Technical Documentation
Group 4: grabtastic[2015]

Fachhochschule Vorarlberg
Mechatronics

submitted to
Prof. (FH) Dipl.-Ing. Robert Amann
submitted by
Roman Passler
Connor Reekers
Antti Friman
Kyeungun Kim
Philipp Simoner

Dornbirn, December, 2015

Abstract

The *grabtastic* is built to grab a circular disc and then moved from one position to one other target position. These positions are predefined and can be two targets: home or Repository position. Also the machine has to go to the reference position, but this cannot be done with the disc attached. Controlling the *grabtastic* will be done with the PLC and with the uC. The PLC will control the X and Y axis while the uC will handle the movement of the Z axis. The Z axis also measures the force that is applied to the strain gauge. The manipulator can be controlled by a programmed user interface, which also is used to monitor the status and analyse the force.

Torque from the stepper motor is transformed into linear motion. To hold the disc a repository was designed. In addition to this a snap connector was created to carry the disc from target to home position and backwards.The mechanical parts were designed and manufactured in the given system boundaries.

The project team consists of five team members, these are Connor Reekers, Antti Friman, Kyeungun Kim, Philipp Simoner and Roman Passler.

Contents

List of Figures

List of Tables

Listings

List of Abbreviations

SPI	Serial Peripheral Interface
uC	Microcontroller
PLC	Programmable Logic Controller
HMI	Human Machine Interface
UML	unified modelling language
PCB	printed circuit board
ADC	analogue digital converter
RS232	serial communication transmission of data
TTL	Transistor–transistor logic
Cycle	Row of actions the manipulator carries out because of clicking the button for execution
Repository	Apparatus installed for placing a disc
Target position	Where the Repository is located
Reference	The position which can be an origin point. A manipulator is regarded to be at reference position when all switches attached at the end of the axis's are closed.
Home position	The position which is located at the diagonally opposite side from the target position.
ASCII	American Standard Code for Information Interchange
MOSFET	metal-oxide-semiconductor field-effect transistor
VM	Motor power supply voltage range, in this project it is $24V$
VCP	High-side gate drive voltage
VINT	Internal logic supply voltage
I/O	Inputs and outputs
ASF	Atmel® Software Framework
IC	integrated logic
Repository	Device installed in working area of the system to store a workpice

I	command from PLC to uC to reset and initialisation
D	command from PLC to uC to move in the down position
H	command from PLC to uC to move in the home position
P	command from PLC to uC to move in the pre-position
FEA	Finite Element Analysis
TC	Timer Counter
i	command from uC to PLC to confirm that z-Axis is homed and ready for orders
d	command from uC to PLC to confirm that z-Axis is in the down position
h	command from uC to PLC to confirm that z-Axis is in the home position
p	command from uC to PLC to confirm that z-Axis is in the pre-position
ok	command from uC to PLC to confirm that the command is arrived
busy	command from uC to PLC to answer, if uC is already executing a command
UNKNOWN	command from uC to PLC to answer, if PLC send a wrong command
del	is the delimiter in telegrams

1. Introduction

This project started on the seventh of September 2015 and will end on the fifteenth of December. In this fifth semester of our studies, there is an exchange semester. This allows us to have a multi-cultural experience with different students from different backgrounds. It was our goal to combine our background experience to finish this project and also to learn how to work in an international project group.
The project was arranged by the FH Vorarlberg and lead by R. Amann. It consisted of building a manipulator that can pick up and drop a disc, it had to be controlled with a PLC. During the project the project group also participated in courses that supported the build of the project, for example: how to write a requirements document or how to program a PLC. Within this project there were certain boundaries for example the components that had to be used, but this also gave us more time to come up with creative solution for the remaining components. The system had to be built according to the system design that was given in the beginning of the project (Figure 2.1).
To maintain the progress in this project we used a schedule that was given to us by the professors. This schedule contained deadlines for different results and general guidelines. Our first assignment in September was the requirements document, which consisted of the customer needs, requirements and our vision about the end result. In October we started designing all the components, this with the help of the courses there were earlier mentioned. After this we began manufacturing the parts that were designed until the end of November. Finally in December the testing of the build components and the assembly of these started. In the end of the project we are presenting our creation to the professors, students and other stakeholders. Therefore the manipulator had to be fully functional on the fifteenth of December.

1.1. Purpose

This documentation is written for customers of project group *grabtastic* to get information of the manipulator we developed. The manipulator is used to pick up and place an aluminium disc, also move it in third dimention - X, Y, and Z axis. Every steps are made automatically.

1.2. Scope

The machine is consisted of uC, PLC, and mechanical elements such as stepping motor, linear axis and snap connector. We use only one button to execute the machine. After clicking the button, it starts the “cycle-picking” up the disc, moving it, and place it. The location of a manipulator will be indicated on a screen. Error and working situation will be in an error log on the screen.

1.3. Overview

The project group is named *grabtastic* . The manipulator does one cycle at one time. Those are actions that the manipulator does for one cycle.

1. Move from a home position to a target position.
2. Grab a disc from a Repository.
3. Come back to a home position with the disc.
4. Move to a target position and place the disc in the Repository.

A snap connector allowed the manipulator to catch and release the disc. Force sensor KD24s is used to measure the force applied to the snap connector and the force is indicated on the screen. Stepping motor ST5918M1008-A from Nanotec is used for Z-axis and ST5918M3008-B is used for X and Y axis's. To drive the Z-Axis Stepper Motor, a DRV8711 is used. For PLC, Beckhoff CX1020 is used and Beckhoff CX11000 004 is a power supply unit for it.
Linear axis used for constructing Z-axis was purchased. Snap connector, parts for fixing linear axis and uC and Repository are designed for ourselves and manufactured.

1.4. References

All drawings, charts, code listings and datasheets are indicated in the appendix.

1.5. Division of the Tasks

There are responsible people for each part (Table 1.1).

#	Part name	Developer	Function
1	User interface	R. Passler, A. Friman	Provides the human machine interaction
2	PC	-	Shows the GUI and provides the development programs for the PLC and the uC
3	PLC	R. Passler, A. Friman	Executes tasks, like movement of the x and y axis.
4	Power amplifier x-axis	-	Amplifies the power for the x-axis
5	Power amplifier y-axis	-	Amplifies the power for the y-axis
6	Emergency button	R. Passler	Safety feature to prevent damage of injuries
7	RS232 level shifter	R. Passler	Establishes the communication between the PLCand the uC
8	Stepper motor x-axis	-	Motor to make the movement of the x-axis possible
9	Stepper motor y-axis	-	Motor to make the movement of the y-axis possible
10	Microprocessor system	R. Passler	Executes tasks like movement for the Z-axis and converts the analog signal from the amplifier to a digital signal
11	x-y positioning mechanism	-	Encoder sensors that define the position of the x and y-axis.
12	Motor driver	R. Passler	Controls the movement of the stepper motor that drives the z-axis
13	Signal amplifier	C. Reekers	Amplifies the incoming signal to a better detectable and distinguishable signal
14	Stepper motor z-axis	-	Motor to make the movement of the z-axis possible
15	Strain gauge	-	A sensor that is measures the force in a voltage level
16	Z-axis	P. Simoner, A. Friman	Linear movement that allows the snap connection to grab the workpiece
17	x-y-z movement	-	The overall housing and machine that makes the movement possible
18	Gripper (snap connection)	P. Simoner	Grabs the workpiece
19	Workpiece	K. Kim	The disc that needs to be moved
20	Repositories	K. Kim	The place where the workpiece is stationed

Table 1.1.: System overview with developers

2. System Description

Within this chapter there will be discussed what the function is of the system and there will be more information about the development of the final product. Next to this there will be given a figure which shows the connection between each sub-system, so the connections between them are clearer.

2.1. Product Overview

For this project several components were already available for the project group to use:

- The PLC, without functional program
- The uC, without functional program
- The strain gauge
- The stepper motor for the X, Y and Z axis
- I/O connectors of for the PLC
- A prebuild housing
- Movement system for the X and Y axis
- The movable disc

Thus the following missing components had to be designed:

- The Z-Axis
- The snap connection
- The Repository
- Brackets for the mechanical and electrical components
- The communication between the PLC and the uC. with RS232
- The amplifier circuit for the strain gauge
- The motor controller for the Z-axis
- The PLC program
- The uC. program

For this product the project group decided that the *grabtastic* should be able to function autonomously while the user only gives the command to move. Therefore it has to sense if the disc is grabbed or he has to get the disc from the Repository, this is done with the strain gauge. The signal from the strain gauge will be amplified by the amplifier circuit and the send to the ADC in the uC. Then the RS232 communication will send this via a telegram to the PLC, this is done via the SPI protocol. The disc will be placed in the Repository that is designed so the disc can be easily removed by the snap connection. When the *grabtastic* moved to its target position the Z axis has to be moved in order to grab or release the disc, this is done via the designed Z axis and via the motor controller. The user is able to control and monitor the machine with the user interface that is made in the PLC. All the components are installed on the brackets, which are placed on the base of the system above the Z-axis and the snap connection.

2.2. System Overview

In Figure 2.1 the system overview can be found and in Table 1.1 the description of these parts are mentioned.

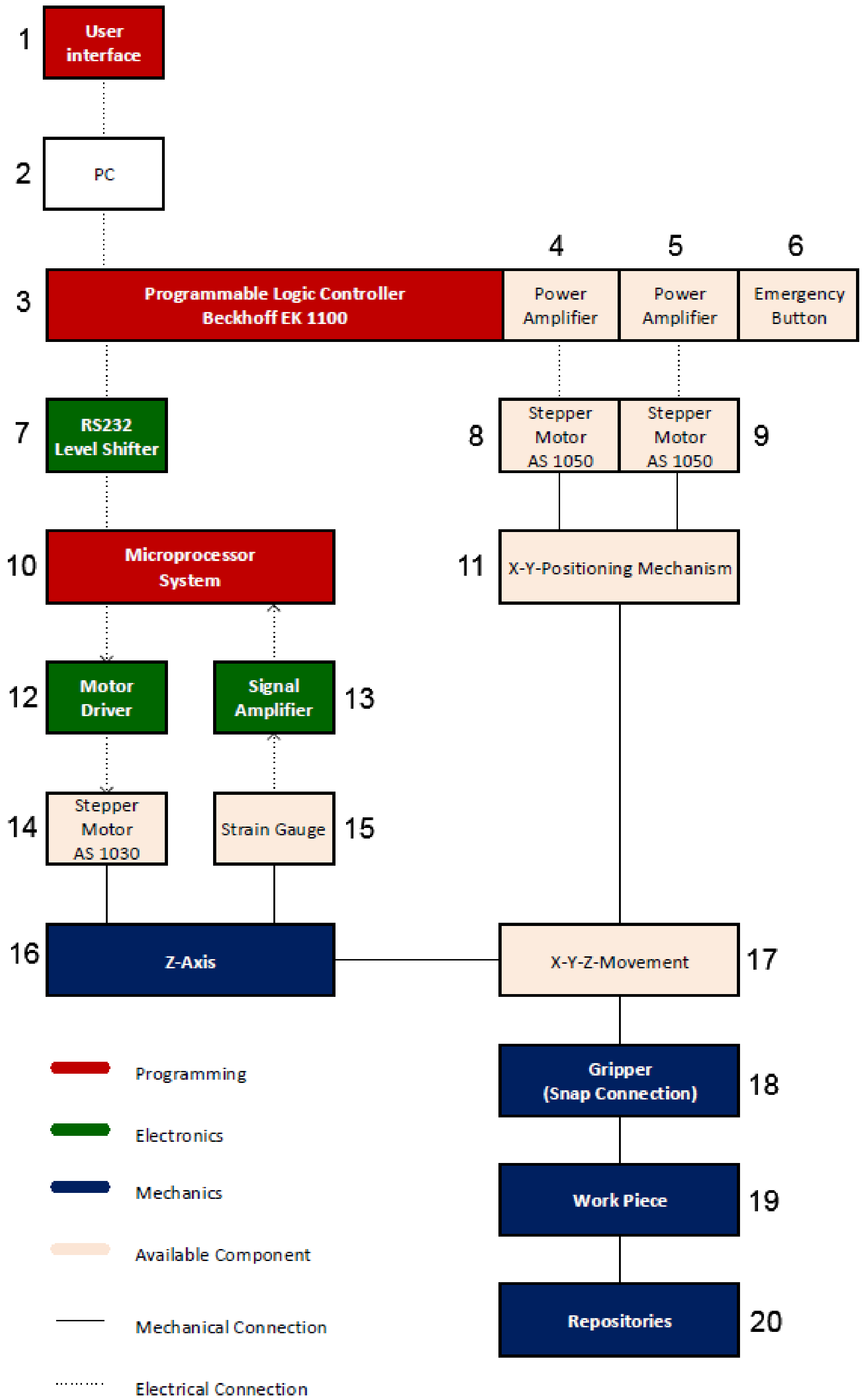
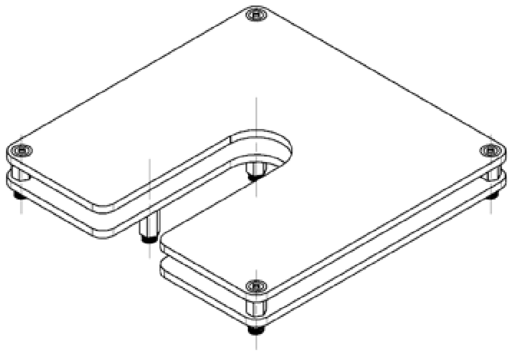


Figure 2.1.: System overview
Source: ilias

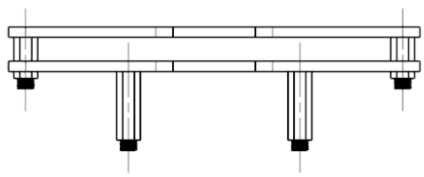
3. Mechanical Components

3.1. Repository

We need an apparatus to grab and release a disc. There are some functions or characteristics that it must perform. First, it is used as a holder to fix the disc with a hole. Second, it needs enough space for moving a snap connector and z-axis. Third, it should be strongly fixed to the floor of a manipulator. Last, it should be better if a structure and assembly are easier. Considering these points, we designed a unique type of an apparatus for a Repository.
These are isometric (Figure 3.1a) and front view (Figure 3.1b) of the apparatus. We can easily grab and release the disc by sliding in to the long hole of the plates. All we needed to manufacture were two plates because we use bolts and nuts which already exists.



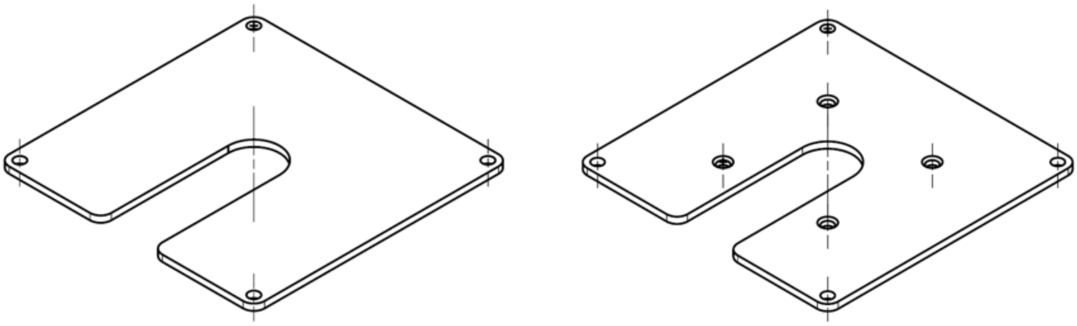
(a) Side View



(b) Front view

Figure 3.1.: Complete assembly

There are four simple holes with the diameter of 5 mm on the upper steel plate to fix it to the lower plate (Figure 3.2a).
And there are eight simple holes whose holes are also 5mm wide to fix it to the upper plate as well as the floor of the manipulator (Figure 3.2b).



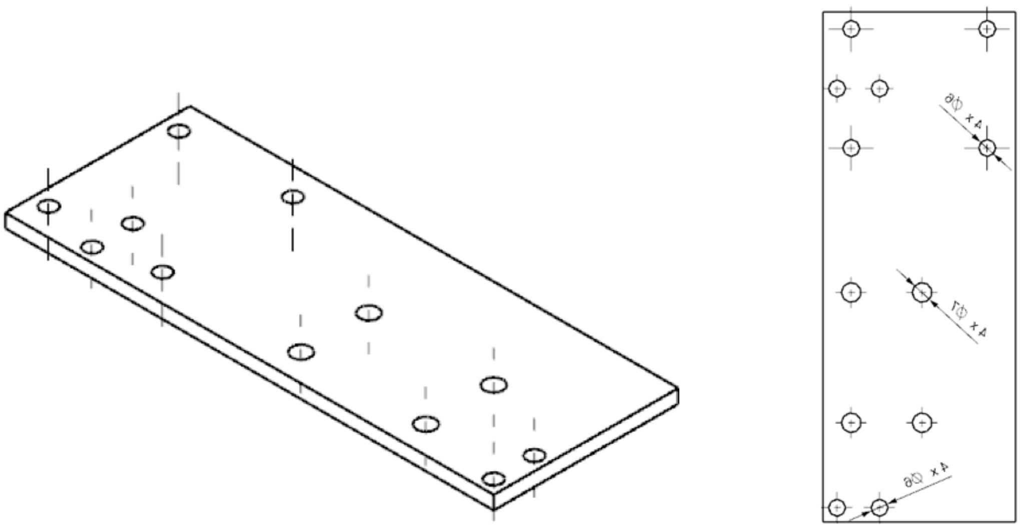
(a) Top (b) Bottom

Figure 3.2.: Top and bottom plate

3.2. Z-Axis

3.2.1. Frame

Frame fix the other parts in to the X, Y axes. It has 12 holes in total from where 4 are diameter of 6*mm* and others diameter of 7*mm*. Bigger holes are used to fix frame to the axes. Others are to fix linear axis and motorholder to the plate. By using this plate we were able to use motorholder part which was possible to manufacture in school.

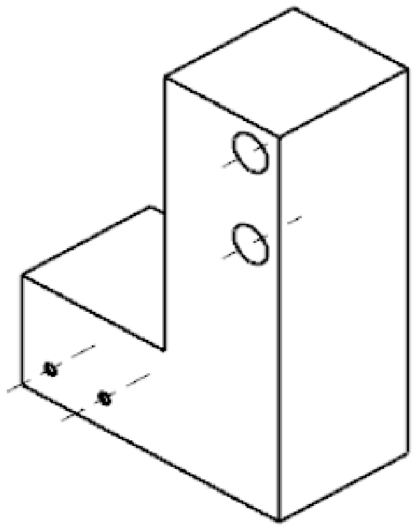


(a) side view (b) top view

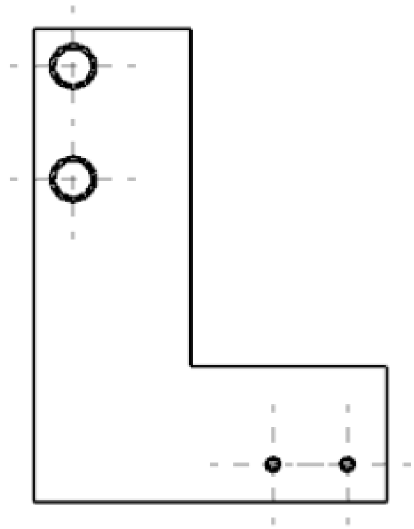
Figure 3.3.: Frame side and top view

3.2.2. Mounters for linear Axis and Limit Switch

The main function of the mounter linear axis to a certain distance. Using designed L-shaped mounters we were able to have linear axis at its desired place. Secondly we designed these to have places to attach a limit switch as well. The limit switch is placed to side of linear axis to minimize the stress and also protect it in a case of malfunction. There are places for two limit switches, one for each mounter at the top and the down of linear axis. We are only using a limit switch at the top one. The down one is in reserve.



(a) side view



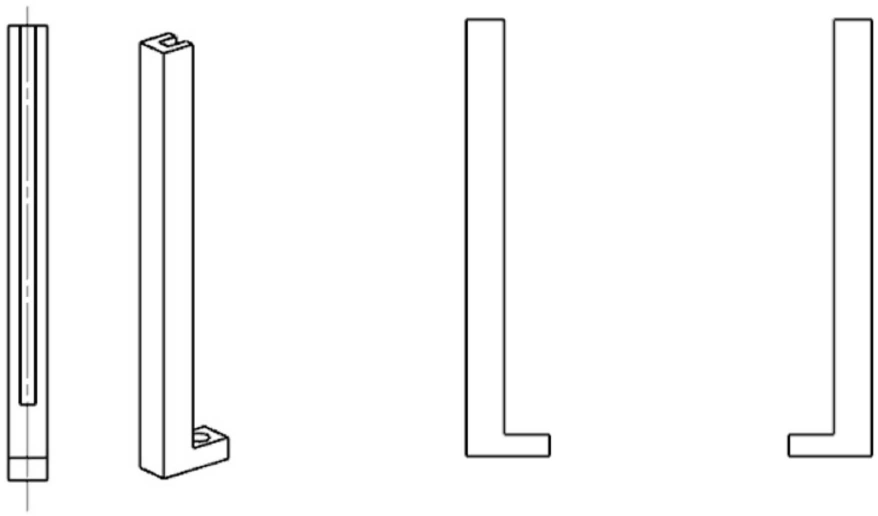
(b) front view

Figure 3.4.: Mounters for linear axis and limit switch
Source: Group 4

Mounters have four holes two diameter of $6mm$ holes for fitting it to frame, and two diameter of $2mm$ holes to mount limit switch to it (Figure 3.4).

3.2.3. Mounter for Electrical Boards

The mounter has two similar L-shaped parts. For mounting the electrical boards our goal was to have it as easily detached as possible. That's why we were ended up with the design (Figure 3.5) in which you can attach it by just simply sliding it between the two parts of the mounter.



(a) Side view

(b) Front view

Figure 3.5.: Mounting for the PCB
Source: Group 4

3.2.4. Rackbar

This part is placed on the carriage of the linear axis. On this part is the strain gauge fixed. This part is fixed with four holes of diameter $3mm$ to the linear axis. The other hole (diameter $5mm$) is to fix the strain gauge. In Figure 3.6 the part is shown.

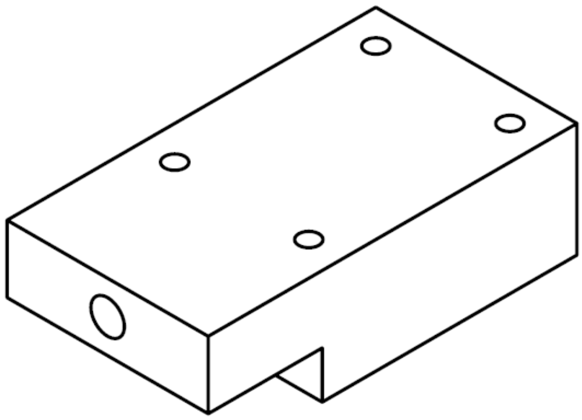
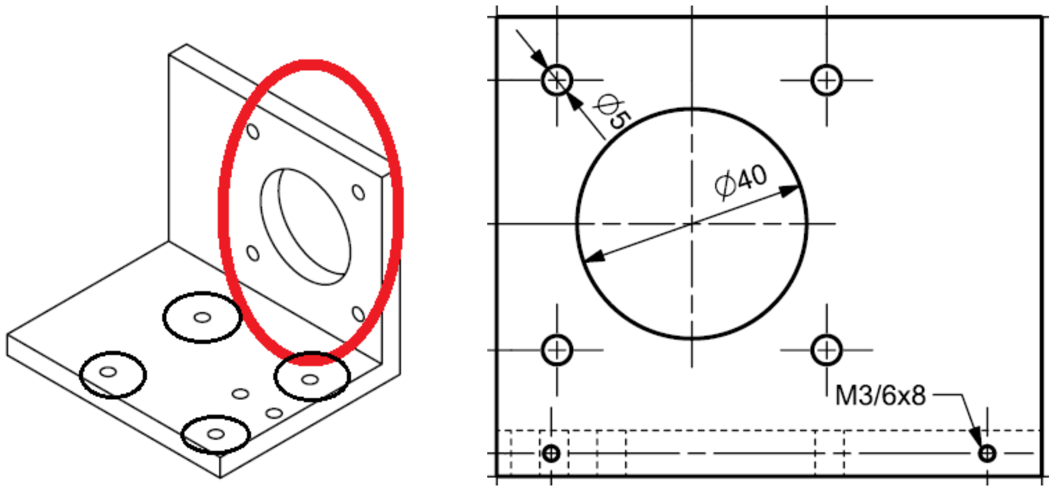


Figure 3.6.: Rackbar
Source: Group 4

All of those five holes are clearance holes to provide connection through the body of this part. The thickness of this part is important because if the part is to thin there will be a collision between the snapper and the linear axis. The thickness of $17mm$ guarantees, that the snapper won't hit the axis at any time.

3.2.5. Motor Frame

This part has several tasks to fulfil. The main function is to fix the stepper motor. In addition to this the holding elements for the uC are attached to this part. Figure 3.7a shows the holes which are used to fix the motor.



(a) side view (b) front view

Figure 3.7.: Motor frame
Source: Group 4

This part is fixed to the baseplate with four holes. Those 4 holes are marked with four black ellipsis in Figure 3.7a above. To fulfil the fixation of the uC there are two additional holes in this plate. This holes are used to fix the parts that are necessary to hold the uC board. This holes can be seen in Figure 3.7b above.
There are two threaded holes (M3) to attach the uC fixation. The uC fixation parts are described in subsection 3.2.3.

3.3. Mechanical Assembly

In Figure 3.8 is the assembled construction shown and in **??** are the corresponding single parts shown with the quantity.

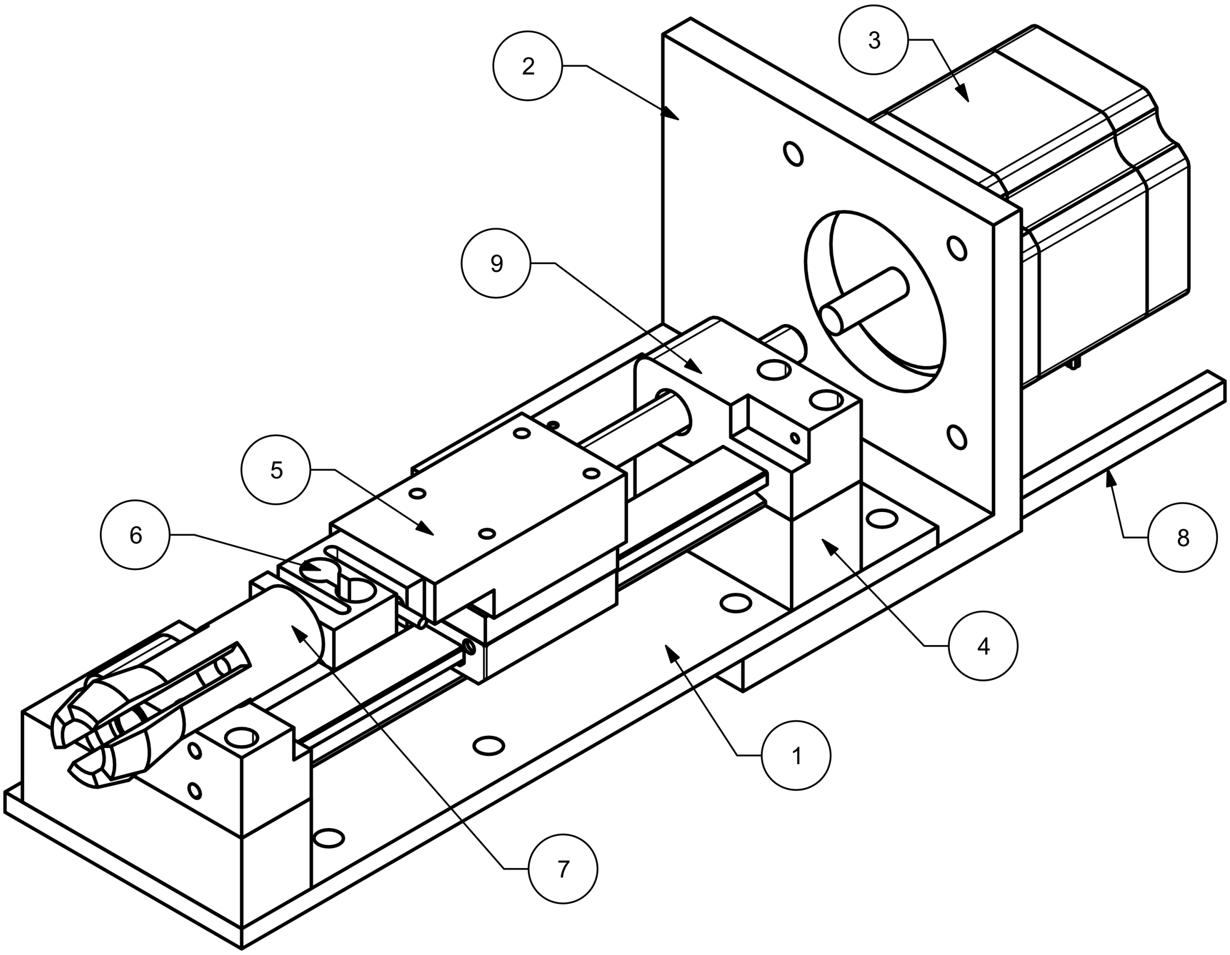


Figure 3.8.: Mechanical assembly
Source: Group 4

Number	Name	Quantity
1	Baseplate	1
2	Motorholder	1
3	Motor	1
4	Linear axis fitting	2
5	Rackbar	1
6	Strain gauge	1
7	Snap connection	1
8	Microfix	2
9	Linear axis 100m	1

Table 3.1.: Parts lists

3.4. Snap Connection

For grabbing the object (disc) there is a grabber needed. For this task the best and easiest solution is a snap connection. With the snapper it is possible to grab the disc and you can also drop it with a special construction. This construction is called Repository and is described in section 3.1. The force which is needed to get through the hole of the disc is measured with a strain gauge (section 4.6) This strain gauge has a measuring range of $+/-10N$. For designing the snap connection this means that the maximum force must not exceed $+10N$ and the same is for the force which is needed to get out of the hole. Otherwise the force will be out of range and this means that the force can't be measured. In the following figure there is the design of the snap connector.

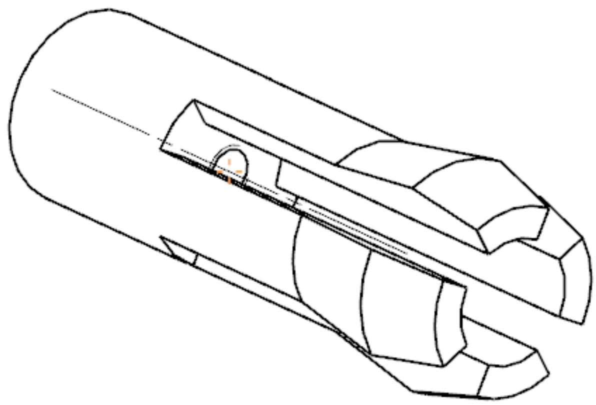


Figure 3.9.: Snap connector
Source: Group 4

The snap connector has four arms. The length of each arm is $40mm$ and the thickness is $3mm$. This thickness guarantees a certain stiffness of the snapper. The snapper has to be that stiff that the disc with a weight of approximately $100g$ $(1N)$ can't drop itself just because of its weight.

3.4.1. Calculation of the Forces

To guarantee that the forces are within the range of the gauge, the forces of the snap connector has to be calculated. The calculation is simplified by assuming the circle-section form to a rectangular form. Because the shape of the circle-section is nearly the same than the shape of the rectangular. So the difference in the calculation is not that big. The diameter of the hole in the disc is $20mm$. The outer diameter of the designed snapper is $22mm$. This means that each arm of the snap connector needs to be displaced at least 1 mm. There are two different forces. One for pushing the snapper through the hole of the disc and the second one is the force for pulling the snapper out of the hole.

3.4.1.1. Calculation of the Force for Grab Cycle

The following values are given for the calculation:

- $f = 1mm$ (displacement)
- $b = 7mm$ (width of the finger)
- $h = 3mm$ (thickness of the wall)
- $\mu = 0,5$ (friction factor; Plastic on Metal)
- $\alpha = 14,03°$ (angle of the snapper)
- $l = 40mm$ (length of the arm)
- As material for the simulation was chosen ABS
- $ES = 2500N/mm^2$ (ABS)

With the needed displacement of each arm of about $1mm$ the following equation leads to the shear force. Out of the Equation 3.1 for the displacement the strain can be calculated.

$$f = \frac{2}{3} * \frac{\varepsilon * l^2}{h} \tag{3.1}$$

$$\rightarrow \varepsilon = \frac{3 * f * h}{2 * l^2} \tag{3.2}$$

$$\varepsilon = \frac{3 * 1mm * 3mm}{2 * (40mm)^2} = 0.0028 \tag{3.3}$$

With the result of the strain the shear force can be calculated. But for the calculation of the shear force (Q), the section modulus (W) is needed. The following equation shows how the section modulus is calculated.

$$W = \frac{b * h^2}{6} \tag{3.4}$$

$$W = \frac{7mm * (3mm)^2}{6} = 10.5mm^3 \tag{3.5}$$

Now all values which are necessary for the calculation of the shear force are known.

$$Q = W * \frac{E_S * \varepsilon}{l} \tag{3.6}$$

$$Q = 10.5mm^3 * \frac{2500\frac{N}{mm^2} * 0.0028}{40mm} = 1.8375N \tag{3.7}$$

The axial force can be calculated out of the shear force with the angle of the snapper. The following equation shows how to calculate this force.

$$F = Q * \frac{\mu + \tan(\alpha)}{1 - \mu * \tan(\alpha)} \tag{3.8}$$

$$F = 1.8375N * \frac{0.5 + \tan(14.03)}{1 - 0.5 * \tan(14.03)} = 1.575N \tag{3.9}$$

This means with a force of $1.575N$ one arm of the snap connection displaces about $1mm$. For each arm is the same force needed. This means that the whole force for the four arms is calculated as follows:

$$F_{tot} = 4 * F \tag{3.10}$$

$$F_{tot} = 4 * 1.575N = 6.298N \tag{3.11}$$

The calculated total force is within the range of the strain gauge.

3.4.1.2. Calculation for the Drop Cycle

The values for this calculation are almost the same. Just the length changes from $40mm$ to $32mm$ and the angle is now 9.46°.

