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# Report

# Portable and reliable DRSSTC demonstrator

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## Abstract

Universities, knowledge centers and other institutions has the need for equipment that demonstrates physical phenomena in interesting and audience friendly ways. An example of this is a Double Resonant Solid State Tesla Coil (DRSSTC). It is desirable that the instrument is portable, reliable, and safe to use.

The system should take audio as input and output acoustic audio by means of an high voltage electric discharge in air creating plasma (streamer) by the means of a resonant transformer (tesla coil). The system should also be designed such that it will always be functional, and in the case of the system not being functional should fail in a safe and non-destructive way (safe having priority over non-destructive). As well as indicating witch part of the system is non-functional. The system should also be designed in such a way that this non-functioning part may be swapped for a spare functioning part. This was acheived with implementing a back plane architecture with detection of if modules are present, and signals that can be used by modules to report errors.

Before any improvements the system had a probability of failure P(F)= 0,71. After improvements we have removed F0 and F9 from the general fault tree, and F2, F3 from the destructive fault tree (F8) and the probability of failure is reduced to P(F)= 0,18. The probability for destructive failure P(F8) is reduced from 0,67 to 0,10.

The existing circuit design and implementation had problems with reliability. The reliability of the system was calculated by the use of a source tree based on logged faults to P(F)=0,71. After implementing a back plane design, and adding carrier wave detection on the input signal the reliability increased to P(F)=0,18. The probability of destructive failure was reduced from 0,67 to 0,10. This is a large increase in reliability. Portability was present in the existing implementation, and has been increased by removing failure sources that occurred when moving the system.

# Preface

Omega Verksted has a long tradition with providing Tesla Coil shows for the line union 'Omega' and for other student societies at NTNU. The current implementation is based on some inadequate documentation from the 2009 implementation. The 2009 implementation was in use up to 2014 and was notorious for blowing output transistors. As well as for being put together with hot glue. In 2014 an effort was begun to improve the reliability and portability of the tesla coil. A new implementation was created with the design split into modules to ease the further development. The connectors and the casing for the driver was replaced improving portability greatly. The coil rig was also replaced as it had the tendency to catch fire. This implementation still has some problems as outlined and attempted corrected in this report.

Thanks should be made to Omega Verksted who has financed the parts used for this project.

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# 1 Introduction

Universities, knowledge centers and other institutions has the need for equipment that demonstrates physical phenomena in interesting and audience friendly ways. An example of this is a Double Resonant Solid State Tesla Coil (DRSSTC). This is a contraption that by the use of high voltage generates a sequence of electrical discharges. When these discharges happen in air a sound wave is generated. By modulating the frequencies of these discharges one can generate sound with different tones. A DRSSTC can in this way be made into a musical instrument. For demonstration purposes it is important to control both streamer length and tone quality on such an musical instrument. It is further desirable that the instrument is portable, reliable, and safe to use. In a portable DRSSTC consisting of several modules it is desirable to quickly detect if errors occurs, i.e. in the context of transport. With the base in an existing circuit design it should be designed a robust implementation with possibility to detect errors. It is further desirable to develop a rough understanding of how different design parameters affects the performance of an DRSSTC.

The system should take audio as input and output acoustic audio by means of an high voltage electric discharge in air creating plasma (streamer) by the means of a resonant transformer (tesla coil). The system should also be designed such that it will always be functional, and in the case of the system not being functional should fail in a safe and non-destructive way (safe having priority over non-destructive). As well as indicating witch part of the system is non-functional. The system should also be designed in such a way that this non-functioning part may be swapped for a spare functioning part.

Figure 1 shows a DRSSTC in use where a streamer has formed from the top load to a grounded copper object.

## 1.1 Tesla

The Tesla Coil is a form of resonant transformer invented by Nikolai Tesla and used for experiments with artificial illumination [9]. A resonant transformer consists of two inductively coupled coils, each loaded with a capacitance such that they get the same resonance frequencies. The resonant transformer has since gotten a lot of applications, among others; RFID, NFC, and Wireless charging. The resonant transformer in the form of the Tesla Coil has also become a popular entertainment device.

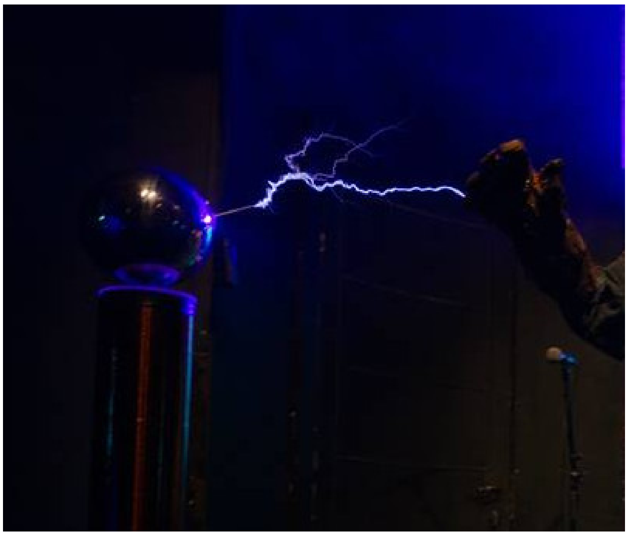


Figure 1: A tesla coil in use
Foto: Sindre Vaskinn Hunn

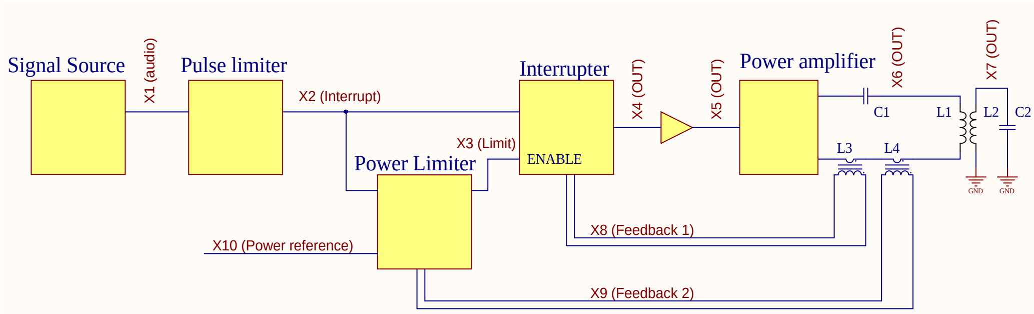



Figure 2: Block diagram

## 1.2 DRSSTC

DRSSTC is an acronym for Dual Resonant Solid State Tesla Coil. Dual resonant means that we have two resonant circuits inductively coupled, and tuned to the same resonance frequency. Solid state means that we drive these resonant circuits actively with transistors. The origins of the DRSSTC is not well documented but it is commonly accepted that it was conceived on "The tesla coil mailing list" [2].

The signal pathway consists of a signal source, pulse limiter, power limiter, interrupter, amplifier, and power amplifier see fig. 2. The signal source provides the signal to be output on the coil, often the signal source is a

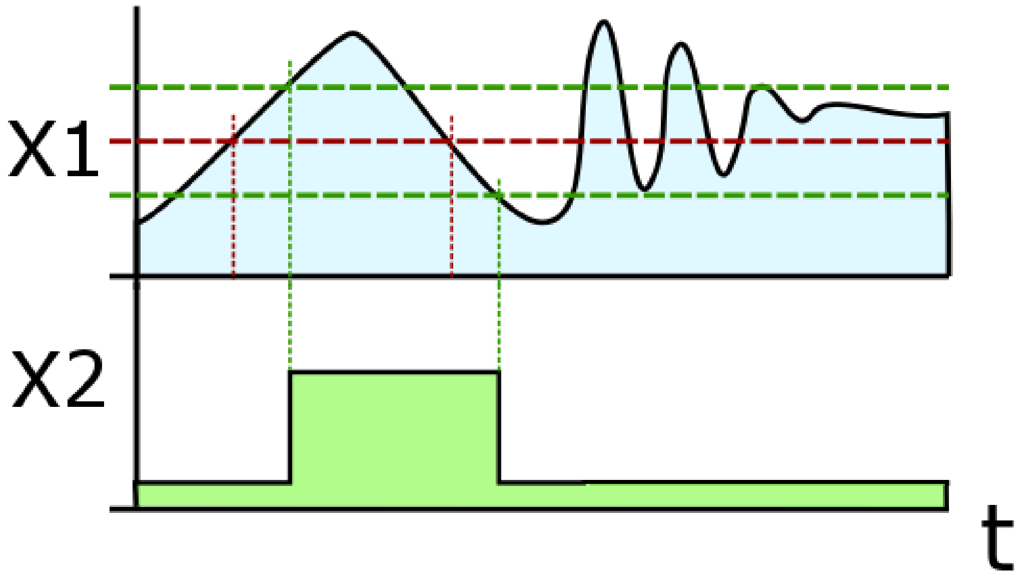



Figure 3: Tranformation of $X1$ to two level [5]

musical recording. The input signal should be monophonic, arpeggio[1] may be used. The input signal may be two level.

First the input signal $X1$ goes into the pulse shaper, which transforms the signal to two, level limits on-time of each pulse, and enforces a minimum time between pulses. In fig. 3 an example $X1$ is shown and a corresponding $X2$, here we see that the transformation to two level is done with a schmitd trigger, and that the pulses following immediately after the first pulse is suppressed. (section 1.2.2). Then the signal X2 is connected to the interrupter which on a positive flank outputs a positive flank X4, which is amplified $X5$ and $X6$ and sent into the resonant circuit (C1, and L1). This triggers the step response of the resonant circuit. Then a positive feedback loop $X8$ drives $X4$ at the resonant frequency of the resonant circuit (the resonant frequency is in the order $f_0 = 100k\text{Hz}$). This is achieved by inverting the output when the current through C1 and L1 passes through zero (as measured through L3). This continues until either the input pulse $X2$ goes low or the limit signal from the limiter X3 goes low. The limiter also measures the current flowing through C1 and L1, but this signal X9 is rectified and fed through a low pass filter before being compared to a preset level X10. This comparison measures the power dissipated in the resonant circuit. If the power exceeds the preset level the enable signal X3 is set low

[1]The sounding of the notes of a chord in rapid succession instead of simultaneously.

until the next rising edge of the input signal X2. X10 is set by a multi turn potentiometer.

The resonant circuitry consists of C1, L1, C2 and L2, where L2 is magnetically coupled with L1 with a degree of approximately 0.2. C1 is a bank of capacitors with high voltage and current rating and low equivalent series resistance (ESR). L1 is an inductor with high cross section area and few turns (in the magnitude of 5 turns). L2 is an inductor with low cross section area and a high number of turns (in the magnitude of 4000 turns). C2 consists of a sphere or toroid for one plate, and the grounded (safety ground) surroundings. Ground is connected through the safety ground in the electrical socket used to power the DRSSTC. L3 and L4 are current sensing transformers.

Figure fig. 4 shows a measurement of these signals. Channel 2 (Green) shows the feedback signal $X8$ after it is fed through a protection network limiting the voltage (See the schematic for TK514 in appendix B). Channel 4 (Red) shows an internal signal $Y1 = X2 \;\&\&\; \overline{X3}$ in the interrupter. This as long as this signal is high the output signal $X4$ will swing at the resonant frequency. Note that we would expect $X8$ to be zero as long as channel 4 is low, but there is some delay before the resonant circuit stops swinging after the supply of energy stops. Also note the interference on $X3$ and $Y1$ from the output signal $X6$.

### 1.2.1 Triggering signal

The triggering signal $X2$ is two level and contains two pieces of information from $X1$, the frequency $f$ (tone) and the volume (intensity). The frequency is given by the time $T$ between the positive flanks of the signal $f = \frac{1}{T}$. This is the base harmonic of the acoustic tone heard at the output of the system. The volume is given by the duty cycle of the pulses (the relationship between the pulse being high and the total period $T$ of the pulse. Figure 5 shows different tones, and fig. 6 shows different volumes.

### 1.2.2 Timing diagrams

fig. 7 to fig. 12 shows different examples of input pulses, and corresponding output pulses. Note that the timings and frequencies are not to scale, only relative timings.

Figure 7 shows a single pulse on the input signal $X1$, here we see $X2$ is limited to a certain width. We also see that $X4$ and $X8$ goes high when $X2$ goes high, oscillates at the resonance frequency of the resonance circuit, and goes low when $X2$ goes low. Figure 8 shows the same principle, only with a


Figure 4: Measurements of signals.
Channel 1 (Yellow): $X2$, 2 (Green): $X8$, 3 (Blue) $X3$, 4 (Red): $X2$ && $\overline{X3}$. Voltage axis: 5V/div. Time axis: 200$\mu$s/div.

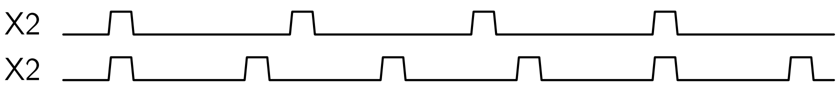



Figure 5: Different tones

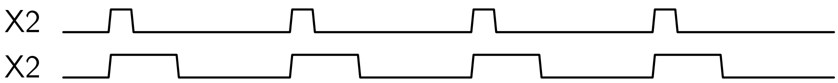



Figure 6: Different volumes

longer pulse on $X1$.

Figure 9 shows the same input signal as fig. 8 but with a different setting of the on-time on the pulse limiter (allowing longer on-time).

Figure 10 to fig. 12 shows multiple pulses on $X1$ and corresponding signals on $X2$. With on-time set to 2 units and minimum time between pulses set to 12 units.

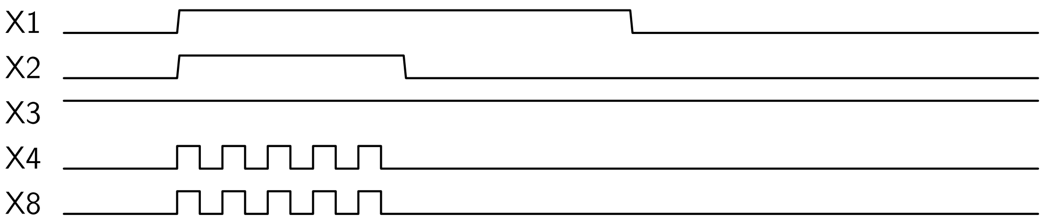



Figure 7: One pulse on X1

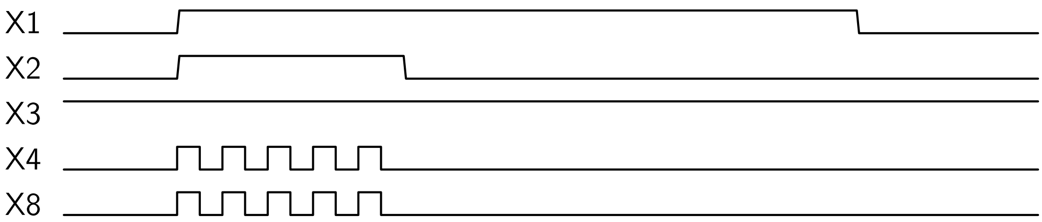



Figure 8: One pulse on X1, longer input pulse

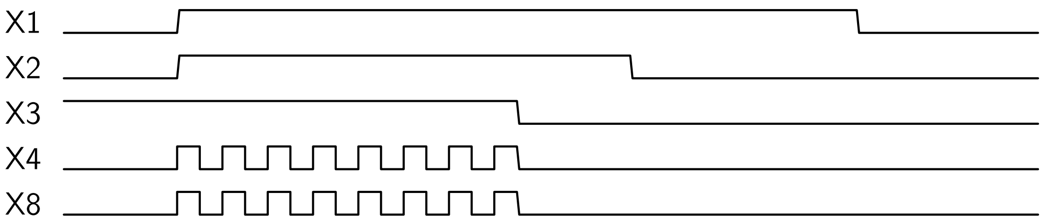



Figure 9: One pulse on X1, longer on time

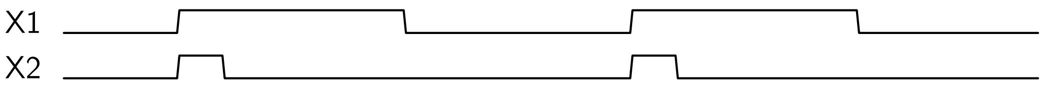



Figure 10: Multiple pulses on X1 (max on: 2, min between: 12)

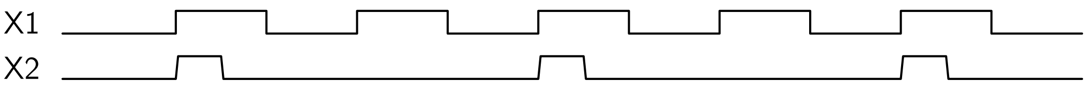



Figure 11: Multiple pulses on X1 (max on: 2, min between: 12)

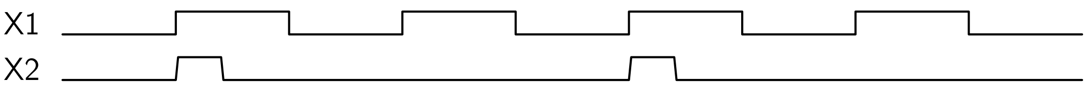



Figure 12: Multiple pulses on X1 (max on: 2, min between: 12)

## 1.3 Reliability

In every system there is certain demands for reliability (reliablilty describes the ability of a system to function under certain condiditons for a specified period of time). The DRSSTC should function in indoor conditions and dry outdoors weather, the DRSSTC should also function after sitting in storage for up to one year. And should function after transportation by trolley and or car. And after sitting on a stage during rigging. The DRSSTC should function for several years with transportation and rigging up to 30 times a year.

