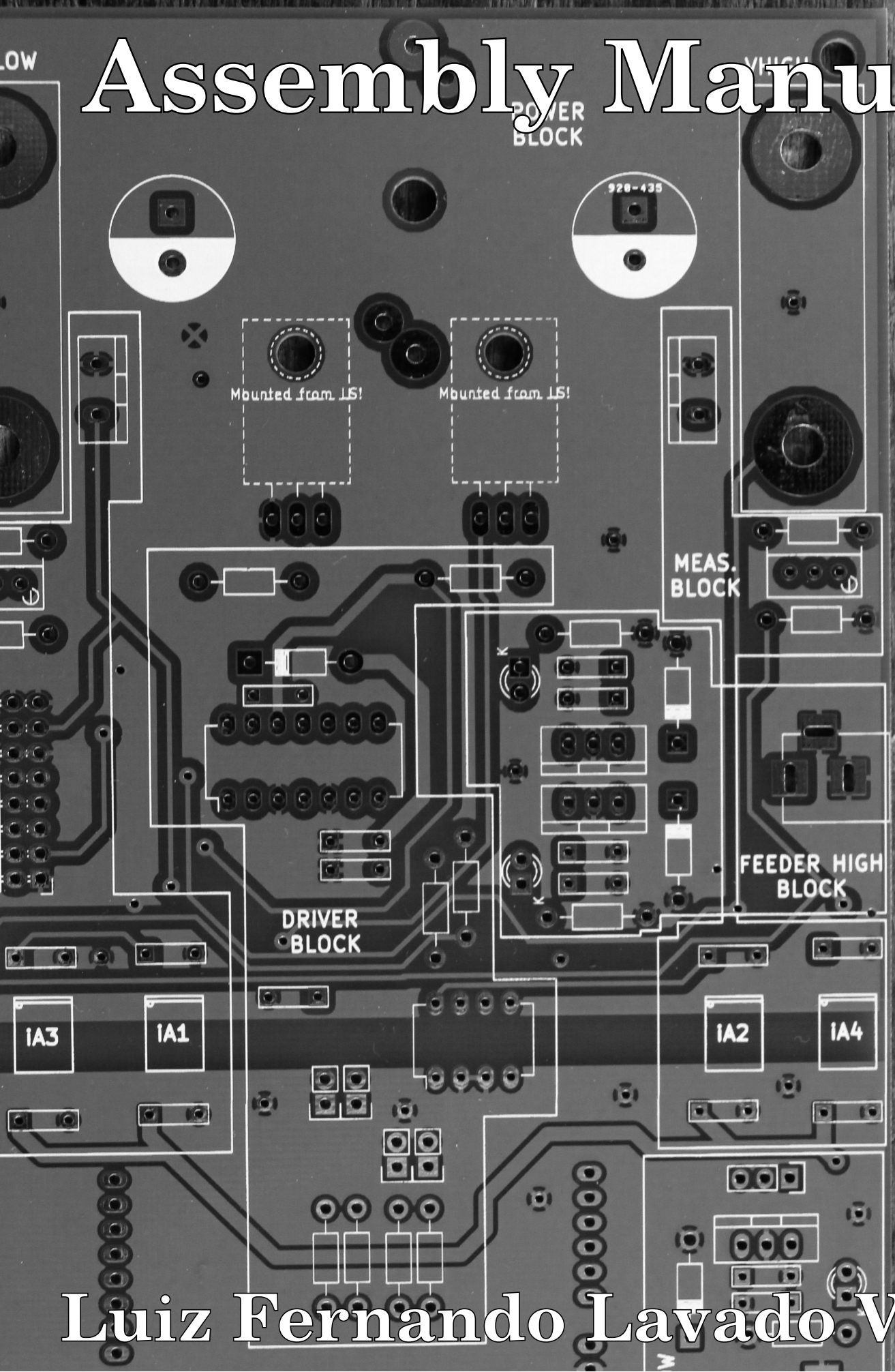
Power Converter Assembly Manual



Luiz Fernando Lavado Villa

Power Converters: A Crash-Course

This section is a crash-course on what a power converter is and what you need to know to build one. The idea here is to avoid the theoretical part and cut straight to the chase. Brace yourself, this will be fun!

What is a power converter

A power converter is a device capable of adapting electric energy in its many different forms. The figure below gives an overview of several converting capabilities of power converters.

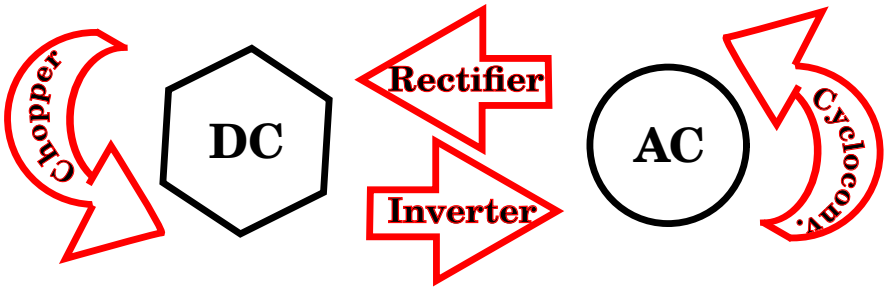


Figure 1: Overview of power conversion

In this manual we will focus on the DC to DC power conversion by building a chopper. This chopper allows to convert a lower voltage to a higher one and vice-versa.

Inside the black-box: Functions of a power converter

The power converter is a closed loop system. It takes in power, measures input and/or output variables, takes those measurements into a control system and generates the pulses for controlling the power elements. This loop is represented in the figure below.

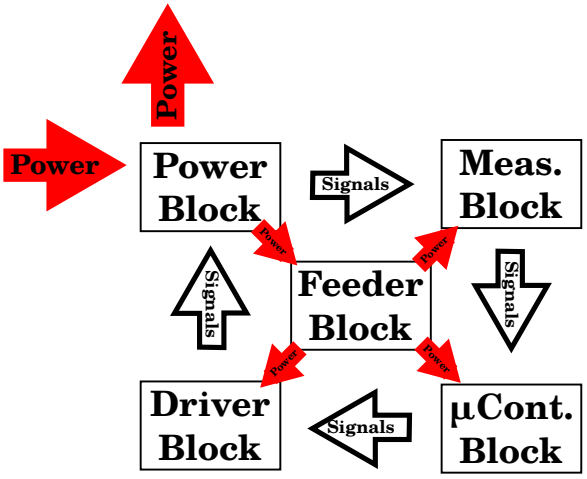


Figure 2: Overview of the blocks composing a power converter

The power converter described in this manual has the same blocks described in figure 2.

About the DC/DC converter in this manual

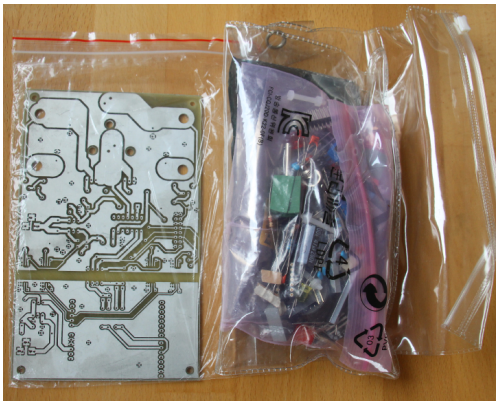
The DC/DC converter in this manual was designed to be universal. This means that it is bi-directional in terms of input and output, thus it can raise a low voltage or lower a high voltage input. This converter measures current and voltage in both input and output, giving its control system all the information it needs to adapt its operation.

However, since nothing is totally universal, this converter also has its limitations. The table below describes its specifications.