- $f = 1mm$ (displacement)
- $b = 7mm$ (width of the finger)
- $h = 3mm$ (thickness of the wall)
- $\mu = 0.5$ (friction factor; Plastic on Metal)
- $\alpha = 9.46°$ (angle of the snapper)
- $l = 32mm$ (length of the arm)
- As material for the simulation was chosen ABS
- $ES = 2500N/mm^2$ (ABS)

The equations are the same than before. Just the values for the length of an arm and the angle are different.

$$f = \frac{2}{3} * \frac{\varepsilon * l^2}{h} \tag{3.12}$$

$$\rightarrow \varepsilon = \frac{3 * f * h}{2 * l^2} \tag{3.13}$$

$$\varepsilon = \frac{3 * 1mm * 3mm}{2 * (32mm)^2} = 0.0044 \tag{3.14}$$

The calculation for the section modulus is exactly the same than in the point above.

$$W = \frac{b * h^2}{6} \tag{3.15}$$

$$W = \frac{7mm * (3mm)^2}{6} = 10.5mm^3 \tag{3.16}$$

$$Q = W * \frac{E_S * \varepsilon}{l} \tag{3.17}$$

$$Q = 10.5mm^3 * \frac{2500\frac{N}{mm^2} * 0.0044}{32mm} = 2.8839N \tag{3.18}$$

$$F = Q * \frac{\mu + \tan(\alpha)}{1 - \mu * \tan(\alpha)} \tag{3.19}$$

$$F = 2.8839 * \frac{0.5 + \tan(14.03)}{1 - 0.5 * \tan(14.03)} = 2.097N \tag{3.20}$$

$$F_{ges} = 4 * F \tag{3.21}$$

$$F_{ges} = 4 * 2.097N = 8.389N \tag{3.22}$$

The total force is now $8.389N$ and this means that the force is within the range of the gauge.

3.4.2. FEA

With the finite element analysis it's possible to show and to check the occurring stresses and displacements. The FEA was made with the program NX 10. The first step for this simulation was to split the whole object into small elements. The elements are tetrahedron elements. Figure 3.10 shows how the object looks like when it's divided into a finite number of elements.

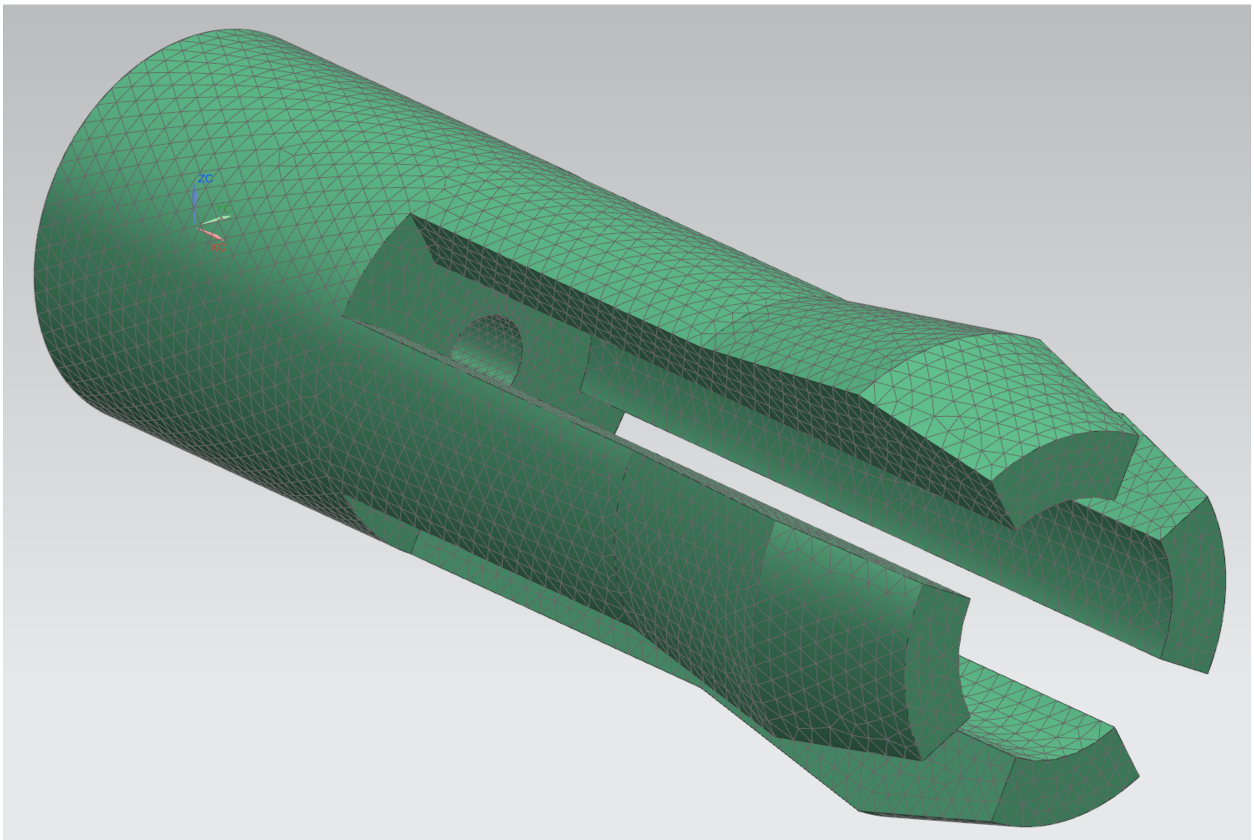


Figure 3.10.: Dividing into a finite number of elements
Source: Group 4

The bending behaviour of different materials is different, so a material has to be defined that behaviour is acceptable. The chosen material for the simulation was ABS because it is a good material for bending tasks. The next point was to define where the snapper is fixed and where the loads are acting. As seen in Figure 3.11 there is shown where the object is attached and where the loads act.

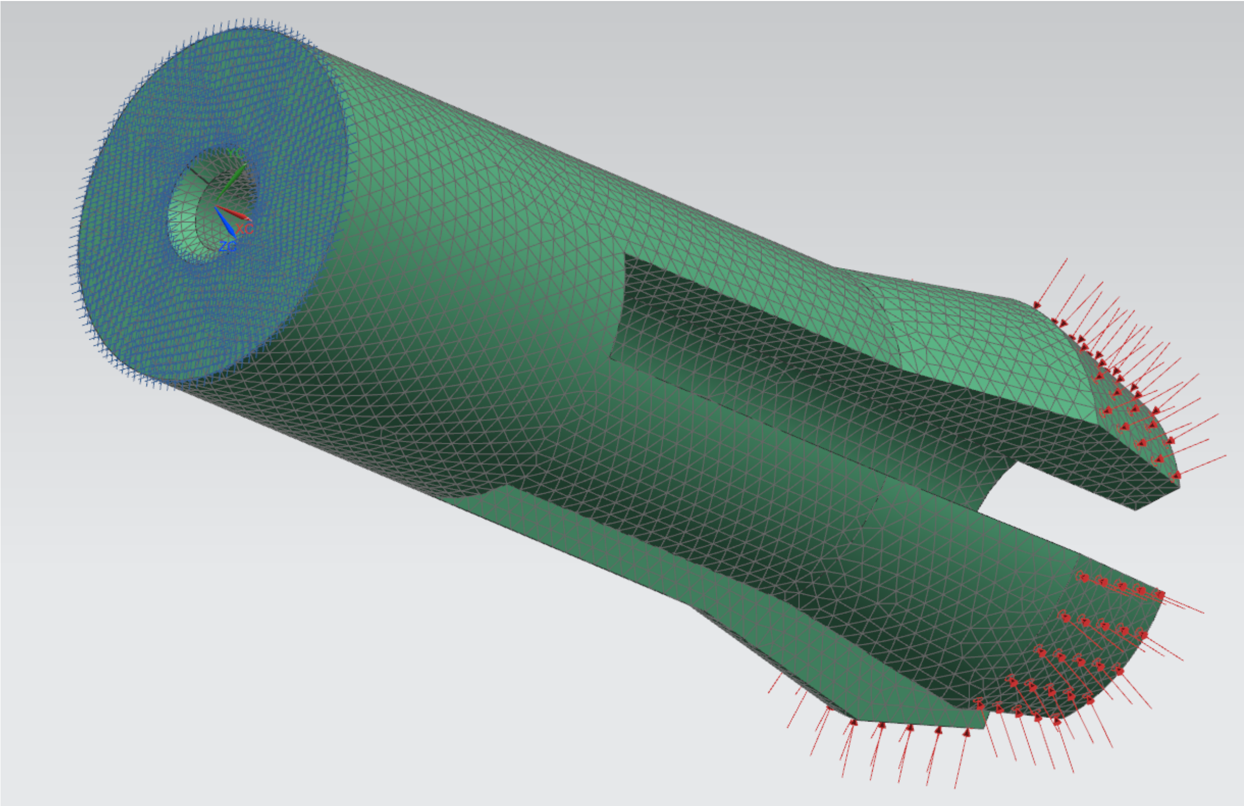


Figure 3.11.: Attached object and loads
Source: Group 4

In the figure above you can see that the area where the snapper is fixed is marked blue. The loads are represented by the red arrows acting on four areas. The pressure is calculated as follows. The area where the pressure is acting is about $86.35mm^2$ big. The force which is acting on one area is about $2,5N$. The pressure for the simulation is $0.029N/mm^2$.

$$p = \frac{F}{A} \tag{3.23}$$

$$p = \frac{2.5N}{86.35mm^2} = 0.0289\frac{N}{mm^2} \tag{3.24}$$

3.4.3. Analysis of the Simulation for the Displacement

The snapper has to be deformed at least one mm at each arm that the snapper is able to snap into the disc. In Figure 3.12 is the displaced snapper shown.

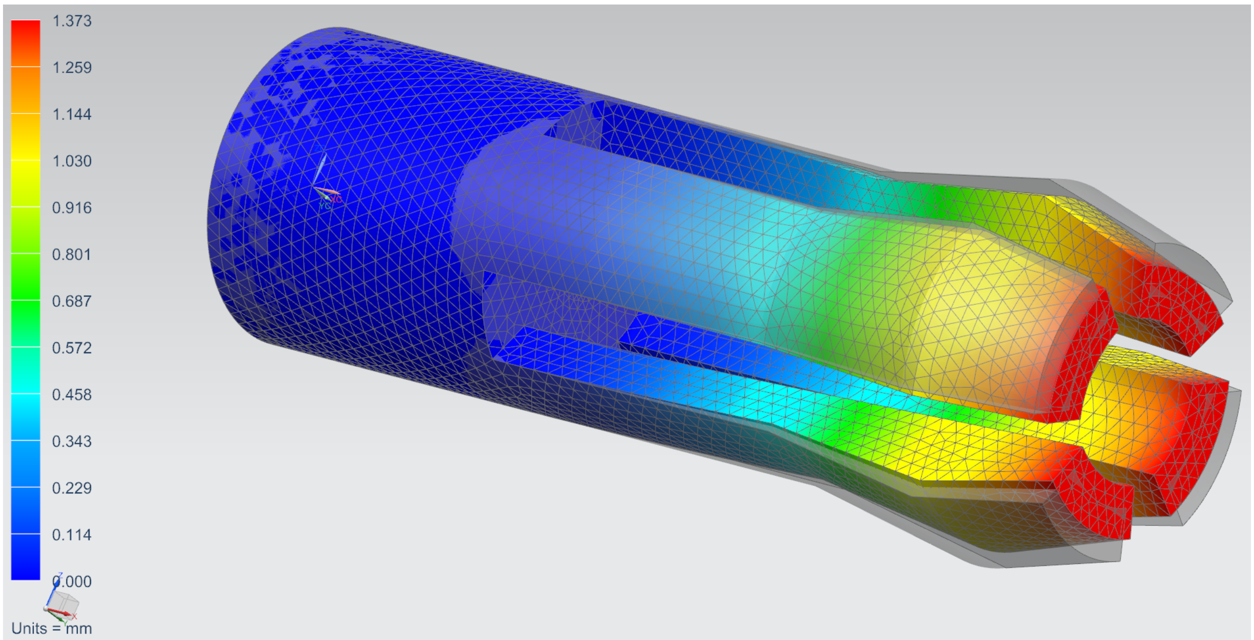


Figure 3.12.: Displaced snapper
Source: Group 4

The colours stands for different displacements. The scale on the left side in the picture shows which colour stands for which displacement value. At the yellow region the displacement is bigger than 1mm. The yellow region is the important region because the edge there should be deformed at least 1mm. The used material for manufacturing is Polyamide. The ABS was chosen for calculation because this two materials are really similar. The Polyamide is the softer material, so the displacement will be bigger for the same force or the force to displace the snapper for the same distance will be a little smaller.

3.4.4. Analysis of the Simulation for the Stresses

The simulation result for the stresses looks similar to the simulation result of the displacement. The scale on the left side shows the stress and the colours shows the location of the acting stresses. Figure 3.13 shows the result of the simulation.

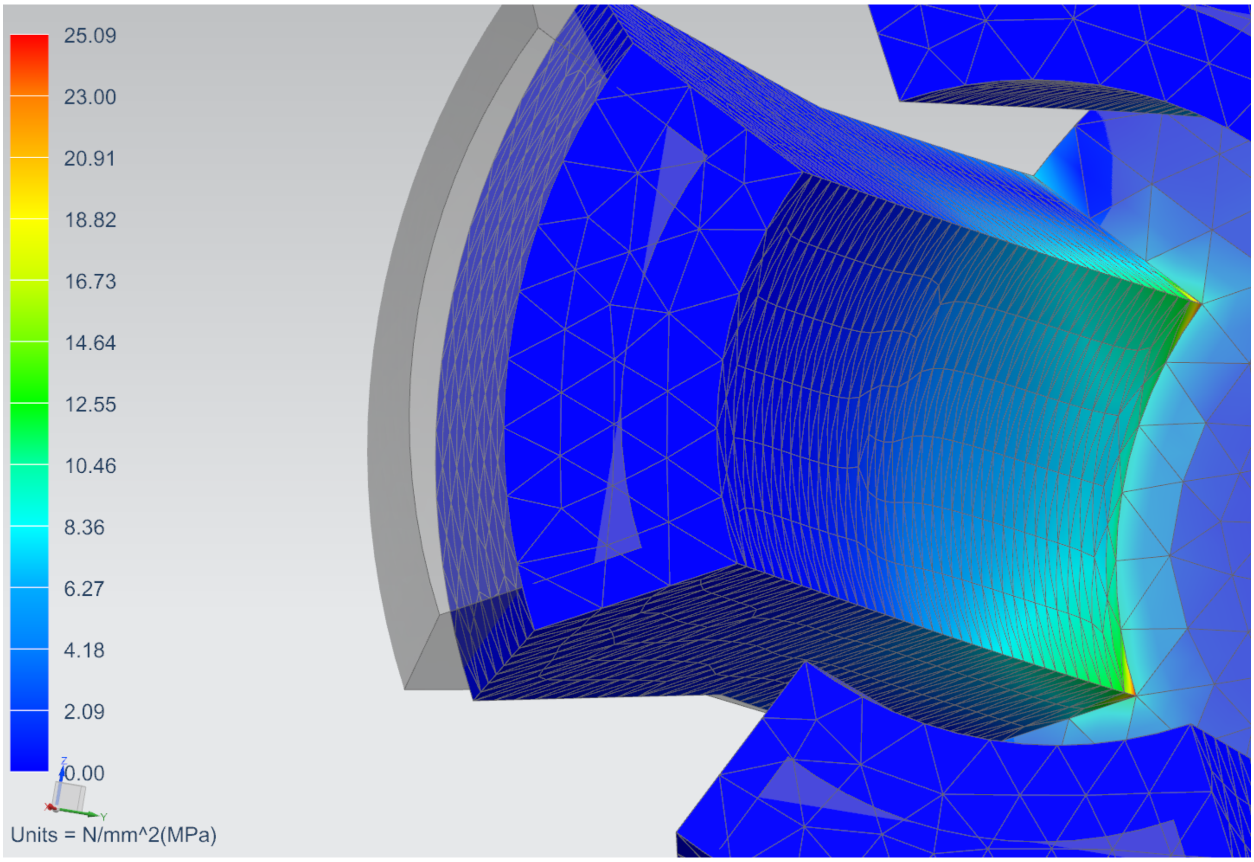


Figure 3.13.: Simulation result
Source: Group 4

The maximum stress occurs at the corners as seen in figure above. The value of the maximum stress is $25.09 N/mm^2$.

4. Electronic Components

4.1. System Overview

Figure 4.1 shows the parts that are connected together and which interface is used. The parts will be discussed in this chapter.

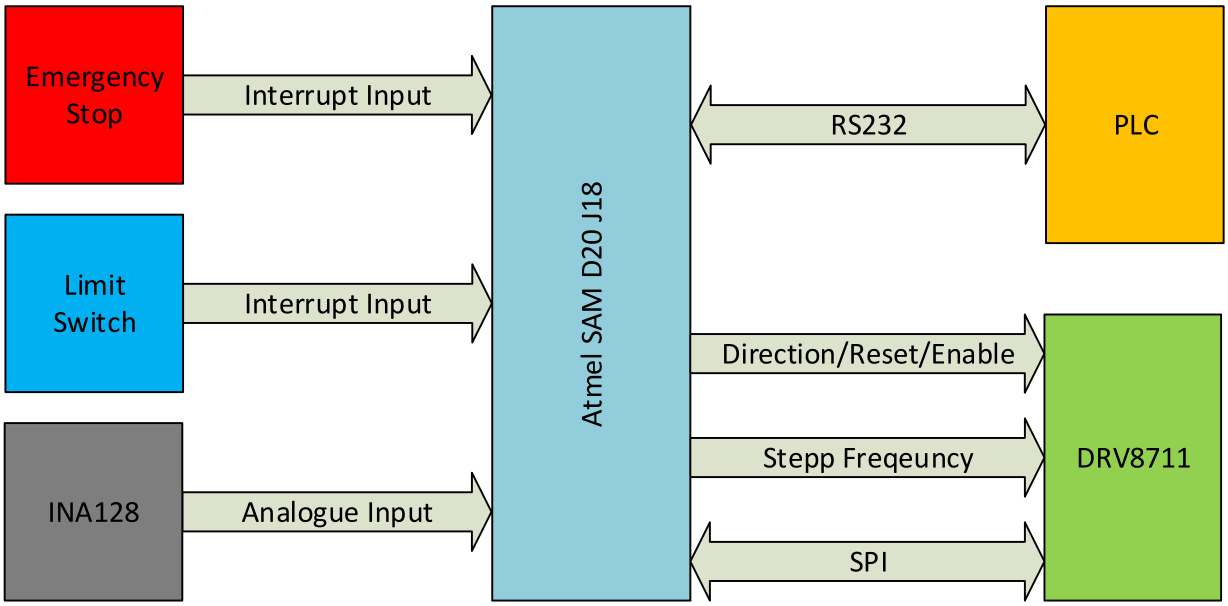


Figure 4.1.: System Overview
Source: Group 4

4.2. Linear Voltage Regulator

The linear voltage regulator is primarily to supply the amplifier with a constant voltage, but the $5V$ are also used for the uC and the RS232 level converter. A “LM1086” is used, because it satisfies the needs for our schematic and it is in stock at the FHV.

4.3. Schematic

In the left top corner in Figure 4.2 the linear voltage regulator can be found. There are two capacitors (C13, C14) for bypassing[1]

[1] the values are chosen from the “LM1086” data sheet page 18

4.4. Calculation

The maximum current has to be calculated, because if the current is to high, a heat sink has to be used. With the following equation it leads us to the maximum current.

$$P_D = (V_{in} - V_{out}) * I_L \tag{4.1}$$

P_D*...power consumption*
I_L*...load current*

$$R_{therm} = \frac{T_j - T_a}{P_D} \tag{4.2}$$

$$R_{therm} = \frac{T_j - T_a}{(V_{in} - V_{out}) * I_L} \tag{4.3}$$

T_j*...junction temperature*
T_a*...ambient temperature* With the following values[2], the maximum current can be calculated.
$T_j = 125°$ $T_a = 25°$ $R_{therm} = 40,8°C/W$

$$\rightarrow I_L = \frac{T_j - T_a}{(V_{in} - V_{out}) * R_{therm}} \tag{4.4}$$

$$I_L = \frac{125°C - 25°C}{24V - 5V) * 40,8°C/W} = 0,129A \tag{4.5}$$

The result of Equation 4.5 is higher then the the measurements in section 4.5. Consequently no heat sink is needed.

4.5. Measurements

The current and the voltage is measured under load. Current was about $50mA$ and the voltage constant at $5V$.

4.6. Amplifier Circuit

4.6.1. Description

The main purpose of the circuit (Figure 4.2) is to amplify the differential voltage between the positive and negative bridge input from the strain gauge. This amplified differential voltage then is send to the ADC converter that is located on the Atmel board. The board is operating on a 5V supply voltage and with a reference voltage of $1,65V$. The amplification factor is 660 (Equation 4.9), which is explained later in the document.

[2]they can be found in the "LM1086" data sheet at page 4 and 5

4.6.2. Schematic

On the right side image (Figure 4.2) the schematic for the amplifier can be found. The circuit for the amplifier is connected to the RS232 and the linear voltage regulator. This because the RS232 and the amplifier use the same 5V supply voltage that the linear voltage regulator is supplying. The circuit consists of an INA128UA1, a gain resistor (U1), a resistor to adjust the reference voltage (R1) and a capacitor (C5). The values can bee found at Table 4.1. The amplifier circuit get the positive and negative bridge input from the DMS connector 3 and 4. The amplified output signal is given to the 3th pin of the Atmel board.

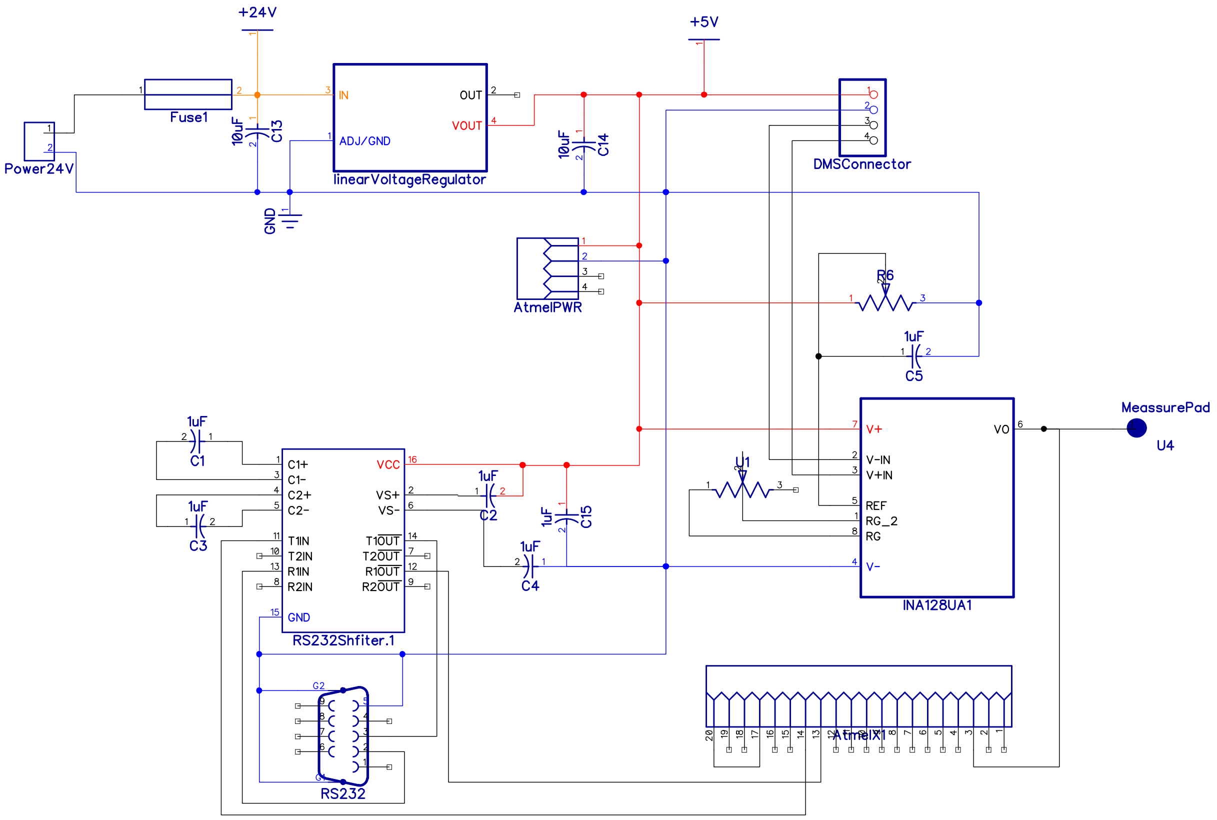


Figure 4.2.: Schematic of power, RS232 and strain gauge
Source: Group 4

4.6.3. Calculation

The following calculation can be found in the datasheet of the INA128UA and is used to calculate the gain of the gain resistor:
With Equation 4.6 the necessary gain is calculated.

$$
\begin{aligned}
G &= \frac{U_a}{U_e} && (4.6)\\
G &= \frac{3,3V}{5 * 10^{-3}V} = 660 && (4.7)
\end{aligned}
$$

The Equation 4.8 is from the IN128UA1 Datasheet.

$$G = 1 + \frac{50k\Omega}{R_g} \tag{4.8}$$

With Equation 4.8 the R_g is calculated.

$$R_g = \frac{50k\Omega}{G - 1} \tag{4.9}$$

With Equation 4.9 the necessary R_g is calculated as $75,8\Omega$
The reference voltage is calculated with the generally voltage divider formula. The reference voltage should be $1,65V$, because the strain gauge has $0n$ with no load.

$$
\begin{aligned}
\frac{U_2}{U} &= \frac{R_2}{R_1 + R_2} && (4.10)\\
\frac{U_2}{U} &= \frac{R_2}{R_{ges}} && (4.11)\\
\rightarrow R_2 &= \frac{U_2 * R_{ges}}{U} && (4.12)\\
R_2 &= \frac{1,65V * 500\Omega}{5V} = 165\Omega && (4.13)
\end{aligned}
$$

The potentiometer R1 has to be adjusted to 165Ω.

4.6.4. Layout

The layout of the top and bottom side of the board is shown in Figure 4.13.

4.6.5. Measurement

The measurement is done so there is proof that the amplifier works and so the machine can function well. In Figure 4.3 the test results can be seen, the sinus shaped line (yellow probe) represents the output voltage that is given to the ADC.

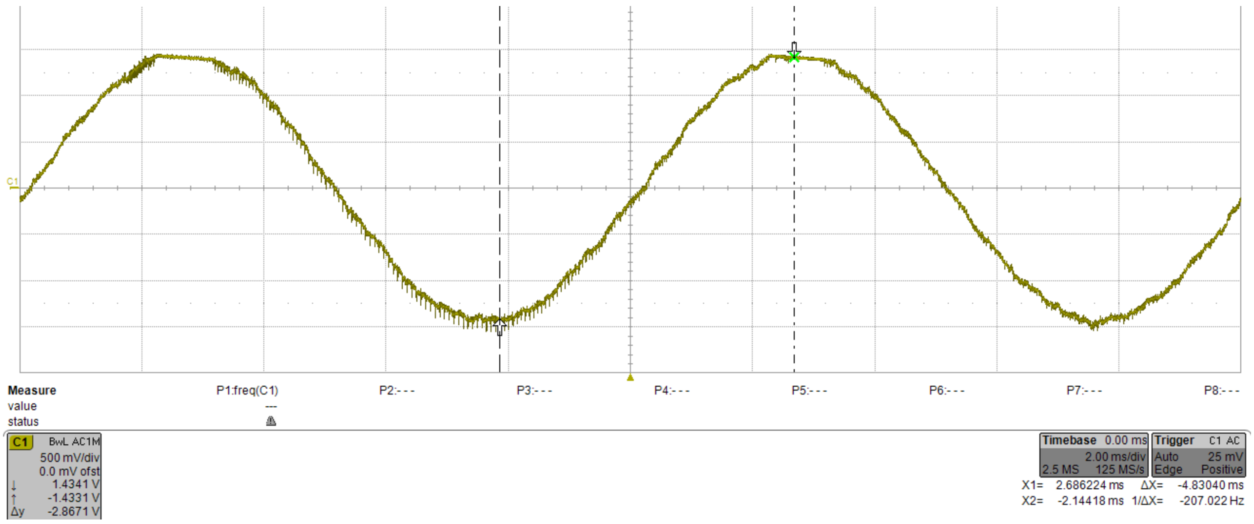


Figure 4.3.: Test of the strain gauge
Source: Group 4

To test the amplifier it is connected to a power supply, a function generator and the oscilloscope. The function generator simulates the positive and negative bridge input, with an offset of 1.675V and a maximum amplitude of 2.5mV.

4.7. RS232 Circuit

4.7.1. Description

The main purpose of the circuit (Figure 4.2) is to change the TTL signal ($0V ... 3,3V$) to RS232 ($+15V ... -15V$). This is necessary, because the uC has only a TTL interface and the PLC only a PLC interface. And one good thing is, that the RS232 is stable against disruptions.

4.7.2. Schematic

On the left side image (Figure 4.2) the schematic for the amplifier can be found. The RS232 circuit is connected to the linear voltage regulator, because the power supply of the RS232 is $5V$. The circuit consists of a MAX232, two charge pumps(C1, C3) and three other capacitors (C2, C4, C5). The components were chosen with the guideline of the data sheet, the values can bee found at Table 4.1. “R1IN” are the line data input (from PLC) and “T1OUT” the line data output (to PLC). “T1IN” are the logic data input (from uC) and “R1OUT” are logic data output (to uC). “VS+” is the positive charge pump output and “VS-” is negative charge pump output.

4.7.3. Measurement

To test the RS232 it is connected to a power supply, the uC and a USB to RS232 adapter to send and receive data from a computer. First the charge pumps are measured with a voltage meter (values $8V$ and $-6,5V$). Secondly a ASCII transmission is send by uC. In Figure 4.4 is the telegram shown as a scope. In Figure 4.4 the yellow probe shows the telegram transmission.

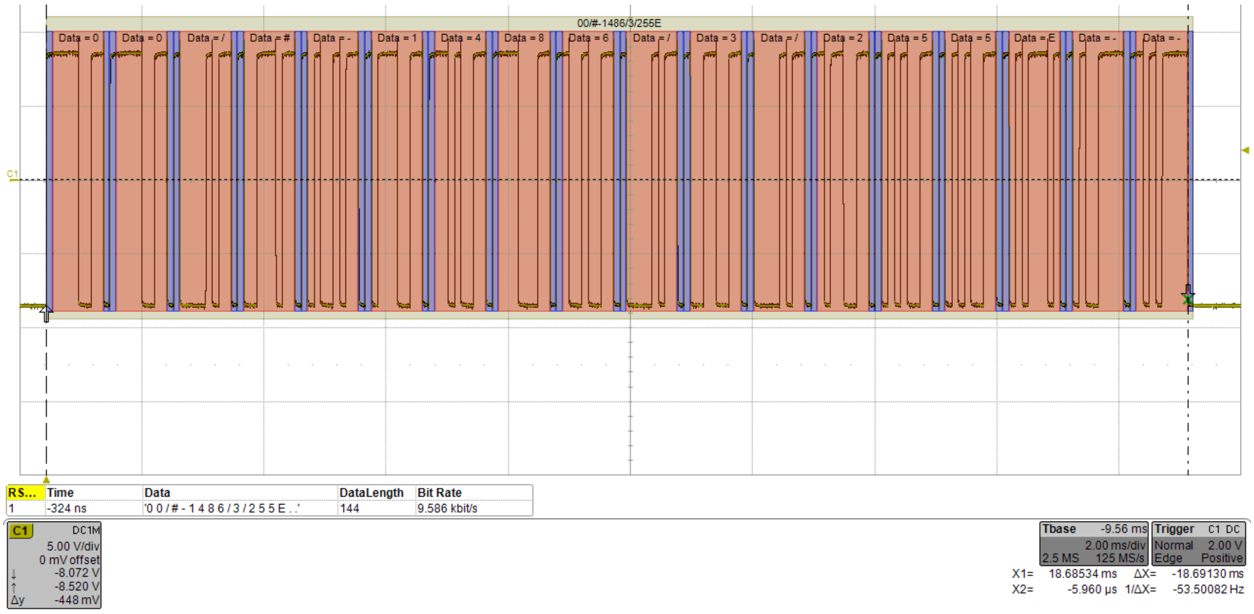


Figure 4.4.: RS232 telegram scope
Source: Group 4

As we can see, the telegram is transmitted correctly.

4.7.4. Layout

The layout of the top and bottom side of the board is shown in Figure 4.13.

4.8. DRV8711 Circuit

4.8.1. Description

The Z axis of the system is moved by a bipolar stepper motor. To convert low power control signals of any logic device into power signals for the motor a driver circuit had to be implemented. These motor drivers consist basically of a full bridge circuit for each of the both motor windings.