To achieve this the system should also have high maintainability. It should take a maximum of one day to fix an error.

### 1.3.1 Fault tree

A method for analyzing reliability of a system is using a fault tree [3]. The fault trees for this system is shown in fig. 13 and fig. 14. The inputs are failure sources that can occur these are listed in table 1. The probability P for each failure source is calculated from the number of times this failure has occurred divided by the number times the system has been used. These numbers are extracted from the log entries in Omega Verksteds log book for their tesla coil [11]. A total of 33 uses are logged in the period 2013-08-22 to 2016-11-07, the real number of uses should be assumed higher as the log book is not written at each use due to human error. The fault sources that does not occur in the log book is assumed to have a probability P of less than 0,03. Some of these failure sources are due to operator error and is outside of this report to fix. These failures sources are F3, F5, and F7 they are attempted to fix with procedures [12]. The failure source with the highest probability $P = 0,12$ is F8 this is a failure that does not occur by itself but as a consequence of other failure sources as shown in fig. 13 and must thus be fixed by addressing the failure sources leading to this failure. The failure source remaining with the highest probability $P = 0,09$ is F2 defective optical cable. By using the standard rules of combining probabilities with logic functions we get a calculated probabiliy of failure of P(F)= 0,71. The probability for destructive failure P(F8) used in calculating the probability for failure P(F) is the value gotten from calculating the output from the destructive failure fault tree P(F8)=0,666, and not the value listed in table 1.

### 1.3.2 Maintainability

The goal of errors taking a maximum of one day to fix is set so that you will always have a functioning system by testing it one day before it is to be used

| | P | Description |
|---|---|---|
| F0 | 0,03 | System is transported and vibrations shakes loose the wires on the high voltage side of the system. |
| F1 | <0,03 | No carrier wave (CW) detection is implemented in the optical reciever of the driver TK500, or this detection is defective. |
| F2 | 0,09 | Optical cable is defective (someone has stepped on it). |
| F3 | 0,03 | Optical cable is missing. |
| F4 | < 0,03 | Pulse shaper (TK100) is defective. |
| F5 | 0,06 | Pulse shaper is set to too high volume. |
| F6 | 0,03 | Power limiter is defective. |
| F7 | 0,06 | Power limiter is set to too high power. |
| F8 | 0,12 | Destructive failure happens, power amplifier or the load capacitor C1 catches fire. |
| F9 | 0,03 | Internal cables are disconnected due to vibrations while transporting the system. |

Table 1: Failure sources

for a performance. By partitioning the system into modules with limited components, the assembly time for one module is kept short. By keeping spare modules, and spare components. You will be able to either just switch the module, wich by the use of a backplane takes only a matter of minutes. Or assemble a new module wich should take less than one day.

## 1.4 Mass producability

To be able to mass produce the system some care needs to be taken during the design process.

When drawing the schematics each component has a link to a database with ordering information, price, and number and location in local warehouse.

Altium designer contains tools for automatic bill of materials (BOM) generation. This can be tailored to ones supplier, such that the output file can be uploaded to the supplier to order the components needed for manufacturing the design.

Components needs to be placed, and footprints drawn according to IPC7351(A,B, or C) to be able to manufacture the design at a factory.

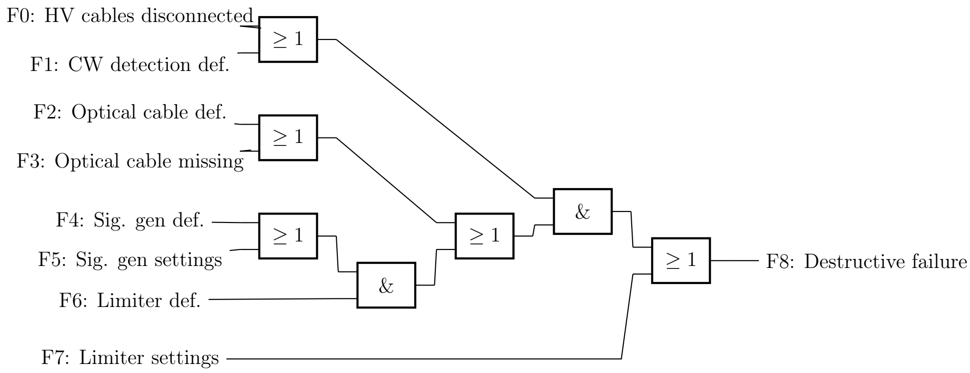



Figure 13: Fault tree for destructive failure of DRSSTC

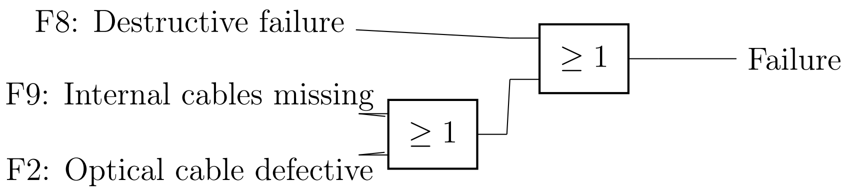



Figure 14: Fault tree for non-destructive failure of DRSSTC

### 1.5 Customer

The customers of the system is Omega Verksted[2], research projects, and amusement parks. These customers can be divided into two groups, customers who will be moving the DRSSTC and packing it down when not in use, and customers who will have it in a permanent installation. We will focus on the customers moving the DRSSTC around since this will put the toughest requirements on the design.

# 2 System Architecture

To achieve the goal of high maintainability a back plane architecture was chosen. The choice of back plane is also defended as a way to eliminate wires and connectors between different pcbs, as wires can fall out during transport, and glue is not an alternative as it should be easy to change a module. The back plane provides a good electrical and mechanical connection as well as some additional features (card detection). The back plane is split in two, one signal back plane and one power back plane. On the signal back plane

[2]Omega Verksted is a association of electronics and hobby interested students at the Norwegian University of Science and Technology (NTNU) founded in 1971.

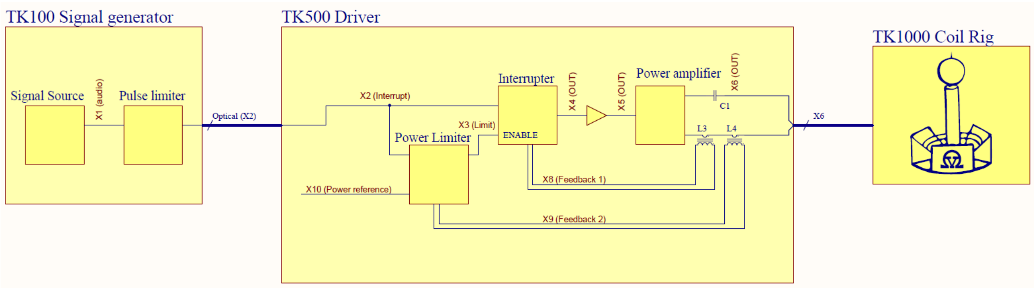



Figure 15: Block diagram

there is six module slots plus three power supply slots. On the power back plane there are two power amplifier slots (the power amplifier is split into two identical circuits), and one slot for the load capacitor.

The signal source needs to be a long distance away from the coil rig due to safety reasons, and the power amplifier needs to be as close to the coil rig as possible to keep ohmic losses in the resonant circuit as low as possible. The Interrupter and power limiter has low voltage feedback signals X8 and X9 as inputs. Because of the nature of a tesla coil, there is a lot of electromagnetic interference (EMI) present such that low voltage signals needs to be sent through a channel that is robust against electromagnetical noise. Thus the system is partitioned such that the signal source and pulse shaper TK100 is placed together, and the rest of the system placed together in a shielded enclosure TK500. The signal from the pulse shaper X2 should then be sent through a robust channel. Optical plastic fibre is chosen described in section 2.2. X8 and X9 are then short and inside a shielded enclosure, and no other protection from EMI is required.

Inside TK500 we have both high power and low power signals. These should be separated such that the high power signals does not provide interference for the low power signals. And so that the electronics with low power signals can be designed with lower voltage and power requirements. This is solved by creating a signal back plane TK510 and a power back plane TK530, connected via an galvanic isolation TK520.

In addition some user interface is needed on the driver TK500 This is partitioned into a sub system called TK540.

## 2.1 Card inserted bus

When partitioning the system into several modules physically spread over multiple pcbs there is a risk of one module not being connected to the system, either because of issues with transportation, or by human error.

To mitigate this risk, detection of wich cards is inserted into the back plane is implemented. This is done by a bus. The bus consists of one wire named Card_inserted, pulled high by a $10k\Omega$ resistor, fig. 16 shows how each card slot interfaces to the card inserted bus, S1D shorted when a card is inserted and Card_iserted is the bus. When no card is inserted into the slot the gate of the nmos is pulled high by R1 and the nmos goes into the triode region and pulls the bus low. When a card is inserted it pulls the gate low. And the nmos goes into cut-off. This circuit is replicated at each card slot.

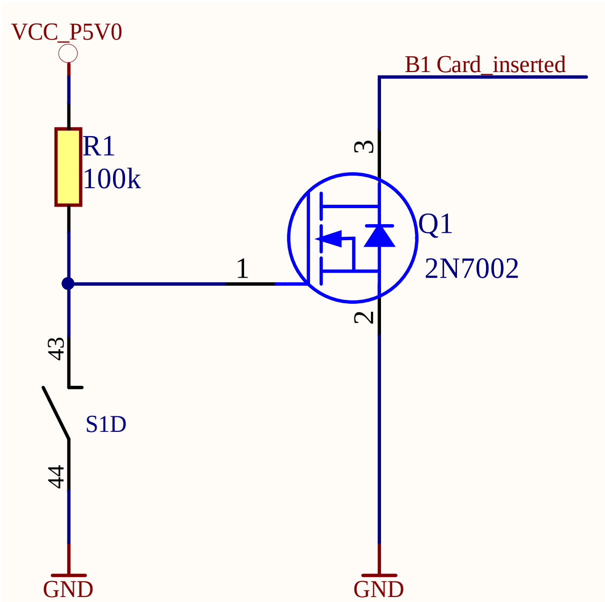



Figure 16: Bus interface

## 2.2 Optical channel

As mentioned in section 2 a robust channel is needed for signal X2. For this plastic optical fibre is chosen. To further increase the robustness the signal (X2) should be modulated. To reduce complexity a simple modulation should be chosen. To remove the failure source of the optical cable missing (F3) and possibly some cases of defective optical cable (F2) the carrier wave (CW) should be chosen so that it is easily detectable in the receiving end.

### 2.2.1 Carrier wave

The carrier wave CW for the optical channel is a square wave, and should have a sufficiently high frequency $f = \frac{1}{T}$ to transfer the triggering signal X2,

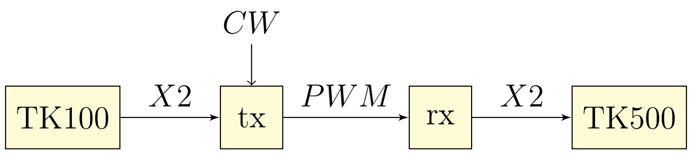



Figure 17: Diagram of optical channel

in addition to be easily detected in the receiving end. X2 contains two parts of information the frequency and the volume. The period $T$ should be shorter than the lowest desirable positive pulse on X2 $T_{X2min} = 4\mu$s. $f_{CW} > \frac{1}{T_{X2min}}$ The shortest desirable pulse on X2 is a length that allows turning the volume down without a noticeable step before shutoff. This length is taken from the previous implementation of this system.

### 2.2.2 Modulation

The triggering signal should be pulse width modulated PWM with a logical high having a duty cycle of 80% and logical low having a duty cycle of 20%.

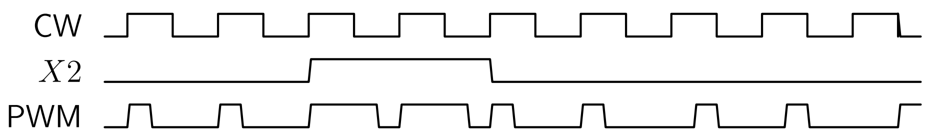



Figure 18: Modulated signal timing diagram

## 2.3 Bus

A set of signals should be available to all card slots on the signal back plane these signals are signals $B1$ to $B14$ in table 2. The reason these signals should be present on all connectors is so that any module can be inserted in any slot of the back plane. In addition some unique signals should be present on each connector these are the other signals in table 2. Signals n_KI, n_FE, n_ST, and n_INT are signals wich should drive leds on the front panel to indicate status of the module to the operator. The signal n_KNP should be connected to a button on the front panel for each card module slot on the signal back plane, for the operator to give simple feedback to the module.'n' is an integer from 0 to N denoting the id of the module slot. The signals FP_1 to FP_5 are signals to the front panel reserved for future use. The signals AUX1_A & AUX1_B and AUX2_A & AUX2_B are connectors used for the signals $X5$, $X8$, $X9$, $X10$ and the PWM signal from the optical channel, and added to all slots so that any module can be inserted into any slot, given that the aux connections are connected at the correct slot. The pinout of the connector is shown in fig. 19

| | Signal name | Description |
|---|---|---|
| B1 | Card_inserted | The card inserted bus described in section 2.1 |
| B2 | Trigger | The triggering signal $X2$ |
| B3 | Limit | The output from the power limiter $X3$ |
| B4 | Interrupt | The output from the interrupter $X4$ |
| B5 to B14 | N.A. | Reserved for future use |
| A1 | n_KI | Card inserted (low when card is inserted floating otherwise as described in section 2.1) |
| A2 | n_FE | Active when fault detection of module detects a fault |
| A3 | n_ST | A status signal from the module |
| A4 | n_INT | Interrupt signal from the module, low when the module accepts the system firing, high otherwise. |
| A5 | n_KNP | Button input to the module from the front panel |
| A6 to A10 | FP_1 to FP_5 | Signals to the front panel reserved for future use |
| A11 | AUX1_A | 'A' branch of, Auxillary input/output to the module terminated in a connector close to the card slot connector. |
| A12 | AUX1_B | 'B' - branch of AUX1 |
| A13 | AUX2_A | Same as AUX1 |
| A14 | AUX2_B | Same as AUX1 |

Table 2: Backplane signals.
'n' is the id of the connector slot

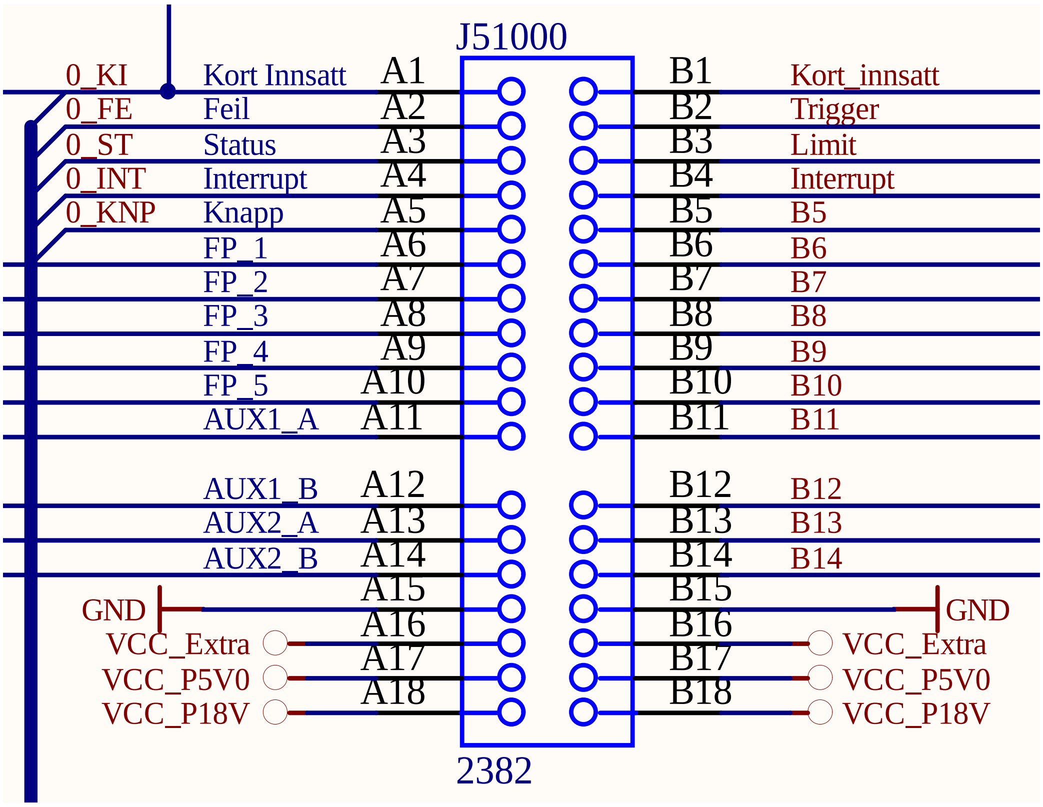



Figure 19: Signal module card slot connector (detail from schematic of TK510 Signalbakplan (slot 0))

# 3 Schematics

The schematics for this system is drawn in Altium designer and is attached in appendix B. Note that appendix B is best printed on A3 paper. All digital produced material have been stored in a central Git-based version control system which is accessible at [13]. The schematics is found under '05_HardwareTK500_DriverProjectOutputsTK500_design_documentation.PDF' Also note that not all of the schematics are finished, and that the schematics are in norwegian.

