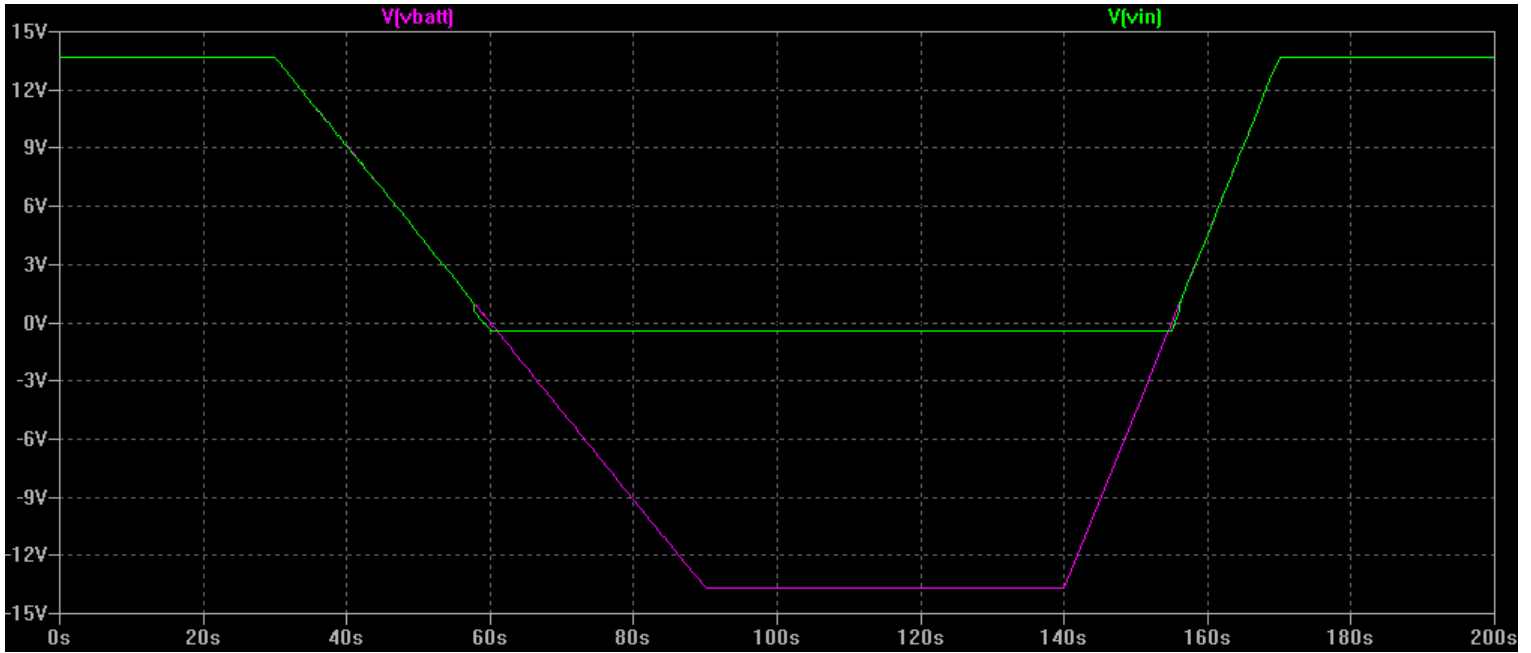
9.1. Simulated circuit (LVD)



9.2. Normal functionality



9.3. Reversed battery polarity



10. Notes

I was planning to implement load current depending charge current limiting, but ended up just limiting total output current of charger unit by using a fixed resistor. I came up to this decision after lots of research on the issue in question and finding out following: This additional feature would have dramatically increased the total complexity and costs of the circuit. Also when using Constant Voltage Charging method (as in our case) Lead Acid batteries seems to be drawing only the charging current they need and not getting damaged even if current available exceeds 0.1C (see terminology). Charging current is although limited to maximum of 2.25A (can be selected to be smaller if needed) to protect feeding power supply from getting over loaded.

Even though Jaldi Charger is a very robust device, it requires quite good and stable power supply being able to produce 17-18Vdc/2.5A (higher input voltage can be accepted if proper cooling of L200-ic can be ensured). This leads us facing a problem of poor quality mains power in Himachals and continuously burning low quality PSUs. I have came up with three possible solutions:

- **High quality commercial switching power supply**
 - Pros
 - Easy to use, “plug’n’play”
 - No need for modifications
 - Wide efficient input voltage area (100-300V)
 - Cons
 - Very high price
 - Supply quality is hard to ensure over time

- **Simple transformer**
 - Pros
 - Very Cheap
 - Highly reliable (as long as fuses doesn’t burn)
 - Requires only few extra components
 - Cons
 - Narrow efficient input voltage area (200-230V)
 - Low efficiency (lots of heat dissipation)

- **Simple transformer + Step-Up/Step-Down Converter (whole new charger unit)**
 - Pros
 - Highly reliable
 - Very wide efficient input voltage area (80-300V)
 - Affordable (after succeeded development)
 - High efficiency
 - Cons

- Lots of development work
- Some parts probably hard to find

IC1, L200 in charger unit produces quite much heat especially when charging totally empty battery and running big load and/or when using high input voltage (>18Vdc). This heat has to be properly dissipated. IC1 has been located so, that it can be attached either to a separate heat sink or to the wall of a metallic enclosure.

R5, 470 Ω NTC Resistor acts as a thermometer measuring ambient temperature to lower the charging voltage when battery heats up. This resistor might need to be placed outside of the box (the closer to the battery the better) to prevent heating components IC1 and D1 from affecting on the measurement. **Update in V.1.6:** added screw terminal for connecting NTC remotely. Preferred way is to use short cat5 ethernet cable to connect battery to the charger by using 3 pairs for power and one pair for NTC taped on top of the battery.

UPDATE 24.7.2007:

I couldn't solve problems with LVD delay, temporary solution is to disable it by letting capacitor C3 off. Also some problems with manual reset (doesn't work every time) I'll try to fix these problems after getting back to home.

11. References

- [1]L200 datasheet, <http://www.ortodoxism.ro/datasheets/stmicroelectronics/1318.pdf>
- [2]A designer's guide to the L200 voltage regulator, http://bwir.de/downloads/L200_englisch.pdf)
- [3]L200 Charger example: Sealed Lead-Acid Battery Charger Circuit, <http://www.myra-simon.com/bike/charger.html>
- [4]LM393 datasheet, <http://www.national.com/ds.cgi/LM/LM193.pdf>
- [5]Understanding Schmitt Trigger, http://en.wikipedia.org/wiki/Schmitt_trigger
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- [7]Program used to design schematics and PCB layout: CadSoft Online: Home of the EAGLE Layout Editor, : <http://www.cadsoftusa.com/>
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- [9]Understanding POE: POE = Power Over Ethernet, http://www.altair.org/labnotes_POE.html
- [10]Definition of Printed Circuit Board: Wikipedia, http://en.wikipedia.org/wiki/Printed_circuit_board