4.8.2. Schematic

A DRV8711 has to be used, so a schematic was designed (Figure 4.5) to control the stepper motor. The components were chosen with the guideline of the data sheet. Only the IRF520, a N-Channel power MOSFET, was chosen, because Mr. Schneider recommend it.
The circuits consists of

- the DRV8711,
- a charge pump (C8),
- two resistors (R1, R2) $50m\Omega$ for the current measurement,
- two red LED's for stall and error debugging with a dropping resistor (R4, R3) of $220m\Omega$ (see subsection 4.8.3,
- two bulk capacitors, one electrolyte (C10) and one ceramic (C11)
- a pull up resistor for the SDATO (SPI), because it's a open-drain output,
- a bypass to ground (C9) for the $5V$ pin (5)
- a capacitor(C6) is placed between the VM and VCP,
- a bypass capacitor (C7) from VINT to ground,
- 8 MOSFET's (T1-T8) for the power section,
- a plug (motor connector) to connect to the motor,
- a connector (Atmel X2) with 10x2 pins,
- two connectors (J1, J2) with each 19 pins

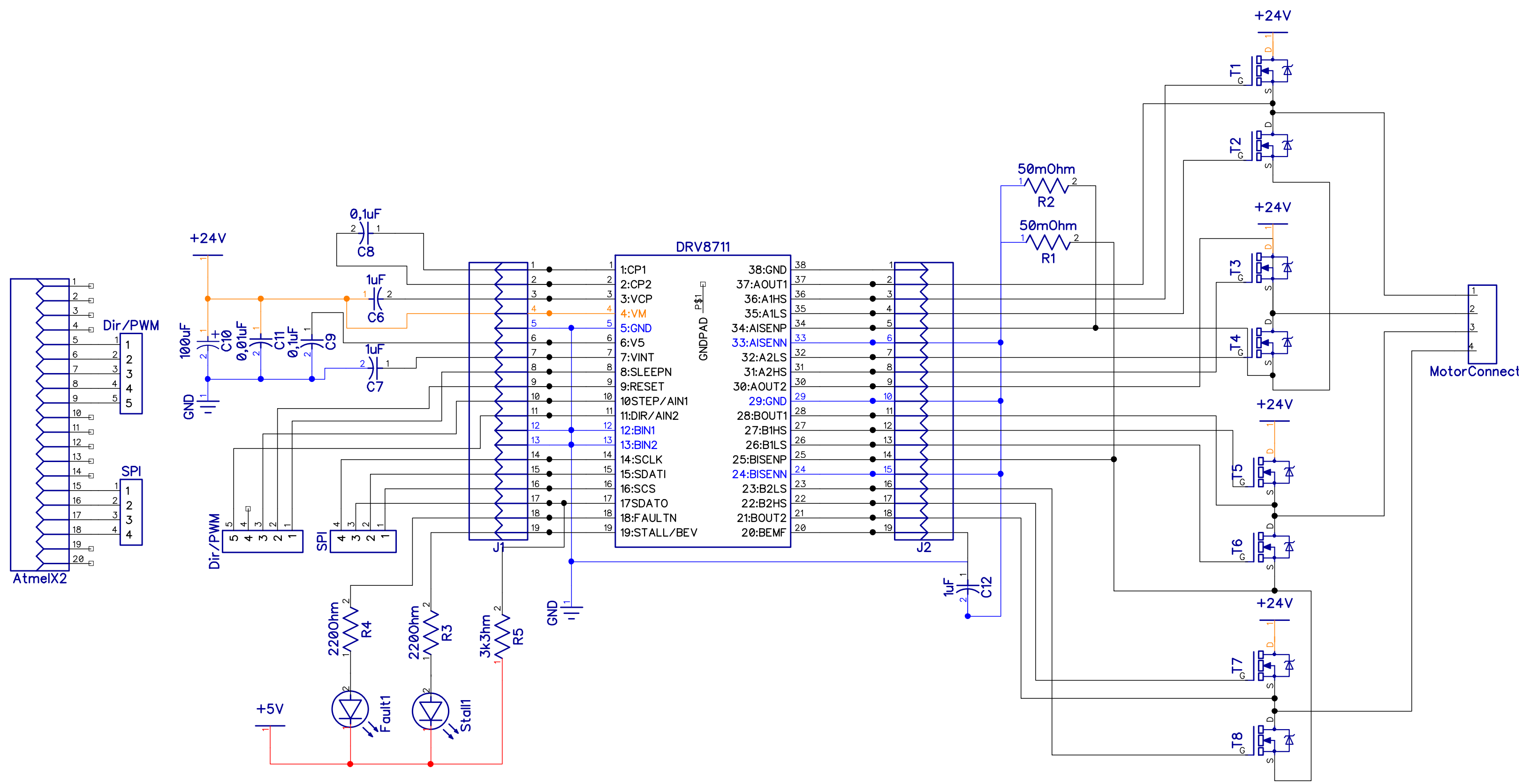


Figure 4.5.: DRV8711 layout
Source: Group 4

4.8.3. Calculation

4.8.3.1. Power Consumption of Sense Resistors

The power dissipated by the sense resistor equals to Equation 4.14.
$R_{ISENSE} = 50 * 10^{-3}\Omega$
$I_{FS} = 0,5371A$
$I_{FSpeak} = 0,5371A * 4 = 2,15A$

$$\begin{aligned} P &= I^2_{IFSpeak} * R_{ISENSE} && (4.14) \\ P &= 2,15^2 * 50 * 10^{-3}\Omega = 0,23W && (4.15) \end{aligned}$$

The sense resistor has a maximum P_{dead} of $3W$ [3]. That means with the result of Equation 4.15, the sense resistor will never reach the P_{dead}.

4.8.3.2. Drive Current

From the data sheet [4], the following equation is used to calculate the drive current.

$$I_{FS} = \frac{2,75V * TORQUE}{256 * ISGAIN * R_{ISENSE}} \quad (4.16)$$

With the following values [5] and the Equation 4.16 the I_{FS} is calculated. The result can bee seen at Equation 4.17.
$TORQUE = 40$
$ISGAIN = 100$
$R_{ISENSE} = 50 * 10^{-3}\Omega$

$$I_{FS} = \frac{2,75V * 100}{256 * 40 * 50 * 10^{-3}\Omega} = 0,5371A \quad (4.17)$$

4.8.3.3. Maximum allowed Drive Current

It is necessary to calculate the maximum current for the MOSFET's, because we don't have a heat sink. The following values are from the data sheet [6]
$T_j = 25°C\, to\, 150°C$
$T_a = 25°C$
$R_{DS(on)} = 0,27\Omega$
$R_{thJA} = 80°K/W$

[3] see data sheet 3W_0R050
[4] see data sheet DRV8711 page 13
[5] see at the register settings (Figure 7.6) and Table 4.1
[6] see at IRF520 data sheet page 2

With the following equations, the maximum allowed current I_{max} is calculated.

$$\begin{aligned}
T_j - T_a &= R_{thJA} * P_d && (4.18)\\
P_d &= U_{DS(on)} * I_{DS(on)} = I^2_{DS(on)} * R_{DS(on)} && (4.19)\\
T_j - T_a &= I^2_{DS(on)} * R_{DS(on)} * R_{thJA} && (4.20)\\
\rightarrow I_{max} &= \sqrt{\frac{T_j - T_a}{R_{DS(on)} * R_{thJA}}} && (4.21)\\
I_{max} &= \sqrt{\frac{150°C - 25°C}{0,27\Omega * 80°K/W}} = 2,4A && (4.22)
\end{aligned}$$

As we can see, the result from the Equation 4.22 is lower than the maximum drive current (Equation 4.17). We chose a fuse (Fuse) with a value of $1,5A$ release current to protect the circuit.

4.8.4. Measurements

First the charge pump was measured and checked if there are $33V$ (Figure 4.6) and also the VCP should be $33V$ constantly. The measurement was done during the motor was driving. In Figure 4.6 the yellow probe shows the charge pump and the red probe shows VCP.

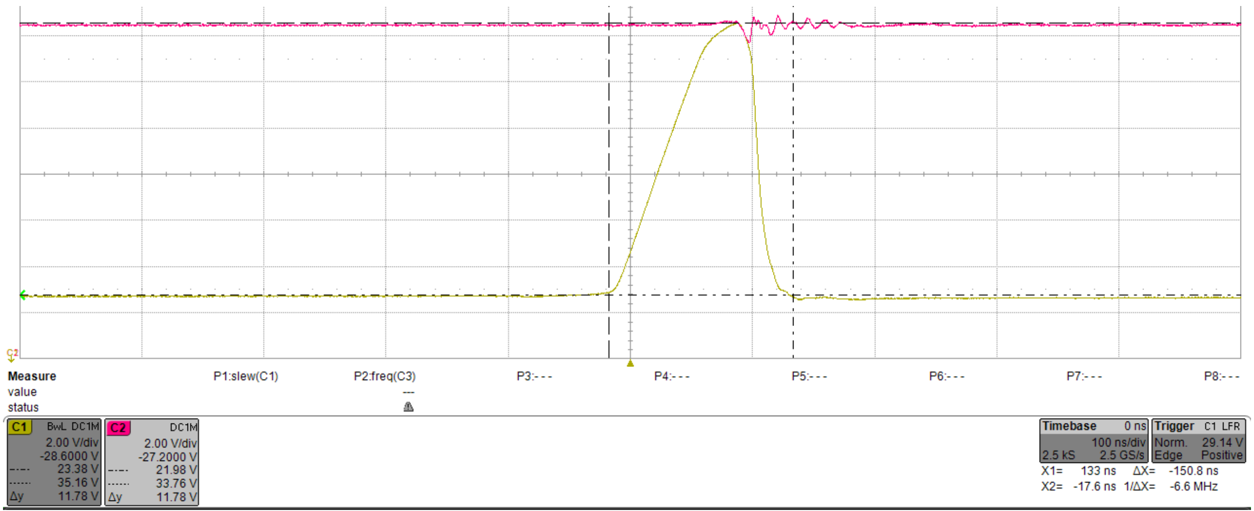


Figure 4.6.: charge pump and VCP
Source: Group 4

AS can be seen, the values are like we expected it.
Secondly the SPI configuration is send with an SPI simulator. Figure 4.7 shows the telegram for the configuration and Figure 4.8 shows the telegram to get the status. Channel 1 (yellow probe) shows the SPI data output, Channel 2 (red probe) shows the SPI clock, Channel 3

(blue probe) shows the SPI data input from the DRV8711 and Channel 4 (green probe) shows the SPI chip select. Don't bee confused, about the chip select, its an active high output.

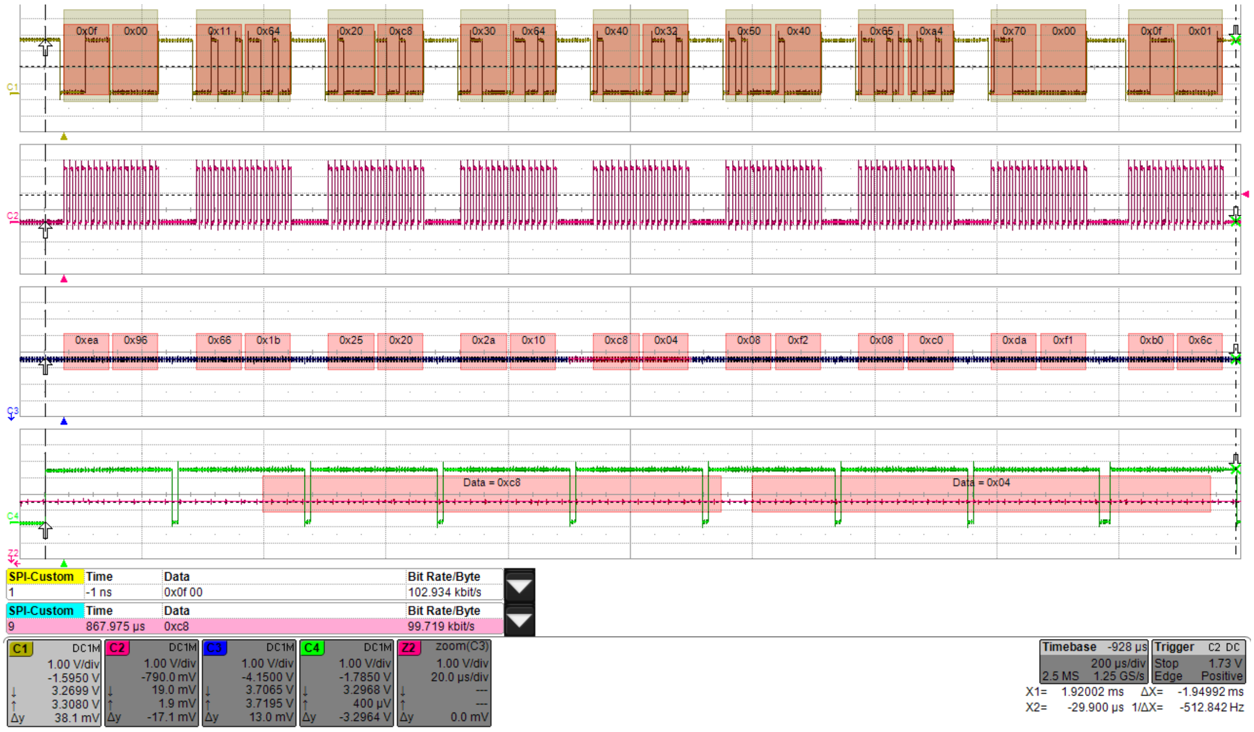


Figure 4.7.: SPI send configuration
Source: Group 4

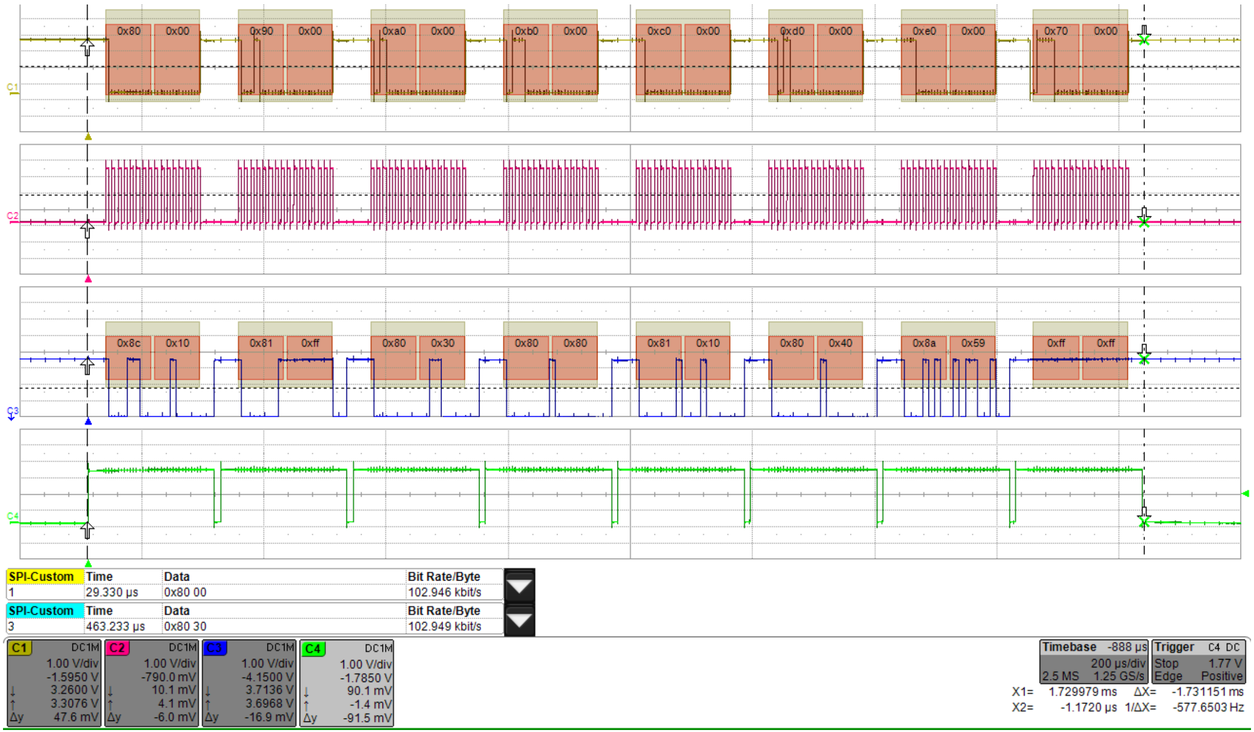


Figure 4.8.: SPI get status
Source: Group 4

As can bee seen, the SPI works good.
Thirdly the H-bridges are measured and the motor current (Figure 4.9). The yellow probe is the A1HS and the red one the B1HS. The blue probe is the frequency the uC is sending.

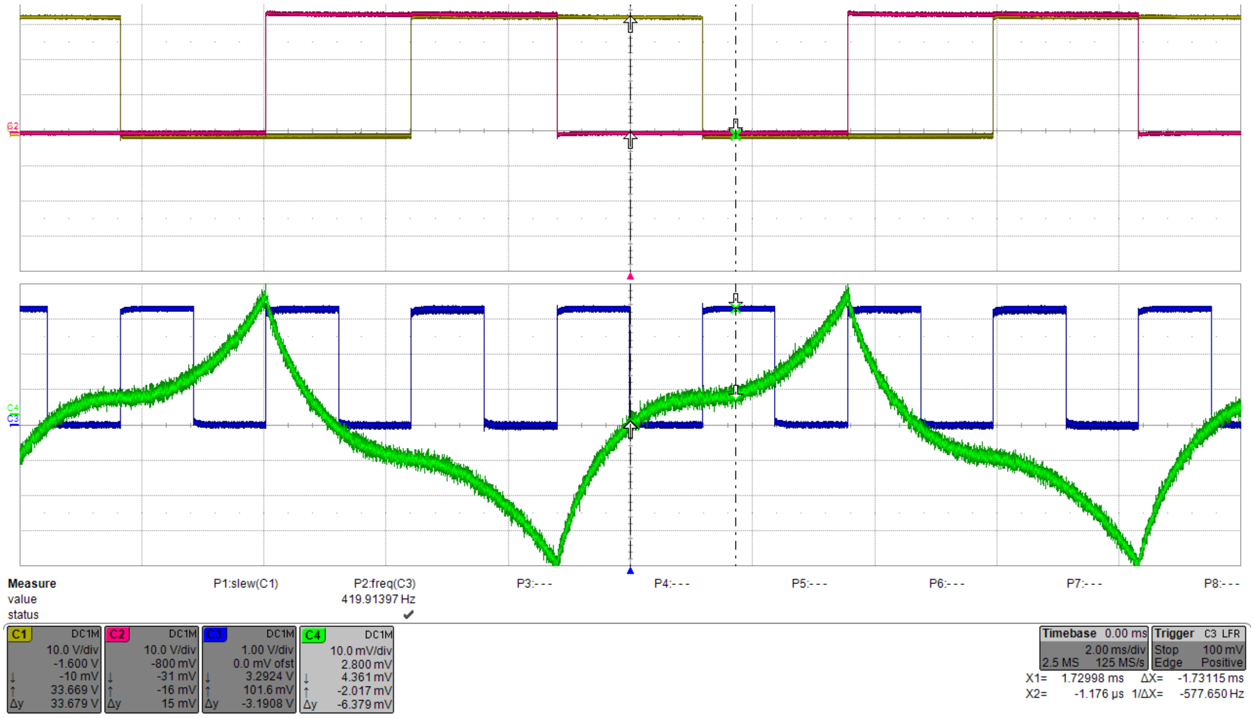


Figure 4.9.: DRV8711 H-Bridges and motor current
Source: Group 4

As can bee seen, the H-bridges are switching perfectly, but the motor current is not like it should be. We tried hard to get a nice sinus, but we did not find any other good configuration. Therefore we chose this configuration, because it drives smoothly.

4.9. Emergency Stop and limit Switch Circuit

4.9.1. Description

The emergency stop is a potential free contact. The available parts has a safety relay, a left over contact is used to switch the relay (Relais, Schrack, A1, A2). The uC uses a a contact (5, 4) of the relay, to detect if the emergency circuit is released. A capacitor (C17) is used to debounce the signal.
The limit switch is used to detect the home position. It is implemented as normally closed contact, to detect wire breaks. It is also a A capacitor (C16) used to debounce the signal.
There are 4 connectors (AtmelX3, LimitSwitch, EmergencyStop24V, EmergencyStoptouC) to linkt the wires to the uC, limit switch and the Schrack relay.

4.9.2. Measurement

the signal was analysed without (Figure 4.10) and with (Figure 4.11) capacitor. To test if it works correctly in the field, the limit switch and the emergency circuit are called in an interrupt for each switch in the uC. The interrupt is called correctly, the value of the capacitor to debounce is correct.

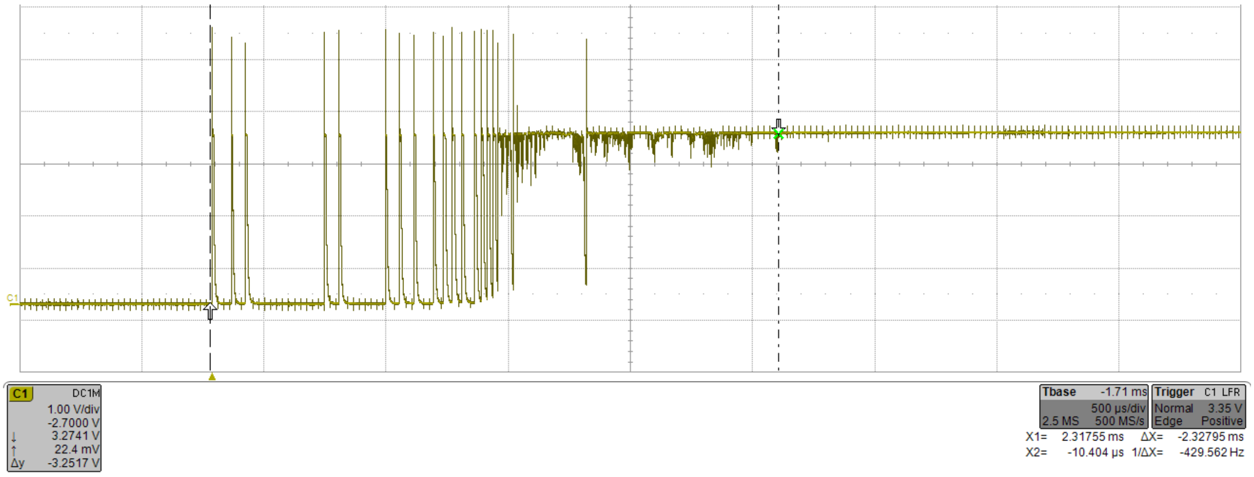


Figure 4.10.: Switch without capacitor
Source: Group 4

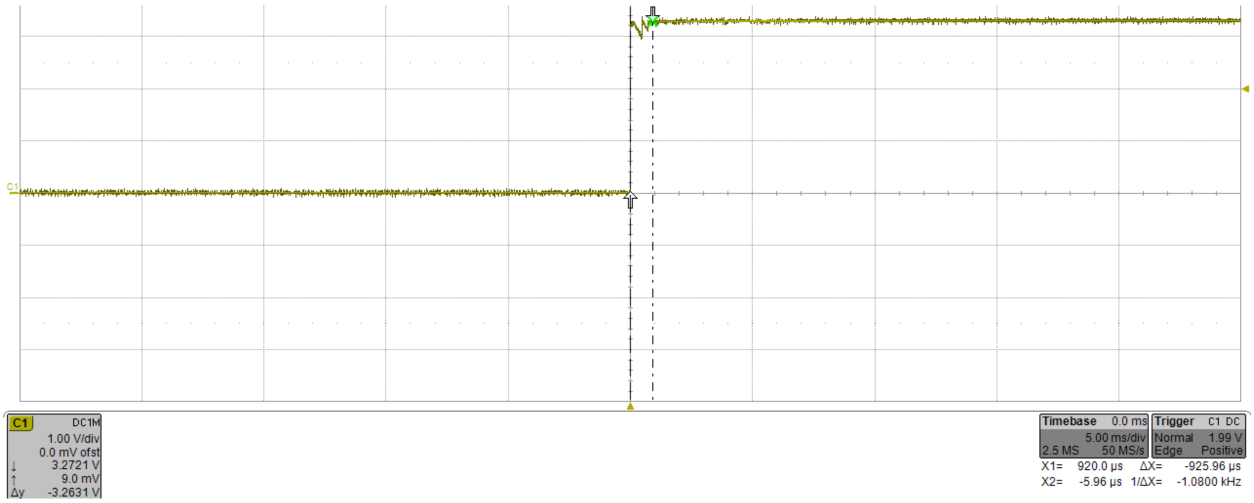


Figure 4.11.: Switch with capacitor
Source: Group 4

4.9.3. Schematic

In Figure 4.12 is the schematic shown from the emergency relay and the limit switch. There was no need to do a PCB layout, because we soldered it just together.

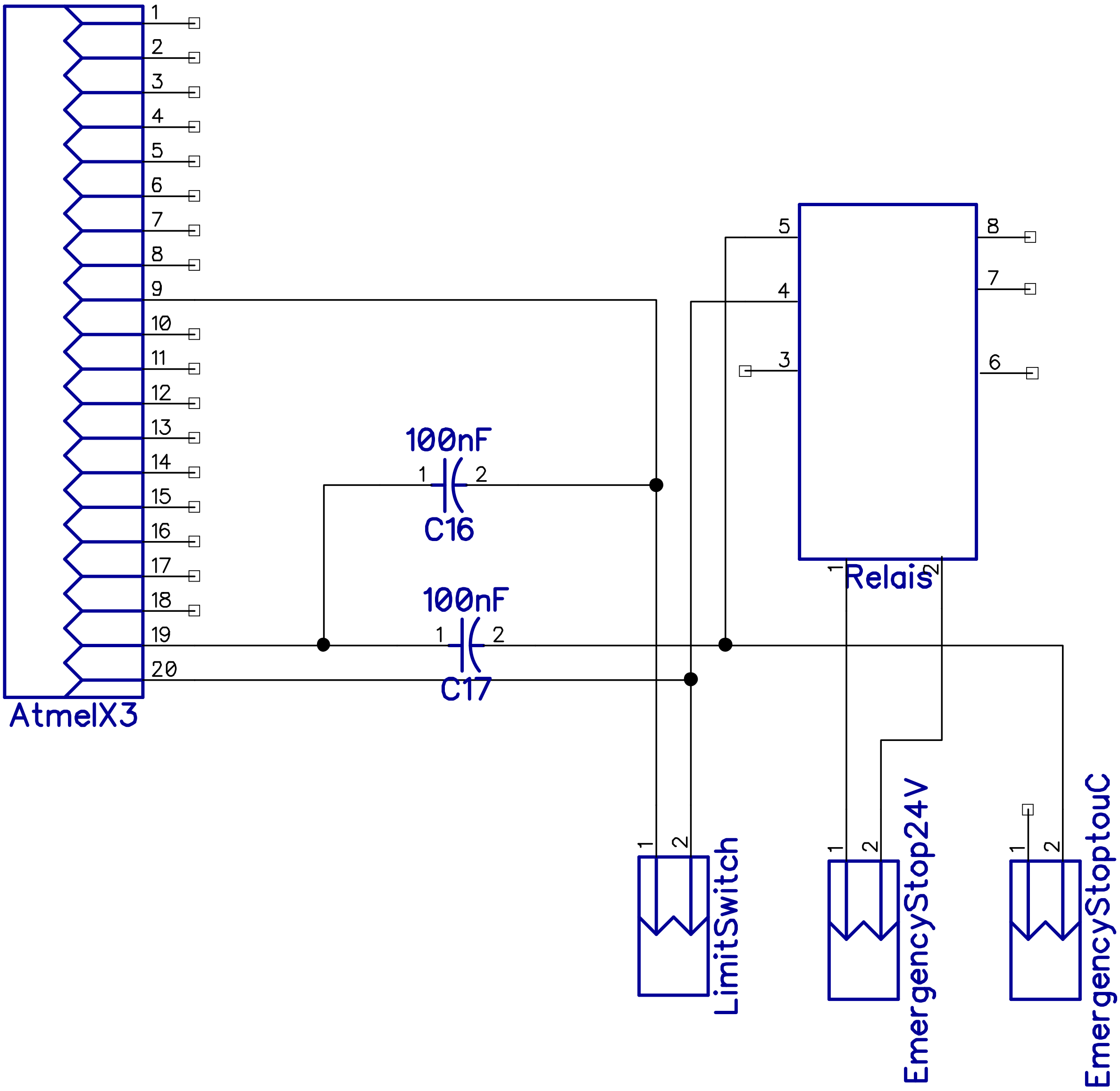


Figure 4.12.: Emergency and limit switch schematic
Source: Group 4

4.10. Bill of materials

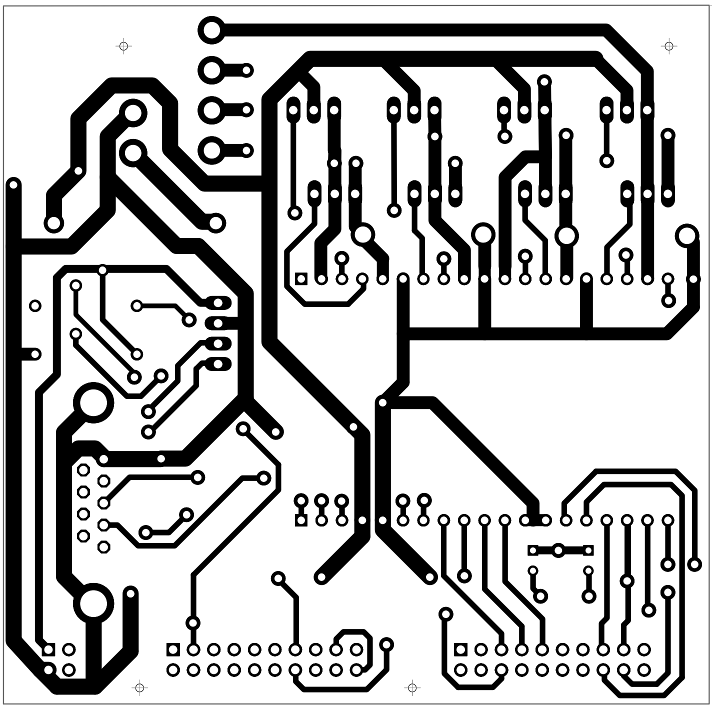
In Table 4.1 the bill of materials can be found for parts that are used to build the amplifier.

Definition in circuit	Value	Name	Quantity
AtmelPWR		PPTC022LFBN-RC	1
AtmelX1, AtmelX2, AtmelX3		PPTC102LFBN-RC	3
C1, C2, C3, C4, C5, C6, C7, C12, C15	$1\mu F$	CAP_0603 (ceramic)	9
C8, C9	$0,1\mu F$	CAP_0603 (ceramic)	2
C10	$100\mu F$	EEE–CASE-E (electrolyte)	1
C11	$0,01\mu F$	CAP_0603 (ceramic)	1
C13, C14	$10\mu F$	CAP_1206 (tantalum)	2
C16, C17	$100\mu F$	CAP100 (ceramic)	2
DMSConnector		PINHD-1X4	1
DRV8711		DRV8711	1
EmergencyStop24V, EmergencyStoptouC, LimitSwitch		HDR-1x2	3
Fault1, Stall1		LED	2
Fuse1		Fuse	1
INA128UA1		INA128UA	1
J1, J2		HDR-1x19	2
linearVoltageRegulator		LM1086IS-5.0	1
MotorConnector		MSTB 2-5-5,08x4	1
Power24V		MSTB 2-5-5,08x2	1
R1, R2	$50m\Omega$	PowerResistor	2
R3, R4	220Ω	RES_0603	2
R5	$3,3k\Omega$	RES_0603	1
R6, U1	500Ω	POT	2
Relais		Schrack	1
RS232Shfiter		MAX232	1
T1, T2, T3, T4, T5, T6, T7, T8		IRF520	8

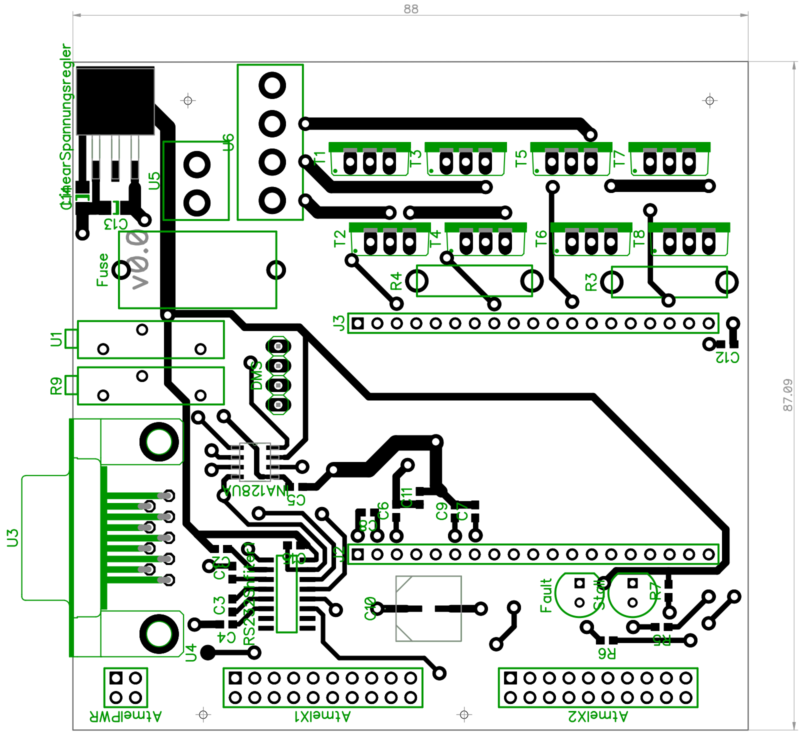
Table 4.1.: List of materials

4.11. PCB layout

In Figure 4.13 the designed layout is shown. We tried to separate the power (motor driver) and digital (amplifier, RS232 shifter) circuits to reduce noises. We also used star point grounding for the analogue components, such as the amplifier. Additional we tried to separate the analogue and digital ground. We decided to do the soldering for the most parts with the pick and place machine. Only the IC's and the connectors has to be soldered by hand.



(a) Bottom



(b) Top

Figure 4.13.: bottom and top PCB layout
source: group 4

In Figure 4.13 the rendered PCB layout is show.

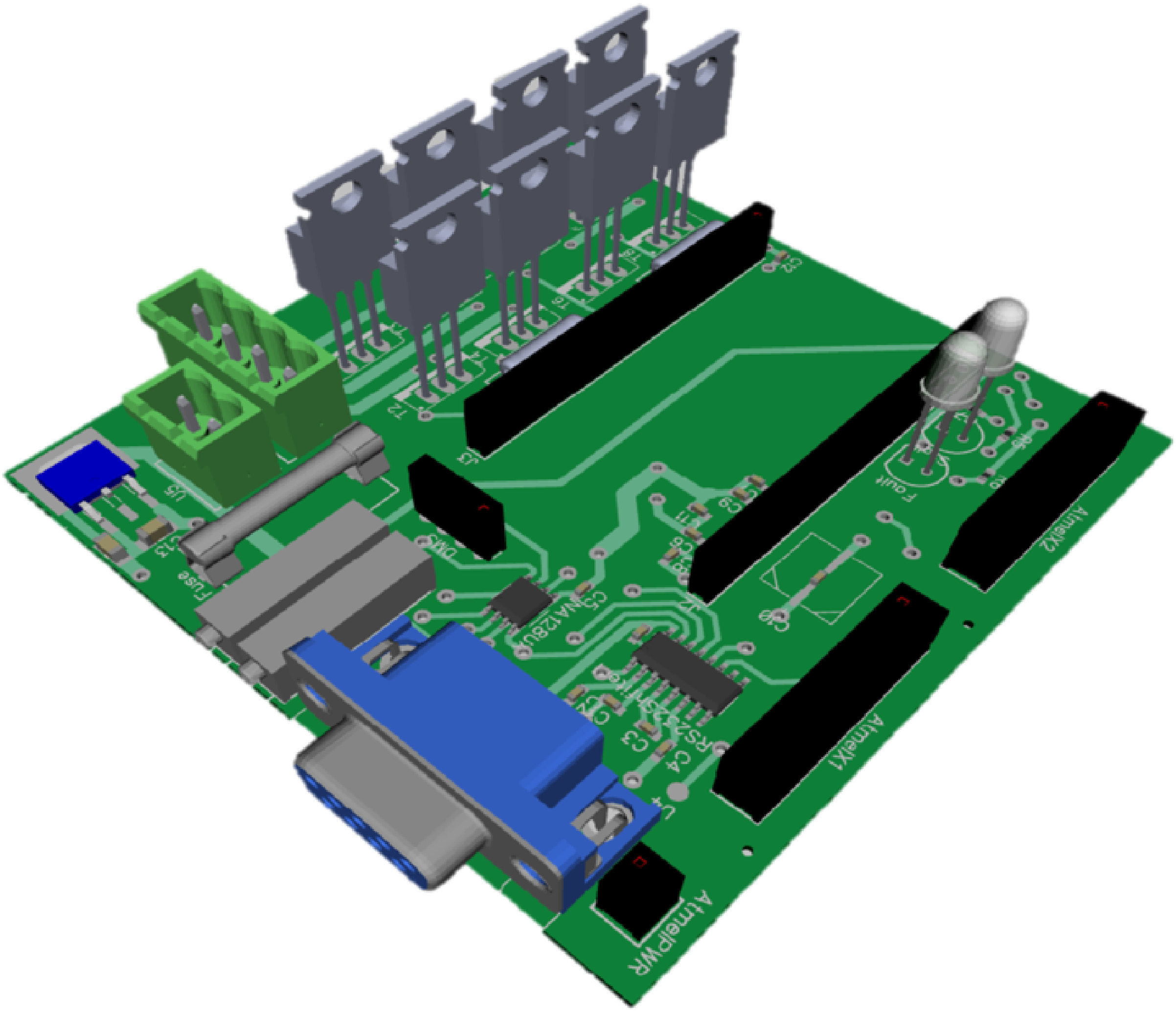


Figure 4.14.: Rendered PCB Layout
Source: Group 4

5. PLC-Program

The program which controls the whole system runs on regular PC. Programming is mainly made using Visual Studio and on it twinCAT3 extension. The program controls the X, Y and Z axes and provides HMI for that. The main focus of the program is to provide cycles for picking and dropping the object. The other parts of the program manage information, for example managing data provided by uC and showing the force when picking the object. It also have an error handling functions such as “emergency button pressed” or “too much force applied”.