## 3.1 Altium designer

Altium Designer [1] is a powerful CAD tool for designing printed circuit boards (PCB). This type of tool allows the designer to first design or import each component one by one into the program, that also is used in the full design. When this is finished, the the schematics can be drawn and synced with a layout tool.

Alternatives to Altium Designer is Eagle [10], kicad [7], Proteus [4], ultiboard [6] and orcad [8]. The reasons for Altium designer to be chosen over the others is Eagle, and kicad (where kicad is considered an open source version of Eagle) is that Eagle has very few automations, thus you end up spending a lot more time to do the same work. The rest of the programs were not chosen of more subjective reasons. In addition to these reasons these CAD programs are very expensive so a key point in choosing Altium Designer is that NTNU has a licence for students. Also we have previous experience using Altium Designer, both from hobby work and relevant summer internships.

# 4 Layout

The layout for this system is also done in Altium desginer and is attached in appendix C. The layout for TK510, TK511, TK520, TK530, TK531, and TK532 is completed, and attached. The source files in Altium format can be found at [13].

## 4.1 PCB identification

To easily identify the pcbs (and modules) markings are placed in silk screen of all the pcbs in the same way. The Part number of the module, the date manufactured. And Omega Verksteds logo. See fig. 20.

## 4.2 Power back plane (TK530)

The stackup for the power back plane is two layers with no copper plane fill. Two layers is chosen because of the low complexity of the layout, and no copper plane fill is chosen to increase separation of low and high voltage signals. The traces for the HVDC supply voltage are drawn as thick as reasonable and the supply connections are placed in the middle between the two power amplifier modules. The connections for the output signal are


Figure 20: Detail from TK530 PCB

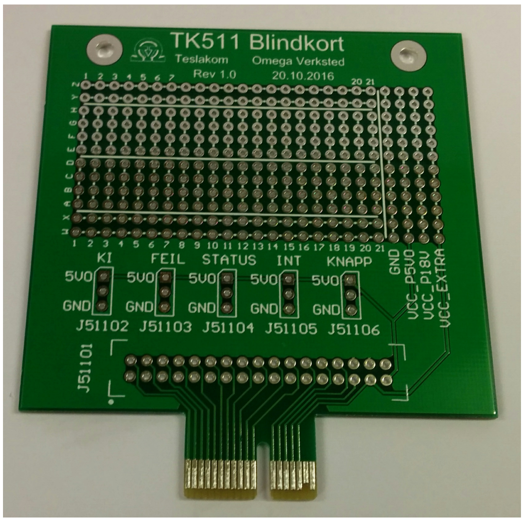



Figure 21: Signal module pcb

placed as close to the card connectors as possible, and the solder mask on the trace from the power amplifier and the load capacitor is omitted so that additional solder may be added to the trace to increase the area of the trace. Warning labels are added next to all exposed metal with higher than 50V (peak) voltage. The width of the pcb is chosen from the price breaks of the pcb supplier. Card holders to add mechanical stability to the inserted modules are mounted directly to the pcb, these guide the modules and ensures the module mates correctly with the connector. Some mechanical fastening to the chassis should also be used to fix the module in place. The thickness of the substrate was chosen to be 3mm to increase the mechanical strength.

## 4.3 Signal back plane

The connectors for the power modules are offset to prevent power modules to be inserted in signal module slots and vice versa. The same card holders as used on the power back plane are used on the signal back plane. The width of the signal back plane is chosen from the price breaks of the pcb supplier.

### 4.3.1 Signal module form factor

The width of the signal module is given by the width of the signal back plane minus the space used for the card holders. The height is chosen from the height of the card holders, and the closest price break of the pcb supplier. The form factor chosen is shown in fig. 21

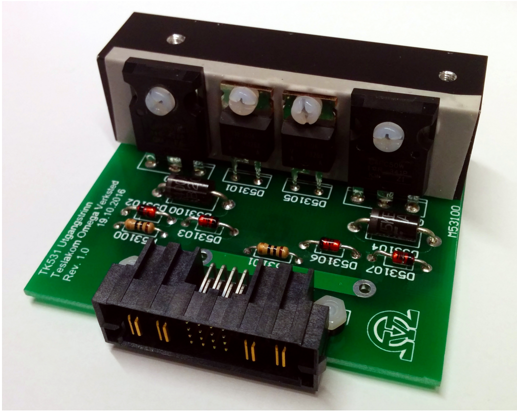


Figure 22: Power module form factor

#### 4.3.2 Power supply module form factor

The form factor for the power supply modules is the same as for the signal modules with the exception of the connector being offset.

#### 4.3.3 Power module form factor

For the power modules back plane connectors from samtec with four powerful pins and 16 signal pins was chosen. The width is chosen as the same as the signal modules. The form facor chosen is shown in fig. 22.

# 5 Results

Before any improvements the system had a probability of failure P(F)= 0,71. After improvements we have removed F0 and F9 from the general fault tree, and F2, F3 from the destructive fault tree (F8) and the calculated probability of failure is reduced to P(F)= 0,18. The updated fault trees are shown in fig. 23 and fig. 24. The calculated probability for destructive failure P(F8) is reduced from 0,67 to 0,10.

In fig. 25a the power amplifier with and without back plane is shown

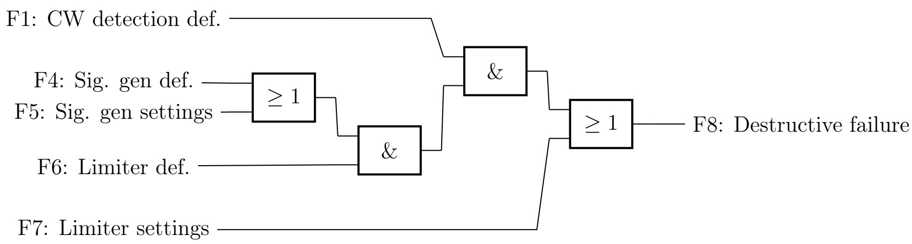



Figure 23: Fault tree for destructive failure of DRSSTC

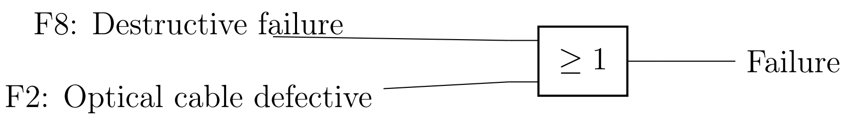
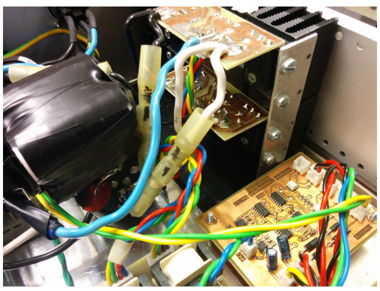
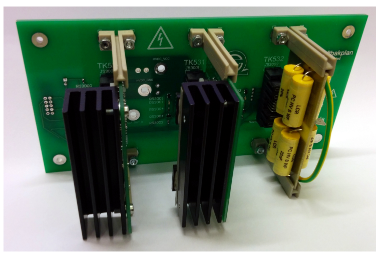



Figure 24: Fault tree for non-destructive failure of DRSSTC



(a) Power amplifier without back plane



(b) Power amplifier with back plane

# 6 Conclusion

The existing circuit design and implementation had problems with reliability as described in section 1.3. The reliability of the system was calculated by the use of a source tree based on logged faults to P(F)=0,71. After implementing a back plane design, and adding carrier wave detection on the input signal the calculated reliability increased to P(F)=0,18. This is a large increase in reliability. Portability was present in the existing implementation, and has been increased by removing failure sources that occurred when moving the system.

# 7 Further work

The next step in increasing reliability in the system is adding more complex fault detection on each module, and exploiting the status signals made available. The next step in improving the DRSSTC is looking at how different design parameters affects the performance with relation to streamer length and tone quality.

# References

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# Appendices

## A Specification

The system has been partitioned into sub-systems listed below. The sub systems has been assigned an arbitrary part number with the prefix "TK".

1. TK100 Signalgenerator
2. TK500 Driver
   (a) TK501 Frontpanel
   (b) TK502 Frontpanel LEDS
   (c) TK510 Signalbakplan
   (d) TK511 Blindkort
   (e) TK512 Optisk Mottaker
   (f) TK513 Limiter
   (g) TK514 Interrupter
   (h) TK516 Ekstra-PSU
   (i) TK517 P5V0-PSU
   (j) TK518 P18V-PSU
   (k) TK519 Spenningsvakt
   (l) TK520 GDT-Trafo
   (m) TK530 Kraftbakplan
   (n) TK531 Utgangstrinn
   (o) TK532 Kondensatorkort
3. TK1000 Spolerigg

### A.1 TK100 Signal generator

The Signal generator Should take a wide range of inputs and output the triggering signal X2 for the driver. It consists of the pulse shaper and signal source mentioned in section 1.2 and shown in fig. 2. The output signal X2 should be sent through a optical plastic fibre to be against EMI as mentioned in section 2 and section 2.2. The output signal should also be modulated on a carrier wave as described closer in section 1.2.1 and section 2.2.1.

## A.2 TK500 Driver

The driver should take the output of the signal generator (TK100) as input, and output a 160VDC signal at the resonant frequency of the coil rig while the input signal is high and the peak power output does not exceed a configurable level. The driver should also have the capacitor of the primary resonant circuit integrated.

#### TK501 Frontpanel

Should have a height of 4 standard rack units (4U) (17.78cm). Partitioned into multiple parts.

#### Signal back plane card matrix

Use the entire height, height divided into equal parts for each card in the signal back plane card. Each division should contain four LEDs; Green (Card inserted), Red (Fault), Green (status), Yellow (led in button). A field for card name. Space for buttons depending on the needs of the specific card.

#### Power back plane card matrix

Three leds for each of the three cards in the power back plane. Green (card inserted), Red (fault), Green (status).

#### Display

Voltage meter for output voltage. Ampere meter for output current.

#### Power buttons

Emergency stop Spring loaded rotary switch: slow start Momentary switch: Power on Momentary switch: Power off

### TK510 Signalbakplan

The signal back plane should have six slots for signal modules, and three slots for power supplies.

#### Signal module slot

The signal module slot should have the following signals:

- 1 bus with straps for pull up and pull down on bus lines. (B1-B14)

- Card inserted detection (A1)
- LED signals to front panel (A1-A5)
- Misc signals to front panel (A6-A10)
- Two contacts for signals other places inside chassis (A11-A14)
- Supply voltages and ground (A15-A18 & B15-B18)

The pinout on the module slot connector is shown in fig. 26

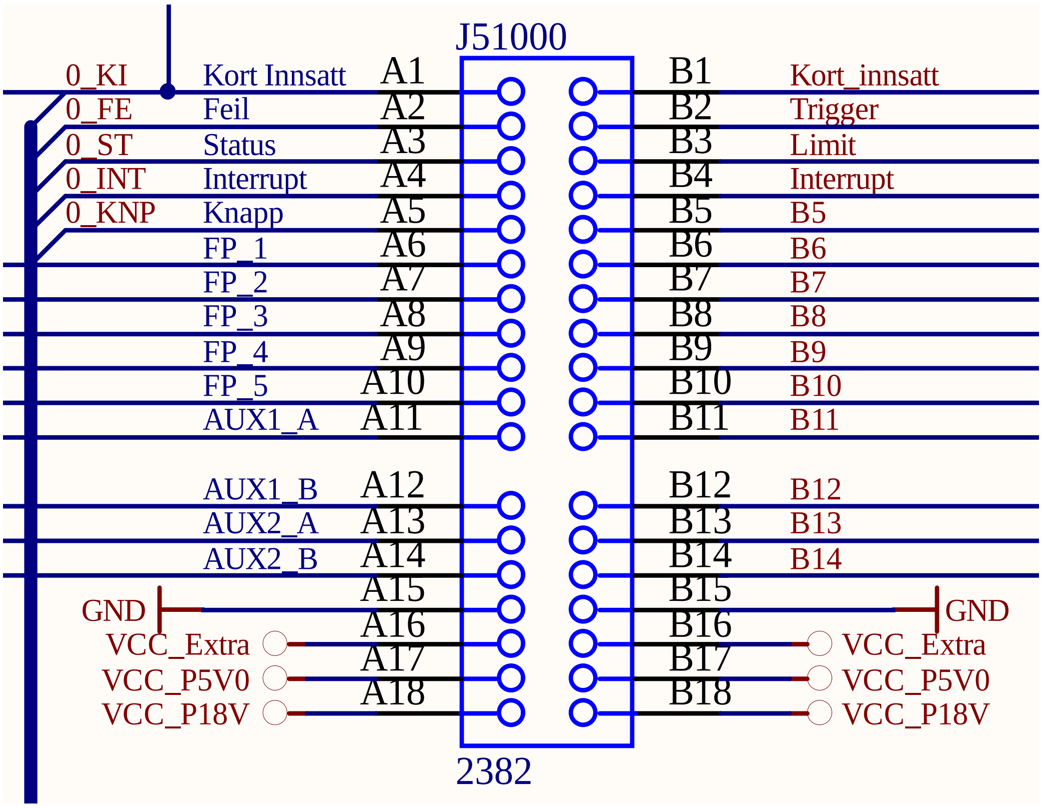


Figure 26: Signal module card slot connector (detail from schematic of TK510 Signalbakplan)

## TK511 Blindkort

The purpose of $TK511$ is to take the space where no module is inserted into the signal back plane, and emulate an inserted module.

### TK512 Optisk Mottaker

The purpose of $TK512$ is to convert the optical signal input into the driver $TK500$ to an electrical signal, and a carrier wave detected signal.

### TK513 Limiter

The purpose of $TK513$ is to prevent the coil rig $TK1000$ from catching fire, and to keep the spark from turning yellow.

### TK514 Interrupter

The purpose of 514 is to fire the tesla coil when receiving input signal and to tune the output signal via a positive feedback loop to the systems resonance frequency.

### TK516 Ekstra-PSU

The purpose of $TK516$ is to reserve a slot for future voltages.

### TK517 P5V0-PSU

The purpose of $TK516$ is to provide 5V DC to the driver $TK500$.

### TK518 P18V-PSU

The purpose of $TK516$ is to provide 18V DC to the driver $TK500$.

### TK519 Spenningsvakt

The purpose of $TK516$ is to monitor the supply voltages in the driver $TK500$.

### TK520 GDT-Trafo

The purpose of $TK516$ is to provide galvanic isolation between the signal back plane and the power back plane.

### TK530 Kraftbakplan

The purpose of $TK516$ is to provide the connections and monitoring for the output stage $TK531$ and the load capacitor $TK532$.

### TK531 Utgangstrinn

The purpose of $TK516$ is to step up the voltage on the output.

### TK532 Kondensatorkort

The purpose of $TK516$ is to provide the capacitance of the primary resonance circuit.

## A.3 TK1000 Spolerigg

The purpose of $TK516$ is to look good and output the voltage arc or corona discharge.