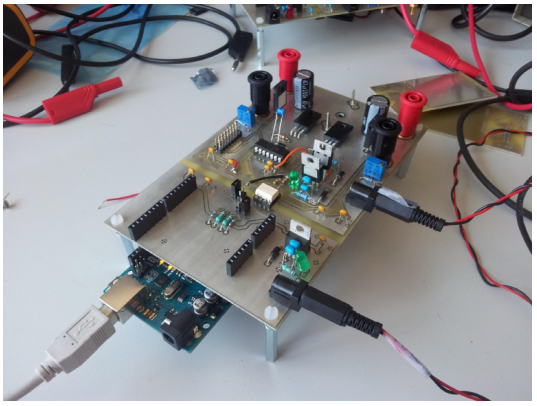
Table 1: Converter ratings

Variable	*Description*	*Value*
$V_{LOW_{MAX}}$	Low side maximum voltage	100 V
$V_{HIGH_{MAX}}$	High side maximum voltage	200 V
$i_{LOW_{MAX}}$	Low side maximum current	50 A
f	Operating frequency	30 to 150 kHz
$\Delta V_{L_{OUT}}$	Low side voltage ripple	?? V
$\Delta V_{H_{OUT}}$	High side voltage ripple	?? V
$\Delta i_{L_{OUT}}$	Low side current ripple	?? V
$\Delta i_{H_{OUT}}$	High side current ripple	?? V

The assembly of this converter will be made in a block-by-block approach. For each block you will assemble and test the components that compose that block. All the components are available in the component pouch and they will be assembled onto the PCB. The figures below show before and after the assembly of the converter.



(a) PCB and component pouch



(b) Final converter assembly

Figure 3: Global figure caption

The converter explained in this manual will be represented by its component map, as shown in the figure below. Each block of the power converter is represented in the component map.

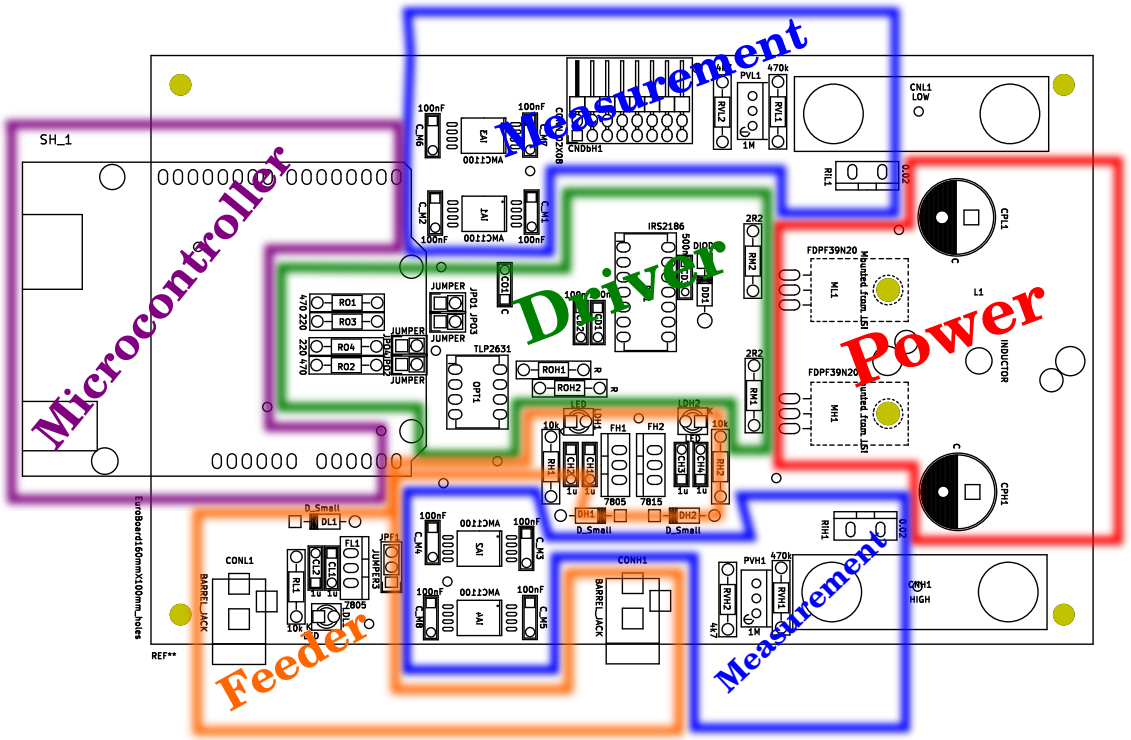


Figure 4: Overview of power conversion

Important Notice: Working with power electronics requires an extra care with voltage ratings and short circuits. Please be careful when manipulating power systems. Any tests should be conducted after considering all the safety issues possibly involved.

Preliminaries - PCB Support Legs and Vias

The support legs suspend the PCB and avoid components touching the table. **They are assembled from plastic wire and a metal spacer.**

The vias connect one side of the PCB with another, granting electrical continuity. In this power converter, the vias are supposed to be metallized holes that do not require soldering. **Checking the integrity of the path made by the vias is essential to avoid later errors.**

Table 2: The components of this block

Component	*Description*	*Quantity*
Plastic screws	Nylon screws	4
Plastic nuts	Nylon nuts	4
Metal spacers	Spacers that screw onto the nylon screws	4

Table 3: The tools needed to assemble/test this block

Tool	*Description*	*Quantity*
Multimeter	Used to check the continuity in the vias	1
Soldering iron	Used to repair any vias	1
Soldering wire	Used to repair any vias	-
Thin wire	Component legs or other thin wire for repairing vias	-

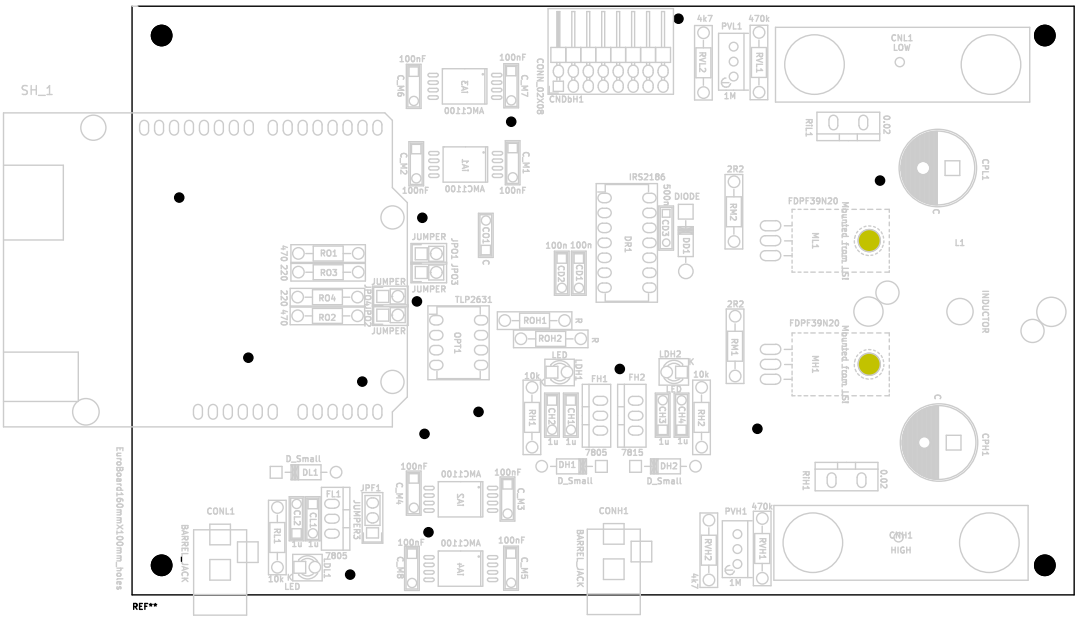


Figure 5: Components map

Assembly procedure

Follow these steps to assemble the four support legs of the converter.