5.1. Main Program

Main program contains all the functions to move axes and subprograms to do error handling and force measuring. The homing function is executed after the button is pressed. When homing the first time the X and Y axes will first reference, using the limit switches. After that moving from the reference position (X: $0,0$, Y: $0,0$) to the home position. After pick or drop cycle the axes move right to the home position.
The picking cycle can be executed from the home position by pushing the button. As an example of programming, picking disc from Repository has three steps. The first step is to move above the disc. The second is snapping the disc. And the third is sliding the disc away from the Repository and moving to the home position. Every executed function that is set true, must be set false afterwards as seen from the examples.

Listing 5.1: Homing axes

```
15: IF NOT readInfoAxisX.Status.Homed or NOT readInfoAxisY.Status.Homed THEN
  homeX.Execute := TRUE;
  homeY.Execute := TRUE;
  iState := 20;
  ELSE
    iState := 21; //--> if already referenced, go home position
  END_IF
20: IF homeX.Done AND homeY.Done THEN
    homeX.Execute := FALSE;
    homeY.Execute := FALSE;
    NotHomed.RESET := FALSE;
    iState := 21;
  END_IF
21:   moveAbsX.Velocity := posHomeVelocityX;
    moveAbsX.Position := posHomeX;
    moveAbsX.Execute := TRUE;
    moveAbsY.Velocity := posHomeVelocityY;
    moveAbsY.Position := posHomeY;
    moveAbsY.Execute := TRUE;
    iState :=  22;
```

Listing 5.2: Moving above the disc

```
125:  IF  rTrigStartCycle.Q OR bDauerlauf THEN
    moveAbsX.Velocity := posPrepositioningVelocityX;
    moveAbsX.Position := posPrepositioningX;
    moveAbsX.Execute := TRUE;
```

```
      moveAbsY.Velocity := posPrepositioningVelocityY;
      moveAbsY.Position :=posPrepositioningY;
      moveAbsY.Execute := TRUE;
      iState :=  130;
      maxForceValuePos := 0;
      maxForceValueNeg := 0;
    END_IF
  130:  IF  moveAbsX.Done AND moveAbsY.Done THEN
      moveAbsX.Execute:= FALSE;
      moveAbsY.Execute:= FALSE;
      iState := 135;
    END_IF

  135:  moveAbsX.Velocity :=  posRepositoryVelocityX;
      moveAbsX.Position :=  posRepositoryX;
      moveAbsX.Execute :=   TRUE;
      moveAbsY.Velocity :=  posRepositoryVelocityY;
      moveAbsY.Position :=  posRepositoryY;
      moveAbsY.Execute := TRUE;
      iState :=  140;

  140:  IF  moveAbsX.Done AND moveAbsY.Done THEN
      moveAbsX.Execute:= FALSE;
      moveAbsY.Execute:= FALSE;
      iState :=  141;
      END_IF
```

Listing 5.3: Snapping the disc

```
42  31: SCL.Crtl := 'D';
43    SCL.bSend := TRUE;
44    istate := 32;

46  32: IF NOT SCL.bSendBusy THEN
47      SCL.bSend := FALSE;
48      SCL.Crtl := '';
49      istate := 33;
50    END_IF

52  33: IF waitToLongForRespond.Q THEN
53      istate := 31;
54      END_IF
55    IF respondD.Q1 THEN //Move Down
56      respondD.RESET := TRUE;
57      respondD.SET1 := FALSE;
58      bLoaded := TRUE;
59      istate := 35;
60    END_IF
```

The values of different steps are stored in array when the program starts running. The steps are:

- postRepository: Repository during picking or dropping. (X: $136, 75$, Y: $0, 2$)
- pastPrepositioning: Before/after moving sideways in/out of the Repository. (X: $136, 75$, Y: $125, 0$).
- posHome: The home position. (X: $15, 0$, Y: $400, 0$).

If the system response from system takes too much time the program retry. In the code it can be seen, for example in line 33 of Listing 5.3. After failing the program tries again from line 31.

In Figure 5.1 the loop of the main program is shown according to the UML standards.

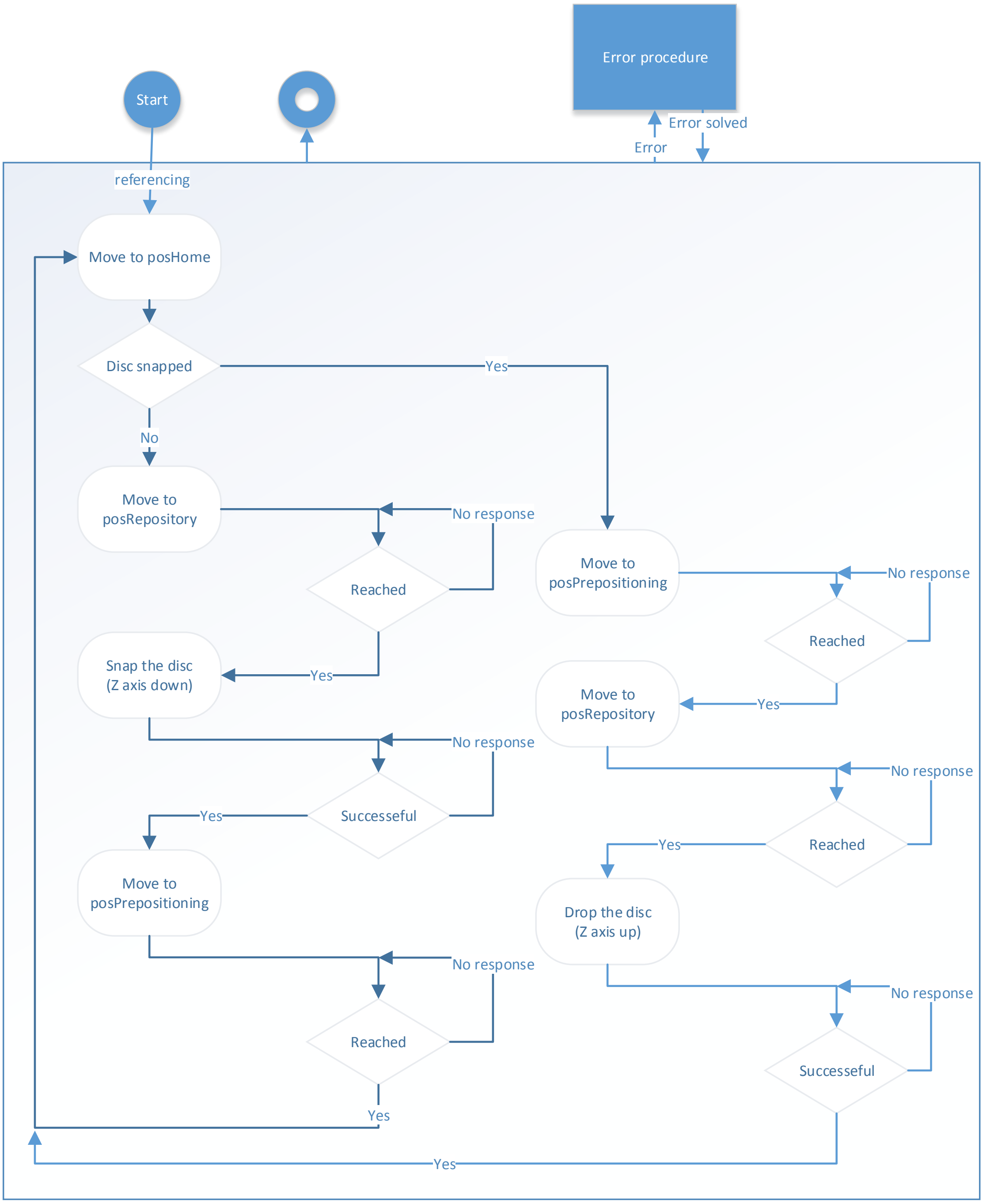


Figure 5.1.: Flowchart of pick and drop cycle
Source: Group 4

5.2. Error Procedure

The program has some error handling functions in addition of emergency stop. These are:

- No disc detected
- Too much force on strain gauge. (the maximum and minimum forces are 10N)
- No power from the motors of X, Y axes
- Error signal from uC
- Emergency stop is pressed

If the system counters error during run, all of the movement stops. If the disc is on the snapper it must be manually removed. After solving other possible error/errors the reset button must be pressed to run the system again. The Z-axis referencing every time after error for the X and Y axes that's not necessary.

5.3. HMI

The HMI is made to be as simple as possible. There are however some extra features like continuously run, which is mainly meant for maintaining. The graphs shows the positions of axes in real time, in the graph and also the exact number is shown. Also there is graph and number that have the current status of force gauge. Force units are in mN. The minimum and maximum forces are saved. Status, report and debug messages are kept in a message board, at top right corner of the HMI.

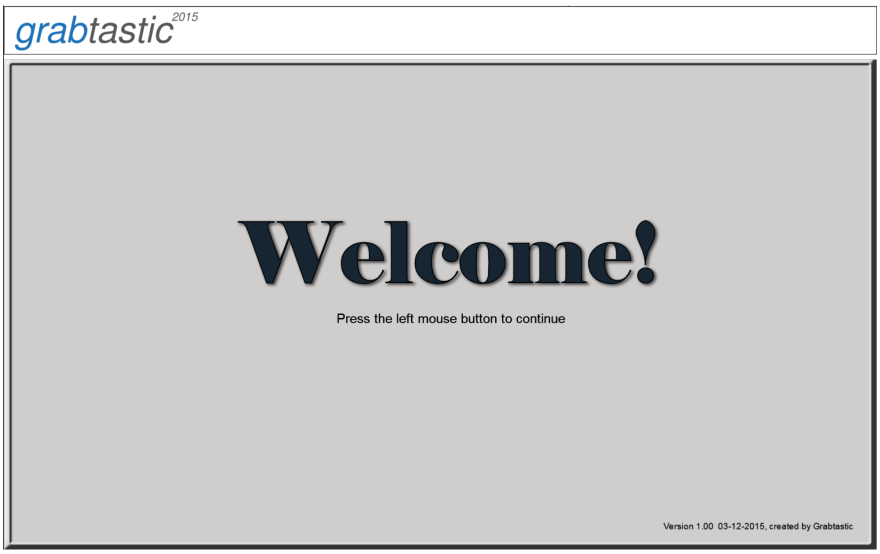


Figure 5.2.: Welcome screen
Source: Group 4

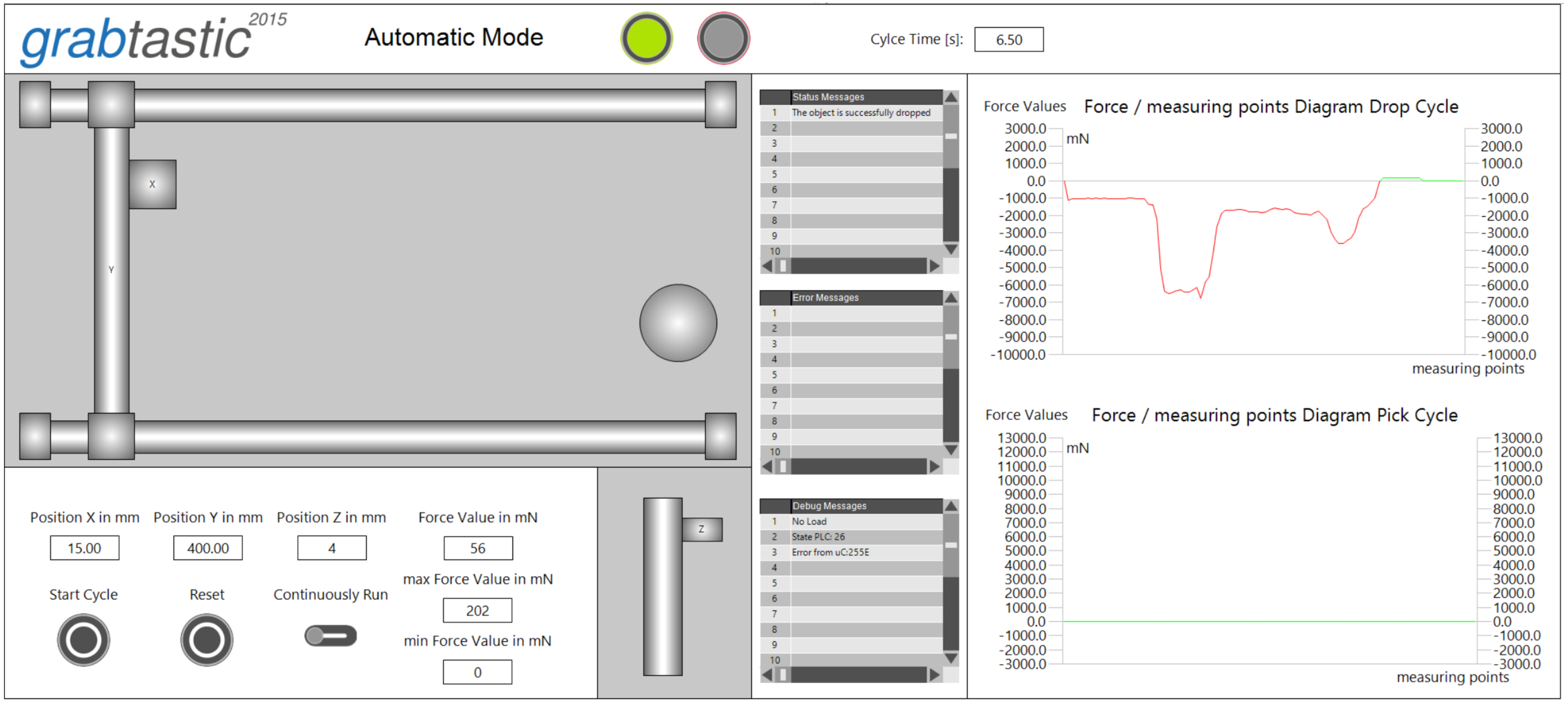


Figure 5.3.: Automatic mode
Source: Group 4

6. Communication PLC - uC

6.1. Configuration of RS232

- $9600 Baud/115,2kBaud$ [1], 8Bit, 1 Stop Bit, no parity, ASCII
- Master: PLC
- Slave: uC
- Frame: no address, no checksum, delimiter: CR ("\r") NL ("\n")

6.2. Commands PLC

- I ... Initialization: axis resets and moves up to to reference point
- H ... Homing: axis moves up to home position
- D ... Down: axis moves down
- P ... Pre Position: axis moves to the pre position

6.3. Reply uC

- ok ... command accepted
- busy ... command not accepted (e.g. when movement is ongoing)
- UNKNOWN ... command unknown
- i ... when axis is referenced
- h ... when axis has reached home position
- d ... when axis has reached down position
- p ... when axis has reached pre position

[1] both are tested, now its running with $115,2kBaud$

6.4. Telegram from uC to PLC

The telegram looks like the following:
<respond>/<# force value>/<z-axis position>/<error>\r \n

- The delimiter / is used to separate each value.
- \r \n are used as suffix.
- # to mark the value as force

In Table 6.1 there are examples of the respond from the uC. The z-axis is a value in mm, the force value is a value in mN.

respond	del	# force value	del	z-axis position	del	error	\r	\n
i	/	#-1000	/	4	/	0E	\r	\n
d	/	#-1100	/	5	/	0E	\r	\n
h	/	#-1200	/	6	/	0E	\r	\n
p	/	#-1300	/	7	/	0E	\r	\n
ok	/	#-1400	/	8	/	0E	\r	\n
busy	/	#-1500	/	9	/	0E	\r	\n
UNKNOWN	/	#2000	/	10	/	0E	\r	\n

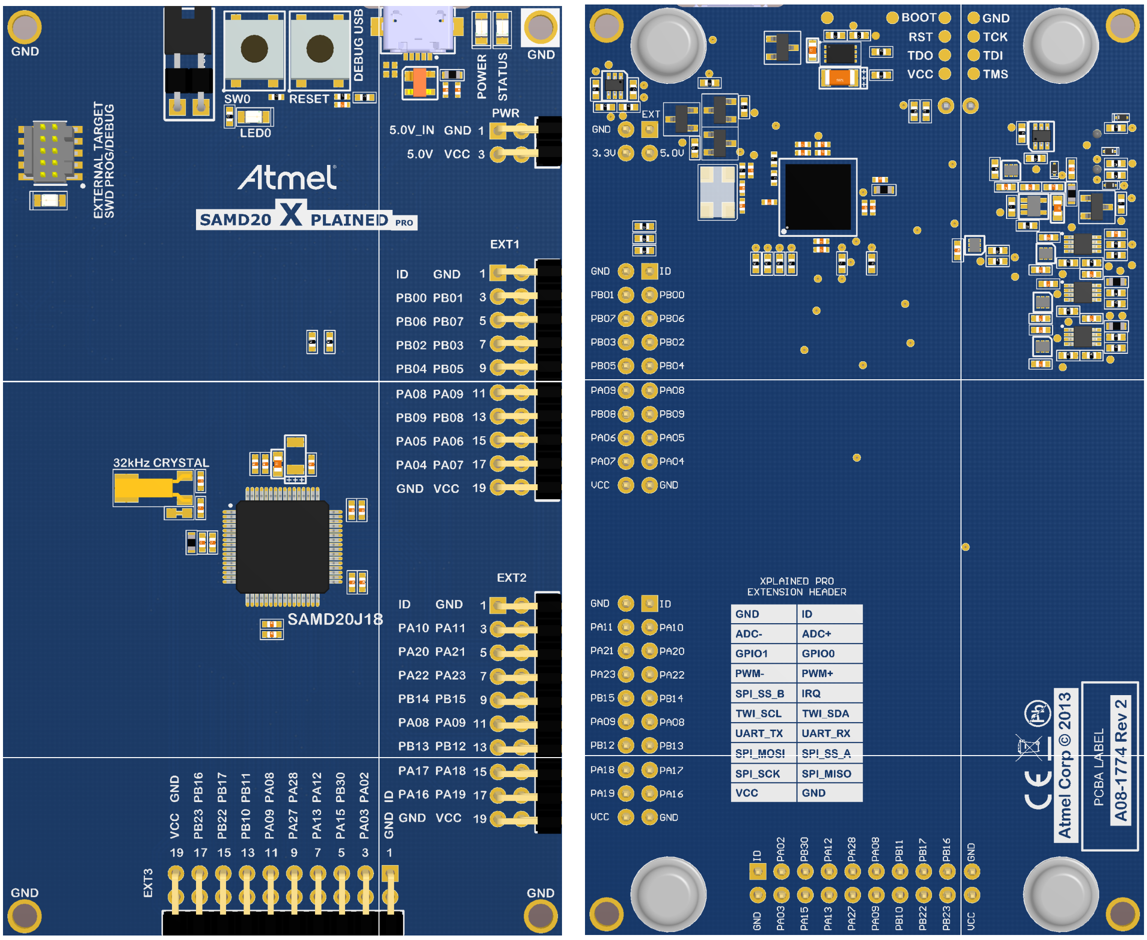
Table 6.1.: Examples of telegrams

6.5. Heartbeat

The value of the Force Sensor is used as the heartbeat, if there is no heartbeat for two second, the communication between the PLC and the uC is disturbed.

7. uC Program

An Atmel AT-SAM-D20-J18 is used to control the Z-Axis. It has a micro USB connector for programming and debugging and three identical but separate external ports (PWR, EXT1, EXT2, EXT3) for making connections. To program the uC the Atmel Studio is used. It bases on Microsoft Visual Studio. The coding guideline from Doxygen[1] is used.



(a) Top (b) Bottom

Figure 7.1.: Top and bottom view of the used atmel board
Source: Atmel data sheet design documentation, page 10-11

7.1. ASF Library

The ASF is a collection of free embedded software for Atmel uC devices. It simplifies the usage of Atmel products, providing an abstraction to the hardware and high-value middleware. ASF is designed to be used for evaluation, prototyping, design and production phases. ASF is

[1] see at Doxygen Documentation

integrated in the Atmel Studio IDE with a graphical user interface or available as a standalone package for several commercial and open source compilers. The basic structure can be seen in Figure 7.2.

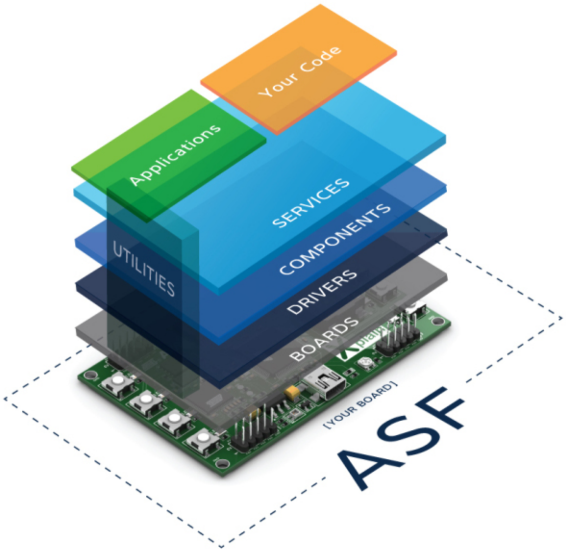


Figure 7.2.: ASF library
Source: Atmel ASF Library data sheet

Used parts of the ASF:

- Generic board support
- IOPORT - General purpose I/O service (service)
- Delay routines (service, systick)
- ADC (driver, callback[2])
- PORT GPIO Pin Control (driver)
- SERCOM SPI(Master Mode, Vectored I/O, driver, callback)
- SERCOM USART Serial Communications (driver, callback)
- SYSTEM Power Management (driver)
- TC (driver, callback)

[2]callback means, that it generates an interrupt request

7.2. Used pins

In Table 7.1, Table 7.2 and Table 7.3 are the used pins shown with the functionality.

Pin on EXT1	SAM D20 pin	Function	Used for
3	PB00	AIN[8]	amplifier ADC
9	PB04	EXTINT[4]	Emergency Stop
13	PB09	SERCOM4 PAD[1] UART RX1	RS232
14	PB08	SERCOM4 PAD[0] UART TX1	RS232
18	PA07	SERCOM0 PAD[3] SPI SCK	Referenc for ADC
19	-	GND	
20	-	VCC	

Table 7.1.: EXT1 used pins

Pin on EXT2	SAM D20 pin	Function	Used for
5	PA20	GPIO	DRV8711 Sleep
6	PA21	GPIO	DRV8711 reset
7	PA22	TC4/WO[0]	DRV8711 stepping frequency
9	PB14	EXTINT[14]	DRV8711 change direction
15	PA17	SERCOM1 PAD[1] SPI SS	DRV8711 SPI
16	PA18	SERCOM1 PAD[2] SPI MOSI	DRV8711 SPI
17	PA16	SERCOM1 PAD[0] SPI MISO	DRV8711 SPI
18	PA19	SERCOM1 PAD[3] SPI SCK	DRV8711 SPI
19	-	GND	
20	-	VCC	

Table 7.2.: EXT2 used pins

Pin on EXT2	SAM D20 pin	Function	Used for
9	PA28	EXTINT[8]	Limit switch
19	-	GND	
20	-	VCC	

Table 7.3.: EXT3 used pins

7.3. Configuration

For the needs you see in Figure 4.1 following configuration[3] at the uC is necessary:

1. **ADC**
    - clock generator 2 ($32kHz$)
    - a clock prescaler of 4
    - uses the reference B
    - the resolution is set to 10 bit
2. **TC**
    - is configured with clock generator 0 ($8MHz$)
    - a counter size of 16 bit's
    - the wave generation is frequency match mode
    - The compare value is moving between 9500 and 7600.
3. **RS232**
    - Is configured with a baudrate of 9600 like it is mentioned in section 6.1
    - on EXT1
4. **SPI**
    - Is configured with the standard values given from the ASF library
    - It has a baudrate of 100000 as you can be seen in Figure 4.7 and Figure 4.8
5. **External interrupt**
   Two external interrupt are configured, one for the emergency and one for the limit switch. Both has the following configuration:
    - Pull down resistor
    - detect both signal edges (limit switch) and detect falling edges (emergency)
    - filtering input signal is enabled
6. **I/O's**
    - all has a pull down resistor
    - as output
    - Pin 5, 6 and 9 are activated

[3]Configuration uses different parts of the ASF library

7.4. Calculations

7.4.1. Sampling Rate of the ADC

$$f = \frac{clock\,generator\,2}{prescaler} \tag{7.1}$$

$$f = \frac{32 * 10^3 Hz}{4} = 8000Hz \tag{7.2}$$

With the reciprocal value the sampling rate is calculated.

$$\frac{1}{f} = \frac{1}{8000Hz} \tag{7.3}$$

$$\frac{1}{f} = 0,000125s = 0,125ms \tag{7.4}$$

$0,125ms$ are fast enough to measure the force.

7.4.2. TC Frequency

With the values mentioned in section 7.3 leads us to the following frequencies, which is the stepping frequency of the DRV8711.

$$f_{out} = \frac{f_0}{compareValue * 2} \tag{7.5}$$

$$f_{out} = \frac{8 * 10^6 Hz}{9500 * 2} = 421Hz \tag{7.6}$$

$$f_{out} = \frac{8 * 10^6 Hz}{7600 * 2} = 526Hz \tag{7.7}$$

7.5. Main Loop

In Figure 7.3 the loop of the main program is shown according to the UML standards.

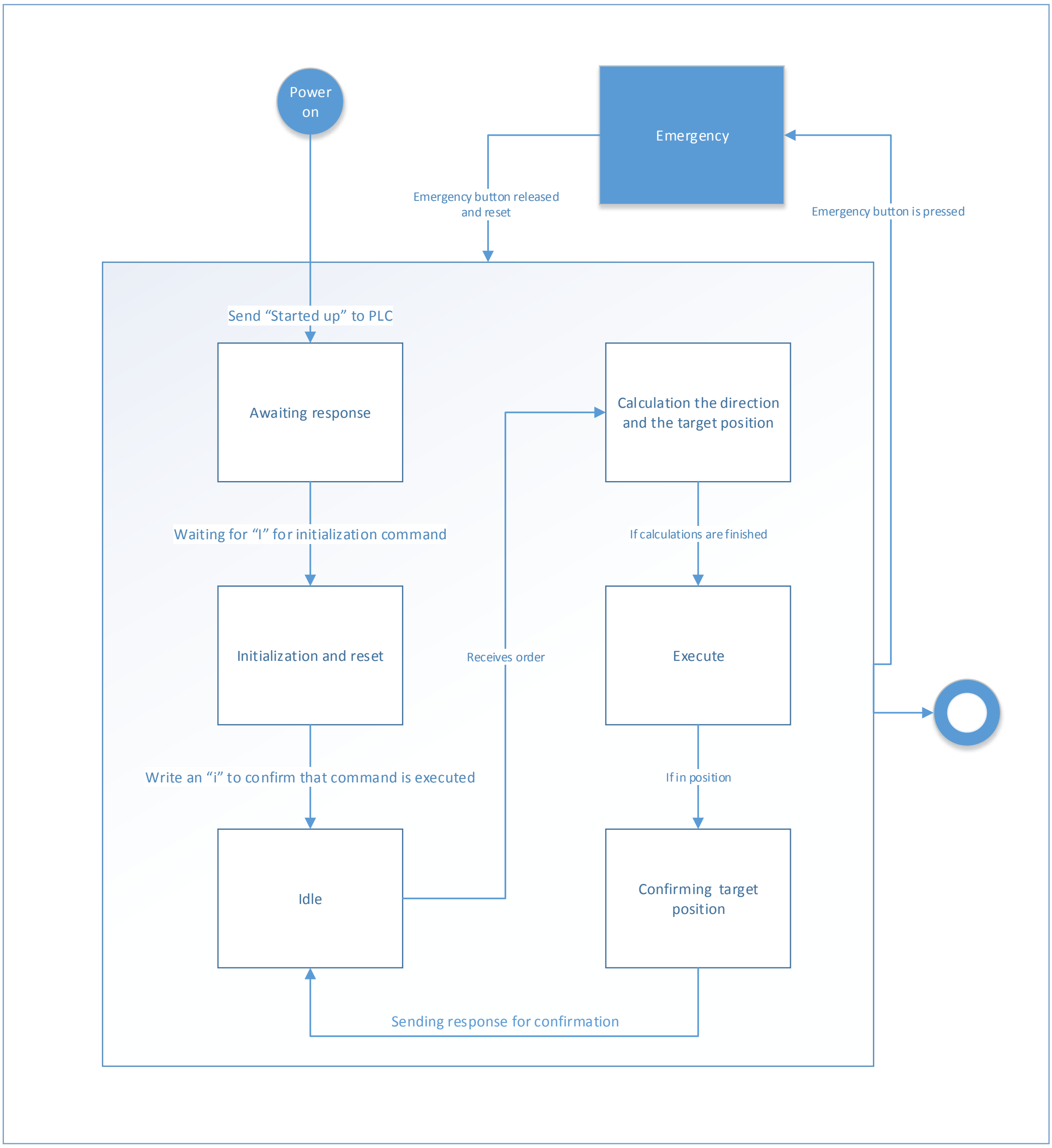


Figure 7.3.: UML Diagram uC
Source: Group 4

7.6. Programmed Functions

Figure 7.4 shows the included header files.

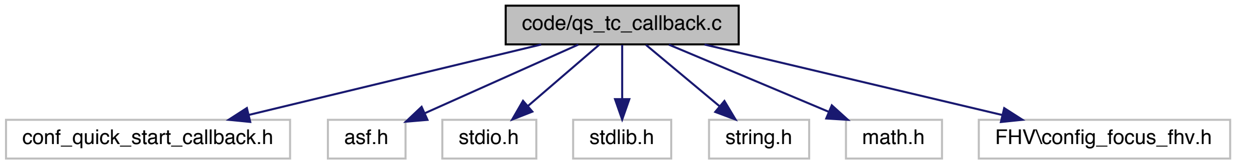


Figure 7.4.: Included header files
Source: Group 4

The config_focus_fhv.t is developed by us. The callgraph of the main loop is shown in Figure 7.5. The following points describes the process:

1. configuration is loaded (section 7.3)
2. main loop starts
3. start a request to read the receive buffer of RS232
4. if an order is received, calculate position of the target and direction and start executing it
5. repositioning if we are in the limit switch in case of referencing (order was “I”)
6. finish the order
7. start repositioning if the order was a “D”
8. send the telegram, every time a ADC measurement is finished
    a) error handling
    b) prepare the telegram[4] for sending
    c) start a request to send the write buffer of RS232
    d) start a new ADC measurement

The positions of the Z-axis are easily expandable if necessary. There is an array of struct, where the positions can be added with the belonging command form the PLC.

[4]the telegram is mentioned in section 6.4

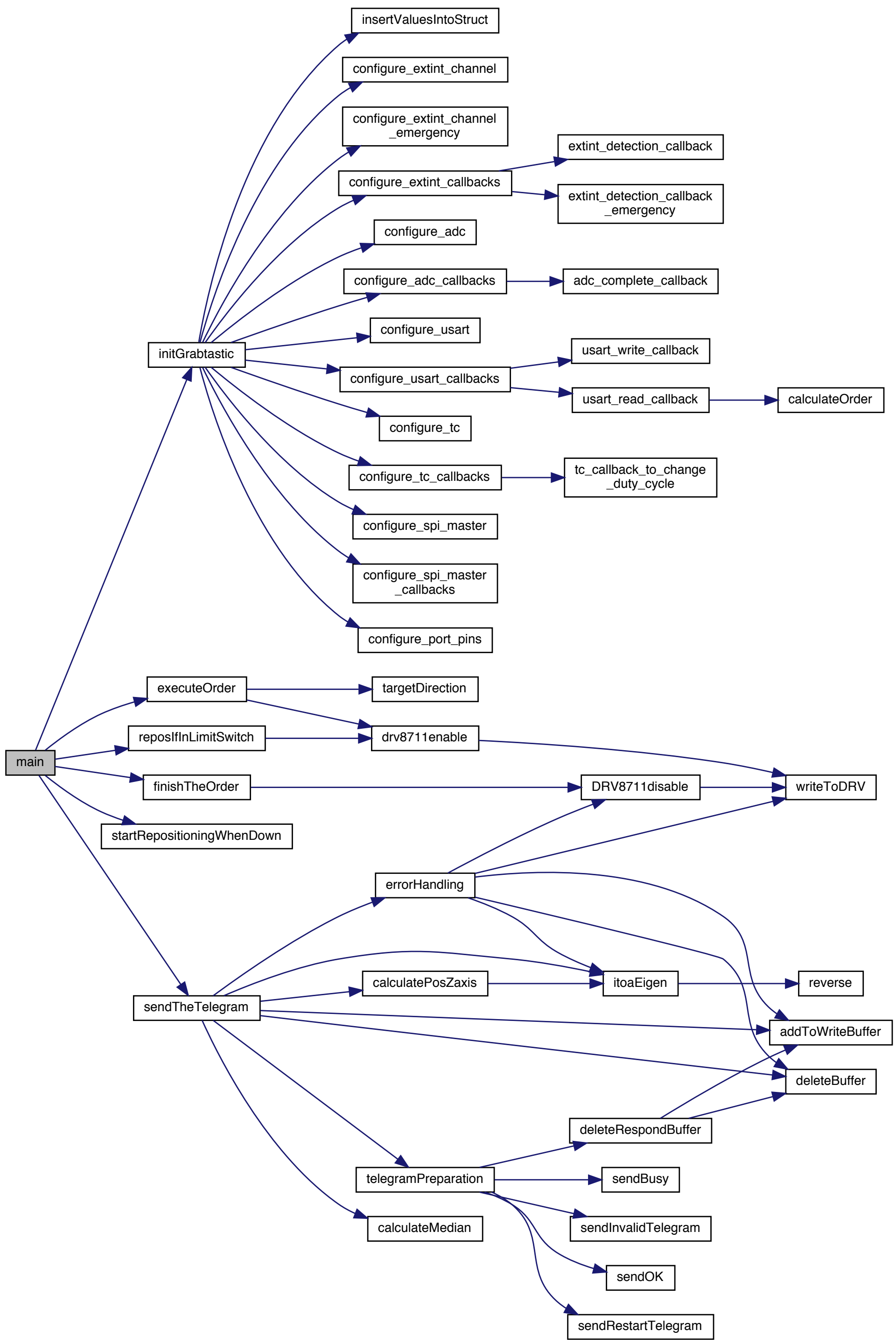


Figure 7.5.: Called functions uC
Source: Group 4

7.7. DRV8711 Register Settings

In Figure 7.6 the adjusted values for the DRV8711 are shown.