# B Schematics

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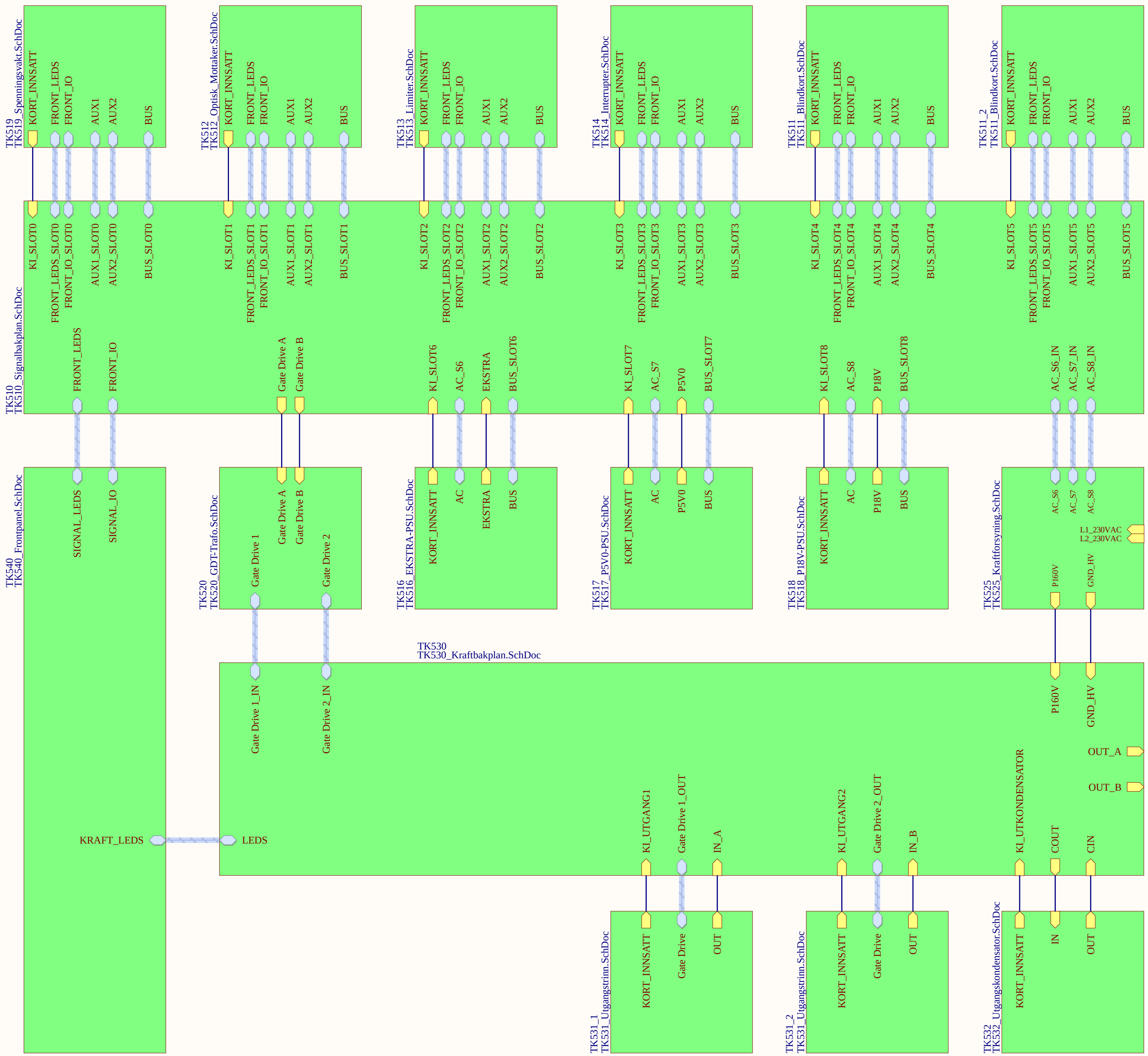


Title: TK500 Driver

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|---|---|---|
| Size: A3 | Revision: 0 | Author: Øystein Smith |
| Date: 26.04.2016 | Sheet 1 of 20 | Omega Verksted |

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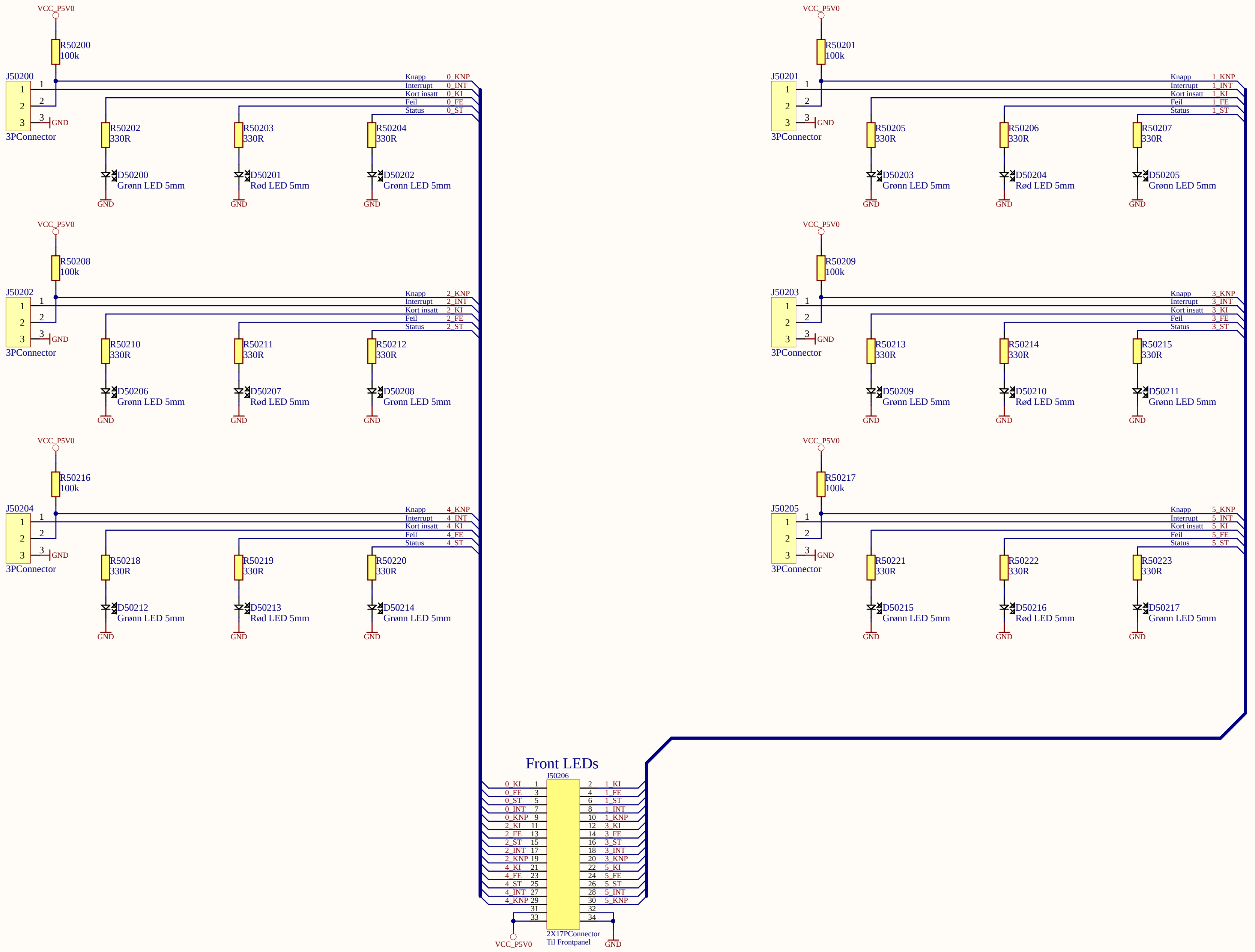


Title: TK502 Frontpanel LEDs

| | | |
|---|---|---|
| Size: A3 | Revision: 1 | Author: Sigurd Heide Rosland |
| Date: 26.04.2016 | Sheet 2 of 20 | Omega Verksted |

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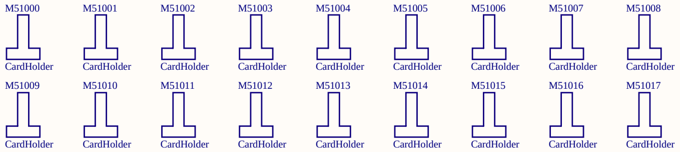


| | | |
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| Size: A3 | Revision: 0 | Author: Øystein Smith |
| Date: 26.04.2016 | Sheet 3 of 20 | Omega Verksted |
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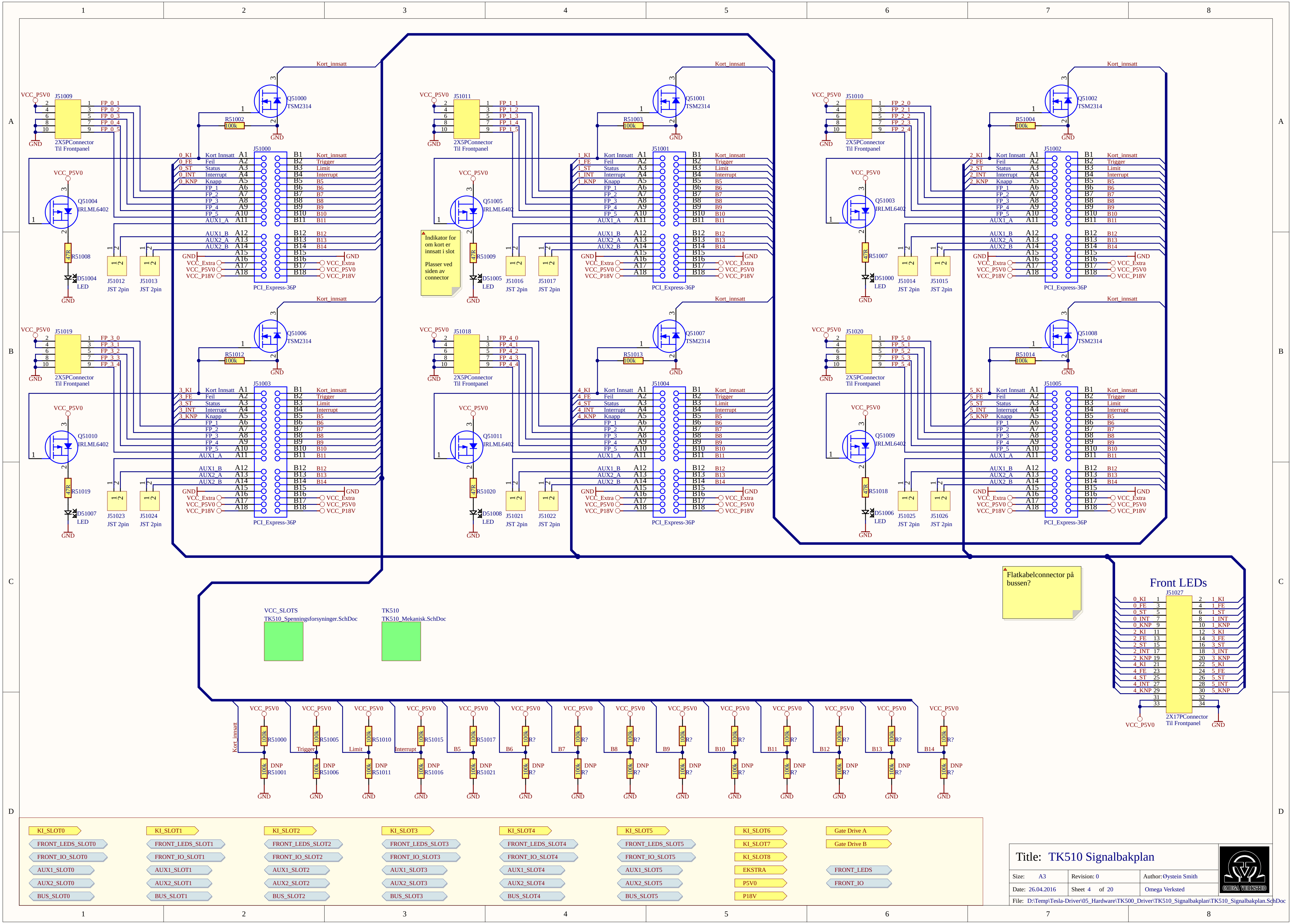
Kort_innsatt
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TSM2314
Q51001
TSM2314
Q51002
TSM2314
Q51006
TSM2314
Q51007
TSM2314
Q51008
TSM2314
Q51004
IRLML6402
Q51005
IRLML6402
Q51003
IRLML6402
Q51010
IRLML6402
Q51011
IRLML6402
Q51009
IRLML6402
VCC_P5V0
GND
J51009
J51011
J51010
J51019
J51018
J51020
2X5PConnector
Til Frontpanel
J51000
J51001
J51002
J51003
J51004
J51005
PCI_Express-36P
Kort Innsatt
Feil
Status
Interrupt
Knapp
Trigger
Limit
VCC_Extra
VCC_P18V
AUX1_A
AUX1_B
AUX2_A
AUX2_B
JST 2pin
LED
47R
100k
Indikator for om kort er innsatt i slot
Plasser ved siden av connector
Flatkabelconnector på bussen?
Front LEDs
J51027
2X17PConnector
Til Frontpanel
VCC_SLOTS
TK510_Spenningsforsyninger.SchDoc
TK510
TK510_Mekanisk.SchDoc
DNP
KI_SLOT0
FRONT_LEDS_SLOT0
FRONT_IO_SLOT0
AUX1_SLOT0
AUX2_SLOT0
BUS_SLOT0
KI_SLOT1
FRONT_LEDS_SLOT1
FRONT_IO_SLOT1
AUX1_SLOT1
AUX2_SLOT1
BUS_SLOT1
KI_SLOT2
FRONT_LEDS_SLOT2
FRONT_IO_SLOT2
AUX1_SLOT2
AUX2_SLOT2
BUS_SLOT2
KI_SLOT3
FRONT_LEDS_SLOT3
FRONT_IO_SLOT3
AUX1_SLOT3
AUX2_SLOT3
BUS_SLOT3
KI_SLOT4
FRONT_LEDS_SLOT4
FRONT_IO_SLOT4
AUX1_SLOT4
AUX2_SLOT4
BUS_SLOT4
KI_SLOT5
FRONT_LEDS_SLOT5
FRONT_IO_SLOT5
AUX1_SLOT5
AUX2_SLOT5
BUS_SLOT5
KI_SLOT6
KI_SLOT7
KI_SLOT8
EKSTRA
P5V0
P18V
Gate Drive A
Gate Drive B
FRONT_LEDS
FRONT_IO
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Size: A3
Revision: 0
Author: Øystein Smith
Date: 26.04.2016
Sheet 4 of 20
Omega Verksted
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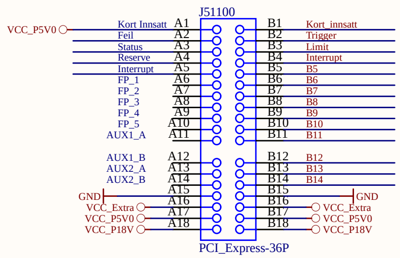
OMEGA VERKSTED

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| Size: A3 | Revision: 0 | Author: Øystein Smith | |
| Date: 26.04.2016 | Sheet 5 of 20 | Omega Verksted | |
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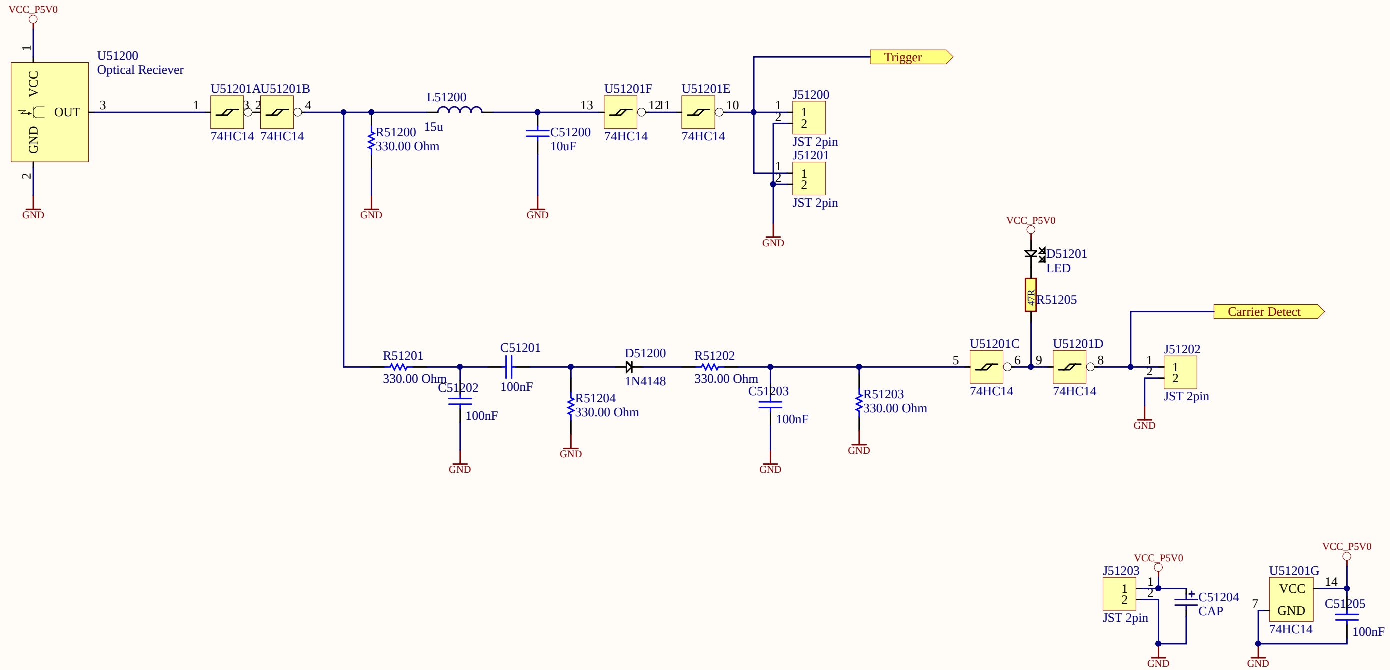