1. **Separate the components -** Identify all the components on the list within the component pouch
2. **Screws and nuts -** Put the plastic screws on the four corners of the PCB and screw their nuts to bolt them together
3. **Spacers -** Once the bolts are in firmly place, screw the metal spacers to the plastic screws

Testing procedure

Testing the spacers is quite straight forward: **they should hold firmly in place**.

To test the vias, follow the procedure below:

1. Put the multimeter in the "continuity test" position
2. Identify the vias by comparing the PCB with figure 5
3. Test their continuity with the multimeter
4. Mark any defective vias
5. Insert the thin wire in the vias and solder them on both sides

Finally, a visual inspection can detect any manufacturing defects on the PCB. **Make a general visual check on the PCB taking care to identify any undesired short circuit or discontinuities on the tracks.** If there is anything that seems wrong, be ready to improvise.

Notes:

Block 1 - PCB Feeder

The feeder is responsible for providing the voltage needed by the components of the power converter. It is important to note that **there are two ground planes in this power converter**, a low voltage and a high voltage ground. Each ground plane has its own voltage regulator.

Table 4: The components of this block

Component	*Description*	*Reference*	*Qty.*
7805	5V Linear voltage regulator	FH1, FL1	2
7815	15V Linear voltage regulator	FH2	1
Barrel Jack	Connectors used to feed the system	CONH1, CONL1	2
Small diodes	Diodes that protect the linear regulators	DH1, DH2, DL1	3
3 Conn. Jumper	Connector used to feed the system from the Arduino or 7805	JPF1	1
LEDs	LEDs used to determine if the feeders are working	LDH1, LDH2, LDL1	3
Resistors	**10k Resistors** used to limit the current in the LEDs	RH1, RH2, RL1	3
Capacitors	**1uF Capacitors** used to stabilize power input and output from the regulators	CL2, CL1, CH4, CH3, CH2, CH1	6

Table 5: The tools needed to assemble/test this block

Tool	*Description*	*Quantity*
Multimeter	Used to check several aspects of the system	1
Soldering iron	Used to solder the components	1
Soldering wire	Used to solder the components	-

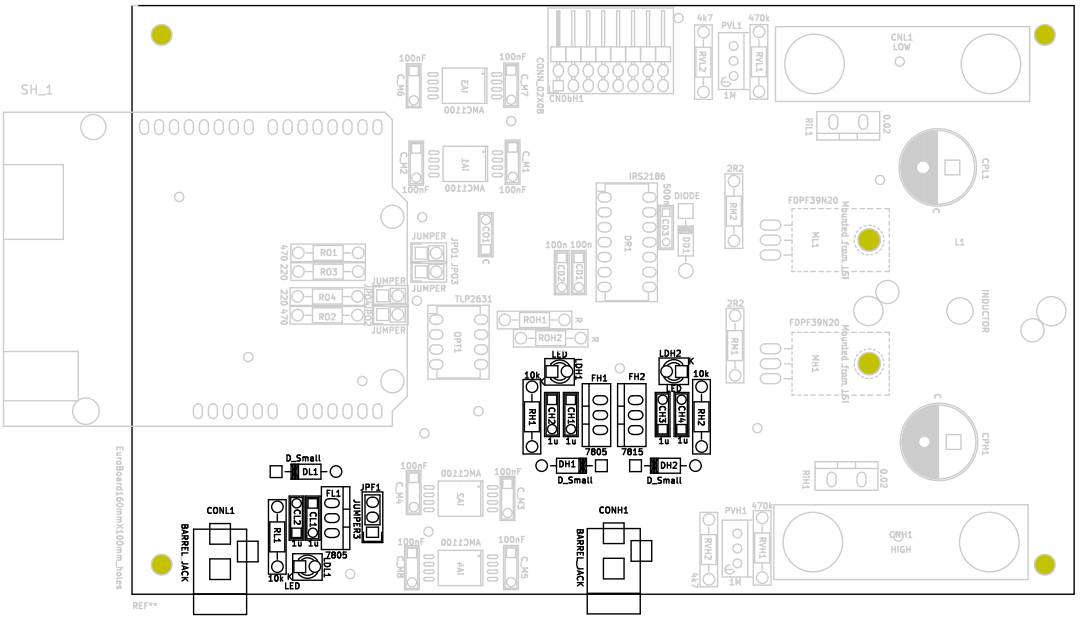


Figure 6: Components map

Assembly procedure

Follow these steps to assemble the feeder.

1. **Separate the components -** Identify all the components on the list in the component pouch
2. **Solder small stuff first -** Solder all the capacitors, diodes, LEDs and resistors. **Remember that there are two ground planes.**
3. **Solder the big stuff afterwards -** With all the small stuff soldered, solder the 7805s and the 7815.
4. **Solder the Barrel Jacks -** The barrel jacks are a convenient way to power the feeder. Find the footprint of the barrel jacks and solder it. **Some improvisation may be required.**
5. **Make some power chords -** Make two power chords using the barrel jacks connectors and some banana plugs.

Testing procedure

Follow the steps below to test the feeder block:

1. Test the input of the feeder for any short circuits
2. If there are no short-circuits connect the feeder to a DC power source
3. Connect the jumper in the low side feeder so that the +5V can flow to the low side tracks
4. Use the multimeter in the "DC voltage" position to check the low side +5V and the high side +5V and +15V
5. Check that the power from the feeder arrives at the power pads of the optocoupler, driver and isolation amplifier (look up their datasheet to find their designated pads)

Notes:

Block 2 - Microcontroller connectors and Arduino

The microcontroller block is essentially 4 connectors dedicated to plug the power converter onto an Arduino platform.

Table 6: The components of this block

Component	*Description*	*Reference*	*Qty.*
6 line Connector	Connector with 6 pins	-	2
8 line Connector	Connector with 8 pins	-	2
Arduino Uno	Arduino Uno System for controlling the power converter	-	1

Table 7: The tools needed to assemble/test this block

Tool	*Description*	*Quantity*
Multimeter	Used to perform several checks in the circuit	1
Soldering iron	Used to solder the components	1
Soldering wire	Used to solder the components	-
Oscilloscope	Used to check the control and output signals of the system	1

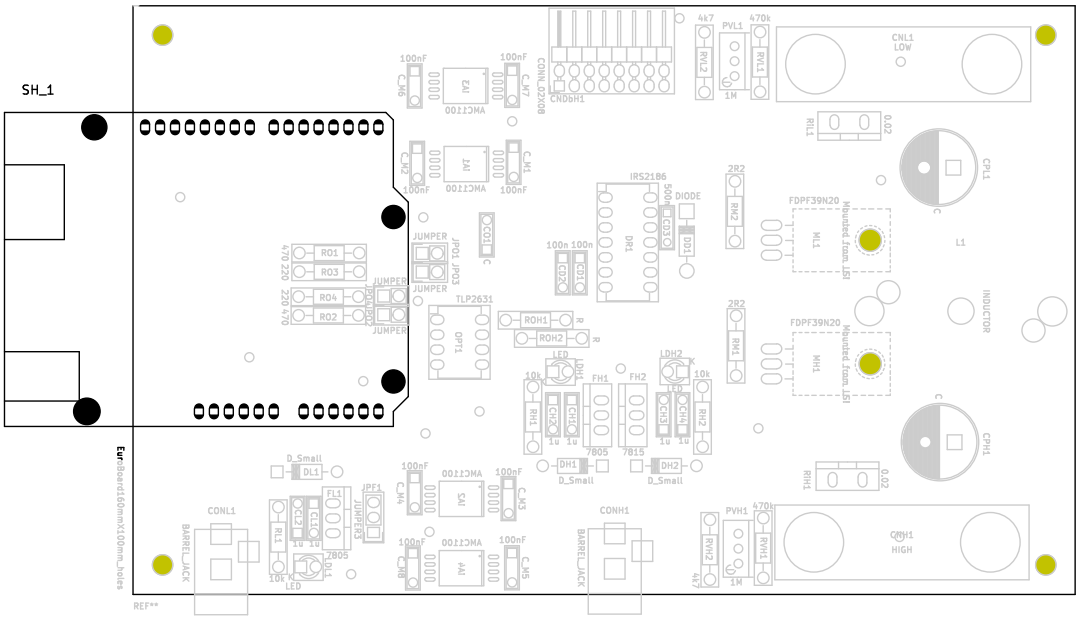


Figure 7: Components map

Assembly procedure

Follow these steps to assemble the microcontroller block.