		CTRL REG	0x00	TORQUE	0x01	OFF Reg	0x02	BLANK Reg	0x03
bit	0	ENBL	0	TORQUE 0	100	TOFF 0	200	TBLANK 0	100
bit	1	RDIR	0	TORQUE 1		TOFF 1		TBLANK 1	
bit	2	RSTEP	0	TORQUE 2		TOFF 2		TBLANK 2	
bit	3	Mode 0	0000: Full-step,	TORQUE 3		TOFF 3		TBLANK 3	
bit	4	Mode 1		TORQUE 4		TOFF 4		TBLANK 4	
bit	5	Mode 2		TORQUE 5		TOFF 5		TBLANK 5	
bit	6	Mode 3		TORQUE 6		TOFF 6		TBLANK 6	
bit	7	EXTSALL	0	TORQUE 7		TOFF 7		TBLANK 7	
bit	8	ISGAIN 0	1	SMPLTH 0	001: 100 µs	PWMMODE	0	ABT	0
bit	9	ISGAIN 1	1	SMPLTH 1		Reserved	0	Reserved	0
bit	10	DTIME 0	1	SMPLTH 2		Reserved	0	Reserved	0
bit	11	DTIME 1	1	Reserved	0	Reserved	0	Reserved	0
bit	12	A0	0	A0	1	A0	0	A0	1
bit	13	A1	0	A1	0	A1	1	A1	1
bit	14	A2	0	A2	0	A2	0	A2	0
bit	15	RW	0	RW	0	RW	0	RW	0
		MSB	F	MSB	11	MSB	20	MSB	30
		LSB	0	LSB	64	LSB	C8	LSB	64
		Copy	[0xF 0x0]	Copy	[0x11 0x64]	Copy	[0x20 0xC8]	Copy	[0x30 0x64]

(a) Register 0-3

DECAY Reg	0x04	Stall Reg	0x05	Drive	0x06	Status	0x07
TDECAY 0	50	SDTHR 0	64	OCPTH 0	0	OTS	0
TDECAY 1		SDTHR 1		OCPTH 1	0	AOCP	0
TDECAY 2		SDTHR 2		OCPDEG 0	1	BOCP	0
TDECAY 3		SDTHR 3		OCPDEG 1	0	APDF	0
TDECAY 4		SDTHR 4		TDRIVEN 0	0	BPDF	0
TDECAY 5		SDTHR 5		TDRIVEN 1	1	UVLO	0
TDECAY 6		SDTHR 6		TDRIVEP 0	0	STD	0
TDECAY 7		SDTHR 7		TDRIVEP 1	1	STDLAT	0
DECMOD 0	000: Force slow decay	SDCNT 0	0	IDRIVEN 0	1	Reserved	0
DECMOD 1		SDCNT 1	0	IDRIVEN 1	0	Reserved	0
DECMOD 2		VDIV 0	0	IDRIVEP 0	1	Reserved	0
Reserved	0	VDIV 1	0	IDRIVEP 1	0	Reserved	0
A0	0	A0	1	A0	0	A0	1
A1	0	A1	0	A1	1	A1	1
A2	1	A2	1	A2	1	A2	1
RW	0	RW	0	RW	0	RW	0
MSB	40	MSB	50	MSB	65	MSB	70
LSB	32	LSB	40	LSB	A4	LSB	0
Copy	[0x40 0x32]	Copy	[0x50 0x40]	Copy	[0x65 0xA4]	Copy	[0x70 0x0]

(b) Register 4-7

Figure 7.6.: DRV8711 PCB Register
Source: Group 4

There are eight registers [5], seven to configure and one status register.

0 CTRL Register is used to enable the H-bridge, set direction, the stepping mode, ISGAIN and DTIME

1 TORQUE Register is used to set the TORQUE and SMPLTH

2 OFF Register is used to set TOFF and PWMMODE

3 BLANK Register is used to set TBLANK and ABT

4 DECAY Register is used to set TDECAY and DECMOD

5 STALL Register is used to set STDHR, SDCNT and VDIV

6 DRIVE Register is used to set OCPTH, OCPDEG, TDRIVEN, TDRIVEP, IDRIVEN and IDRIVEP

7 STATUS register is used to read the status of the DRV8711

7.7.1. Configuring Predrivers

$Q = 30nC$
$RS = 63ns$

$$IDRIVE > \frac{Q}{RT} \tag{7.8}$$
$$IDRIVE > \frac{30nC}{63ns} \tag{7.9}$$
$$IDRIVE > 476,2mA \tag{7.10}$$
$$TDRIVE > 2 * RT \tag{7.11}$$
$$TDRIVE > 2 * 63ns \tag{7.12}$$
$$TDRIVE > 126ns \tag{7.13}$$

$Q...capacitor\ charge$
$RT...risetime$
For best results, the smallest IDRIVE and TDRIVE has to be selected. Consequently, according to the data sheet [6], with Equation 7.10 the IDRIVE has to be adjusted to the highest value ($IDRIVEN = 400mA$, $IDRIVEP = 200mA$) and with Equation 7.13 the TRIVE has to be adjusted to $250ns$ ($TRIVEN and TRIEVEP = 250ns$)

[5]detailed description of each register is found at the data sheet of DRV8711 on page 25-28
[6]DRV8711 page 27-28

7.7.2. External MOSFET's calculation

With the following values the DRV8711 is driving smooth.
$DTIME = 850ns$
$TBLANK = 100\mu s$
$TOFF = 200\mu s$ $Q = 30nC$

$$Q < \frac{20mA * (2 * DTIME + TBLANK + TOFF)}{4} \quad (7.14)$$

$$Q < \frac{20mA * (2 * 0,850\mu s + 100\mu s + 200\mu s)}{4} \quad (7.15)$$

$$Q < 1508,5nC \quad (7.16)$$

With the Equation 7.16 we see, that the configuration will work with the IRF520.

7.7.3. Speed Calculation

$$f_{steps}\,\mu steps/s = \frac{v * 360° * n_m}{60s/min * \phi\,°/step} \quad (7.17)$$

$$\rightarrow v = \frac{60s/min * \phi\,°/step * f_{steps}\,\mu steps/s}{360° * n_m} \quad (7.18)$$

$v ... rotations/min$
With following values the rotational speed is calculated[7]
$\phi = 1,8°/step$
$k = 1,5mm/rot\,pitch\,trapez\,thread$
$n_m = 1$
$f_{steps\,1} = 421Hz$
$f_{steps\,2} = 526Hz$

$$n_1 = \frac{60s/min * 1,8\,°/step * 421\,\mu steps/s}{360° * 1} = 126,3\,rot/min \quad (7.19)$$

$$n_2 = \frac{60s/min * 1,8\,°/step * 421\,\mu steps/s}{360° * 1} = 157,9\,rot/min \quad (7.20)$$

$$v = \frac{n}{k} \quad (7.21)$$

$$v_1 = 126,3rot/min * 1,5mm/rot \quad (7.22)$$

$$v_1 = 189,47mm/min \quad (7.23)$$

$$v_2 = 157,9rot/min * 1,5mm/rot \quad (7.24)$$

$$v_2 = 236,84mm/min \quad (7.25)$$

With the results, we see that one cycle takes about 22 seconds, with a stroke of $80mm$.

[7] found in the motor data sheet and Equation 7.6, Equation 7.7

7.7.4. Conclusion DRV8711

The discerning reader will also have noticed that the register settings did not match the calculations. The reason therefore is, that the motor is not turning smooth with the calculated values. We had to change them to our needs.

8. Results

At the moment of handing in this document the project is in the following state:

- Mechanics: done
- Electronics: done
- Software: PLC up and running, communication between uC and PLC working, ADC is working

8.1. Test runs

The system runs as described in the requirements document.

8.2. Mechanic

In Figure 8.1 the finished Z-axis is shown.

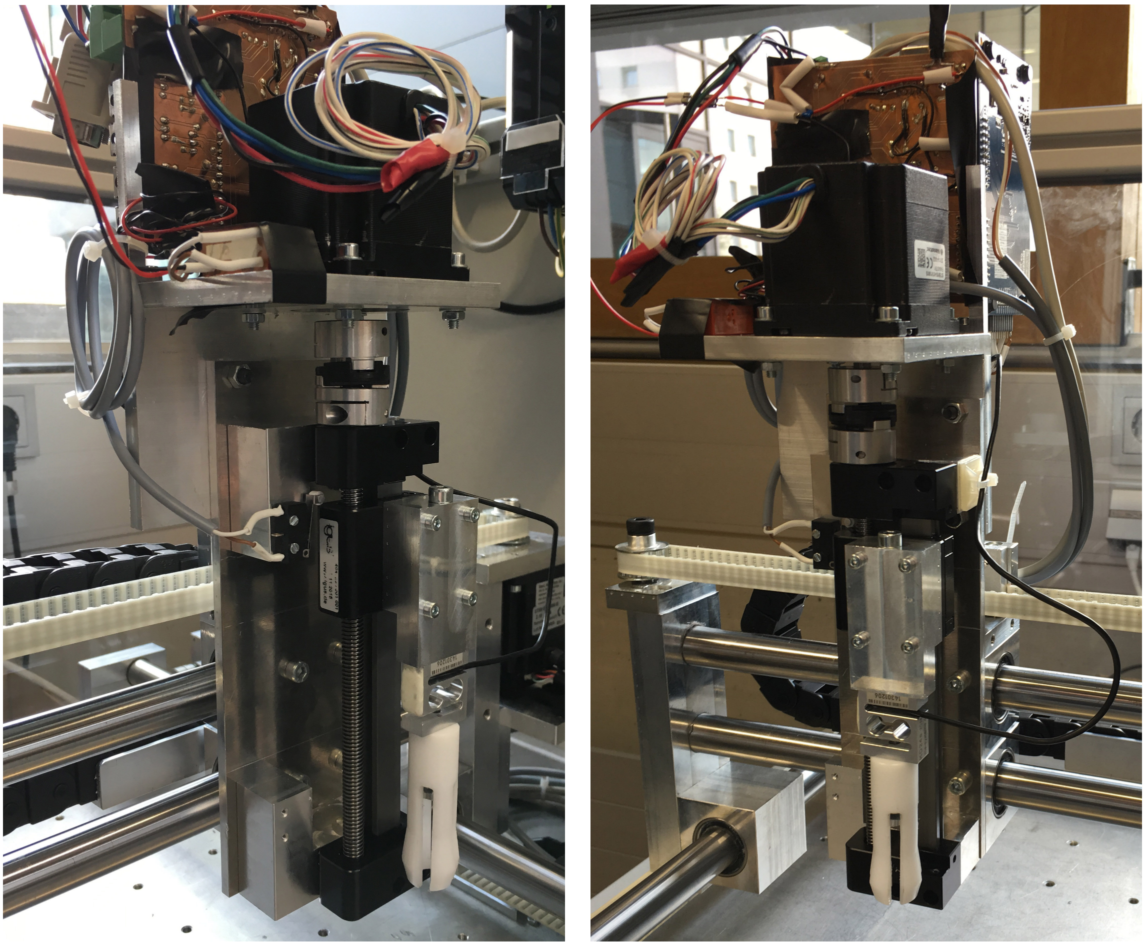


Figure 8.1.: Mechanic assembly
Source: Group 4

In Figure 8.3 and Figure 8.2 is the finished Repository shown.

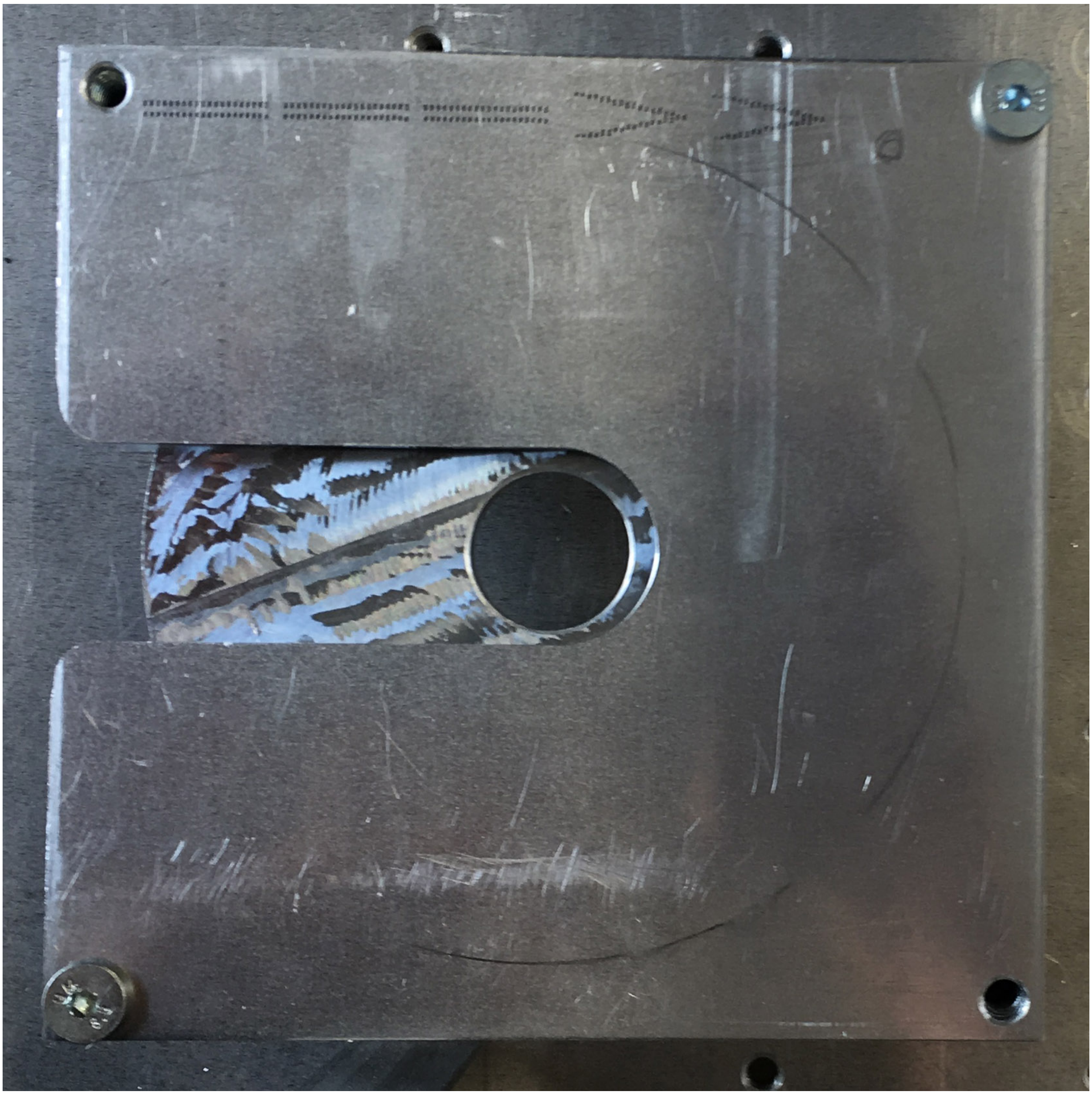


Figure 8.2.: Finished Repository top view
Source: Group 4

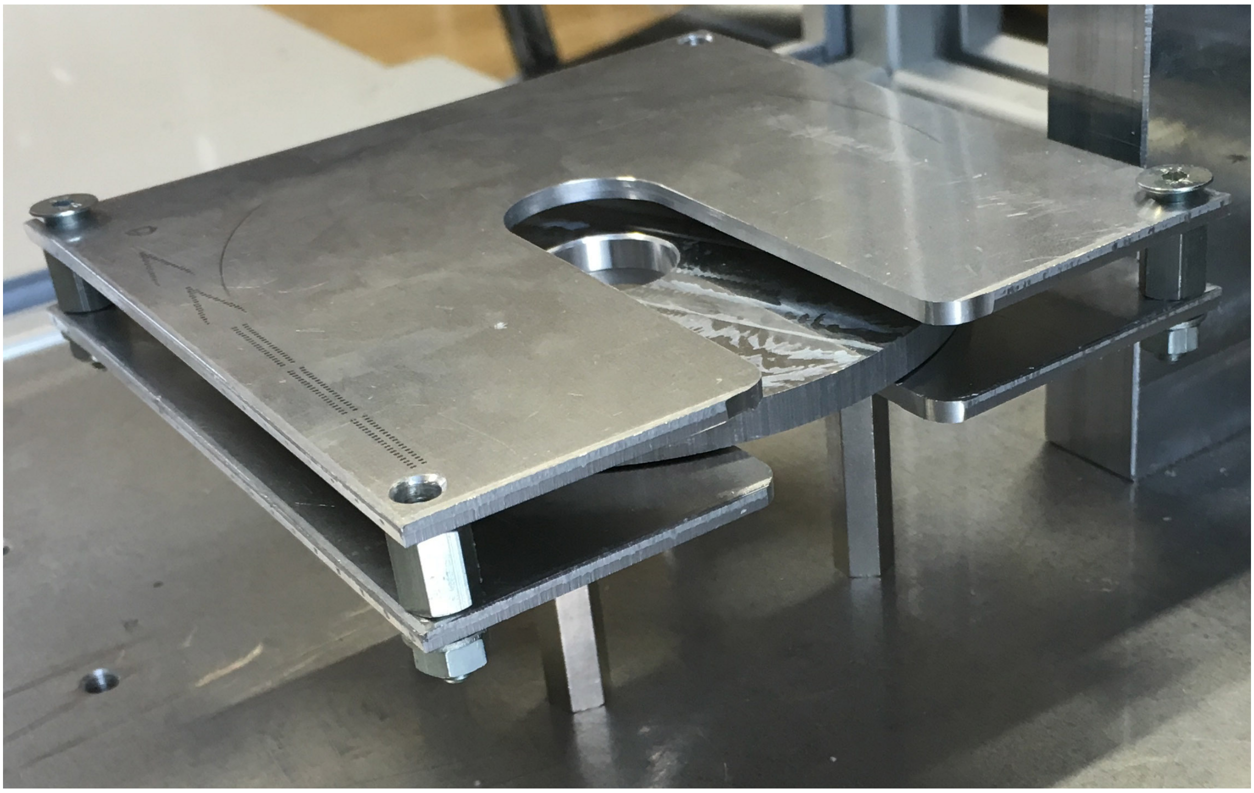


Figure 8.3.: Finished Repository side view
Source: Group 4

8.3. Electronic

In Figure 8.4 the finished PCB is shown with the connected uC mounted on the Z-axis.

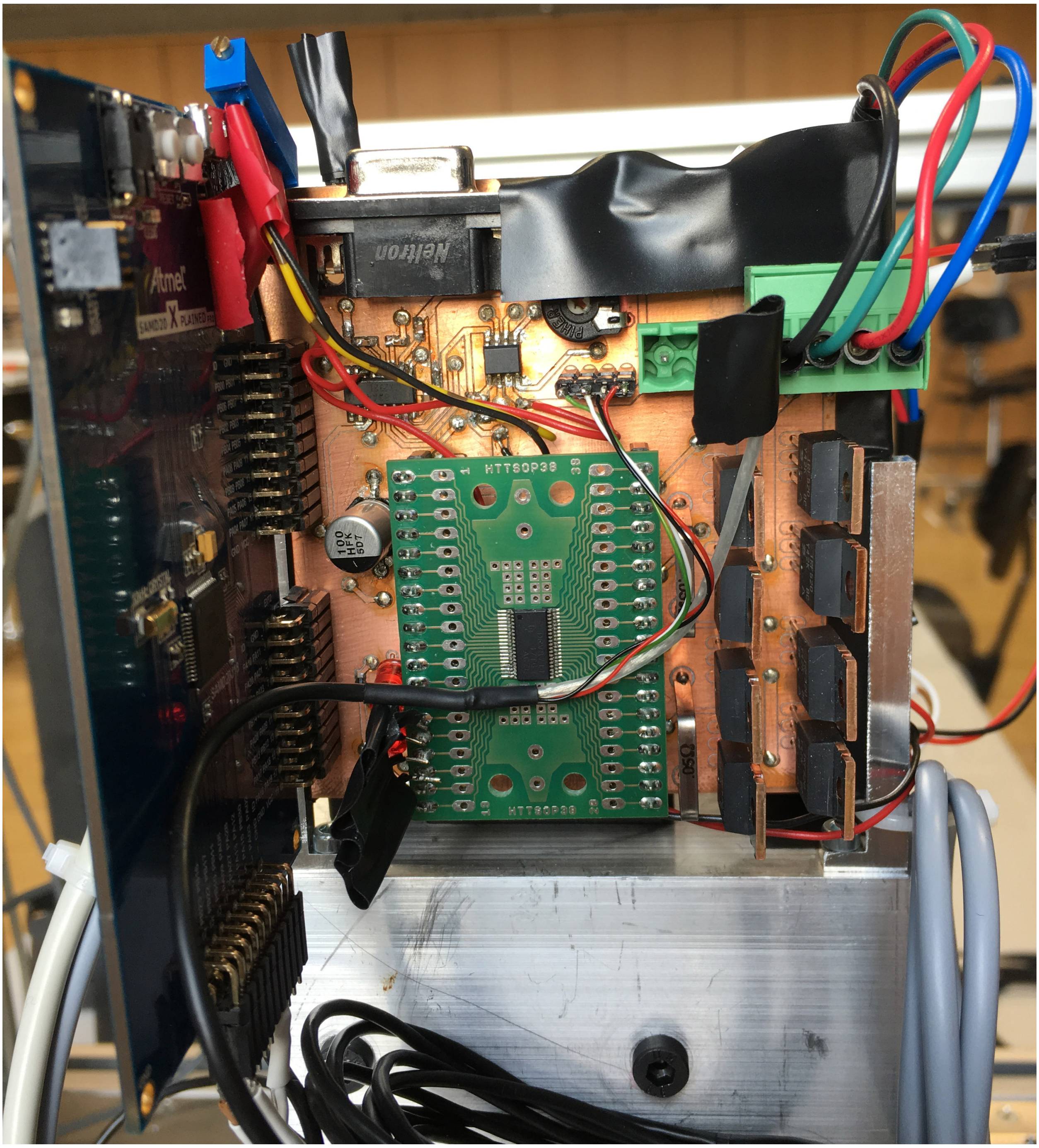


Figure 8.4.: Finished electronic parts
Source: Group 4

8.4. Force Measurement

In Figure 8.6 and Figure 8.5 are the force shown of each cycle.

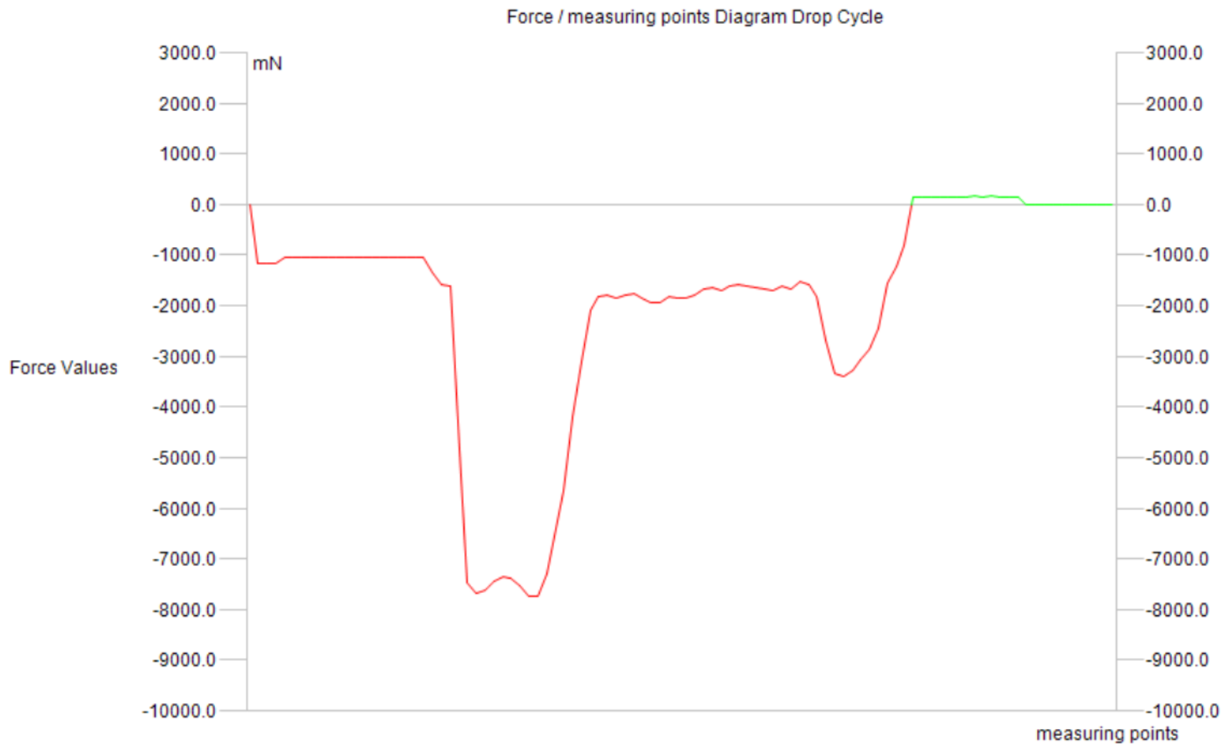


Figure 8.5.: Force measurement drop cycle
Source: Group 4

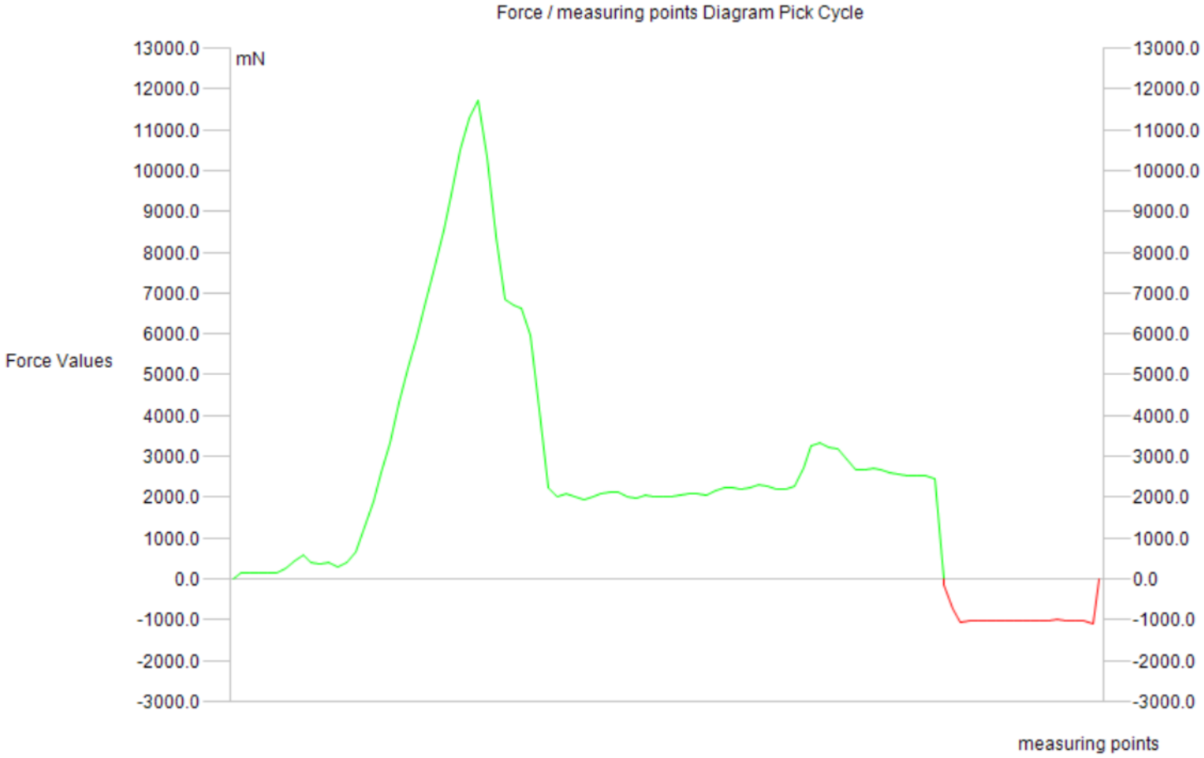


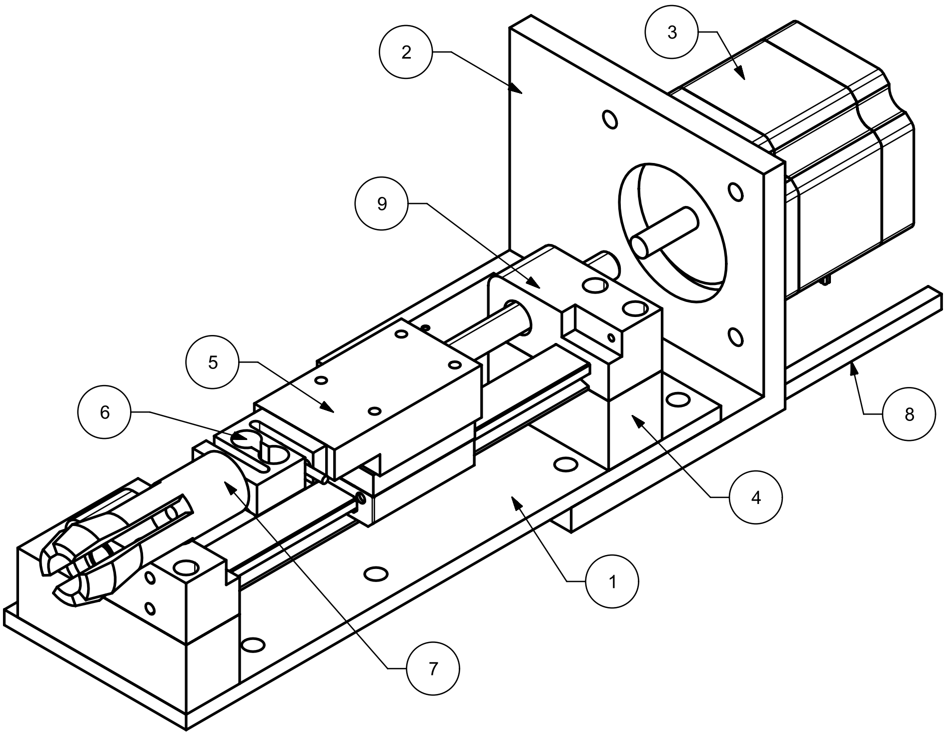
Figure 8.6.: Force measurement pick cycle
Source: Group 4

9. Discussion

In this chapter there will be given some problems that were faced during this project and how they were approached and solved.
For the mechanical part of this projects two problems occurred that affected the progress of the project. The first problem that was faced was the purchase of the linear axis which had to be bought with a shipment time of two weeks. This halted the progress for about two weeks and gave some time to focus more on the different aspects of the project like the Repository and the manufacturing of the parts. And next there was a problem with the snap connection which was designed for the correct forces that were applied on it. The arms of the snapper are bended a little bit to the middle. Therefore the outer diameter of the snapper was just a little bit bigger than the hole in the disc. So the snapper was not able to hold the disc. The solution for this problem was a little aluminium rod with a diameter of $12mm$ which we set into the snap connector. This small rod bends the arms of the snapper to his original position and so the snapper was able to hold the disc.
Despite the problems that were faced for the mechanical part, the electronical part also suffered from some problems. The Atmel board and a DRV8711 broke shortly after the PCB was designed and a new board had to be used, this was caused by an overvoltage on the board. Also multiple parts were fried during the testing of the board, this was caused by a faulty connection or a short circuit. This never broke the board down completely and did not give major setbacks. The biggest problem was, that a view "vias" on the PCB did not conduct correctly. Therefore the charge pump of the DRV8711 did not work at the beginning when the board was recently manufactured. Moreover the pick and place machine did not solder two capacitors and the "MAX232", therefore the board did not work correctly. This was caused by the charge pump because that did not work properly at the time.
As for the programming of the uC and the PLCthe biggest problem was that we did not know how to use the ASF library. But this was solved by using and studying the example programs that were provided by the Atmel studio. Finally, we had some problems with the requirement document. It was not completely clear to us what we had to put in the document. This followed in editing the document several times which took some time. In the end the document was finished and we were all pleased with the result. In the end we changed some aspect of this document mostly because some names were changed during the project or that an extra safety principle was added in the use cases. Also we added some requirements about tolerances, this was done so this is also clear to the customer.

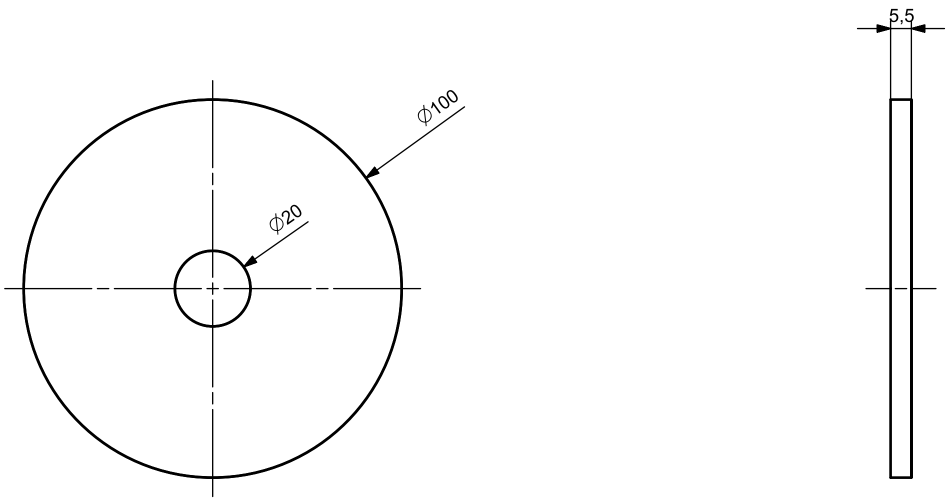
A. Mechanics

A.1. Drawings



1	BASEPLATE	1
2	MOTORHOLDER	1
3	MOTOR	1
4	LINEAR AXIS FITTING	2
5	RACKBAR	1
6	STRAIN GAUGE	1
7	SNAP CONNECTION	1
8	MICROFIX	2
9	LINEAR AXIS 100MM	1
PC NO	PART NAME	QTY

Tolerierung ISO 8015 Projektionsmethode 1	Allgemein-Toleranz ISO 2768mk	Werkstück-Kanten ISO 13715	Massstab: 1:1 / Gewicht:
			Werkstoff:
	Datum	Name	Benennung:
Bearbeitet:	04.12.2015	Simoner Ph.	Z-Axis-Assembly
Geprüft:			
Erstellt:			
Freigabe:			
Zustand / Index / Datum / Name	FHV University of Applied Sciences		Zeichnungsnummer: FHV-NX-004-00001-BZ-01 / Blatt: 1 / Index: A



Tolerance norm ISO 8015	General tolerance ISO 2768mk	Workpiece edge ISO 13715	Scale: 1:1
Projection method 1			Weight:
			Material: Aluminium

State	Modif.	Date	Name
v1.0	Correction Measurement	04.12.2015	Simoner Ph.