Title: TK512 Optisk Mottaker

Size: A3 | Revision: 0 | Author: Øystein Smith

Date: 26.04.2016 | Sheet 6 of 20 | Omega Verksted

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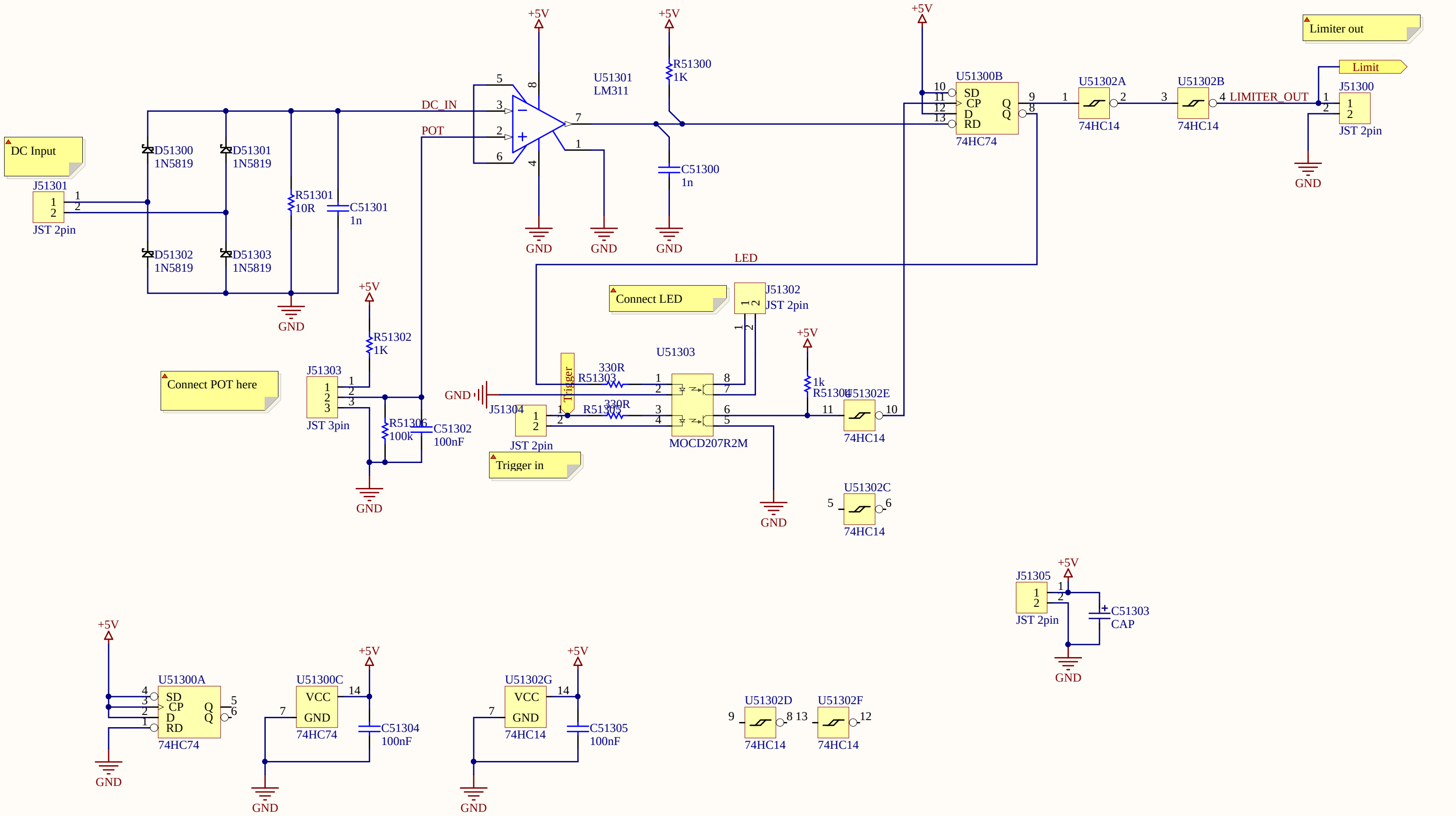


Title: TK513 Limiter

| | | |
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| Size: A3 | Revision: 0 | Author: Øystein Smith |
| Date: 26.04.2016 | Sheet 7 of 20 | Omega Verksted |

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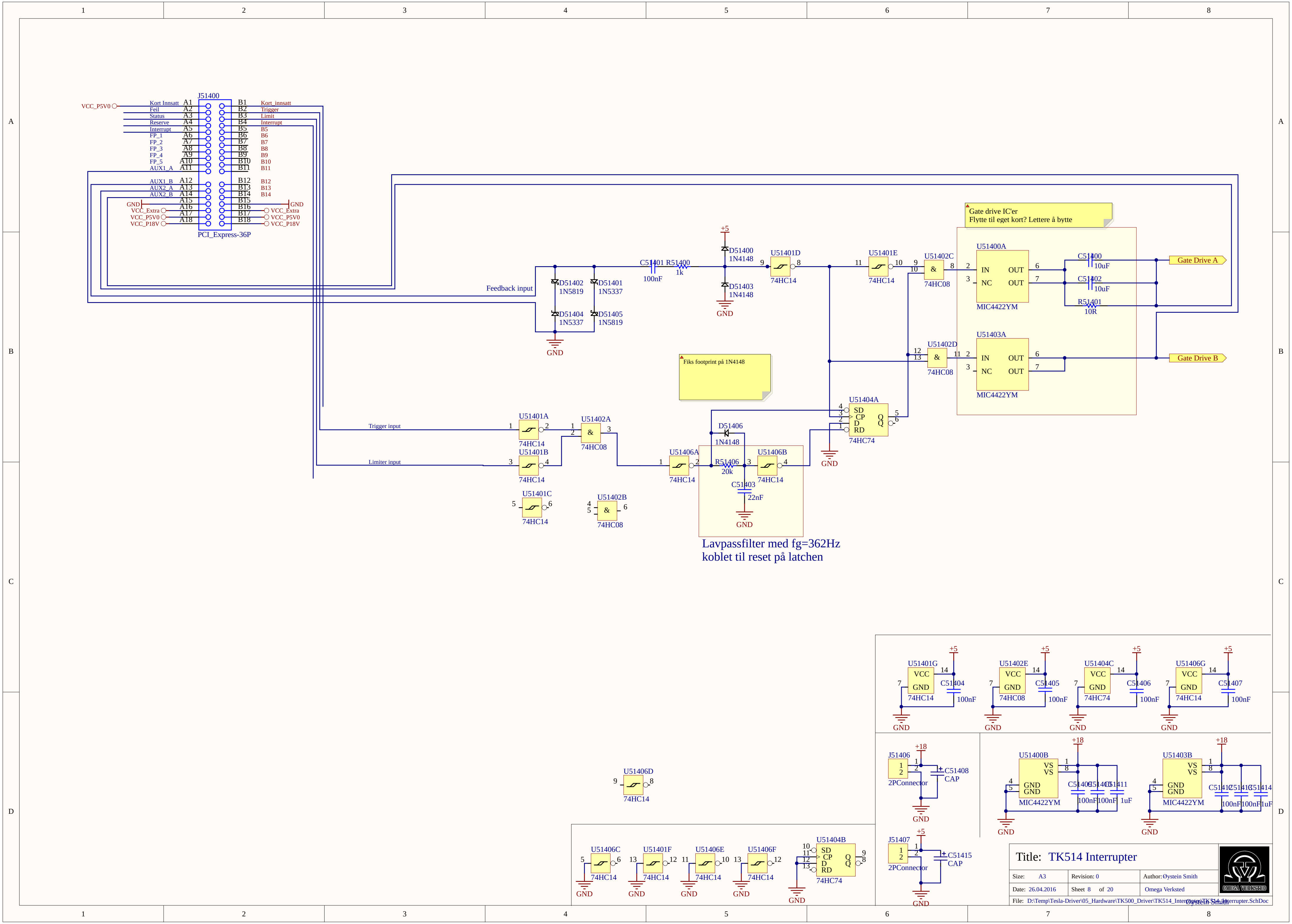
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PCI_Express-36P
VCC_P5V0
Kort Innsatt
Feil
Status
Reserve
Interrupt
FP_1
FP_2
FP_3
FP_4
FP_5
AUX1_A
AUX1_B
AUX2_A
AUX2_B
GND
VCC_Extra
VCC_P18V
Kort_innsatt
Trigger
Limit
Feedback input
Trigger input
Limiter input
Gate drive IC'er
Flytte til eget kort? Lettere å bytte
Fiks footprint på 1N4148
Lavpassfilter med fg=362Hz
koblet til reset på latchen
U51400A MIC4422YM
U51403A MIC4422YM
U51401D 74HC14
U51401E 74HC14
U51402C 74HC08
U51402D 74HC08
U51404A 74HC74
U51406A 74HC14
U51406B 74HC14
D51400 1N4148
D51403 1N4148
D51406 1N4148
D51402 1N5819
D51401 1N5337
D51404 1N5337
D51405 1N5819
C51401 100nF
R51400 1k
R51406 20k
C51403 22nF
C51400 10uF
C51402 10uF
R51401 10R
Gate Drive A
Gate Drive B
J51406 2PConnector
C51408 CAP
J51407 2PConnector
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Title: TK514 Interrupter
Size: A3
Revision: 0
Author: Øystein Smith
Date: 26.04.2016
Sheet 8 of 20
Omega Verksted
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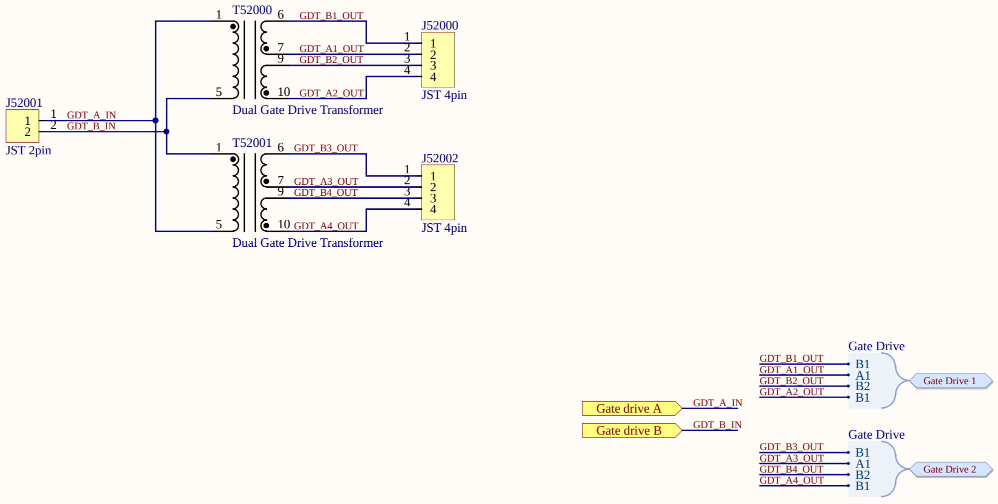
OMEGA VERKSTED




Title: TK520 GDT-Trafo

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| Size: A3 | Revision: 1 | Author: Øystein Smith |
| Date: 26.04.2016 | Sheet 13 of 20 | Omega Verksted |

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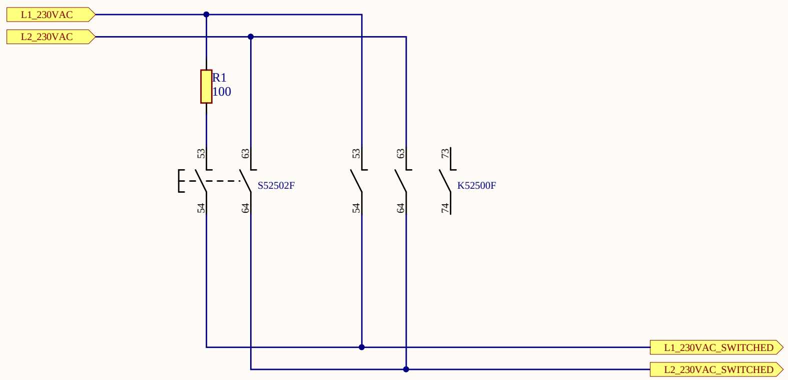


Title: TK525 Hovedstrøm

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|---|---|---|
| Size: A3 | Revision: 0 | Author: Øystein Smith |
| Date: 26.04.2016 | Sheet 14 of 20 | Omega Verksted |

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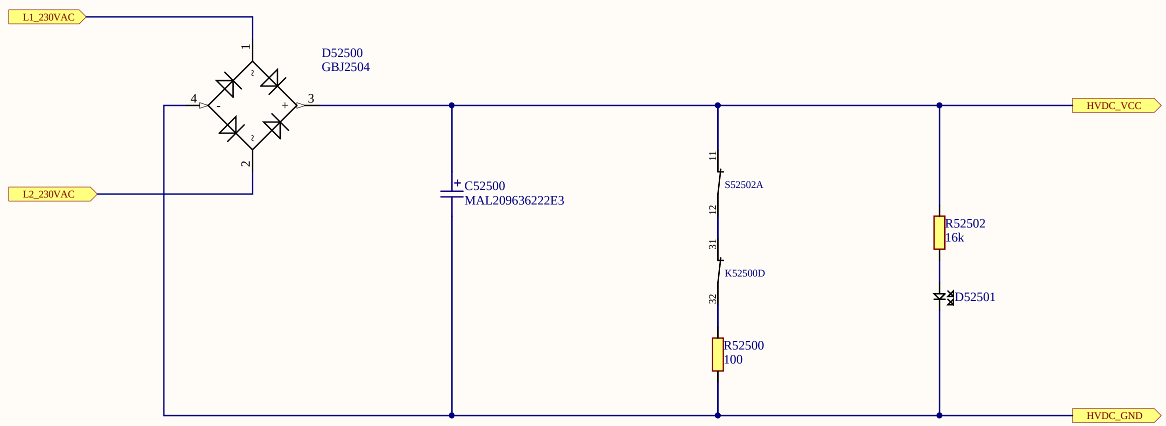


Title: TK525 HVDC

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| Size: A3 | Revision: 0 | Author: Øystein Smith |
| Date: 26.04.2016 | Sheet 15 of 20 | Omega Verksted |

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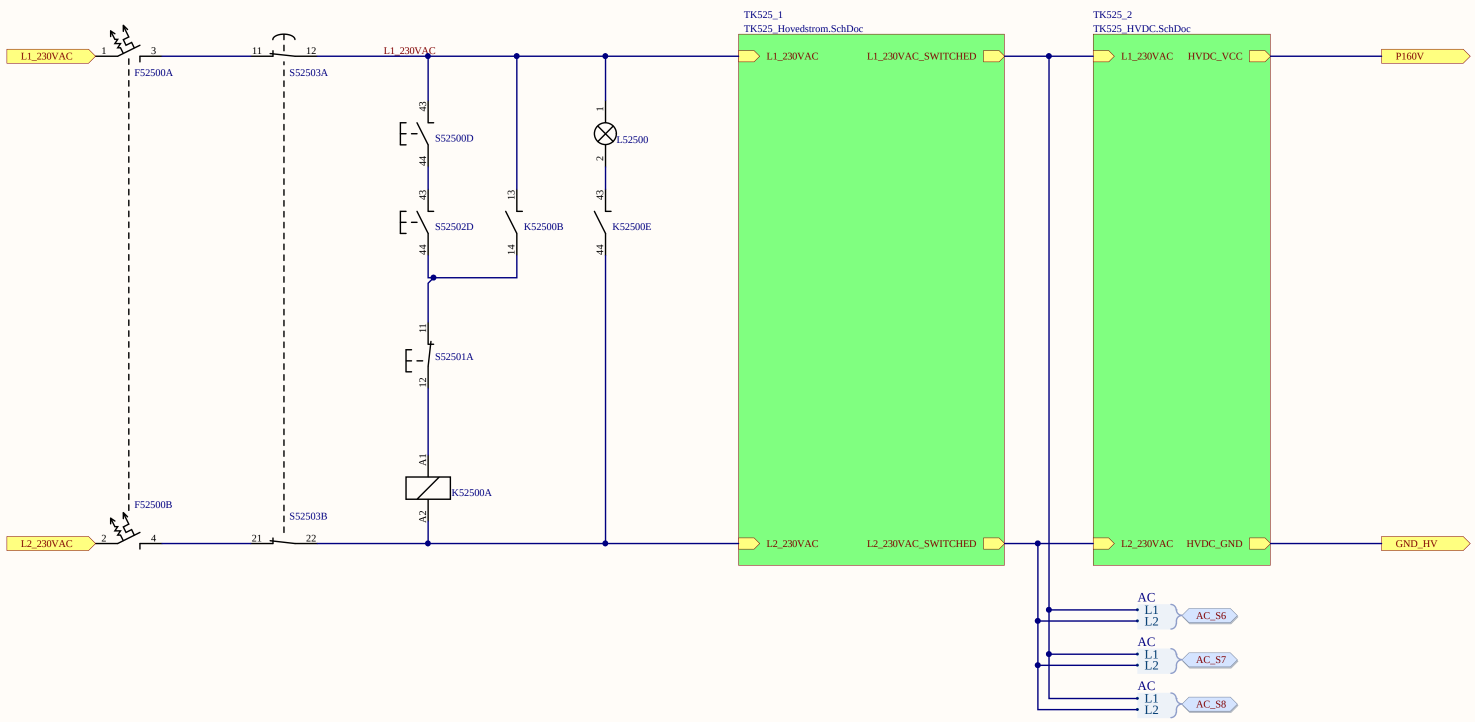


Title: TK525 Kraftforsyning

| | | |
|---|---|---|
| Size: A3 | Revision: 0 | Author: Øystein Smith |
| Date: 26.04.2016 | Sheet 16 of 20 | Omega Verksted |