1. **Separate the components -** Identify all the components on the list in the component pouch
2. **Solder the connectors -** There are two 6-line connectors and two 8-line connectors. **BE SURE TO SOLDER THEM ON THE CORRECT SENSE! THE PINS SHOULD BE DOWNWARDS!**
3. **Plug in the Arduino -** Plug the Arduino firmly in place and upload the code provided.

Testing procedure

Follow the steps below to test the microcontroller block:

1. Test the PWM generation from the Arduino
2. Test that the Arduino Analog Inputs are well connected to the Isolation Amplifiers (AMC1100)

Notes:

Block 3 - Sensors and Measurements

The measurement block converts the input voltage, output voltage, input current and output current into a signal that can be read by the Arduino. The main components used in this block are called isolation amplifiers which are capable of sending the signal from one ground plane onto another. The signal generated by the isolation amplifiers has some special properties which will be studied during the test procedures.

Table 8: The components of this block

Component	*Description*	*Reference*	*Qty.*
Potentiometer	$1M\Omega$ Variable resistances	PVH1, PVL1	2
Shunt resistors	$20m\Omega$ Shunt resistors	RiH1, RiL1	2
Resistor	$470k\Omega$ Voltage divider resistors	RVH1, RVL1	2
Resistor	$4.7k\Omega$ Voltage divider resistors	RVH2, RVL2	2
Amplifier Capacitors	**100nF** capacitor used to stabilize the voltage of the Amplifiers	C_M1 to C_M8	1
Isolation Amplifiers	AMC1100 Isolation Amplifiers	iA1, iA2, iA3, iA4	4

Table 9: The tools needed to assemble/test this block

Tool	*Description*	*Quantity*
Multimeter	Used to perform several checks in the circuit	1
Soldering iron	Used to solder the components	1
Soldering wire	Used to solder the components	-

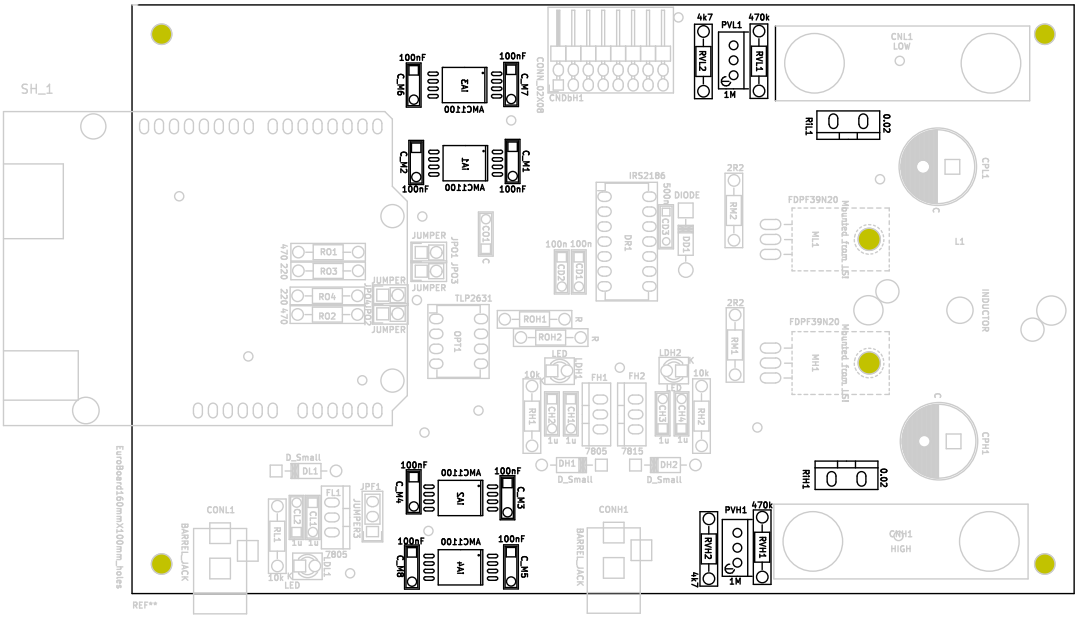


Figure 8: Components map

Assembly procedure

Follow these steps to assemble the measurement block.

1. **Unplug the Arduino -** Make sure the Arduino is unplugged before soldering the block

2. **Separate the components -** Identify all the components on the list in the component pouch
3. **Solder the throughhole components -** Solder the resistors, the potentiometers, the shunt resistors and the capacitors.
4. **Execute the preliminary test 1 -**
5. **Solder the AMC1100 or similar** Cover the small tracks with a little bit of solder wire. Let the AMC1100 rest onto these tracks and press it quickly with the soldering iron.

Testing procedure

Follow the steps below to test the measurement block:

1. **Preliminary test 1 -** Test that the pads of the AMC1100 are receiving the proper voltage on both sides.
2. Test the voltage at the Arduino footprint that connects to the analog ports A0 to A3 are stable.
3. Plug in 12V in the low voltage side and set the potentiometer for the low side voltage measurement. Ideally a 12V in the input should represent a 0.1V of change in the AMC1100 output.
4. Plug in 12V in the high voltage side and set the potentiometer for the high side voltage measurement. Ideally a 12V in the input should represent a 0.05V of change in the AMC1100 output.
5. Plug the Arduino
6. Observe the Arduino measurements in the Serial port without any voltage on either the low or the high voltage side.
7. Plug in 12V in the low voltage side and observe the Arduino measurements in the Serial port.
8. Plug in 12V in the high voltage side and observe the Arduino measurements in the Serial port.

Notes:

Block 4 - Optocoupler and MOSFET Driver

The driver block converts the control signal generated by the microcontroller into a driving signal for the MOSFET. This driver has two main elements: the optocoupler and the driver.

The optocoupler isolates the signal ground from the power ground by sending its inputs signals as light to its output ports. The driver will take in the output of the optocoupler and use it to fire a high current pulse into the gate of the MOSFET, turning it ON.