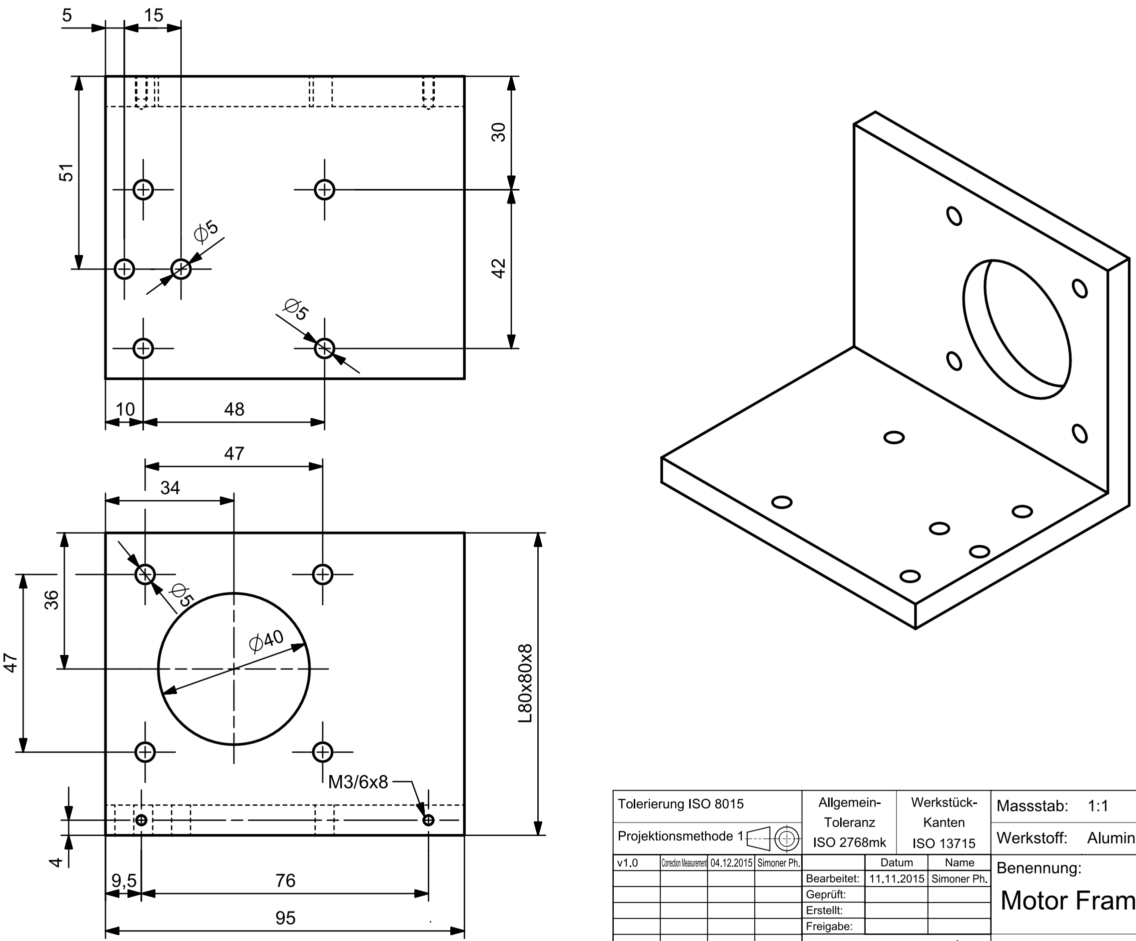
	Date	Name
First issued:	06-11-2015	
Checked by:		
Drawn by:		
Approved by:		

FHV
University of Applied Sciences

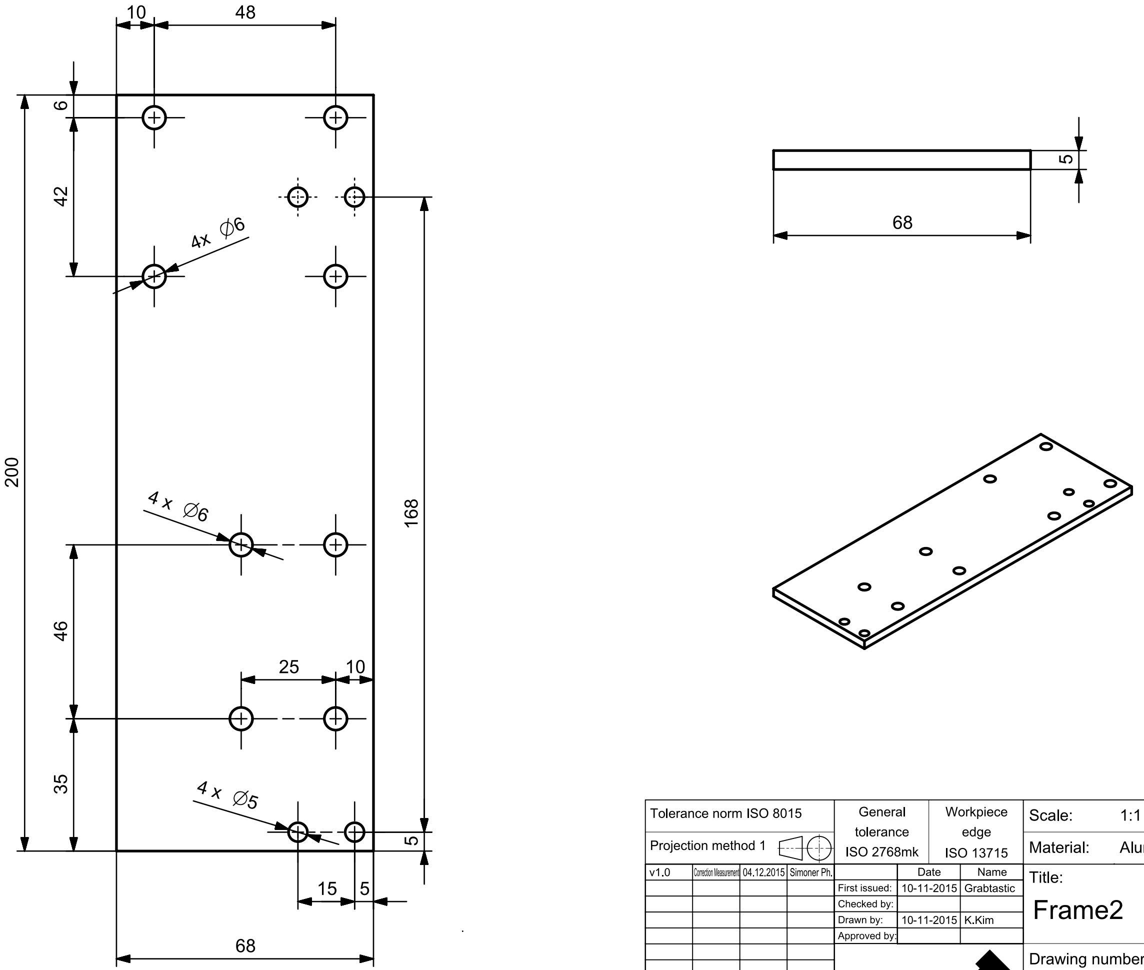
Title:

Disk

Drawing number:	Sheet 1
FHV-NX-004-00007-EZ-01	Rev. A



Tolerierung ISO 8015				Allgemein-Toleranz ISO 2768mk	Werkstück-Kanten ISO 13715	Massstab: 1:1	Gewicht:
Projektionsmethode 1						Werkstoff: Aluminium	
v1.0	Correction Measurement	04.12.2015	Simoner Ph.		Datum	Name	Benennung:
				Bearbeitet:	11.11.2015	Simoner Ph.	Motor Frame
				Geprüft:			
				Erstellt:			
				Freigabe:			
				FHV University of Applied Sciences			Zeichnungsnummer: FHV-NX-004-00002-EZ-01	Blatt: 1
Zustand	Index	Datum	Name				Index: A



Tolerance norm ISO 8015	General tolerance ISO 2768mk	Workpiece edge ISO 13715	Scale: 1:1	Weight:
Projection method 1			Material: Aluminium	

State	Modif.	Date	Name
v1.0	Correction Measurement	04.12.2015	Simoner Ph.

	Date	Name
First issued:	10-11-2015	Grabtastic
Checked by:		
Drawn by:	10-11-2015	K.Kim
Approved by:		

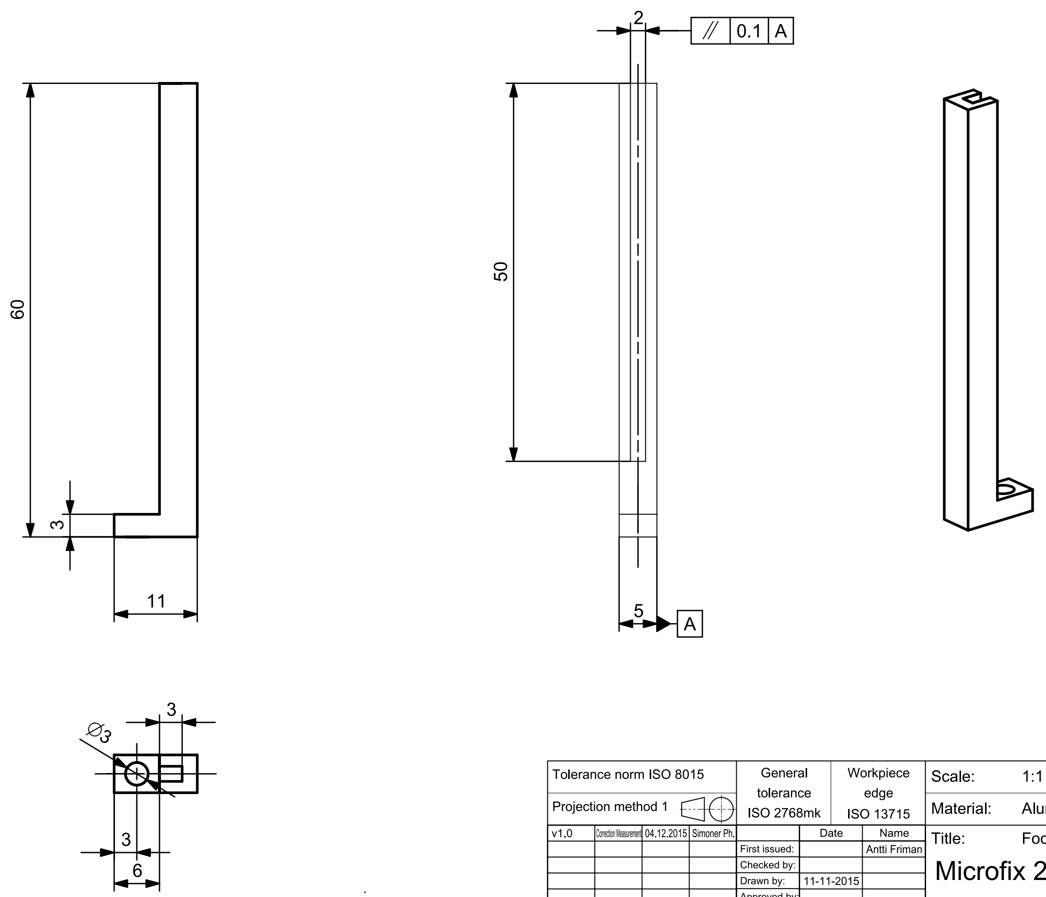
FHV University of Applied Sciences

Title: Frame2

Drawing number: FHV-NX-004-00006-EZ-01

Sheet 1

Rev. A



Tolerance norm ISO 8015	General tolerance ISO 2768mk	Workpiece edge ISO 13715	Scale: 1:1
Projection method 1			Weight:
			Material: Aluminium

State	Modif.	Date	Name
v1.0	Correction Measurement	04.12.2015	Simoner Ph.

	Date	Name
First issued:		Antti Friman
Checked by:		
Drawn by:	11-11-2015	
Approved by:		

FHV
University of Applied Sciences

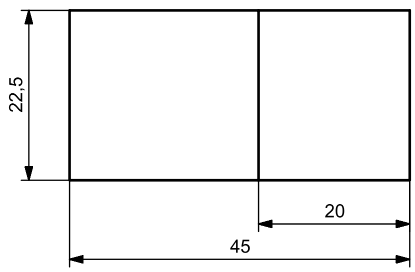
Title: Focus Project

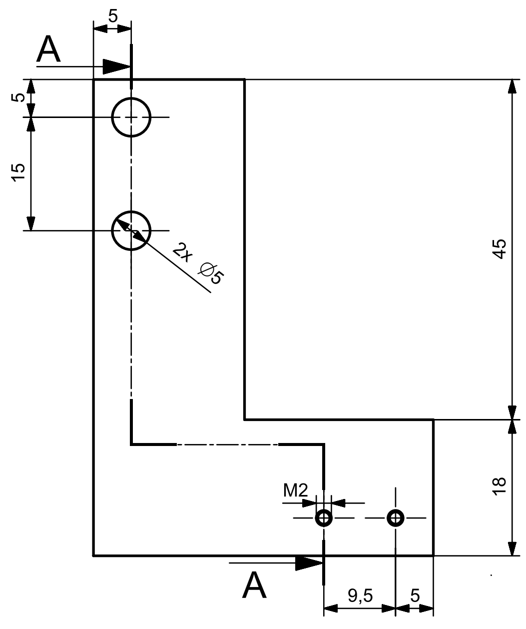
Microfix 2x

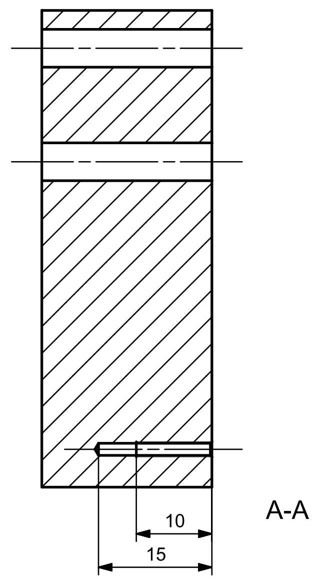
Drawing number: FHV-NX-004-00005-EZ-01

Sheet 1

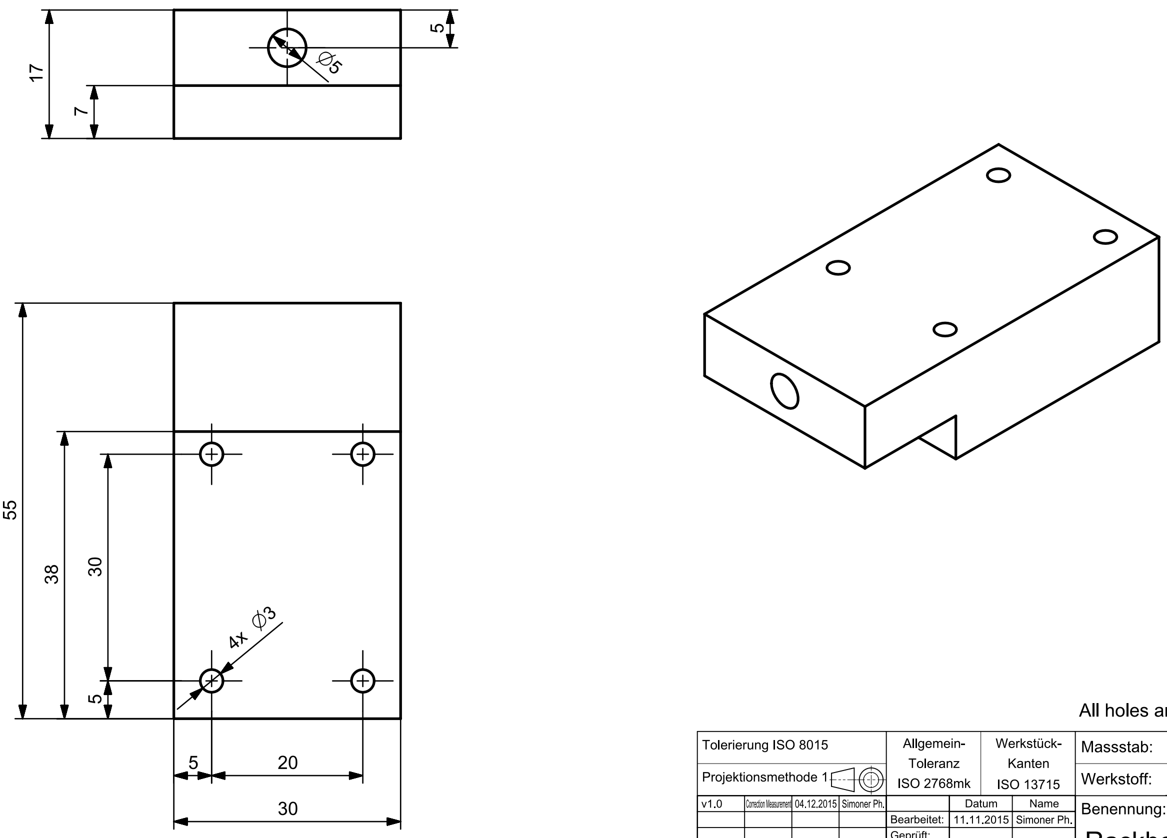
Rev. A







Tolerance norm ISO 8015	General tolerance ISO 2768mk	Workpiece edge ISO 13715	Scale:	1:1	Weight:	
Projection method 1			Material:	Aluminium		
v1.0	Correction Measurements	04.12.2015	Simoner Ph.			
	Date	Name	Title:			
First issued:			Linear-Axis Fitting 2x			
Checked by:						
Drawn by:	11.11.2015	Antti Friman				
Approved by:						
State	Modif.	Date	Name	FHV University of Applied Sciences	Drawing number: FHV-NX-004-00004-EZ-01	Sheet 1 Rev. A



All holes are clearance holes

Tolerierung ISO 8015	Allgemein-Toleranz ISO 2768mk	Werkstück-Kanten ISO 13715	Massstab: 1:1 / Gewicht:
Projektionsmethode 1			Werkstoff: Aluminium

Zustand	Index	Datum	Name
v1.0	Correction Measurement	04.12.2015	Simoner Ph.

	Datum	Name
Bearbeitet:	11.11.2015	Simoner Ph.
Geprüft:		
Erstellt:		
Freigabe:		

FHV
University of Applied Sciences

Benennung:

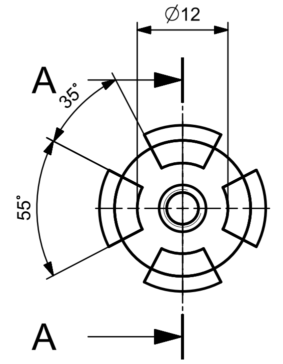
Rackbar

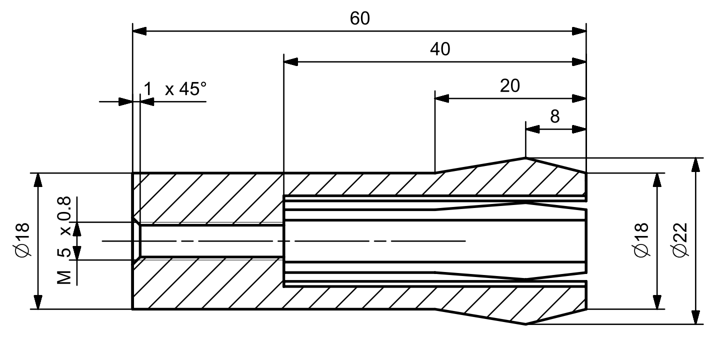
Zeichnungsnummer: FHV-NX-004-00003-EZ-01

Blatt: 1

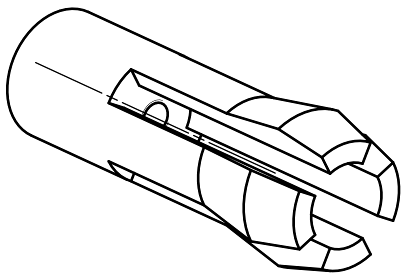
Index: A

1	2	3	4	5	6	7	8





SECTION A-A



Tolerierung ISO 8015	Allgemein-Toleranz ISO 2768mk	Werkstück-Kanten ISO 13715	Massstab: 1:1	Gewicht:
Projektionsmethode 1			Werkstoff: Polyamid	

	Datum	Name
Bearbeitet:	06.11.15	Simoner Ph.
Geprüft:		
Erstellt:		
Freigabe:		

Zustand	Index	Datum	Name

Benennung: Focus (ME)

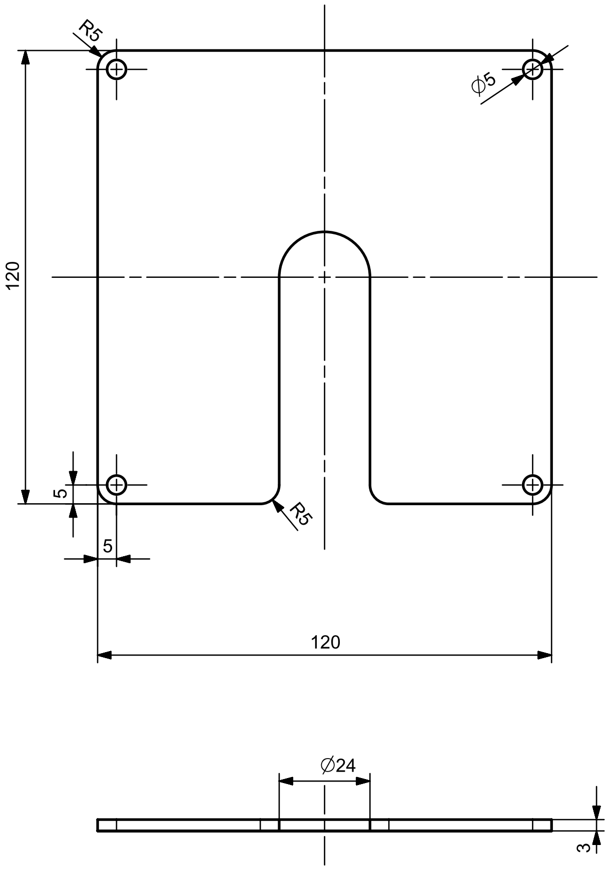
Snap Connector

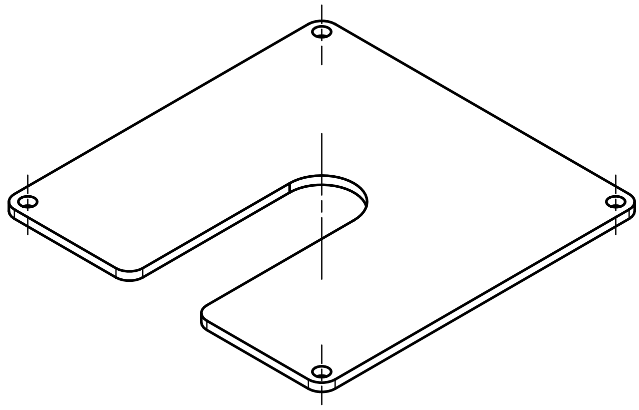
FHV
University of Applied Sciences

Zeichnungsnummer: FHV-NX-004-00001-EZ-01

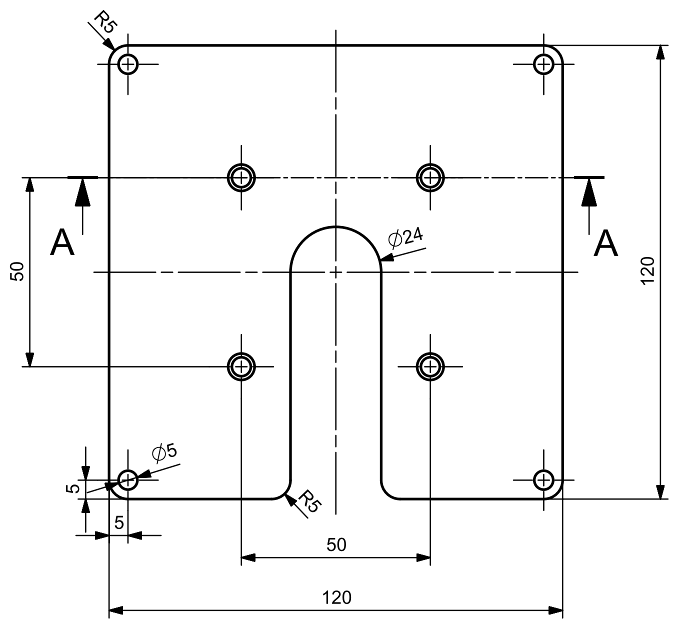
Blatt: 1

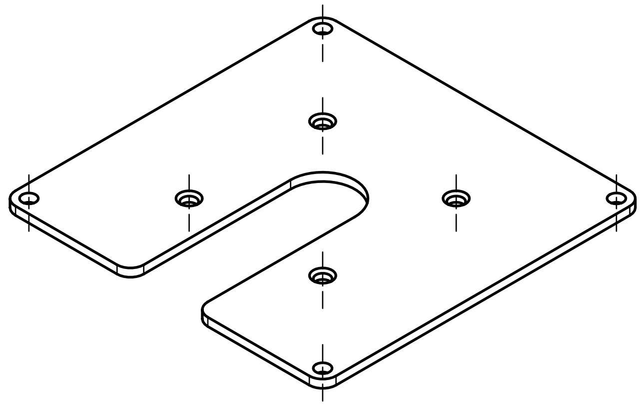
Index: A

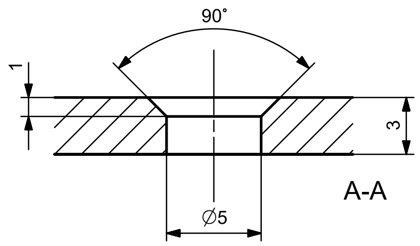




Tolerance norm ISO 8015		General tolerance ISO 2768mk	Workpiece edge ISO 13715	Scale:	1:1	Weight:	
Projection method 1				Material:	Steel		
v1.0	Correction Measurement	04.12.2015	Simoner Ph.				
			Date	Name			
First issued:		28-10-2015	Grabtastic	Title:			
Checked by:				Upperplate			
Drawn by:							
Approved by:							
		FHV University of Applied Sciences		Drawing number:		Sheet 1	
State	Modif.	Date	Name	FHV-NX-004-00009-EZ-01		Rev. A	







A-A

Tolerance norm ISO 8015	General tolerance ISO 2768mk	Workpiece edge ISO 13715	Scale: 1:1	Weight:
Projection method 1			Material: Aluminium	

State	Modif.	Date	Name
v1.0	Correction Measurement	04.12.2015	Simoner Ph.

	Date	Name
First issued:	27-10-2015	Grabtastic
Checked by:	29-10-2015	Michael Brill
Drawn by:		
Approved by:		

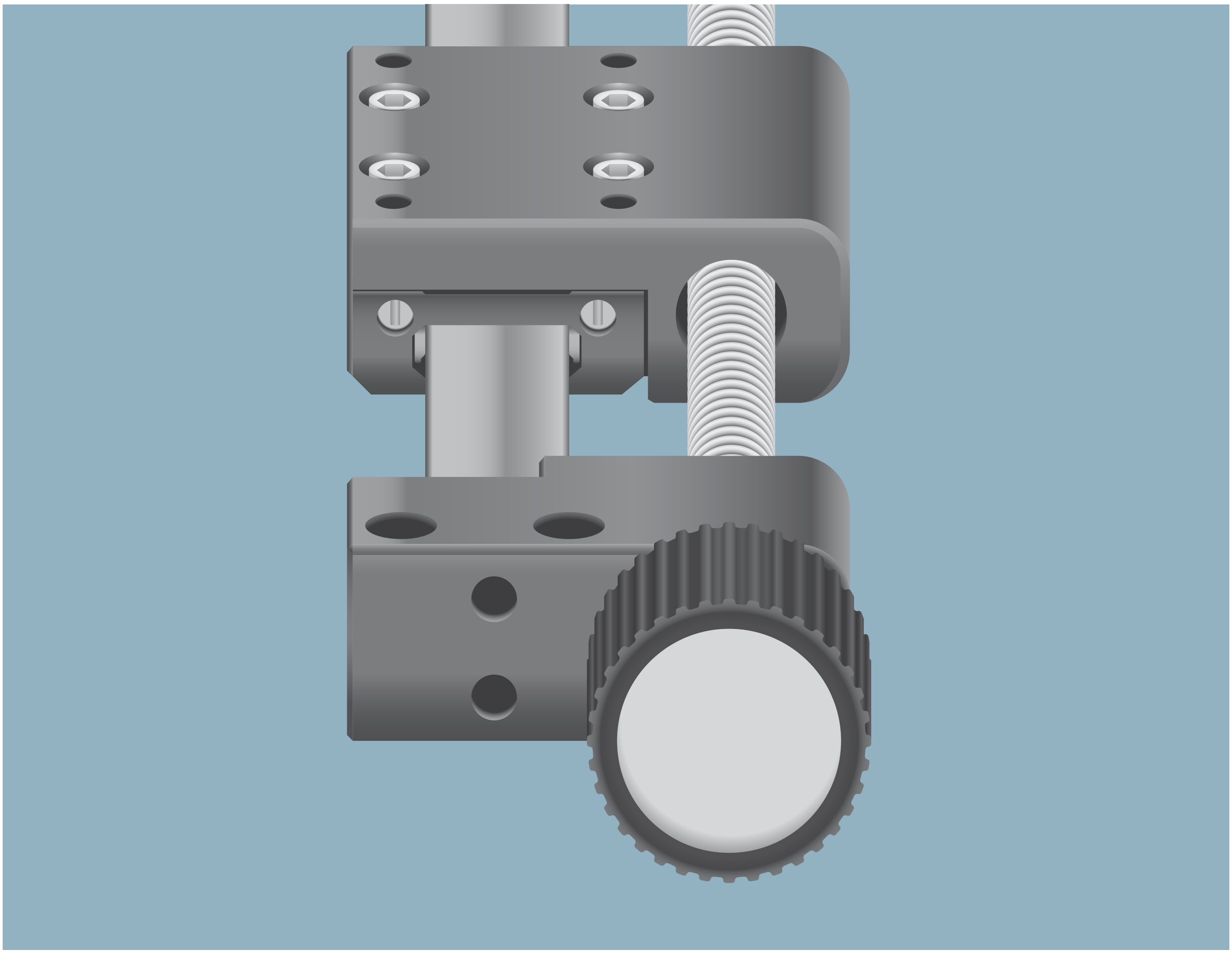
FHV University of Applied Sciences

Title:

Lower Plate

Drawing number:	Sheet 1
FHV-NX-004-00001-EZ-01	Rev. A

A.2. Linear Axis

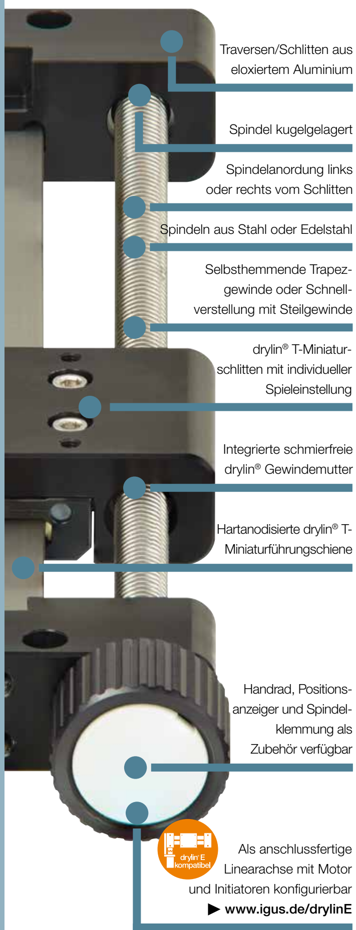


drylin® allgemeine Antriebstechnik: Flaches Linearmodul SLT

- Flach und kompakt
- Basierend auf Miniaturführung drylin® TK-04
- Schlitten mit individueller Spieleinstellung
- Variable Spindelanordnung
- Innovatives Design

drylin® SLT | Vorteile

Flach, leicht, schmierfrei



Linearmodule drylin® SLT

Ein äußerst flacher Aufbau, die seitliche Spindelanordnung,ein markantes Design sind nur einige Gründe, warum das drylin®-Linearmodul SLT mit dem iF Award 2014 ausgezeichnet worden ist. Technisch überzeugt das System durch einen Antrieb mit kugelgelagerten Trapez- oder Steilgewindespindeln für den motorischen als auch manuellen Betrieb. Basis der SLT Baureihe bildet die drylin® T Miniatur-Lineargleitführung in Baugröße 12 und 15.

- Sehr flacher Aufbau durch seitliche Spindelanordnung
- Schmierfrei, korrosionsbeständig, leicht
- Variable Spindelsteigung
- Einstellbarer drylin® T-Miniaturschlitten
- Spindelanordnung links oder rechts wählbar

Typische Anwendungsbereiche:
● Formatverstellungen ● Labor- und Medizintechnik ● Optische Geräte

product design award 2014

Lebensdauerberechnung online
▶ www.igus.de/drylin-experte

max. +90 °C
min. -40 °C

Lieferbar in 3 - 8 Tagen.
Details zur Lieferzeit finden Sie online.