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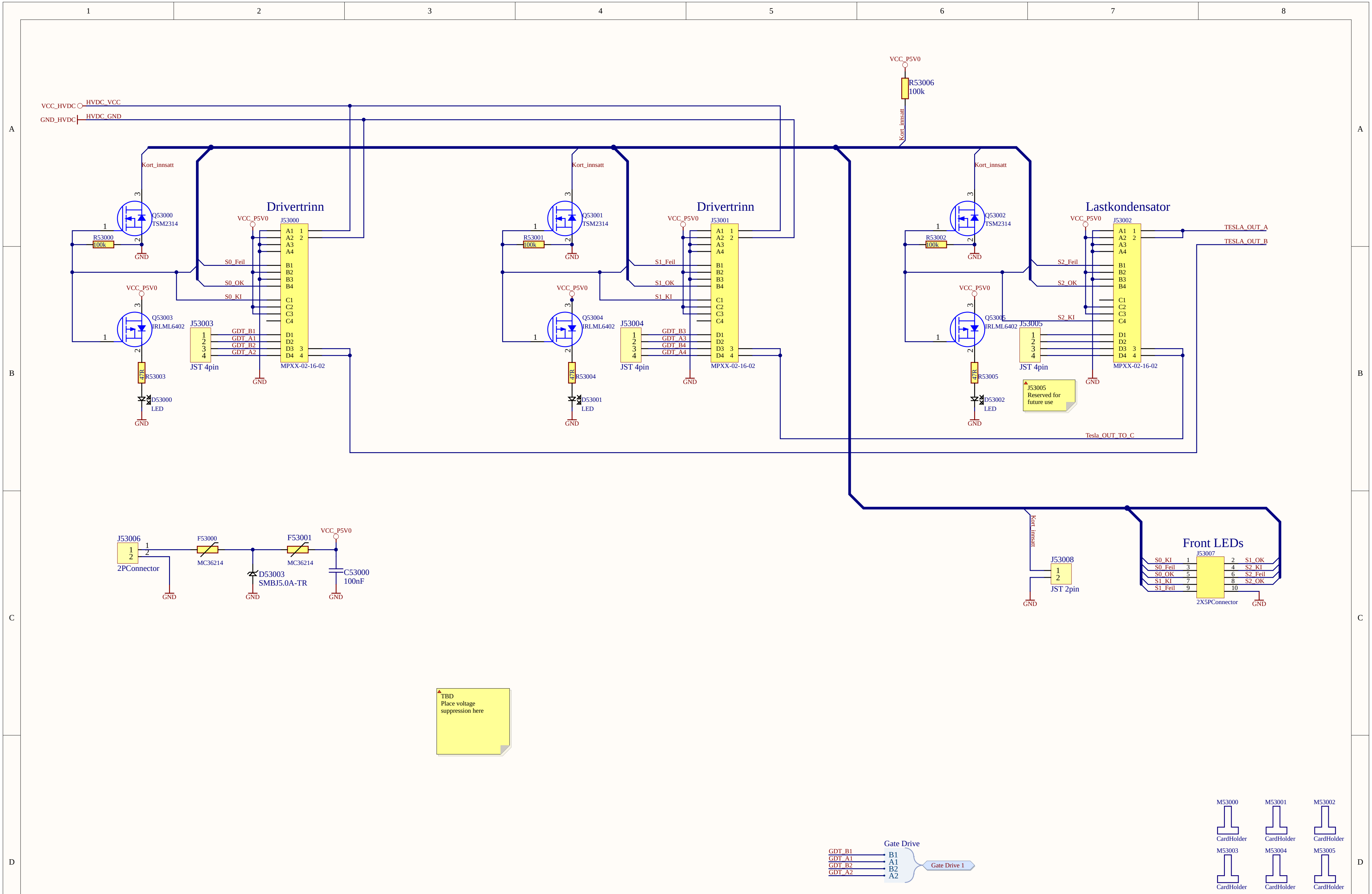


Title: TK530 Kraftbakplan

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|---|---|---|
| Size: A3 | Revision: 2 | Author: Øystein Smith |
| Date: 26.04.2016 | Sheet 17 of 20 | Omega Verksted |

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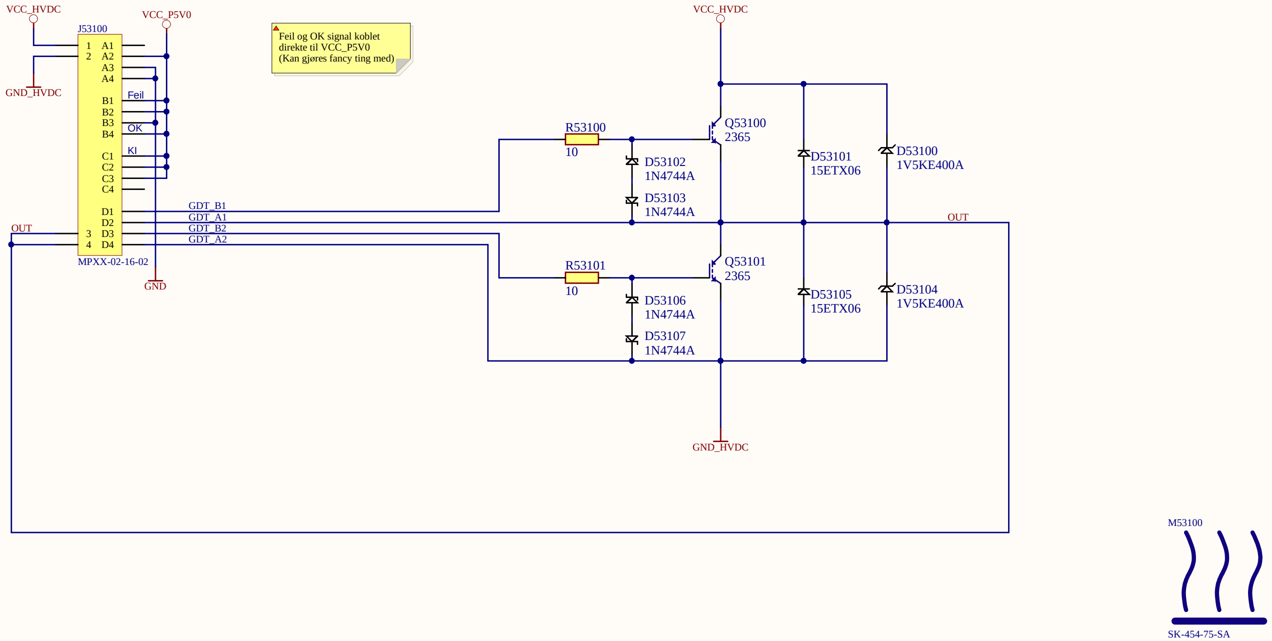


| | | | |
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| Size: A3 | Revision: 2 | Author: Øystein Smith | |
| Date: 26.04.2016 | Sheet 18 of 20 | Omega Verksted | |
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LEDs
TK502_Frontpanel_LEDs.SchDoc

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|---|---|---|---|
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| Size: A3 | Revision: 0 | Author: * | |
| Date: 26.04.2016 | Sheet 20 of 20 | Omega Verksted | |
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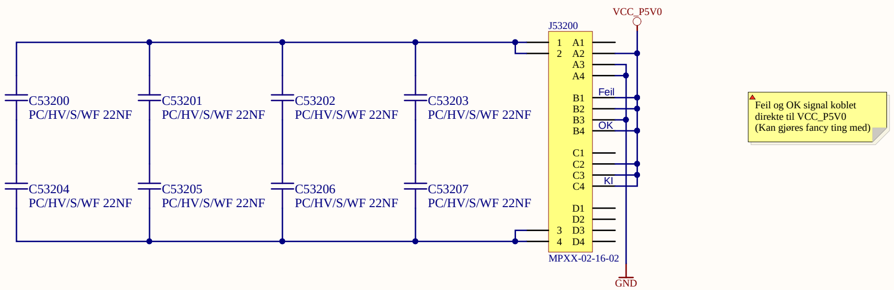


| | | |
|---|---|---|
| Title: TK532 Kondensatorkort | | |
| Size: A3 | Revision: 2 | Author: Øystein Smith |
| Date: 26.04.2016 | Sheet * of * | Omega Verksted |
| File: D:\Temp\Tesla-Driver\05_Hardware\TK500_Driver\TK532_Kondensatorkort\TK532_Kondensatorkort.SchDoc | | |

# C Layout

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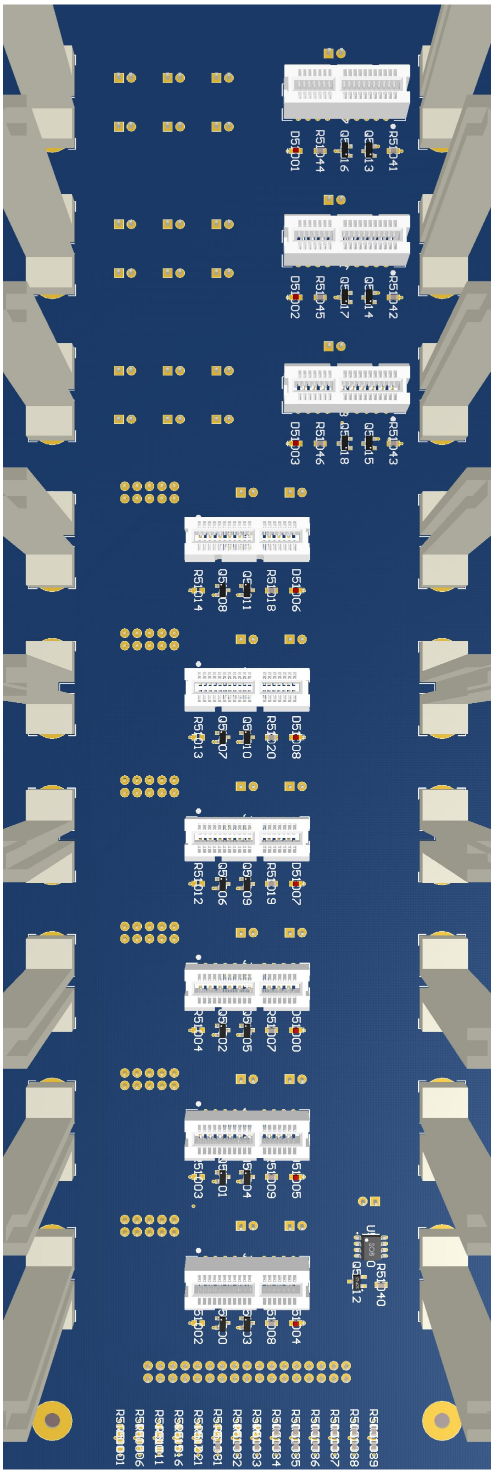
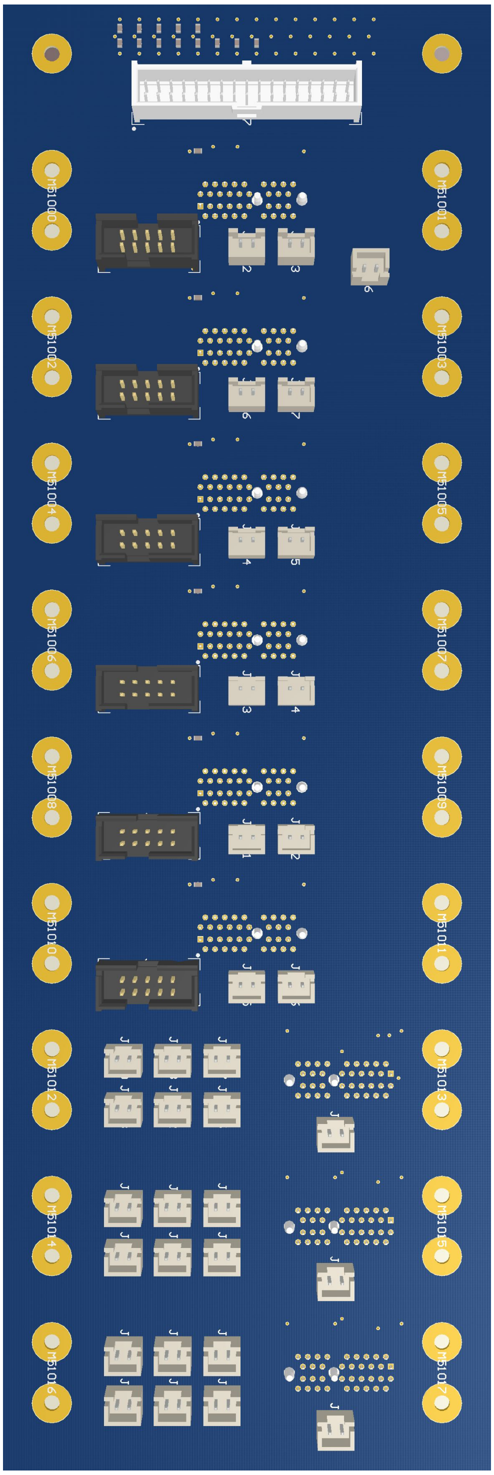
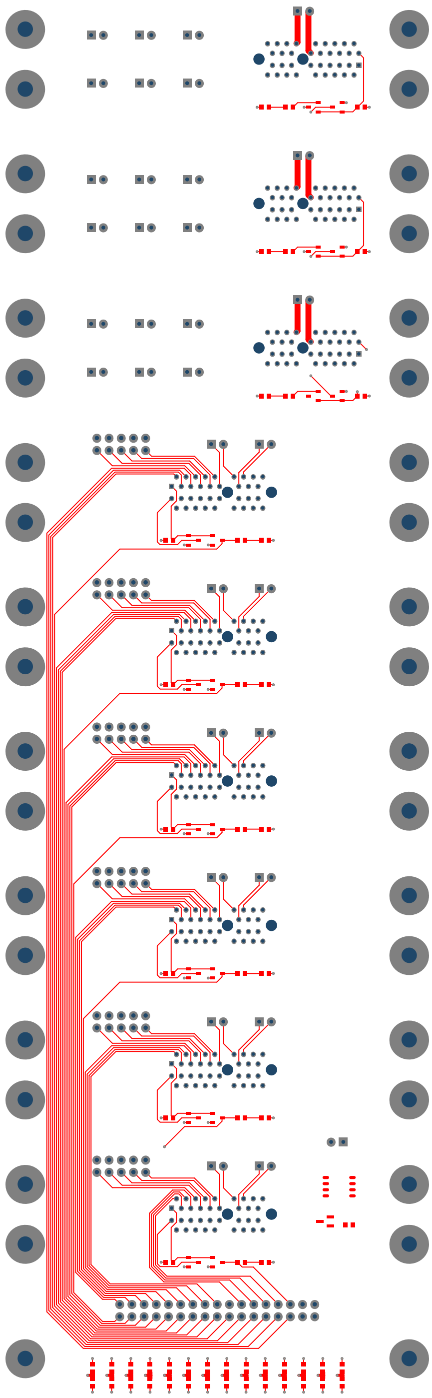
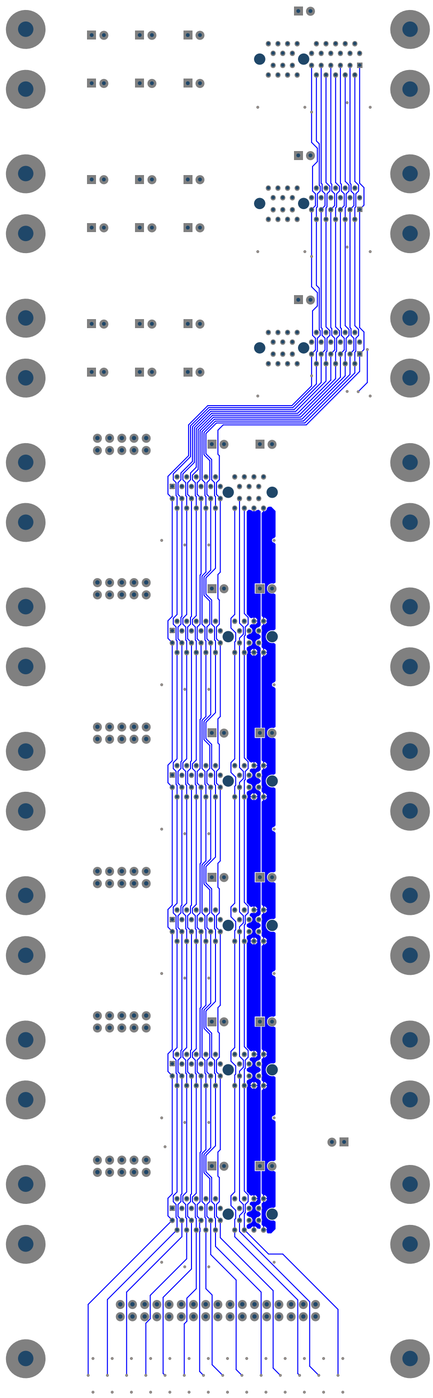
## C.1 TK510