Table 10: The components of this block

Component	*Description*	*Reference*	*Qty.*
Optoc. Input Resistors (3.3V)	220Ω Resistors for 3.3V Microcontrollers	RO3, RO4	2
Optoc. Output Resistors (5V)	470Ω Resistors for 5V Microcontrollers	RO1, RO2	2
Jumpers	Connector used to choose the Optoc. Resistors	JPO1, JPO2, JPO3, JPO4	4
Optocoupler	I.C. used to pass the PWM signal from the control to the power ground	OPT1	1
Optoc. Output Resistors	330Ω Resistors used to interface with the driver	ROH1, ROH2	2
Optoc. Output Capacitor	**100nF** capacitor used to decouple the Optocoupler output	CO1	1
Driver Input Capacitors	**100nF** capacitor used to stabilize the Driver Input	CD1, CD2	2
Driver Bootstrap Capacitors	**500nF** capacitor used in the Driver bootstrap circuit	CD3	1
Driver Bootstrap Diode	Diode used in the Driver bootstrap circuit	DD1	1
Driver	I.C. used to drive the MOSFETs	DR1	1
Driver Output Resistors	2.2Ω Resistors used in the interface between the driver and the MOSFETs	RM1, RM2	2

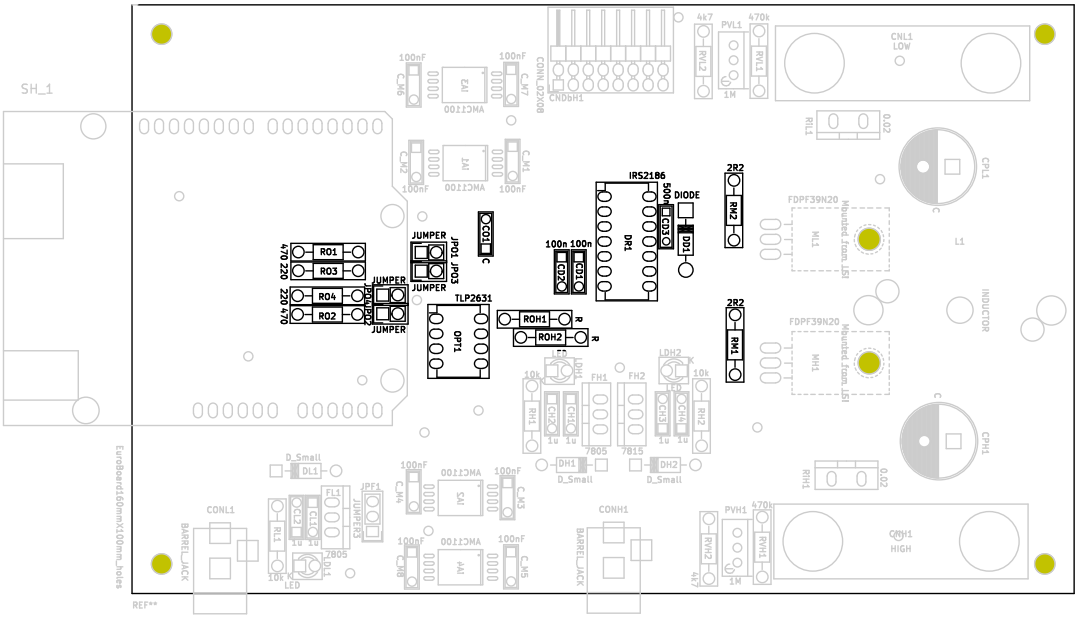


Figure 9: Components map

Table 11: The tools needed to assemble/test this block

Tool	*Description*	*Quantity*
Multimeter	Used to perform several checks in the circuit	1
Soldering iron	Used to solder the components	1
Soldering wire	Used to solder the components	-
Oscilloscope	Used to check the control and output signals of the system	1

Assembly procedure

Follow these steps to assemble the driver.

1. **Unplug the Arduino -** Make sure the Arduino is unplugged before soldering the block
2. **Separate the components -** Identify all the components on the list in the component pouch
3. **Solder the throughhole components -** Solder the resistors, the potentiometers, the shunt resistors and the capacitors.
4. **Solder the connectors - The optocoupler and the driver MUST NOT BE SOLDERED DIRECTLY ONTO THE PCB.** It is their connectors that are soldered, easing their replacement if needed.
5. **DO NOT CONNECT THE OPTOCOUPLER OR THE DRIVER**

Testing procedure

Follow the steps below to test the driver:

1. Test that the feeder voltage arrives at the pads of the connectors for the optocoupler and the driver
2. Plug in the Arduino.
3. Connect the optocoupler. Test with the oscilloscope that the PWM generated by the Arduino gets on the high voltage side correctly.
4. Connect the driver. Test with the oscilloscope that the PWM generated by the Arduino fires the driver correctly.

Notes:

Block 5 - Active and Passive Power Elements

The power block handles the input power through a voltage or current regulation. Its transistors switch at high frequencies, lowering or rising the voltage according to the connection used.

Table 12: The components of this block

Component	*Description*	*Reference*	*Qty.*
Banana Jacks	Jacks used to connect wires to the converter	CNH1, CNL1	2
Transistors	FDPF39N20 MOSFETs used to chop the DC voltage	MH1, ML1	2
Capacitors	Power Capacitors used to filter output voltage	CPH1, CPL1	2
Inductor	Power Inductor used to filter the output current	L1	1

Table 13: The tools needed to assemble/test this block

Tool	*Description*	*Quantity*
Multimeter	Used to perform several checks in the circuit	1
Soldering iron	Used to solder the components	1
Soldering wire	Used to solder the components	-
Oscilloscope	Used to check the control and output signals of the system	1

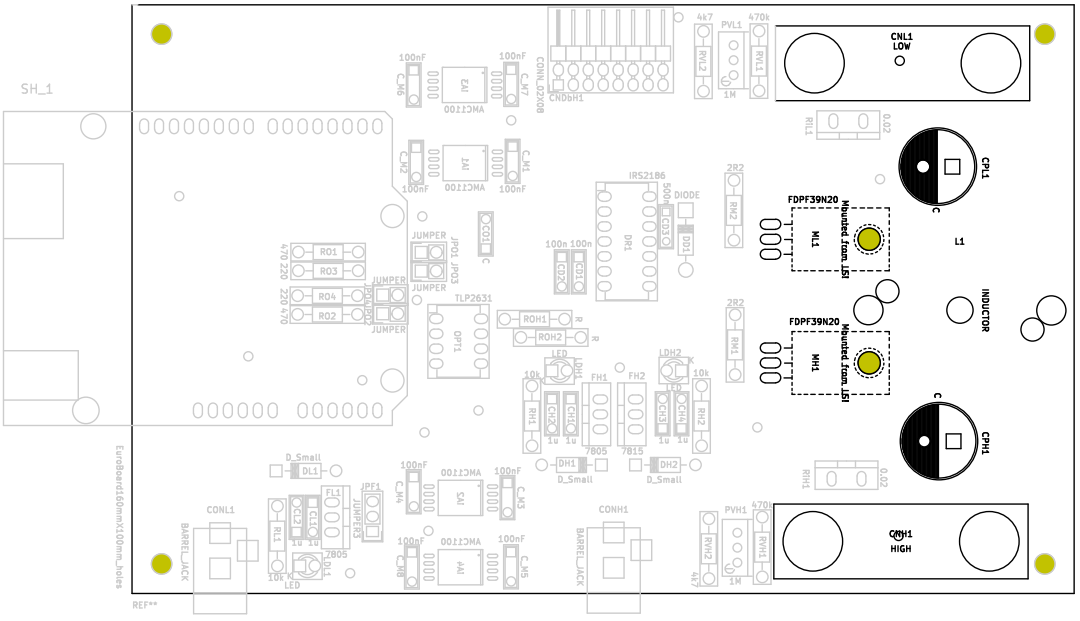


Figure 10: Components map

Assembly procedure

Follow these steps to assemble the power block.