Nach EG-Richtlinie 2011/65/EU (RoHS 2) Beschränkung (der Verwendung bestimmter) gefährlicher Stoffe

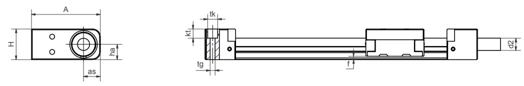
drylin® SLT | Lieferprogramm

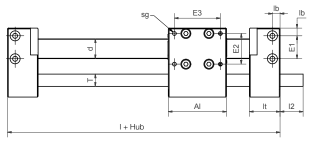
SLT-BB – mit kugelgelagerter Spindel

Bestellschlüssel

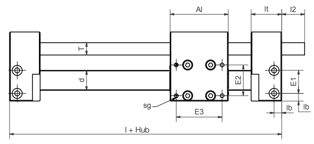
SLT-BB-0412-ER-S0015RG-xxx

- Hublänge in mm
- Spindelzapfen
  - G = Zapfen mit Gewinde
- Gewinde
  - R = rechts
- Spindelsteigung
- Spindel
  - Stahl- oder Edelstahl
- Ausrichtung Spindel
  - R = rechts (Standard)
  - L = links
- Einstellbarer Schlitten TWE
- Baugröße
- Ausführung
  - BB = mit Kugellager
- Typ





Spindelausrichtung links



Spindelausrichtung rechts

Technische Daten und Abmessungen [mm]

Bestellnummer	Steigung	Max. Hublänge	Gewicht [kg]	Gewicht zusätzl. (pro 100 mm) [kg]	Max. stat. Tragfähigkeit axial [N]	Max. stat. Tragfähigkeit radial [N]	Max. Drehzahl [1/min]	Max. Geschw. [m/min]
SLT-BB-0412	Tr08x1,5	300	0,15	0,06	100	200	1.000	1,5
	Sg8x15	300	0,15	0,06	25	100	600	9,0
SLT-BB-0415	Tr12x3	600	0,40	0,12	200	400	1.000	4,5
	Tr12x6	600	0,40	0,12	100	400	750	4,5
	Sg12x25	600	0,40	0,12	50	200	300	7,5

Bestellnummer	A	Al	H	E1	E2	E3	l	l2	d2	ha	sg	tk	kt	tg	f	lb	lt	d	T	as
SLT-BB-0412*	45	38	20	15	20	30	78	15	-	10	M3-7	6,5	6	M3	2,2	5	20	13	Tr08x1,5	11
SLT-BB-0415**	58	45	30	19	25	35	89	17	12	15	M3-13	8	4,5	M5-15	2,8	6,5	22	17	Tr12x3	16

*** ...0412 alternativ mit Steilgewinde: Sg08x15, **...0415 alternativ mit Trapezgewinde Tr12x6 oder Steilgewinde Sg12x25**

B. Electronics

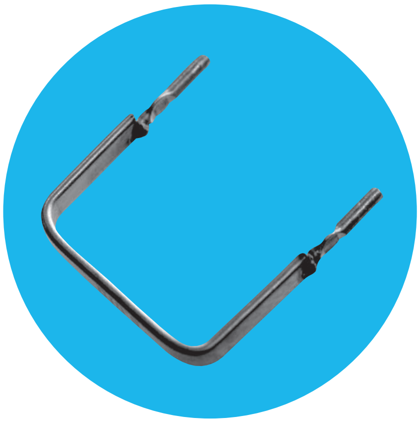
B.1. Power Resistor

TT Electronics
Make Possible

Open Air Resistor
Metal Element Current Sense

OAR & OAR-TP Series

- Power ratings of 1, 3, & 5W @ 85°C
- Superior surge performance
- Hot spot isolated from PCB material
- Resistance wire TCR ±20ppm/°C
- Tolerances to 1%
- Pb-free version is RoHS compliant



RoHS All Pb-free parts comply with EU Directive 2011/65/EU (RoHS2)

Electrical Data

Part Number	Power Rating @ 85°C (watts)	Resistance Range (mΩ)	Tolerance (±%)	Wire TCR (±ppm/°C)	Inductance (nH)
OAR-1 (TP)	1.0	3, 5, 10, *20, *25, 50			
OAR-3 (TP)	3.0	2.5, 5, 10, 15, 20, 25, *30, 50, 100	1, 2[1], 5	20	<10
OAR-5 (TP)	5.0	3, 5, 10, *15, *20, *25, *50			

Notes:
[1] ±2% tolerance available <5mΩ
* denotes resistance values that may have longer lead times than other values listed
* Please contact factory for resistance values not listed

Environmental Data

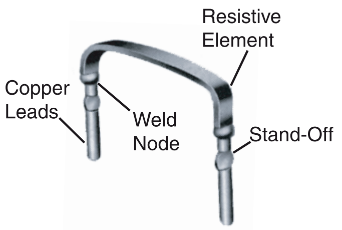
Load Life (1000 hours @ 25°C)	**ΔR/R <1%**
Moisture (no load for 1000 hours)	**ΔR/R <1%**
Temperature Cycling (-40°C to +125°C for 1000 cycles)	**ΔR/R <1%**
Operating Temperature	**-40°C to +125°C**

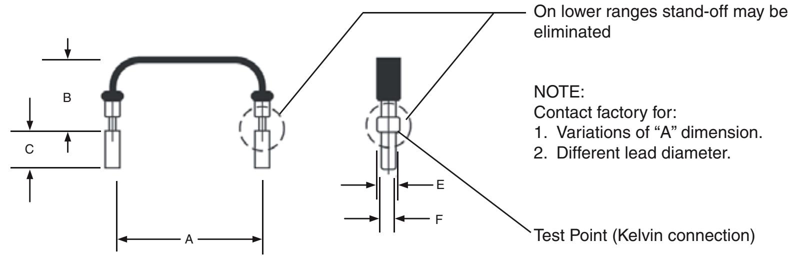
General Note
TT Electronics reserves the right to make changes in product specification without notice or liability.
All information is subject to TT Electronics' own data and is considered accurate at time of going to print.

Bi technologies IRC Welwyn

www.ttelectronicsresistors.com

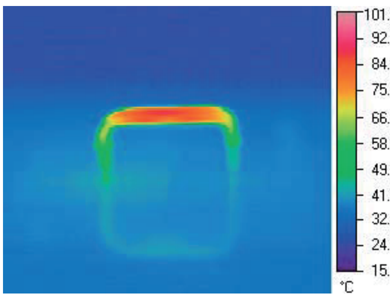
Physical Data





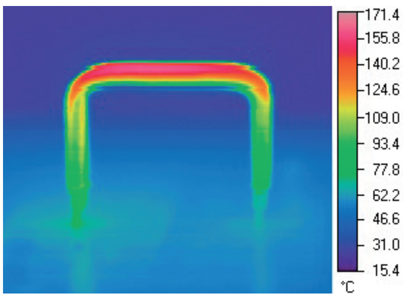
Type	A	B max	C	E	F
OAR1	0.45 +0.04/-0.02 (11.43 +1.02/-0.51)	0.32 (8.12)	0.125 ±0.03 (3.18 ±0.76)	0.065 +0.01/-0.005 (1.65 +0.25/-0.13)	0.04 ±0.002 (1.02 ±0.05)
OAR1TP	0.197 +0.04/-0.03 (5.0 +1.0/-0.8)	0.3 (7.8)			
OAR3	0.60 +0.04/-0.02 (15.24 +1.02/-0.51)	0.92 (23.4)			
OAR3TP <R005	0.275 +0.04/-0.03 (7.0 +1.0/-0.8)	1.0 (25.4)			
OAR3TP ≥R005	0.197 +0.04/-0.03 (5.0 +1.0/-0.8)				
OAR5	0.80 +0.04/-0.02 (20.32 +1.02/-0.51)	0.88 (22.4)			
OAR5TP	0.275 +0.04/-0.03 (7.0 +1.0/-0.8)	1.1 (27.9)			

Thermal Image Data



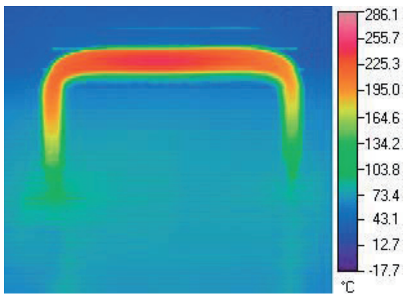
OAR-1 5 mΩ @ 1 Watt

Hot Spot: 87°C
Solder Joint: 45°C



OAR-3 5 mΩ @ 3 Watt

Hot Spot: 160°C
Solder Joint: 70°C



OAR-5 5 mΩ @ 5 Watt

Hot Spot: 230°C
Solder Joint: 96°C

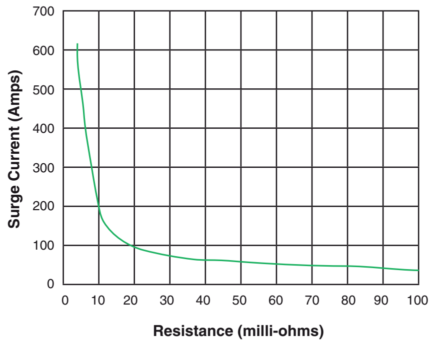
The thermal images (not simulations) above are of the OAR products at their respective power rating. Notice the solder joint temperature is much lower than the hotspot. The unique construction of the OAR isolates the temperature of the hotspot from the circuit board material preventing damage to the circuit board. Additionally, the thermal energy is dissipated to the air instead of being conducted into the circuit board potentially causing a nearby power component to exceed its rating.

The standard test circuit board consists of a four layer FR4 material with 2 ounce (70µm) outer layers and 1 ounce (35µm) inner layers, which is typical of many industry designs. The test conditions were in ambient temperature conditions, approximately 22 °C with no forced air. Contact TT electronics for more details or for other thermal image test data for specific resistance values and power levels.

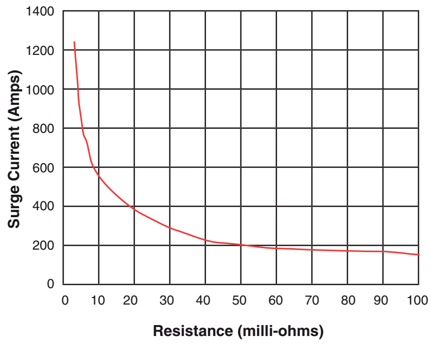
Power Derating

The typical power derating curves are based on conservative design concepts that extend from film based products. The OAR is a solid metal alloy construction that can withstand comparably greater operating power levels than conservative design models permit. Typically the resistive alloys can withstand temperatures in excess of 300°C. Therefore, system thermal design considerations are a more significant design parameter due to the heat limitations of solder joints and/or circuit board substrate materials.

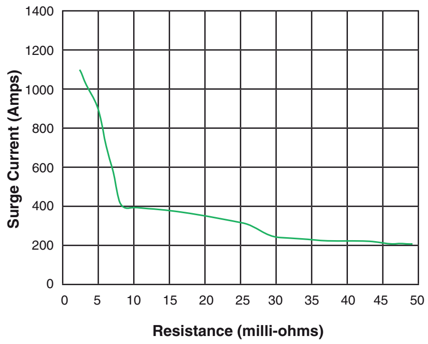
Pulse/Surge Chart @ 50 msec duration



OAR-1(TP)



OAR-3(TP)



OAR-5(TP)

The Surge current charts are approximations of the capabilities of the OAR product and should not be used to the exclusion of actual testing. The relative high surge currents depicted in the charts are as a result of the robust all metal welded construction and the heat carrying capability of metal. Additionally the OAR resistive wire provides large relative cross section for current flow as compared to other resistor technologies, such as thin film, thick film, or metal strip.

Ordering Data

This product has two valid part numbers:

European (Welwyn) Part Number: OAR3-R01JI (OAR3, 10 milliohms ±5%, Pb-free)

O	A	R	3			-	R	0	1	J	I
1				2			3			4	5

1 Type	2 Pitch	3 Value	4 Tolerance	5 Packing
OAR1	Omit for standard	3-5 characters	F = ±1%	I = Bulk
OAR3	TP = Tight Pitch	See Electrical Data	G = ±2%	
OAR5		R = ohms	J = ±5%	

USA (IRC) Part Number: OAR3R010JLF (OAR3, 10 milliohms ±5%, Pb-free)

O	A	R	3			R	0	1	0	J	L	F
1				2		3				4	5	

1 Type	2 Pitch	3 Value	4 Tolerance	5 Termination
OAR1	Omit for standard	4/5 characters	F = ±1%	Omit for SnPb
OAR3	TP = Tight Pitch	See Electrical Data	G = ±2%	LF = Pb-free
OAR5		R = ohms	J = ±5%	

B.2. DRV8711

DRV8711 Stepper Motor Controller IC

1 Features

- Pulse Width Modulation (PWM) Microstepping Motor Driver
  - Built-In 1/256-Step Microstepping Indexer
  - Drives External N-Channel MOSFETs
  - Optional STEP/DIR Pins
  - Optional PWM Control Interface for DC Motors
- Flexible Decay Modes, Including Automatic Mixed Decay Mode
- Stall Detection With Optional BEMF Output
- Highly Configurable SPI Serial Interface
- Internal Reference and Torque DAC
- 8-V to 52-V Operating Supply Voltage Range
- Scalable Output Current
- Thermally Enhanced Surface-Mount Package
- 5-V Regulator Capable of 10-mA Load
- Protection and Diagnostic Features
  - Overcurrent Protection (OCP)
  - Overtemperature Shutdown (OTS)
  - Undervoltage Lockout (UVLO)
  - Individual Fault Condition Indication Bits
  - Fault Condition Indication Pin

2 Applications

- Office Automation Machines
- Factory Automation
- Textile Machines
- Robotics

3 Description

The DRV8711 device is a stepper motor controller that uses external N-channel MOSFETs to drive a bipolar stepper motor or two brushed DC motors. A microstepping indexer is integrated, which is capable of step modes from full step to 1/256-step.

An ultra-smooth motion profile can be achieved using adaptive blanking time and various current decay modes, including an auto-mixed decay mode. Motor stall is reported with an optional back-EMF output.

A simple step/direction or PWM interface allows easy interfacing to controller circuits. A SPI serial interface is used to program the device operation. Output current (torque), step mode, decay mode, and stall detection functions are all programmable through a SPI serial interface.

Internal shutdown functions are provided for overcurrent protection, short-circuit protection, undervoltage lockout, and overtemperature. Fault conditions are indicated through a FAULTn pin, and each fault condition is reported through a dedicated bit through SPI.

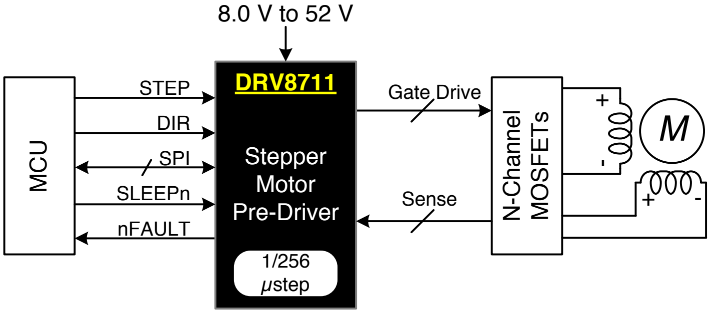
The DRV8711 is packaged in a PowerPAD™ 38-pin HTSSOP package with thermal pad (Eco-friendly: RoHS and no Sb/Br).

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
DRV8711	HTSSOP (38)	9.70 mm × 4.40 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Simplified Schematic



An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.

Table of Contents

4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision D (January 2014) to Revision E **Page**

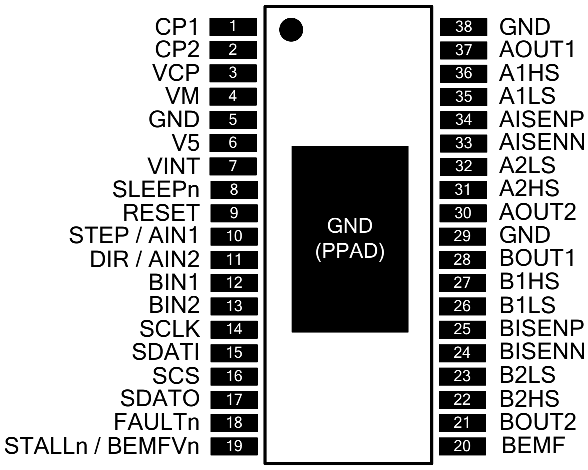
- Added *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section ... 1

Changes from Revision C (December 2013) to Revision D **Page**

- Changed STATUS Register bit descriptions 3 through 5 ... 28

5 Pin Configuration and Functions

DCP Package
38-Pin HTSSOP
Top View



Pin Functions

PIN		I/O[(1)]	DESCRIPTION	EXTERNAL COMPONENTS OR CONNECTIONS
NAME	NO.			
POWER AND GROUND				
GND	5, 29, 38, PPAD	—	Device ground	All pins must be connected to ground
VM	4	—	Bridge A power supply	Connect to motor supply voltage. Bypass to GND with a 0.01-µF ceramic capacitor plus a 100-µF electrolytic capacitor.
VINT	7	—	Internal logic supply voltage	Logic supply voltage. Bypass to GND with a 1-µF 6.3-V X7R ceramic capacitor.
V5	6	O	5-V regulator output	5-V linear regulator output. Bypass to GND with a 0.1-µF 10-V X7R ceramic capacitor.
CP1	1	IO	Charge pump flying capacitor	Connect a 0.1-µF X7R capacitor between CP1 and CP2. Voltage rating must be greater than applied VM voltage.
CP2	2	IO	Charge pump flying capacitor	
VCP	3	IO	High-side gate drive voltage	Connect a 1-µF 16-V X7R ceramic capacitor to VM
CONTROL				
SLEEPn	8	I	Sleep mode input	Logic high to enable device, logic low to enter low-power sleep mode
STEP/AIN1	10	I	Step input/Bridge A IN1	Indexer mode: Rising edge causes the indexer to move one step. External PWM mode: controls bridge A OUT1 Internal pulldown.
DIR/AIN2	11	I	Direction input/Bridge A IN2	Indexer mode: Level sets the direction of stepping. External PWM mode: controls bridge A OUT2 Internal pulldown.
BIN1	12	I	Bridge B IN1	Indexer mode: No function External PWM mode: controls bridge B OUT1 Internal pulldown.
BIN2	13	I	Bridge B IN2	Indexer mode: No function External PWM mode: controls bridge B OUT2 Internal pulldown.
RESET	9	I	Reset input	Active-high reset input initializes all internal logic and disables the H-bridge outputs. Internal pulldown.
SERIAL INTERFACE				
SCS	16	I	Serial chip select input	Active high to enable serial data transfer. Internal pulldown.
SCLK	14	I	Serial clock input	Rising edge clocks data into part for write operations. Falling edge clocks data out of part for read operations. Internal pulldown.
SDATI	15	I	Serial data input	Serial data input from controller. Internal pulldown.

(1) Directions: I = input, O = output, OZ = 3-state output, OD = open-drain output, IO = input/output

Pin Functions (continued)

PIN		I/O(1)	DESCRIPTION	EXTERNAL COMPONENTS OR CONNECTIONS
NAME	NO.			
SDATO	17	O	Serial data output	Serial data output to controller. Open-drain output requires external pullup.
STATUS				
STALLn/ BEMFVn	19	OD	Stall/Back EMF valid	Internal stall detect mode: logic low when motor stall detected. External stall detect mode: Active low when valid back EMF measurement is ready. Open-drain output requires external pullup.
FAULTn	18	OD	Fault	Logic low when in fault condition. Open-drain output requires external pullup. Faults: OCP, PDF, OTS, UVLO
BEMF	20	O	Back EMF	Analog output voltage represents motor back EMF. Place a 1-nF low-leakage capacitor to ground on this pin.
OUTPUTS				
A1HS	36	O	Bridge A out 1 HS gate	Connect to gate of HS FET for bridge A out 1
AOUT1	37	I	Bridge A output 1	Connect to output node of external FETs of bridge A out 1
A1LS	35	O	Bridge A out 1 LS gate	Connect to gate of LS FET for bridge A out 1
A2HS	31	O	Bridge A out 2 HS gate	Connect to gate of HS FET for bridge A out 2
AOUT2	30	I	Bridge A output 2	Connect to output node of external FETs of bridge A out 2
A2LS	32	O	Bridge A out 2 LS gate	Connect to gate of LS FET for bridge A out 2
AISENP	34	I	Bridge A Isense + in	Connect to current sense resistor for bridge A
AISENN	33	I	Bridge A Isense – in	Connect to ground at current sense resistor for bridge A
B1HS	27	O	Bridge B out 1 HS gate	Connect to gate of HS FET for bridge B out 1
BOUT1	28	I	Bridge B output 1	Connect to output node of external FETs of bridge B out 1
B1LS	26	O	Bridge B out 1 LS gate	Connect to gate of LS FET for bridge B out 1
B2HS	22	O	Bridge B out 2 HS gate	Connect to gate of HS FET for bridge B out 2
BOUT2	21	I	Bridge B output 2	Connect to output node of external FETs of bridge B out 2
B2LS	23	O	Bridge B out 2 LS gate	Connect to gate of LS FET for bridge B out 2
BISENP	25	I	Bridge B Isense + in	Connect to current sense resistor for bridge B
BISENN	24	I	Bridge B Isense – in	Connect to ground at current sense resistor for bridge B

Table 1. Critical Components

PIN	NAME	COMPONENT
4	VM	100-µF electrolytic rated for VM voltage to GND 0.01-µF ceramic rated for VM voltage to GND
3	VCP	1-µF ceramic X7R rated 16 V to VCP
1, 2	CP1, CP2	0.1-µF rated for VM + 12 V between these pins
6	V5	0.1-µF ceramic X7R rated 6.3 V to GND
7	VINT	1-µF ceramic X7R rated 6.3 V to GND
17	SDATO	Requires external pullup to logic supply
18	FAULTn	Requires external pullup to logic supply
19	STALLn/BEMFVn	Requires external pullup to logic supply
20	BEMF	1-nF low-leakage capacitor to GND

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) [1][2][3]

	MIN	MAX	UNIT
Power supply voltage	–0.6	60	V
Charge pump voltage (CP1, CP2, VCP)	–0.6	12	V
5-V regulator voltage (V5)	–0.6	5.5	V
Internal regulator voltage (VINT)	–0.6	2	V
Digital pin voltage (SLEEPn, RESET, STEP/AIN1, DIR/AIN2, BIN1, BIN2, SCS, SCLK, SDATI, SDATO, FAULTn, STALLn/BEMFVn)	–0.6	5.5	V
High-side gate drive pin voltage (A1HS, A2HS, B1HS, B2HS)	–0.6	12	V
Low-side gate drive pin voltage (A1LS, A2LS, B1LS, B2LS)	–0.6	12	V
Phase node pin voltage (AOUT1, AOUT2, BOUT1, BOUT2)	–0.6	VM	V
ISENSEx pin voltage (AISENP, AISENN, BISENP, BISENN)	–0.7	0.7	V
BEMF pin voltage (BEMF)	–0.6	5.5	V
Operating virtual junction temperature, T_J	–40	150	°C
Storage temperature, T_{stg}	–60	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltage values are with respect to network ground terminal.
(3) Power dissipation and thermal limits must be observed.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins [1]	±4000	V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins [2]	±1500	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
V_M	Motor power supply voltage range	8		52	V
I_{VS}	V5 external load current	0		10	mA
T_A	Operating ambient temperature range	-40		85	°C

6.4 Thermal Information

THERMAL METRIC [1]		DRV8711 DCP (HTSSOP) 38 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	32.7	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	17.2	
$R_{\theta JB}$	Junction-to-board thermal resistance	14.3	
ψ_{JT}	Junction-to-top characterization parameter	0.5	
ψ_{JB}	Junction-to-board characterization parameter	14.1	
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	0.9	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

6.5 Electrical Characteristics

over operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
POWER SUPPLIES						
I_{VM}	VM operating supply current	VM = 24 V		17	20	mA
I_{VMQ}	VM sleep mode supply current	VM = 24 V, SLEEPn = 0, T_A = 25°C		65	98	μA
V_{UVLO}	VM undervoltage lockout voltage	VM rising		7.1	8	V
		VM falling		6.3		
INTERNAL LINEAR REGULATORS						
V_5	V5 output voltage	VM ≥ 12 V, I_{OUT} = 1 mA – 10 mA	4.8	5	5.2	V
V_{INT}	VINT voltage	No external load – reference only	1.7	1.8	1.9	V
LOGIC-LEVEL INPUTS						
V_{IL}	Input low voltage				0.8	V
V_{IH}	Input high voltage		1.5			V
V_{HYS}	Input hysteresis voltage			300		mV
I_{IL}	Input low current	V_{IN} = 0 V	–5		5	μA
I_{IH}	Input high current	V_{IN} = 5 V	30	50	70	μA
SDATAO, STALLn, FAULTn OUTPUTS (OPEN-DRAIN OUTPUTS)						
V_{OL}	Output low voltage	I_O = 5 mA			0.5	V
I_{OH}	Output high leakage current	V_O = 3.3 V			1	μA
MOSFET DRIVERS						
V_{OUTH}	High-side gate drive output voltage	VM = 24 V, I_O = 100 μA		VM+10		V
V_{OUTL}	Low-side gate drive output voltage	VM = 24 V, I_O = 100 μA		10		V
t_{DEAD}	Output dead time digital delay (dead time is enforced in analog circuits)	DTIME = 00		400		ns
		DTIME = 01		450		
		DTIME = 10		650		
		DTIME = 11		850		
I_{OUTH}	Peak output current gate drive (source)	IDRIVEP = 00		50		mA
		IDRIVEP = 01		100		
		IDRIVEP = 10		150		
		IDRIVEP = 11		200		
I_{OUTI}	Peak output current gate drive (sink)	IDRIVEN = 00		100		mA
		IDRIVEN = 01		150		
		IDRIVEN = 10		200		
		IDRIVEN = 11		400		
t_{DRIVE}	Peak current drive time (source)	TDRIVEP = 00		250		ns
		TDRIVEP = 01		500		
		TDRIVEP = 10		1000		
		TDRIVEP = 11		2000		
t_{DRIVE}	Peak current drive time (sink)	TDRIVEN = 00		250		ns
		TDRIVEN = 01		500		
		TDRIVEN = 10		1000		
		TDRIVEN = 11		2000		
MOTOR DRIVER						
t_{OFF}	PWM off time adjustment range	Set by TOFF register	0.5		128	μs
t_{BLANK}	Current sense blanking time	Set by TBLANK register	0.5		5.12	μs

Electrical Characteristics (continued)

over operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
PROTECTION CIRCUITS						
V_{OCP}	Overcurrent protection trip level (Voltage drop across external FET)	OCPTH = 00	160	250	320	mV
		OCPTH = 01	380	500	580	
		OCPTH = 10	620	750	850	
		OCPTH = 11	840	1000	1200	
t_{TSD}	Thermal shutdown temperature(1)	Die temperature	150	160	180	°C
t_{HYS}	Thermal shutdown hysteresis			20		°C
CURRENT SENSE AMPLIFIERS						
A_V	Gain	ISGAIN = 00		5		V/V
		ISGAIN = 01		10		
		ISGAIN = 10		20		
		ISGAIN = 11		40		
t_{SET}	Settling time (to ±1%)	ISGAIN = 00, ΔVIN = 400 mV		150		ns
		ISGAIN = 01, ΔVIN = 200 mV		300		
		ISGAIN = 10, ΔVIN = 100 mV		600		
		ISGAIN = 11, ΔVIN = 50 mV		1.2		µs
V_{OFS}	Offset voltage	ISGAIN = 00, input shorted			4	mV
V_{IN}	Input differential voltage range		–600		600	mV
CURRENT CONTROL DACs						
	Resolution			256		steps
	Full-scale step response	10% to 90%			5	µs
V_{REF}	Full-scale (reference) voltage		2.50	2.75	3	V

(1) Not tested in production; ensured by design.

6.6 SPI Interface Timing Requirements

over operating free-air temperature range (unless otherwise noted) (see Figure 1)

NO.			MIN	TYP	MAX	UNIT
1	t_{CYC}	Clock cycle time	250			ns
2	t_{CLKH}	Clock high time	25			ns
3	t_{CLKL}	Clock low time	25			ns
4	$t_{SU(SDATI)}$	Setup time, SDATI to SCLK	5			ns
5	$t_{H(SDATI)}$	Hold time, SDATI to SCLK	1			ns
6	$t_{SU(SCS)}$	Setup time, SCS to SCLK	5			ns
7	$t_{H(SCS)}$	Hold time, SCS to SCLK	1			ns
8	$t_{L(SCS)}$	Inactive time, SCS (between writes and reads)	100			ns
9	$t_{D(SDATO)}$	Delay time, SCLK to SDATO (during read)			10	ns
	t_{SLEEP}	Wake time (SLEEPn inactive to high-side gate drive enabled)			1	ms
	t_{RESET}	Delay from power up or RESETn high until serial interface functional			10	µs

6.7 Indexer Timing Requirements

over operating free-air temperature range (unless otherwise noted) (see Figure 2)

NO.			MIN	TYP	MAX	UNIT
1	f_{STEP}	Step frequency			250	kHz
2	$t_{WH(STEP)}$	Pulse duration, STEP high	1.9			µs
3	$t_{WL(STEP)}$	Pulse duration, STEP low	1.9			µs
4	$t_{SU(STEP)}$	Setup time, command to STEP rising	200			ns

Indexer Timing Requirements (continued)

over operating free-air temperature range (unless otherwise noted) (see Figure 2)

NO.			MIN	TYP	MAX	UNIT
5	$t_{H(STEP)}$	Hold time, command to STEP rising	200			ns

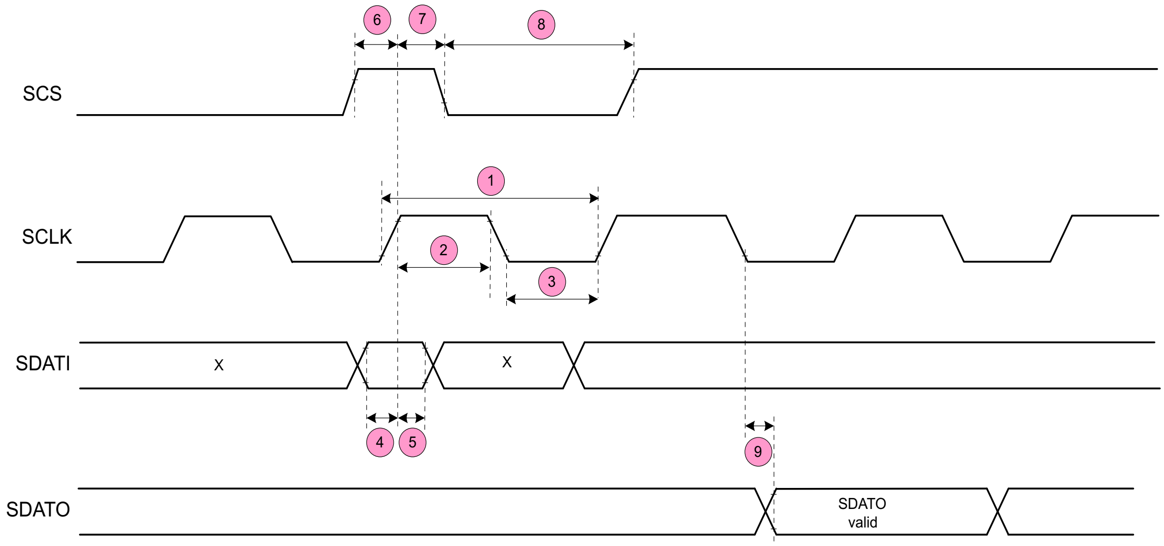


Figure 1. SPI Interface Timing

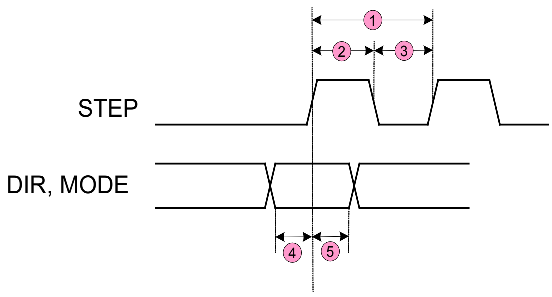


Figure 2. Indexer Timing

6.8 Typical Characteristics

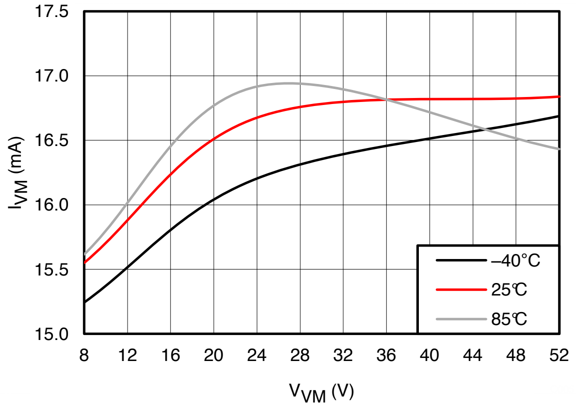


Figure 3. Operating Current

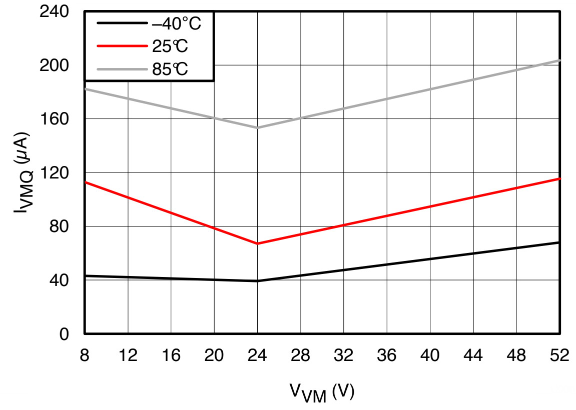


Figure 4. Sleep Current

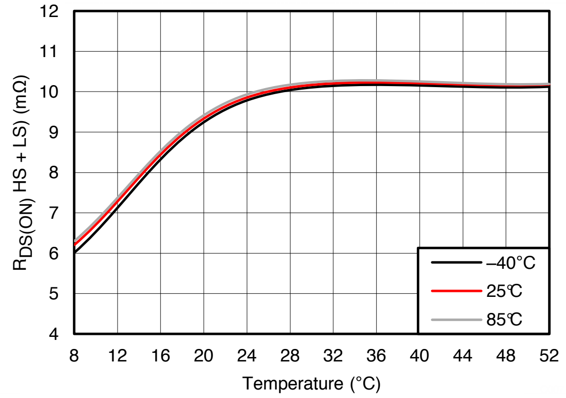


Figure 5. VCP Minus VM

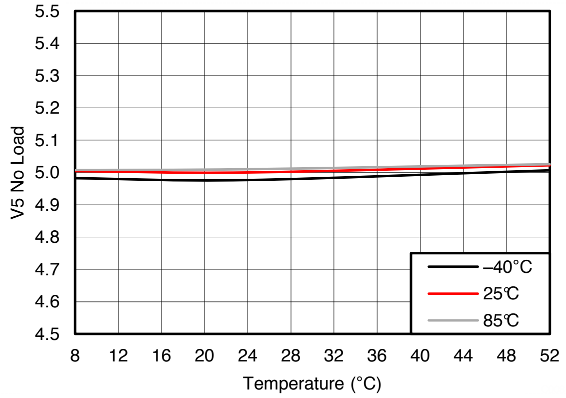


Figure 6. V5 No Load

7 Detailed Description

7.1 Overview

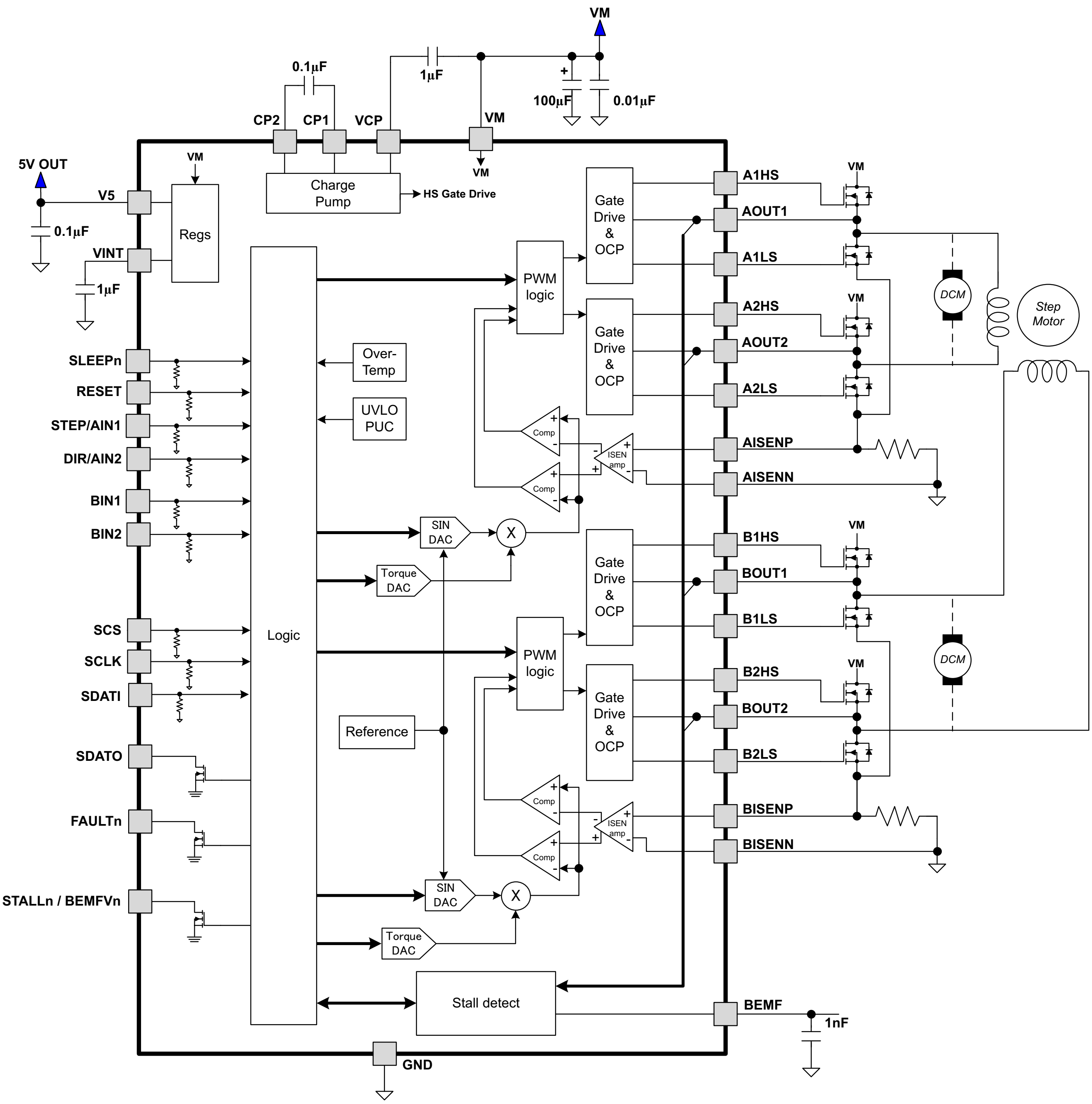
The DRV8711 device is a stepper motor controller that uses external N-channel MOSFETs to drive a bipolar stepper motor or two brushed DC motors. A microstepping indexer is integrated, which is capable of step modes from full step to 1/256-step.