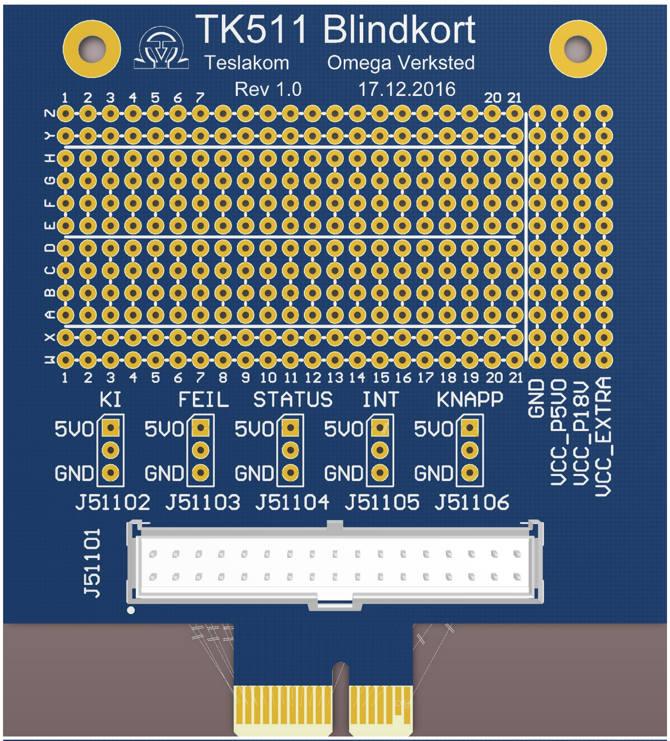


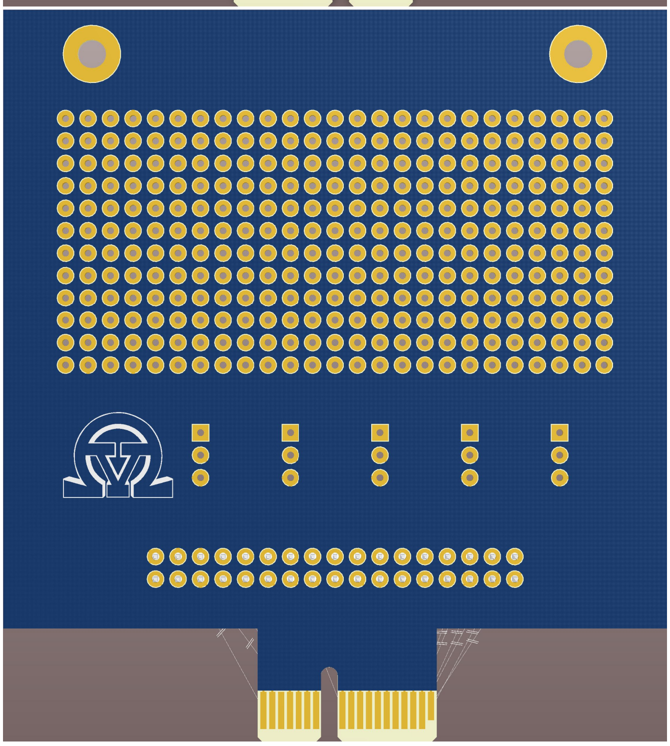


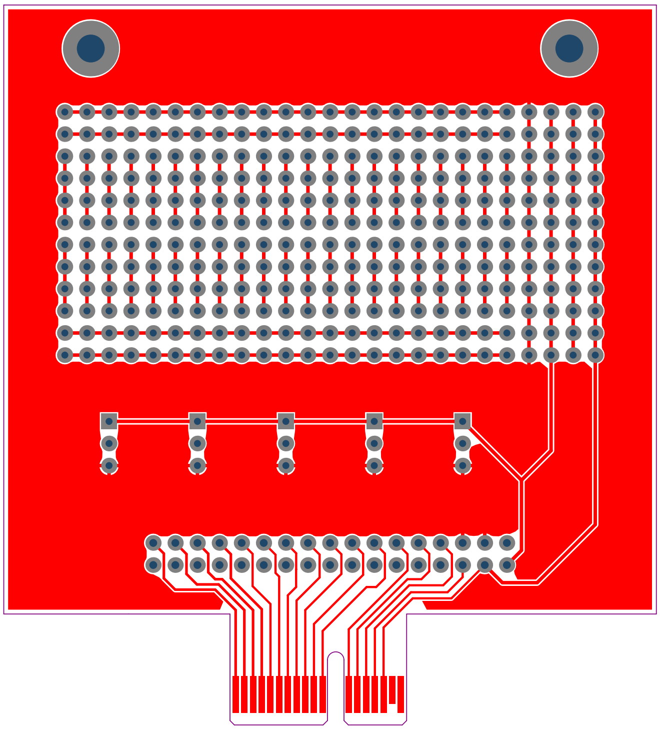


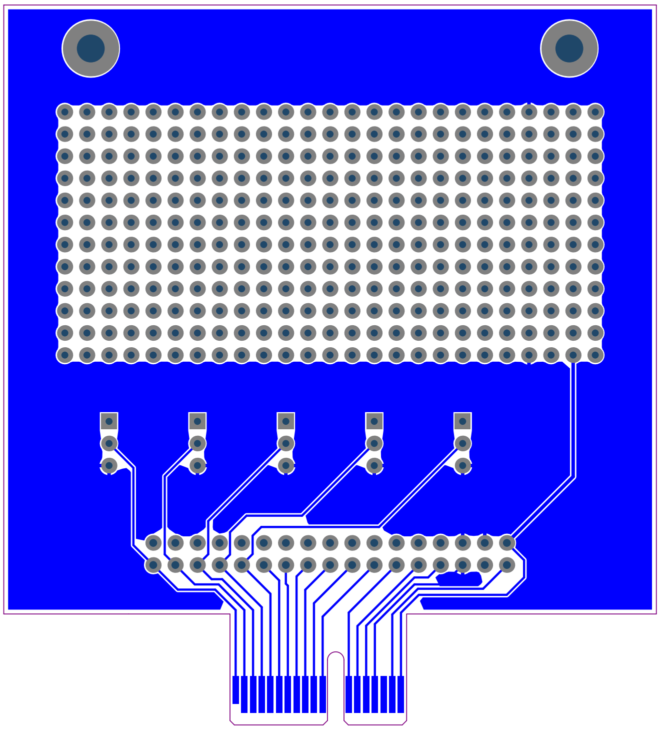


## C.2 TK511

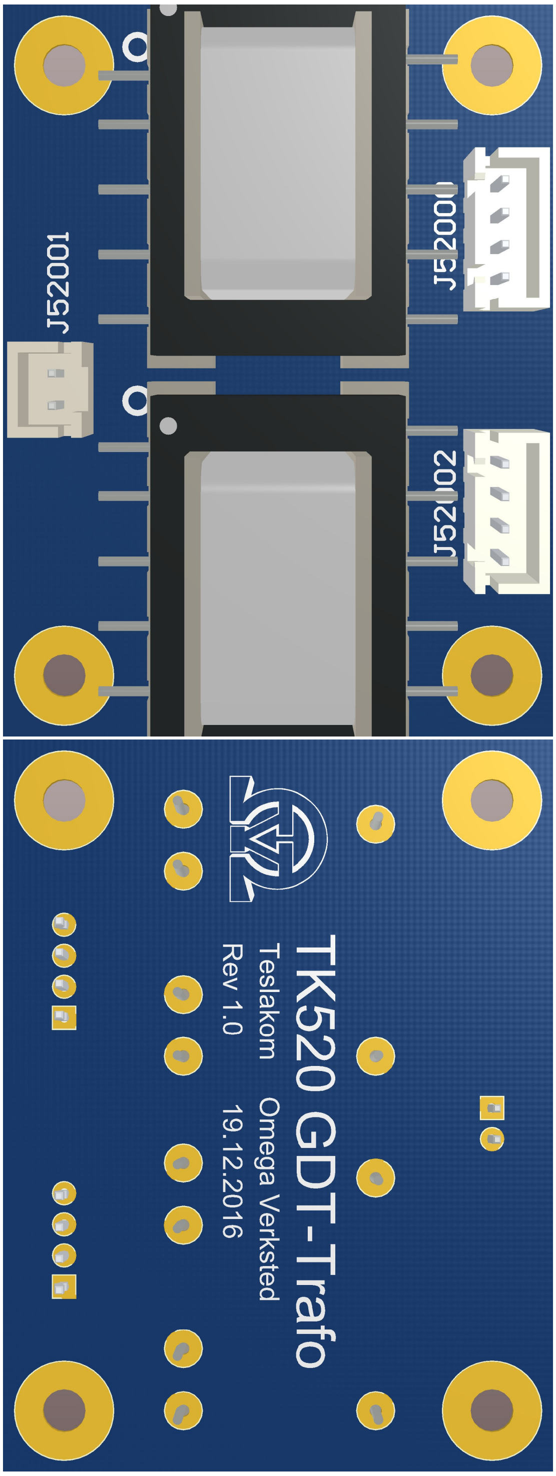

TK511 Blindkort
Teslakom
Omega Verksted
Rev 1.0
17.12.2016
KI
FEIL
STATUS
INT
KNAPP
5V0
GND
J51102
J51103
J51104
J51105
J51106
J51101
GND
VCC_P5V0
VCC_P18V
VCC_EXTRA