1. **Unplug the Arduino -** Make sure the Arduino is unplugged before soldering the block
2. **Separate the components -** Identify all the components on the list in the component pouch

3. **MOSFETs -** Solder the MOSFETs first. **BE CAREFUL WITH THEIR ORIENTATION.**
4. **Do the Preliminary test 1**
5. **Inductor -** Solder the Inductor. **BE CAREFUL TO PLACE THE INDUCTOR UNDERNEATH THE PCB.**
6. **Capacitors -** Solder the Capacitors. **BE CAREFUL: ELECTROLYTIC CAPACITORS HAVE A NEGATIVE THAT MUST BE RESPECTED.**

Testing procedure

Follow the steps below to test the power block:

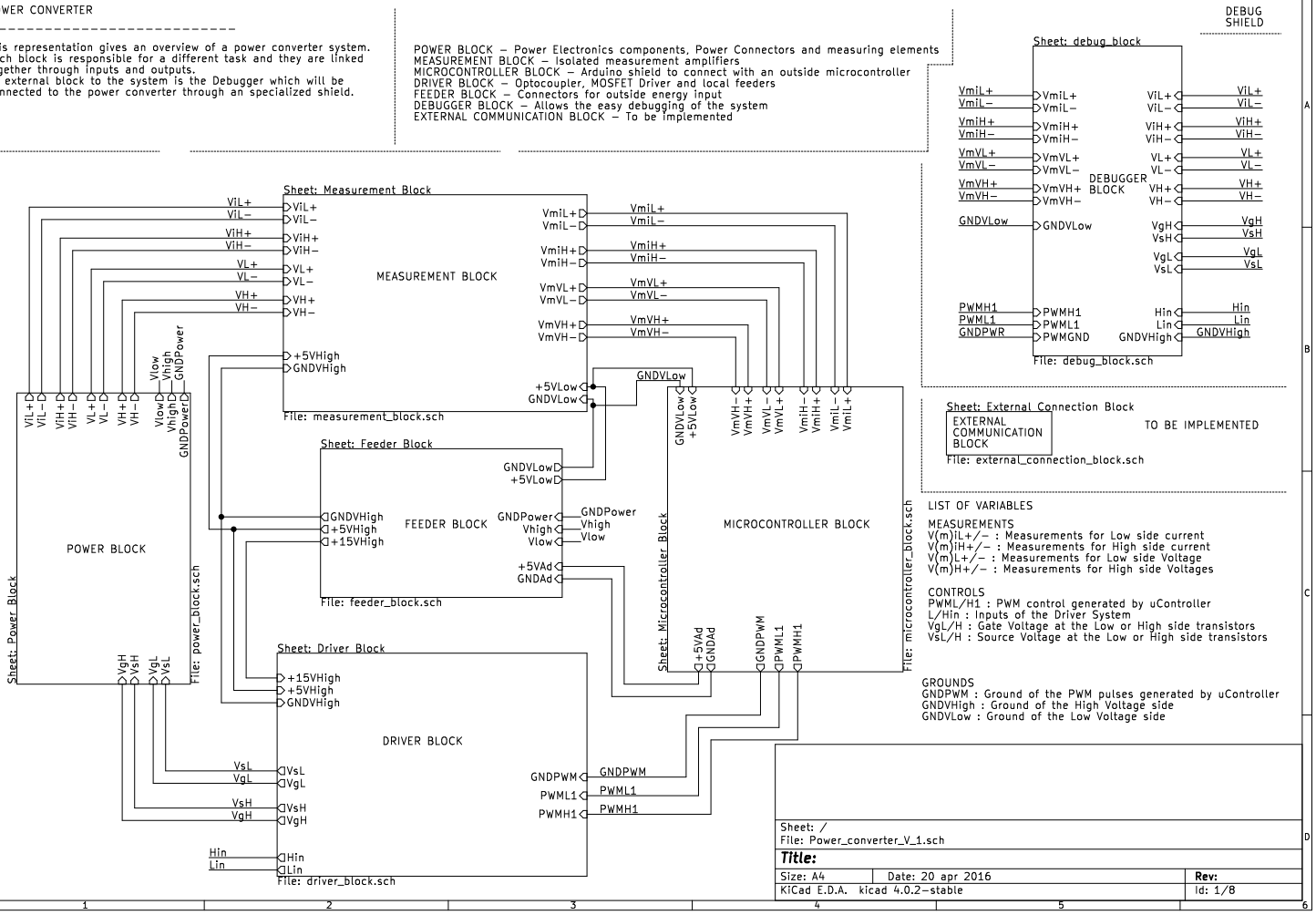
1. **Preliminary test 1 -** Connect the Arduino. Use a thick wire to bridge the inductor pads. Connect a resistors in the output. Check that the Transistors are commutating with the oscilloscope. Unplug the Arduino.
2. **Boost mode test:** Connect the input to the low side. Upload the code onto the Arduino. Connect the voltmeter on both sides. Turn on the feeder and measure the output voltage.
3. **Buck mode test:** Connect the input to the high side. Upload the code onto the Arduino. Connect the voltmeter on both sides. Turn on the feeder and measure the output voltage.
4. **Load test:** Same as above but with a resistor in the output.

Notes:

POWER CONVERTER

This representation gives an overview of a power converter system.
Each block is responsible for a different task and they are linked together through inputs and outputs.
An external block to the system is the Debugger which will be connected to the power converter through an specialized shield.

POWER BLOCK – Power Electronics components, Power Connectors and measuring elements
MEASUREMENT BLOCK – Isolated measurement amplifiers
MICROCONTROLLER BLOCK – Arduino shield to connect with an outside microcontroller
DRIVER BLOCK – Optocoupler, MOSFET Driver and local feeders
FEEDER BLOCK – Connectors for outside energy input
DEBUGGER BLOCK – Allows the easy debugging of the system
EXTERNAL COMMUNICATION BLOCK – To be implemented



LIST OF VARIABLES

MEASUREMENTS
V(m)iL+/– : Measurements for Low side current
V(m)iH+/– : Measurements for High side current
V(m)L+/– : Measurements for Low side Voltage
V(m)H+/– : Measurements for High side Voltages

CONTROLS
PWML/H1 : PWM control generated by uController
L/Hin : Inputs of the Driver System
VgL/H : Gate Voltage at the Low or High side transistors
VsL/H : Source Voltage at the Low or High side transistors

GROUNDS
GNDPWM : Ground of the PWM pulses generated by uController
GNDVHigh : Ground of the High Voltage side
GNDVLow : Ground of the Low Voltage side

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Size: A4	Date: 20 apr 2016	**Rev:**
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BLOCK INPUTS

DETAILS OF THE MEASUREMENT BLOCK

This blocks senses current and voltage of the power block.
It uses four isolated amplifiers AMC1100 or AMC1200.
These amplifiers are are fed with +5V.

There are 4 measurements being isolated:

ViL+/ViL– become VmiL+/VmiL – low side current
ViH+/ViH– become VmiH+/VmiH – high side current
VL+/VL– become VmL+/VmL – low side voltage
VH+/VH– become VmH+/VmH – high side voltage

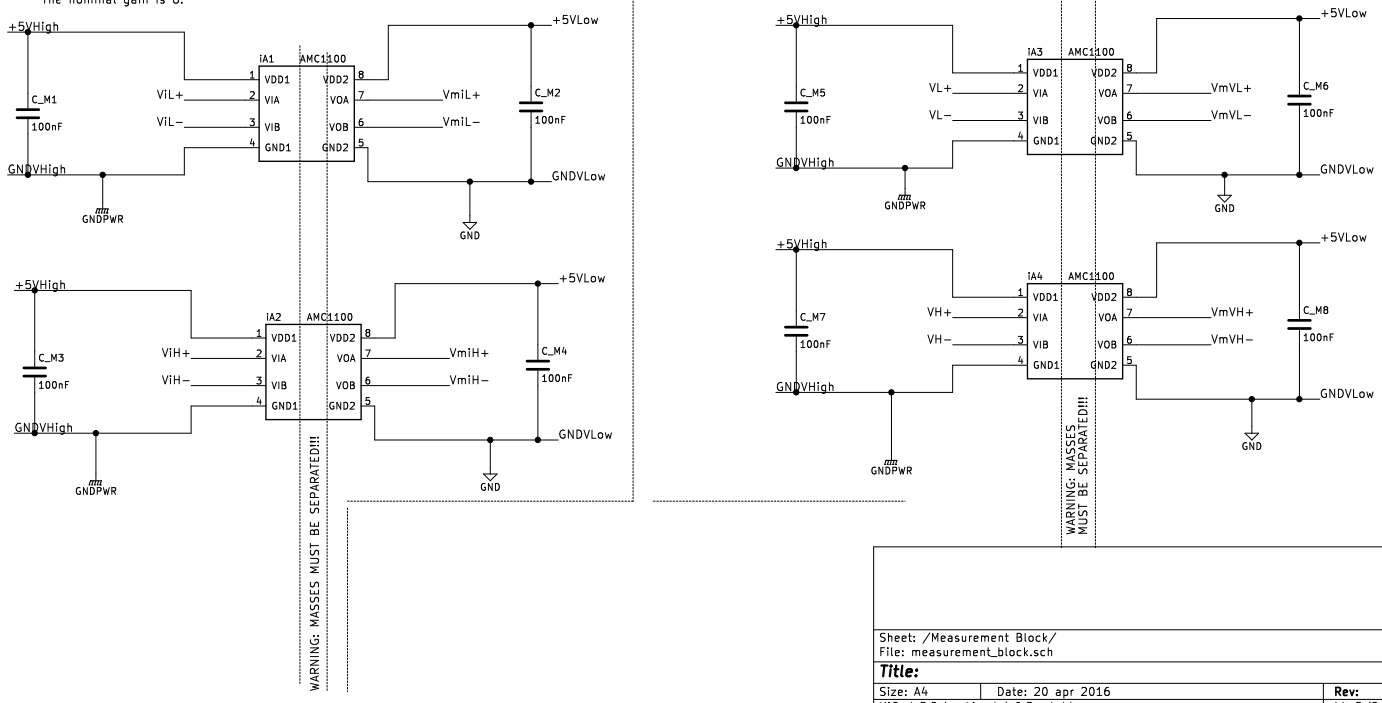
BLOCK OUTPUTS

CURRENT SENSING BLOCK

Senses the current isolated from the high power side.
The nominal gain is 8.

VOLTAGE SENSING BLOCK

Senses the voltage isolated from the high power side.
The nominal gain is 8.



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BLOCK INPUTS

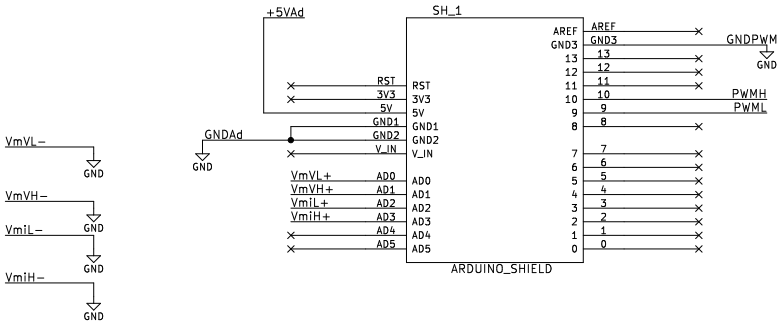
VmVL+ — VmVL+ — VmiL+ — VmiL+
VmVL− — VmVL− — VmiL− — VmiL−
VmVH+ — VmVH+ — VmiH+ — VmiH+ — +5VLow — +5VLow
VmVH− — VmVH− — VmiH− — VmiH− — GNDVLow — GNDVLow

DETAILS OF THE MICROCONTROLLER BLOCK

This blocks connects the power converter with an Arduino Uno shield. The voltage and current measurements are inputs and the PWMs are the outputs.

BLOCK OUTPUTS

PWMH — PWMH1
PWML — PWML1
GNDPWM — GNDPWM
+5VAd — +5VAd
GNDAd — GNDAd



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BLOCK INPUTS

BLOCK OUTPUTS

TO BE IMPLEMENTED

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BLOCK INPUTS

Vlow
Vhigh
GNDPower
+5VAd
GNDAd

FEEDER DETAILS

This is the global feeder circuit.
In this version it is composed by 78x5's.
Later versions should replace this by a more robust solution.

BLOCK OUTPUTS

+5VLow
GNDVLow
+15VHigh
+5VHigh
GNDVHigh

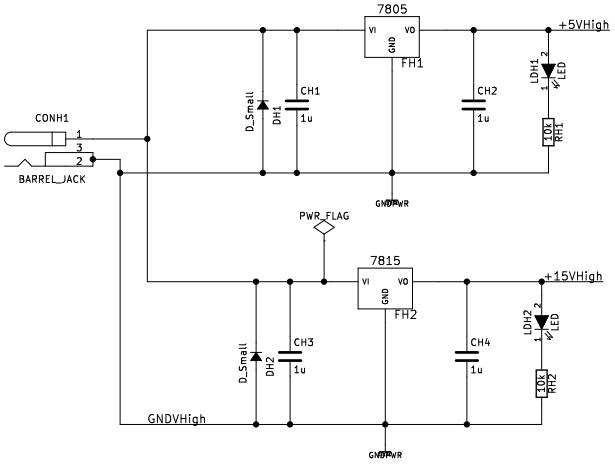
GLOBAL FEEDER

Later solutions should include a global feeder capable of generating energy from the system input/output.

TO BE COMPLETED

HIGH VOLTAGE SIDE FEEDERS

These 78x5's generate +5V and +15V with a high voltage side reference.

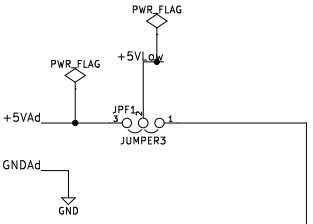


WARNING: MASSES MUST BE SEPARATED!!!

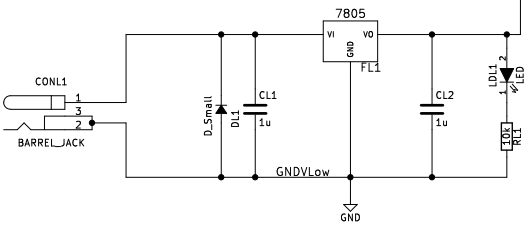
LOW VOLTAGE SIDE FEEDER

This 7805 generates +5V low voltage side reference.
The low side can be fed from the Arduino or from a local source.

ARDUINO FEEDER



LOCAL LOW VOLTAGE FEEDER



Sheet: /Feeder Block/ File: feeder_block.sch		
Title:		
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BLOCK INPUTS

PWMH1
PWML1
GNDPWM
PWMH
PWML
GNDPWM
+5VHigh
+15VHigh
GNDVHigh
GNDPWR

DETAILS OF THE DRIVER BLOCK

This circuit connects the microcontroller to the power transistors.
It uses an optocoupler to separate the grounds from both sides.

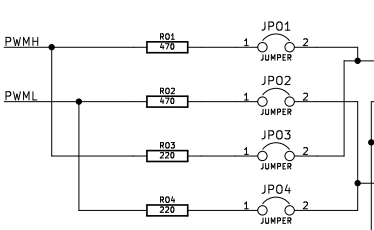
Based on these components the system can go up to 150kHz to 200kHz

BLOCK OUTPUTS

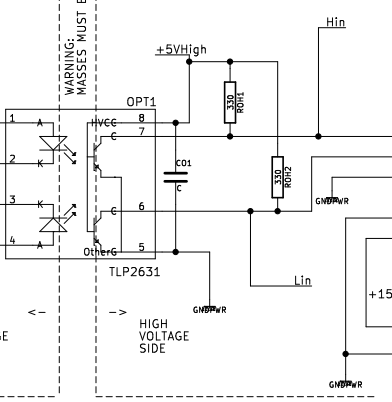
VgH
VsH
VgL
VsL
Hin
Lin

ADAPTABLE JUMPERS

These jumpers allows the user to choose between a 5V or a 3.3V input.