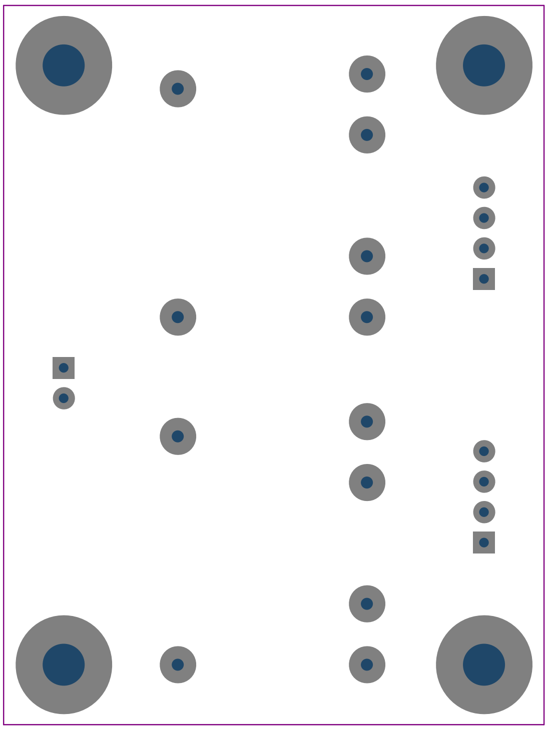


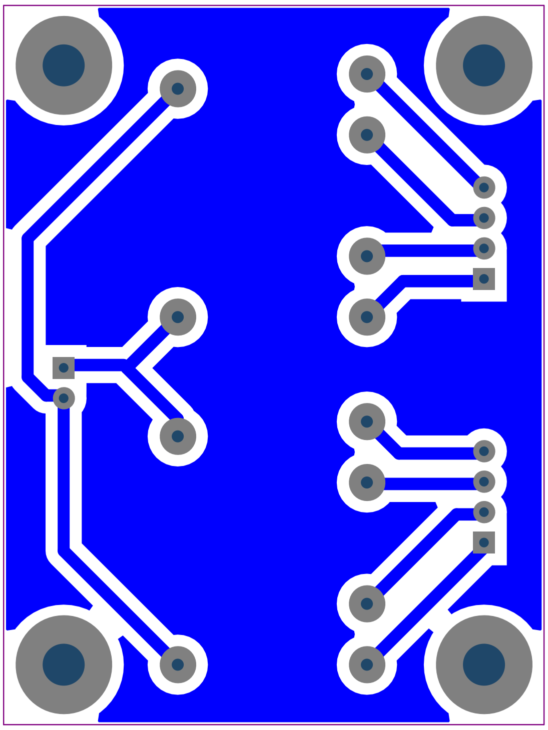




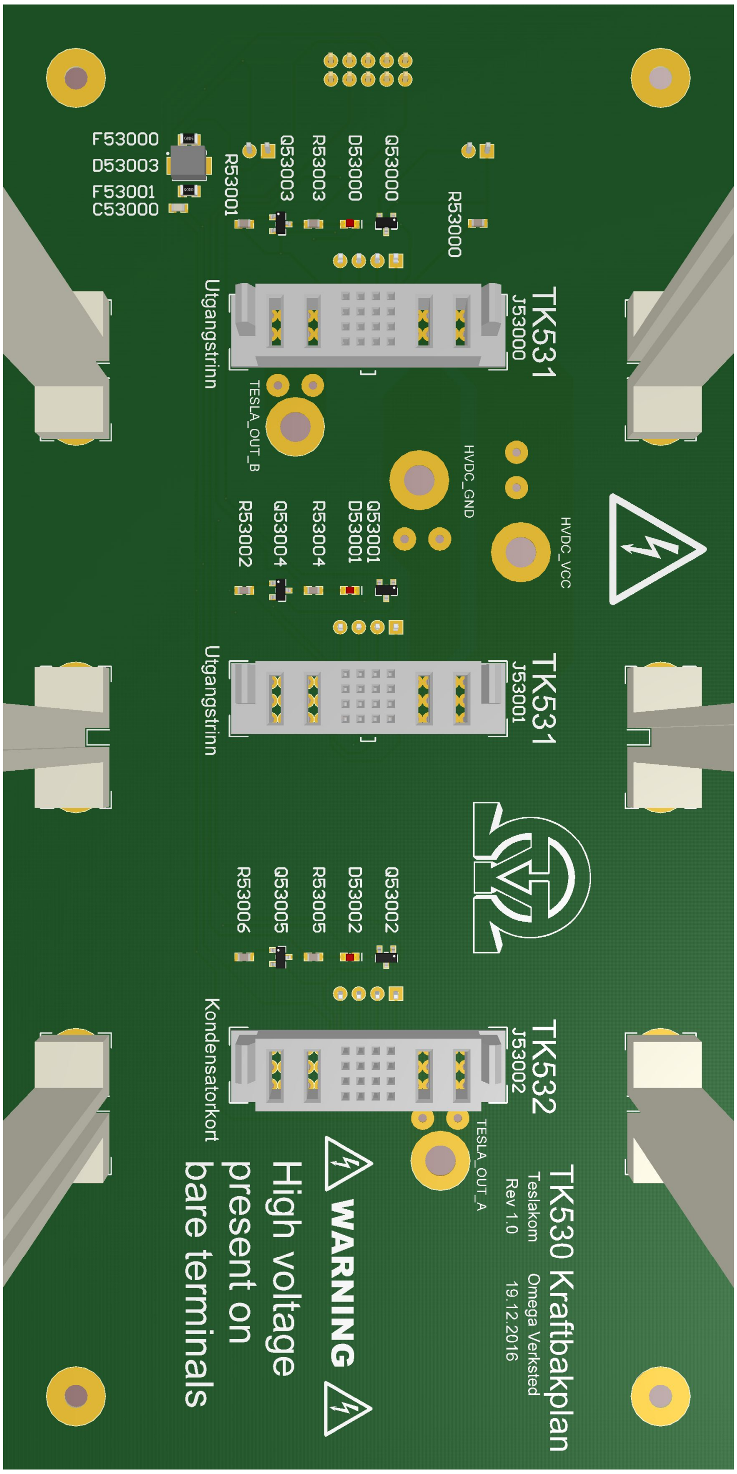
## C.3 TK520

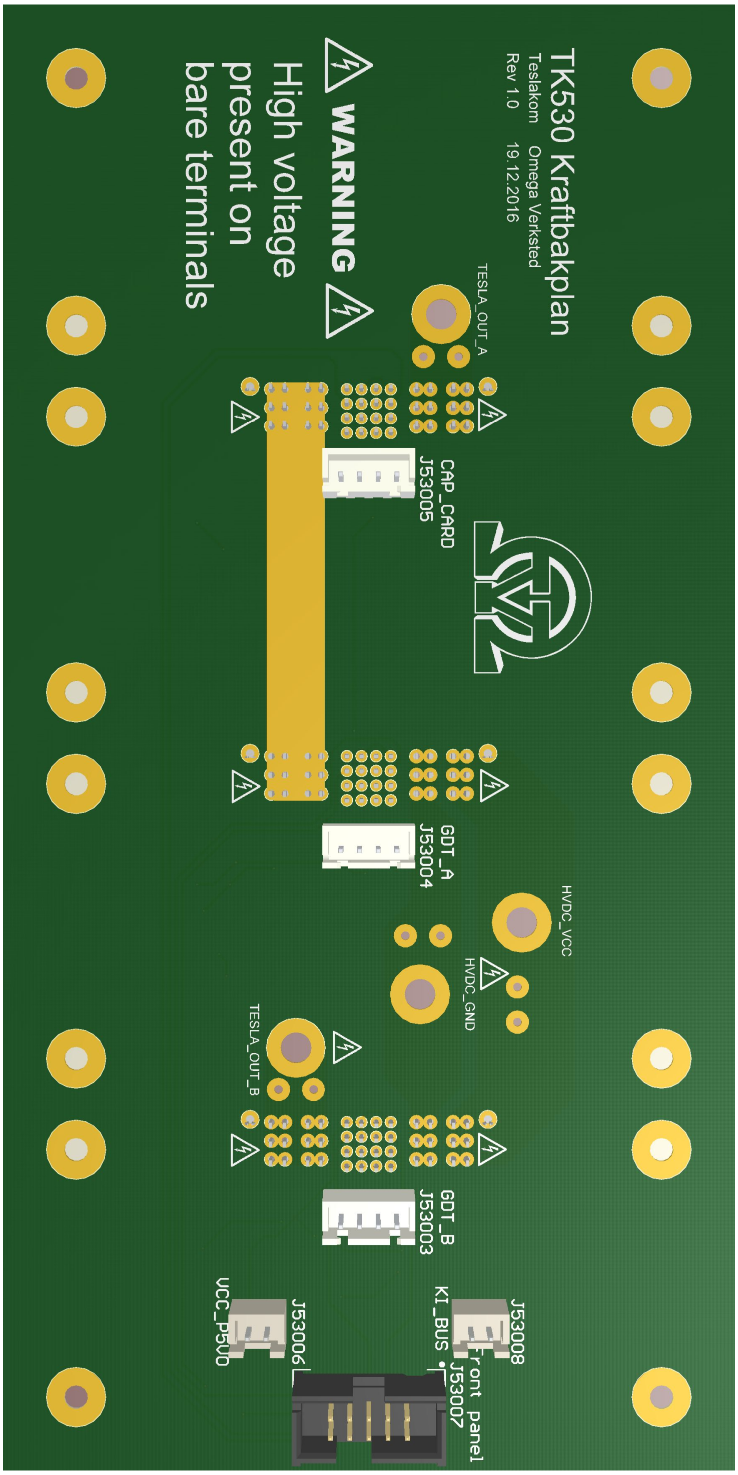

J52001
J52001
J52002
TK520 GDT-Trafo
Teslakom Omega Verksted
Rev 1.0 19.12.2016

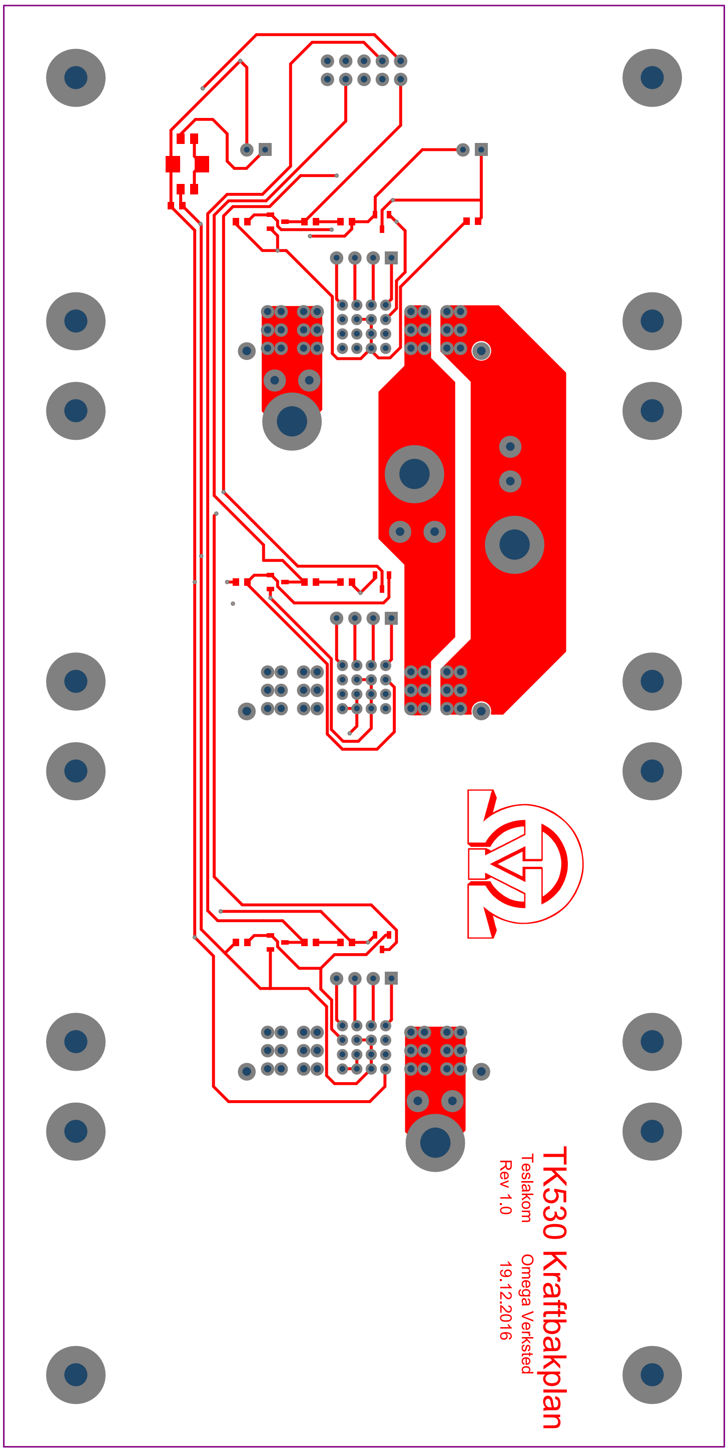


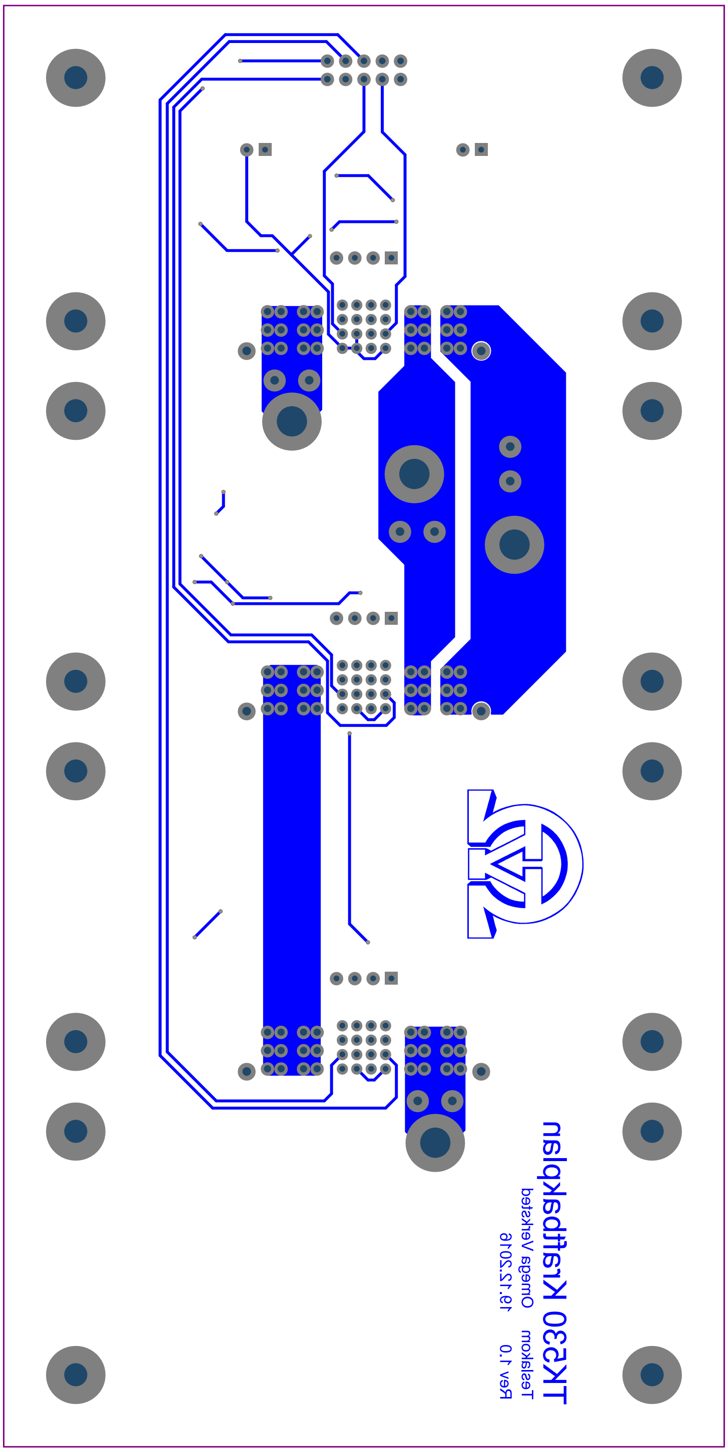


## C.4 TK530

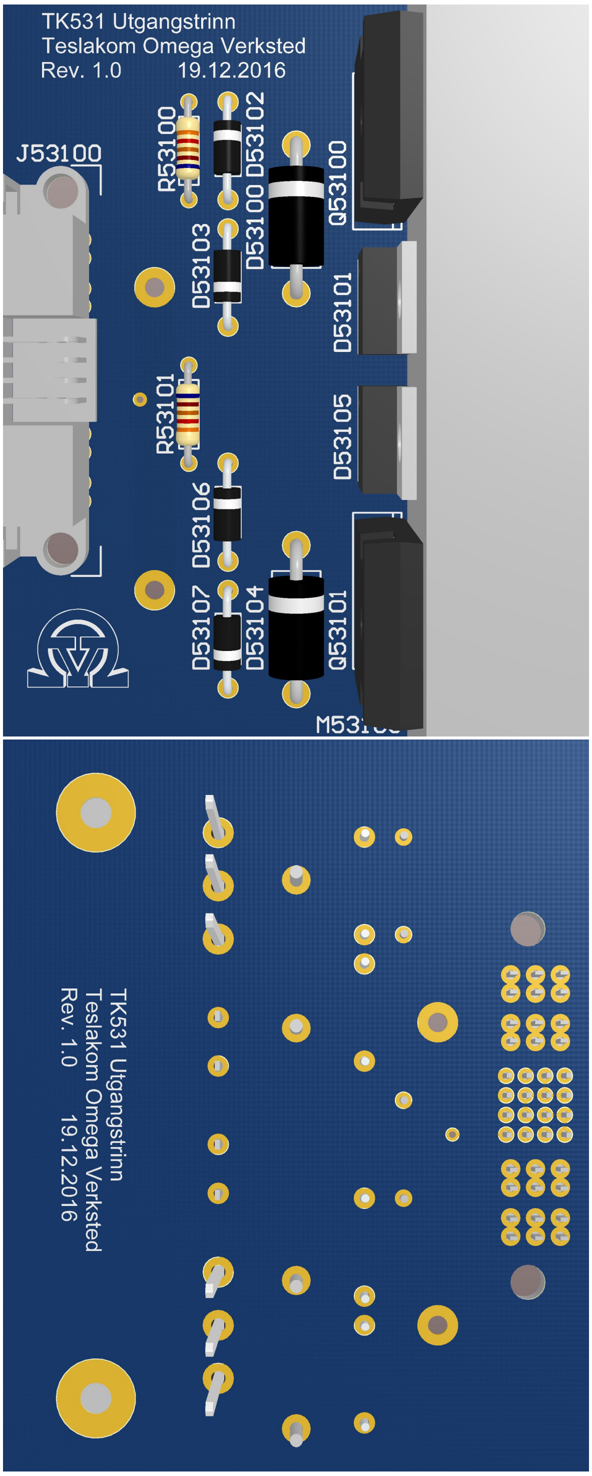

F53000
D53003
F53001
C53000
R53001
Q53003
R53003
D53000
Q53000
R53000
Utgangstrinn
TK531
J53000
TESLA_OUT_B
HVDC_GND
HVDC_VCC
R53002
Q53004
R53004
D53001
Q53001
Utgangstrinn
TK531
J53001
R53006
Q53005
R53005
D53002
Q53002
Kondensatorkort
TK532
J53002
TESLA_OUT_A
WARNING
High voltage
present on
bare terminals
TK530 Kraftbakplan
Teslakom
Omega Verksted
Rev 1.0
19.12.2016

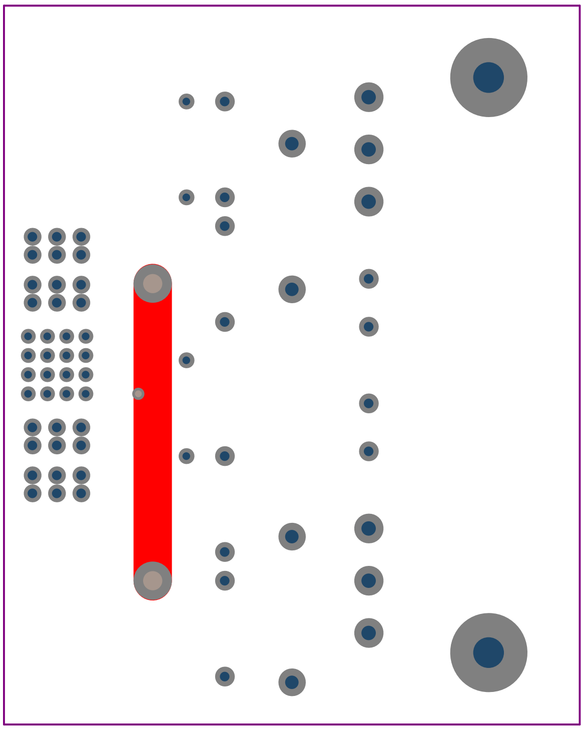

TK530 Kraftbakplan
Teslakom Omega Verksted
Rev 1.0 19.12.2016
WARNING
High voltage present on bare terminals
TESLA_OUT_A
CAP_CARD
J53005
GDT_A
J53004
HVDC_VCC
HVDC_GND
TESLA_OUT_B
GDT_B
J53003
J53006
VCC_P5V0
J53008
KI_BUS
Front panel
J53007

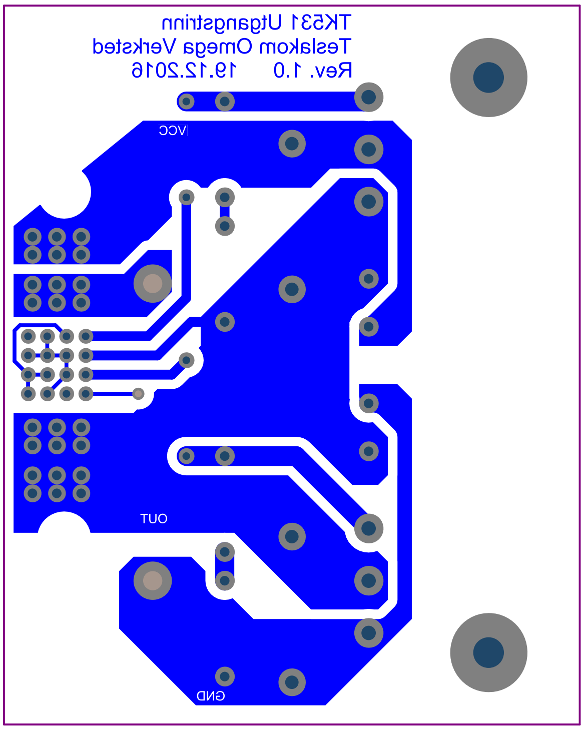

TK530 Kraftbakplan
Teslakom Omega Verksted
Rev 1.0 19.12.2016



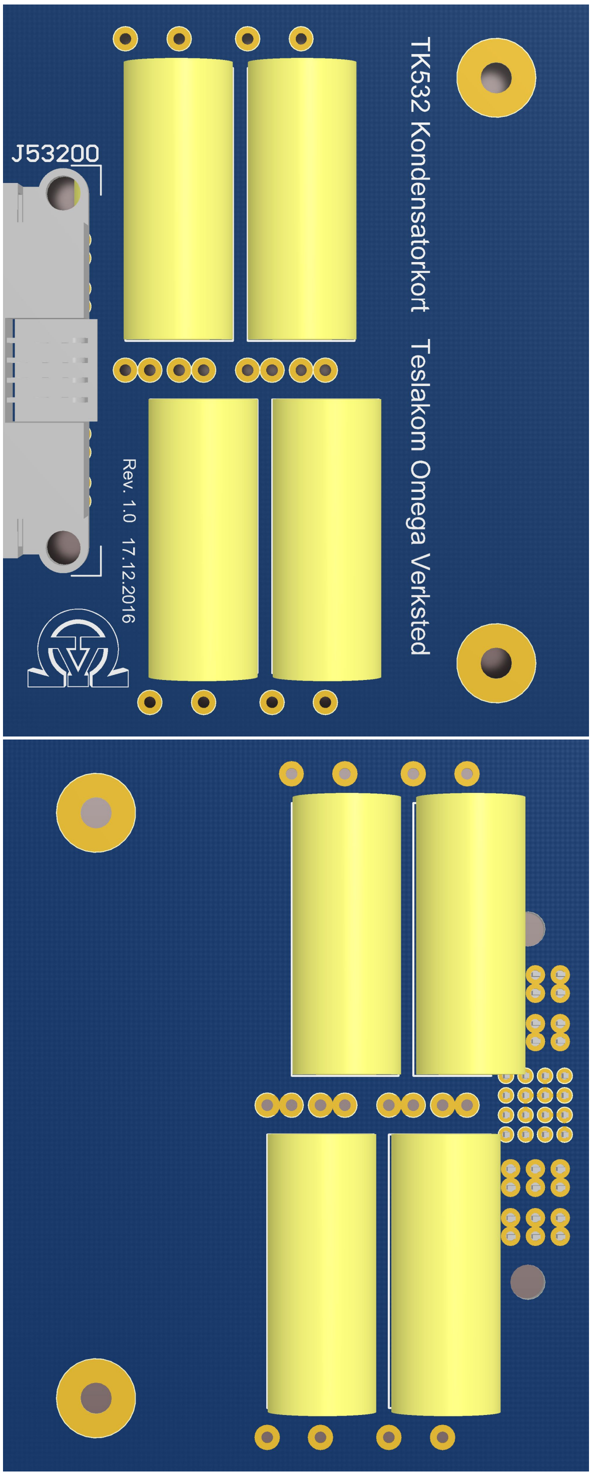
## C.5 TK531


TK531 Utgangstrinn
Teslakom Omega Verksted
Rev. 1.0 19.12.2016
J53100
R53100
D53102
D53100
Q53100
D53103
D53101
R53101
D53105
D53106
D53107
D53104
Q53101




TK531 Utgangstrinn
Teslakom Omega Verksted
Rev. 1.0 19.12.2016
VCC
OUT
GND

## C.6 TK532


TK532 Kondensatorkort Teslakom Omega Verksted
J53200
Rev. 1.0 17.12.2016