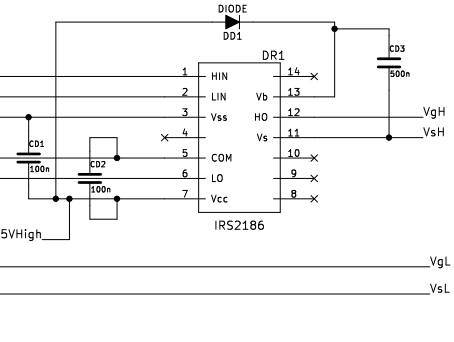


WARNING: MASSES MUST BE SEPARATED!!!



POWER DRIVER

The power driver chosen for this converter is the IR2186 capable of driving a transitor up to 4A at a time. This solution comprises a bootstrap which allows driving both the high and low side transistors from the same IC.



OPTOCOUPLER

The optocoupler chosen for this converter is a TLP2631 which has a VCC of +5V and can go up to 200kHz for low power applications

Sheet: /Driver Block/ File: driver_block.sch		
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BLOCK INPUTS

VgH
VsH
VgL
VsL

DETAILS OF THE POWER BLOCK

This topology employs capacitors both at the input and the output. The inductance in the middle allows it to be a fully reversible buck-boost.

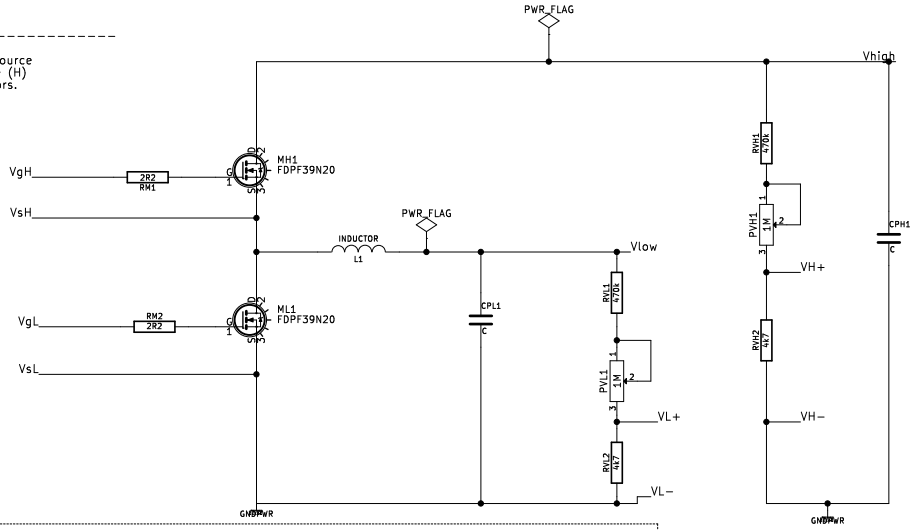
This version of the converter uses 200V MOSFETS capable of handling up to 20A. This converter was designed to have an output up to 120V making its input reasonable up to 60V. The power in this structure should NOT go beyond 500W.

BLOCK OUTPUTS

ViL+ ViL+ VL+ VL+ Vlow Vlow
ViL- ViL- VL- VL- Vhigh Vhigh
ViH+ ViH+ VH+ VH+ GNDPower
ViH- ViH- VH- VH-

CONVERTER INPUT

The inputs are the gate-source voltages for the high-side (H) and low-side (L) transistors. (VgH-VsH/VgL-VsL)



MEASUREMENTS

There are 4 measurements spread among the power elements:

ViL+ and ViL- is the voltage drop of the shunt resistance reading low side current
EQUIVALECE: 1 Amp = 20mV

ViH+ and ViH- is the voltage drop of the shunt resistance reading high side current
EQUIVALECE: 1 Amp = 20mV

VL+ and VL- is the voltage drop of the resistance reading low side voltage
EQUIVALECE: 100V = 0.33V to 1V

VH+ and VH- is the voltage drop of the resistance reading high side voltage
EQUIVALECE: 200V = 0.66V to 2V

ENERGY CONNECTORS

Sheet: /Power Block/
File: power_block.sch

Title:

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BLOCK INPUTS

VmVL+ VmVL+ VmiL+ VmiL+
VmVL- VmVL- VmiL- VmiL-
VmVH+ VmVH+ VmiH+ VmiH+
VmVH- VmVH- VmiH- VmiH-
PWMH1 PWMH PWML1 PWML
PWMGND PWMGND
GNDVLow GNDVLow

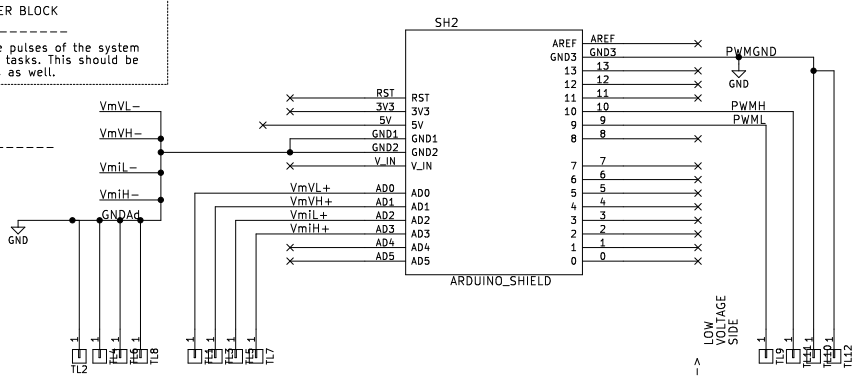
VL+ VL+ ViL+ ViL+
VL- VL- ViL- ViL-
VH+ VH+ ViH+ ViH+
VH- VH- ViH- ViH-
VgH VgH Hin Hin
VsH VsH Lin Lin
VgL VgL
VsL VsL
GNDVHigh GNDVHigh

DETAILS OF THE MICROCONTROLLER BLOCK

This blocks connects most of the pulses of the system to connectors to ease debugging tasks. This should be starndard for other power boards as well.

LOW VOLTAGE DEBUG CONNECTOR

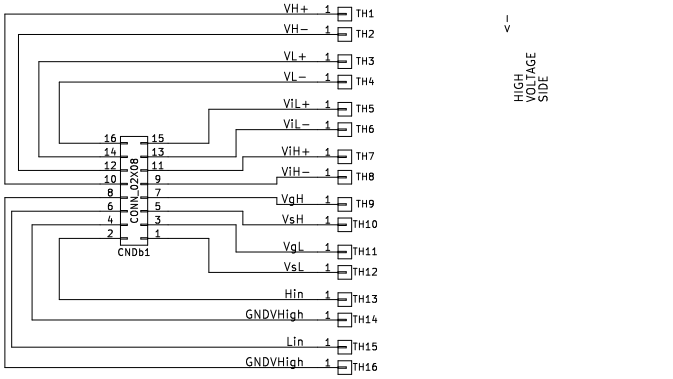
This connector is dedicated to low-voltage measurements and pulses.



WARNING: MASSES MUST BE SEPARATED!!!

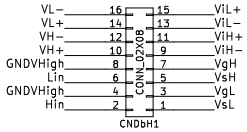
HIGH VOLTAGE DEBUG CONNECTOR

This connector is dedicated to high-voltage measurements and pulses.



POWER DEBUG CONNECTOR

This connector allows the easy debugging of the high power side of the system



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