An ultra-smooth motion profile can be achieved using adaptive blanking time, adjustable decay times, and various current decay modes, including an auto-mixed decay mode. When microstepping, motor stall can be reported with an optional back-EMF output.

A simple step/direction or PWM interface allows easy interfacing to controller circuits. A SPI serial interface is used to program the device operation. Output current (torque), step mode, decay mode, and stall detection functions are all programmable through a SPI serial interface.

Internal shutdown functions are provided for overcurrent protection, short-circuit protection, undervoltage lockout, and overtemperature. Fault conditions are indicated through a FAULTn pin, and each fault condition is reported through a dedicated bit through SPI.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 PWM Motor Drivers

The DRV8711 contains two H-bridge motor predrivers with current control PWM circuitry.

More detailed descriptions of the subblocks are described in the following sections.

Feature Description (continued)

7.3.2 Direct PWM Input Mode

Direct PWM mode is selected by setting the PWMMODE bit in the OFF register. In direct PWM input mode, the AIN1, AIN2, BIN1, and BIN2 directly control the state of the output drivers. This allows for driving up to two brushed DC motors. The logic is shown in Table 2:

Table 2. Direct PWM Input Mode Logic

xIN1	xIN2	xOUT1	xOUT2	OPERATION
0	0	Z	Z	Asynchronous Fast Decay
0	1	L	H	Reverse Drive
1	0	H	L	Forward Drive
1	1	L	L	Slow Decay

If mixed or auto-mixed decay modes are used, they will apply to every cycle, because current change information is not available.

In direct PWM mode, the current control circuitry is still active. The full-scale VREF is set to 2.75 V. The TORQUE register may be used to scale this value, and the ISEN sense amp gain may still be set using the ISGAIN bits of the CTRL register.

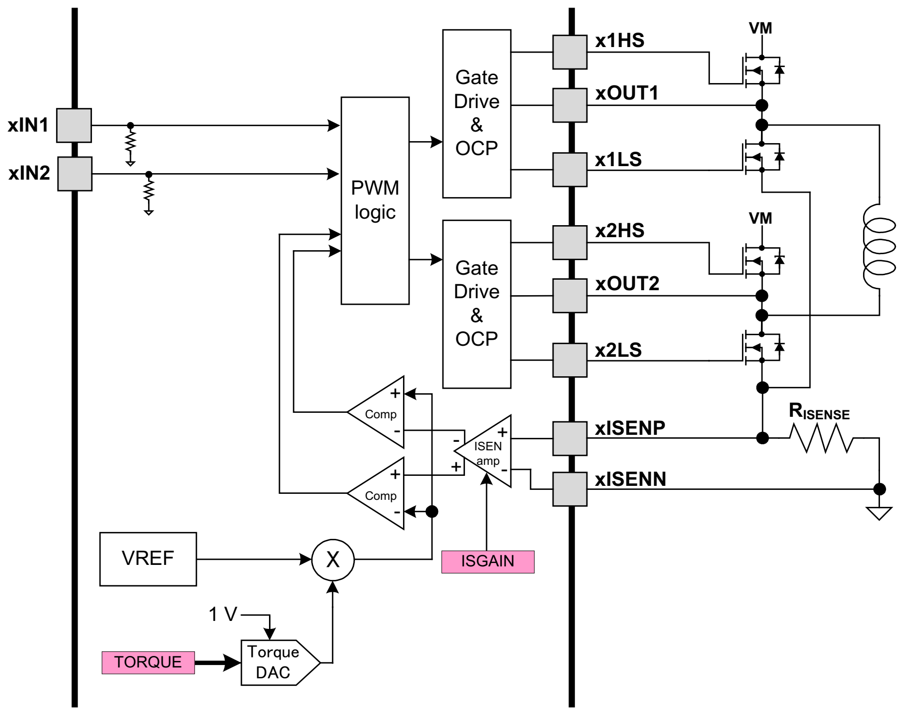


Figure 7. Direct PWM Input Mode

The current through the motor windings is regulated by an adjustable fixed-off-time PWM current regulation circuit. When an H-bridge is enabled, current rises through the winding at a rate dependent on the DC voltage and inductance of the winding and the magnitude of the back EMF present. Once the current hits the current chopping threshold, the bridge disables the current for a fixed period of time, which is programmable between 500 nS and 128 μS by writing to the TOFF bits in the OFF register. After the off time expires, the bridge is re-enabled, starting another PWM cycle.

The chopping current is set by a comparator which compares the voltage across a current sense resistor connected to the xISENx pins, multiplied by the gain of the current sense amplifier, with a reference voltage. The current sense amplifier is programmable in the CTRL register.

When driving in PWM mode, the chopping current is calculated as follows:

$$I_{CHOP} = \frac{2.75V \bullet TORQUE}{256 \bullet ISGAIN \bullet R_{ISENSE}} \quad (1)$$

Where TORQUE is the setting of the TORQUE bits, and ISGAIN is the programmed gain of the ISENSE amplifiers (5, 10, 20, or 40).

7.3.3 Microstepping Indexer

Built-in indexer logic in the DRV8711 allows a number of different stepping configurations. The MODE bits in the CTRL register are used to configure the stepping format as shown in Table 3.

Table 3. Microstepping Indexer Logic

MODE3	MODE2	MODE1	MODE0	STEP MODE
0	0	0	0	Full-step (2-phase excitation) with 71% current
0	0	0	1	1/2 step
0	0	1	0	1/4 step
0	0	1	1	1/8 step
0	1	0	0	1/16 step
0	1	0	1	1/32 step
0	1	1	0	1/64 step
0	1	1	1	1/128 step
1	0	0	0	1/256 step

Table 4 shows the relative current and step directions for full-step through 1/8-step operation. Higher microstepping resolutions follow the same pattern. The AOUT current is the sine of the electrical angle; BOUT current is the cosine of the electrical angle.

The reset state is 45°. This state is entered at power up or application of RESETn. This is shown in Table 4 by cells shaded in yellow.

Table 4. Step Directions

FULL STEP	1/2 STEP	1/4 STEP	1/8 STEP	AOUT CURRENT (% FULL-SCALE)	BOUT CURRENT (% FULL-SCALE)	ELECTRICAL ANGLE (DEGREES)
	1	1	1	0	100	0
			2	20	98	11.325
		2	3	38	92	22.5
			4	56	83	33.75
1	2	3	5	71	71	45 (home state)
			6	83	56	56.25
		4	7	92	38	67.5
			8	98	20	78.75
	3	5	9	100	0	90
			10	98	–20	101.25
		6	11	92	–38	112.5
			12	83	–56	123.75
2	4	7	13	71	–71	135
			14	56	–83	146.25
		8	15	38	–92	157.5
			16	20	–98	168.75
	5	9	17	0	–100	180
			18	–20	–98	191.25
		10	19	–38	–92	202.5
			20	–56	–83	213.75
3	6	11	21	–71	–71	225
			22	–83	–56	236.25
		12	23	–92	–38	247.5
			24	–98	–20	258.75
	7	13	25	–100	0	270
			26	–98	20	281.25
		14	27	–92	38	292.5
			28	–83	56	303.75
4	8	15	29	–71	71	315
			30	–56	83	326.25
		16	31	–38	92	337.5
			32	–20	98	348.75

At each rising edge of the STEP input, or each time a 1 is written to the RSTEP bit in the CTRL register, the indexer travels to the next state in the table. The direction is shown with the DIR pin high and the RDIR bit in the CTRL register set to 0, or the DIR pin low and the RDIR bit set to 1. If the DIR pin is low with the RDIR bit 0, or the DIR pin is high with the RDIR bit 1, the sequence is reversed. Positive current is defined as xOUT1 = positive with respect to xOUT2.

If the step mode is changed while stepping, the indexer will advance to the next valid state for the new MODE setting at the rising edge of STEP.

7.3.4 Current Regulation

The current through the motor windings is regulated by an adjustable fixed-off-time PWM current regulation circuit. When an H-bridge is enabled, current rises through the winding at a rate dependent on the DC voltage and inductance of the winding and the magnitude of the back EMF present. Once the current hits the current chopping threshold, the bridge disables the current for a fixed period of time, which is programmable between 500 nS and 128 µS by writing to the TOFF bits in the OFF register. After the off time expires, the bridge is re-enabled, starting another PWM cycle.

In stepping motors, current regulation is used to vary the current in the two windings in a sinusoidal fashion to provide smooth motion.

The PWM chopping current is set by a comparator which compares the voltage across a current sense resistor connected to the xISENx pins, multiplied by the gain of the current sense amplifier, with a reference voltage. The current sense amplifier is programmable in the CTRL register.

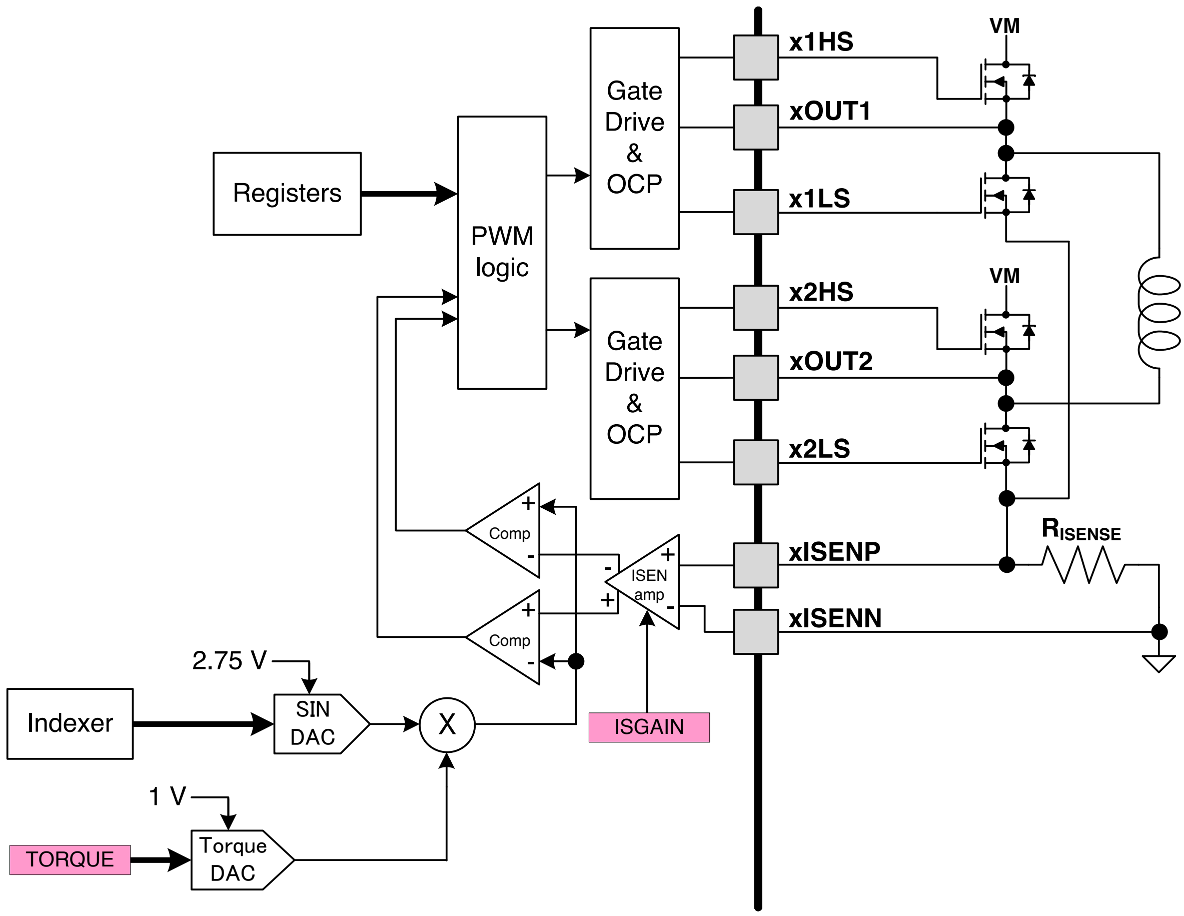


Figure 8. PWM Chopping Current

To generate the reference voltage for the current chopping comparator, the output of a sine lookup table is multiplied by the value of the bits in the TORQUE register. This result is applied to a sine-weighted DAC, whose full-scale output voltage is 2.75 V.

Therefore, the full-scale (100%) chopping current is calculated as follows:

$$I_{FS} = \frac{2.75V \bullet TORQUE}{256 \bullet ISGAIN \bullet R_{ISENSE}} \quad (2)$$

where

- TORQUE is the setting of the TORQUE bits
- ISGAIN is the programmed gain of the ISENSE amplifiers (5, 10, 20, or 40)

Example:

If a 0.1-Ω sense resistor is used, ISGAIN is set to 0 (gain of 5), and TORQUE is set to 255, the full-scale (100%) chopping current will be (2.75 V * 255) / (256 * 5 * 0.1 Ω) = 5.5 A.

7.3.5 Decay Modes

During PWM current chopping, the H-bridge is enabled to drive through the motor winding until the PWM current chopping threshold is reached. This is shown in Figure 9, Item 1. The current flow direction shown indicates positive current flow in the step table below.

Once the chopping current threshold is reached, the H-bridge can operate in two different states, fast decay or slow decay.

In fast decay mode, once the PWM chopping current level has been reached, the H-bridge reverses state to allow winding current to flow in a reverse direction. The opposite FETs are turned on; as the winding current approaches zero, the bridge is disabled to prevent any reverse current flow. Fast decay mode is shown in Figure 9, item 2.

In slow decay mode, winding current is recirculated by enabling both of the low-side FETs in the bridge. This is shown in Figure 9, Item 3.

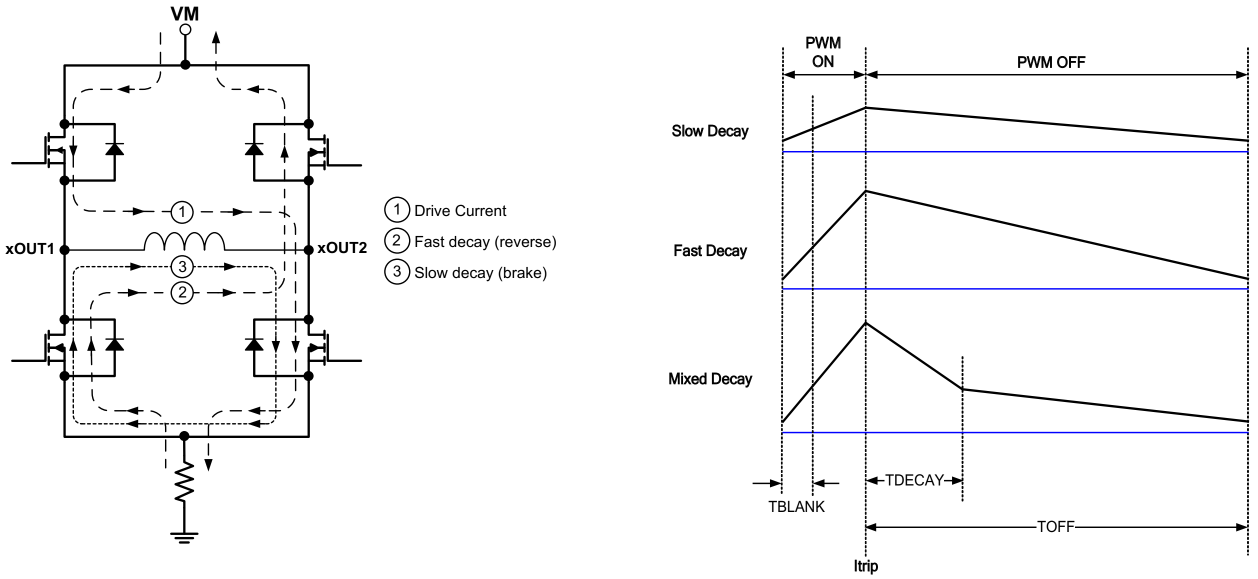


Figure 9. Decay Modes

The DRV8711 supports fast decay and slow decay modes in both indexer and direct PWM modes. In addition, in indexer mode only, it supports fixed mixed decay and auto-mixed decay modes. Decay mode is selected by the DECMOD bits in the DECAY register.

Mixed decay mode begins as fast decay, but after a programmable period of time (set by the TDECAY bits in the DECAY register) switches to slow decay mode for the remainder of the fixed off time. Even if mixed decay is selected, if the current is increasing or remaining the same (per the step table), then slow decay is used.

Auto-mixed decay mode samples the current level at the end of the blanking time, and if the current is above the Itrip threshold, immediately changes the H-bridge to fast decay. During fast decay, the (negative) current is monitored, and when it falls below the Itrip threshold (and another blanking time has passed), the bridge is switched to slow decay. Once the fixed off time expires, a new cycle is started.

If the bridge is turned on and at the end of TBLANK the current is below the Itrip threshold, the bridge remains on until the current reaches Itrip. Then slow decay is entered for the fixed off time, and a new cycle begins.

See Figure 10 and Figure 11.

The upper waveform shows the behavior if I < Itrip at the end of tBLANK. At slow motor speeds, where back EMF is not significant, the current increase during the ON phase is the same magnitude as the current decrease in fast decay, because both times are controlled by tBLANK, and the rate of change is the same (full VM is applied to the load inductance in both cases, but in opposite directions). In this case, the current will gradually be driven down until the peak current is just hitting Itrip at the end of the blanking time, after which some cycles will be slow decay, and some will be mixed decay.

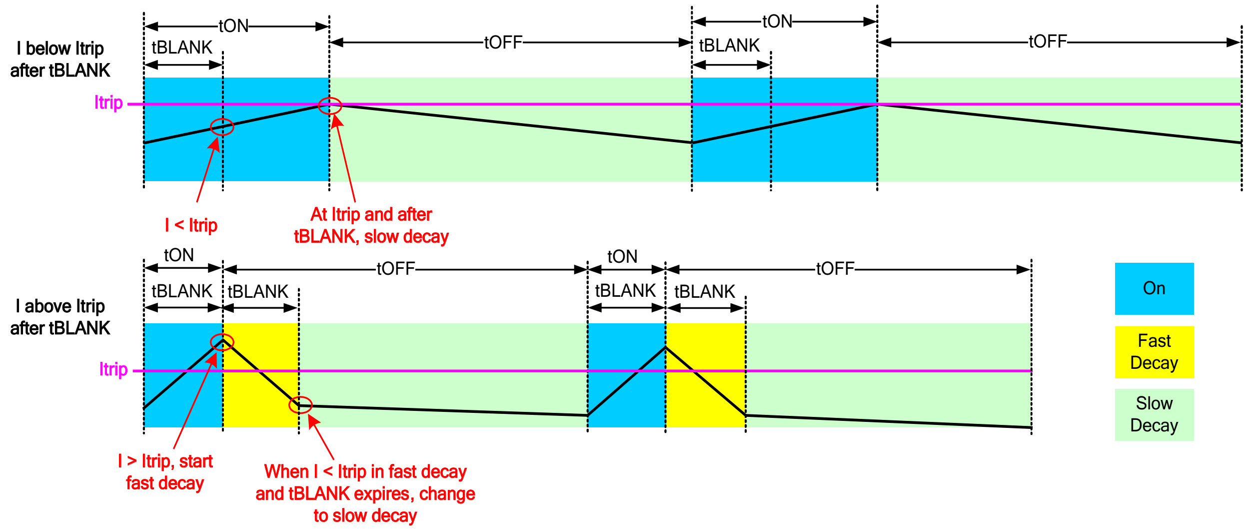


Figure 10. I < Itrip at the End of tBLANK

If the Itrip level changes during a PWM cycle (in response to a step command to the indexer), the current cycle is immediately terminated, and a new cycle is begun. Refer to the drawing below.

If the Itrip level has increased, the H-bridge will immediately turn on; if the Itrip level has decreased, fast decay mode is begun immediately. The top waveform shows what happens when the Itrip threshold decreases during a PWM cycle. The lower Itrip level results in the current being above the Itrip threshold at the end of tBLANK on the following cycle. Fast decay is entered until the current is driven below the Itrip threshold.

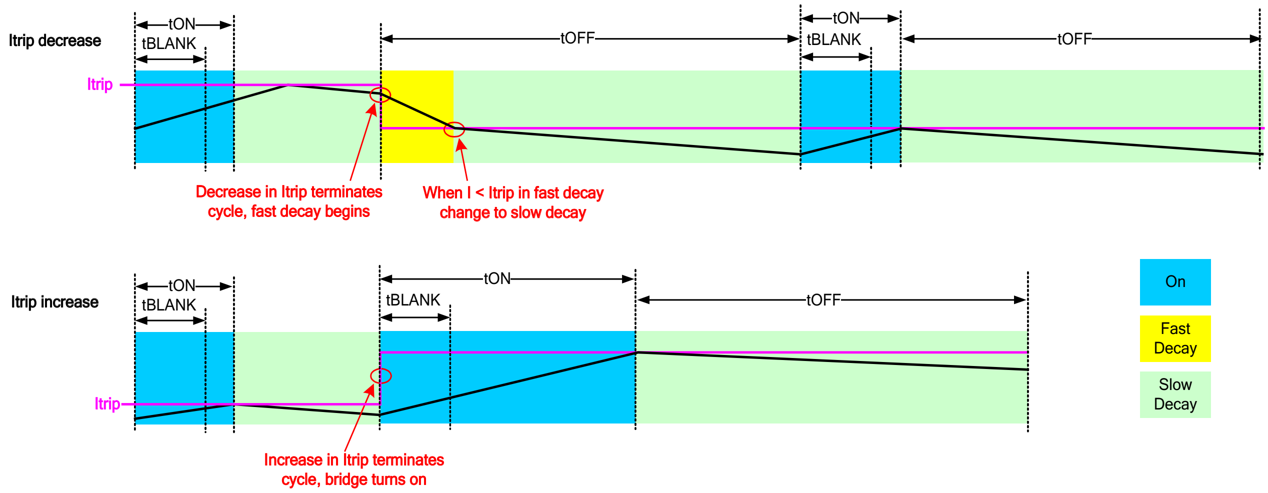


Figure 11. Itrip Level Changing During a PWM Cycle

To accurately detect zero current, an internal offset has been intentionally placed in the zero current detection circuit. If an external filter is placed on the current sense resistor to the xISENN and xISENP pins, symmetry must be maintained. This means that any resistance between the bottom of the R_{ISENSE} resistor and xISENN must be matched by the same resistor value (1% tolerance) between the top of the R_{ISENSE} resistor and xISENP. Ensure a maximum resistance of 500 Ω. The capacitor value should be chosen such that the RC time constant is between 50 ns and 60 ns. Any external filtering on these pins is optional and not required for operation.

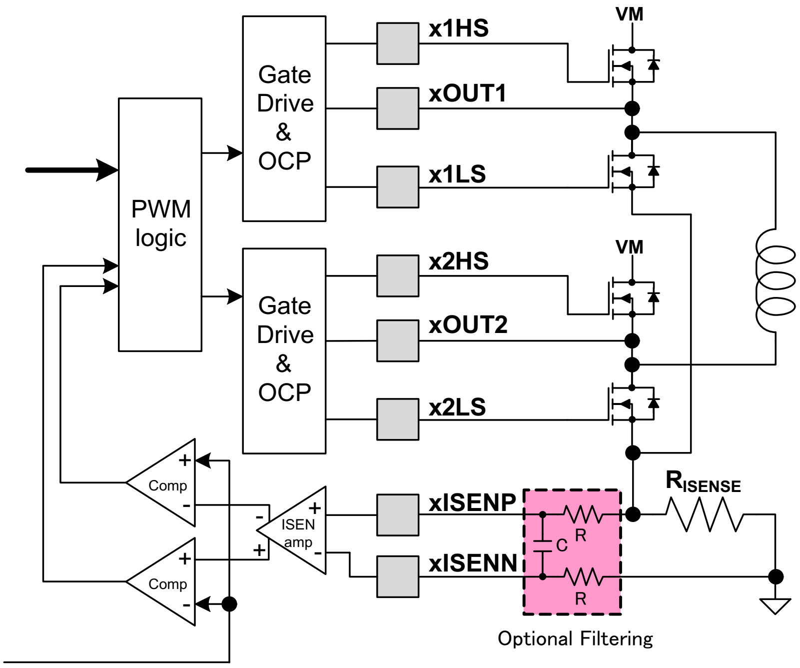


Figure 12. Optional Filtering Between R_{ISENSE} and xINSENx

7.3.6 Blanking Time

After the current is enabled in an H-bridge, the voltage on the ISEN pin is ignored for a period of time before enabling the current sense circuitry. This blanking time is adjustable from 1 μS to 5.12 μs, in 20 ns increments, by setting the TBLANK bits in the BLANK register. Note that the blanking time also sets the minimum on time of the PWM.

The same blanking time is applied to the fast decay period in auto decay mode. The PWM will ignore any transitions on Itrip after entering fast decay mode, until the blanking time has expired.

To provide better current control at very low current steps, an adaptive blanking time mode can be enabled by setting the ABT bit in the BLANK register. If ABT is set, at current levels below 30% of full scale current (as determined by the step table), the blanking time (so also the minimum on time) is cut in half, to 50% of the value programmed by the TBLANK bits.

For higher degrees of micro-stepping, TI recommends enabling ABT bit for better current regulation.

7.3.7 Predrivers

An internal charge pump circuit and predrivers inside the DRV8711 directly drive N-channel MOSFETs, which drive the motor current.

The peak drive current of the predrivers is adjustable by setting the bits in the DRIVE register. Peak source currents may be set to 50 mA, 100 mA, 150 mA, or 200 mA. The peak sink current is approximately 2x the peak source current. Adjusting the peak current will change the output slew rate, which also depends on the FET input capacitance and gate charge.

When changing the state of the output, the peak current is applied for a short period of time (tDRIVE), to charge the gate capacitance. After this time, a weak current source is used to keep the gate at the desired state. When selecting the gate drive strength for a given external FET, the selected current must be high enough to fully charge and discharge the gate during the time when driven at full current, or excessive power will be dissipated in the FET.

During high-side turnon, the low-side gate is pulled low. This prevents the gate-source capacitance of the low-side FET from inducing turnon.

The predriver circuits include enforcement of a dead time in analog circuitry, which prevents the high-side and low-side FETs from conducting at the same time. Additional dead time is added with digital delays. This delay can be selected by setting the DTIME bits in the CTRL register.

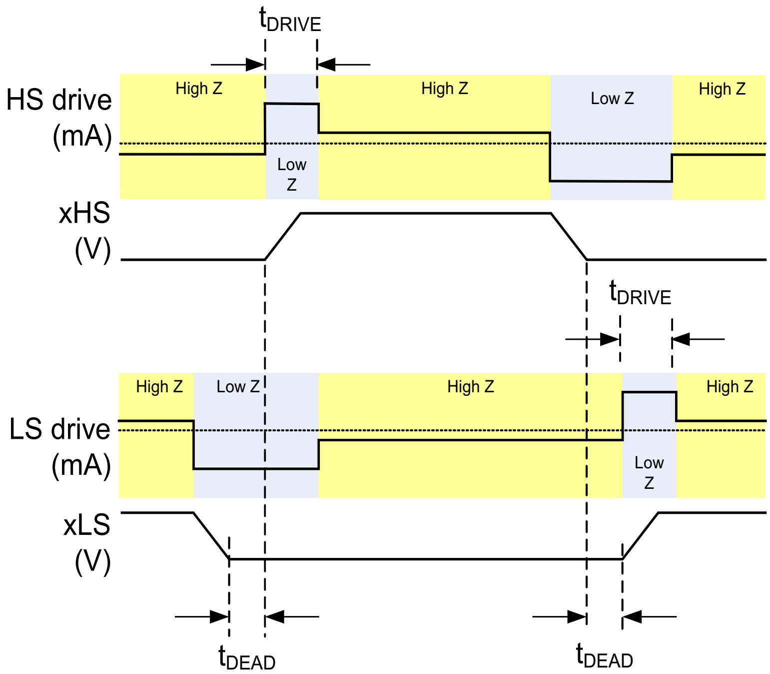


Figure 13. Predrivers

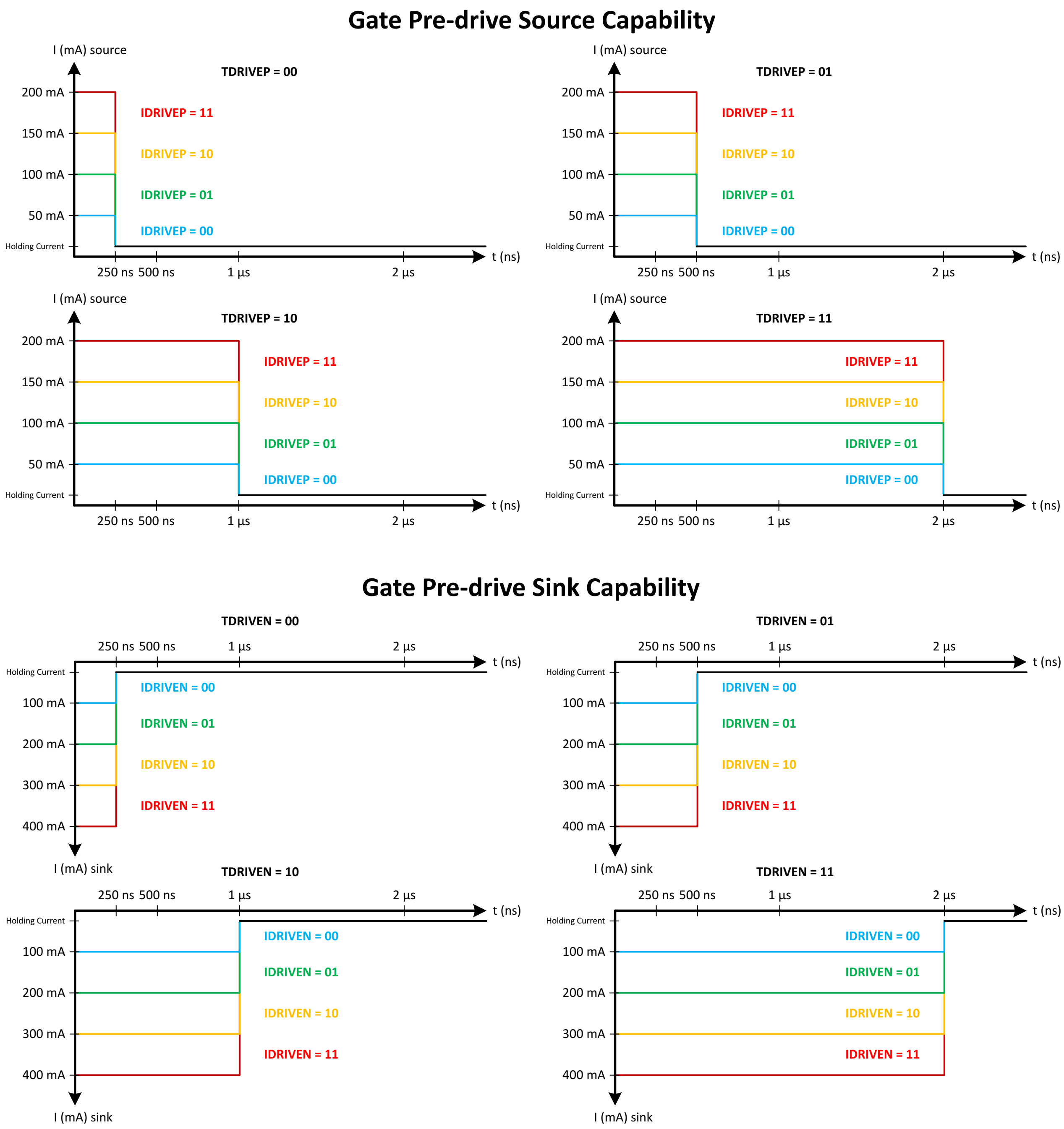


Figure 14. Gate Pre-Drive Source/Sink Capability

7.3.8 Configuring Predrivers

IDRIVE and TDRIVE are selected based on the size of external FETs used. These registers need to be configured so that the FET gates are charged completely during TDRIVE. If IDRIVE and TDRIVE are chosen to be too low for a given FET, then the FET may not turn on completely. TI suggests adjusting these values in-system with the required external FETs and stepper motor to determine the best possible setting for any application.

TDRIVE will not increase the PWM time or change the PWM chopping frequency.

In a system with capacitor charge Q and desired rise time RT, IDRIVE and TDRIVE can be initially selected based on:

IDRIVE > Q / RT

TDRIVE > 2 x RT

For best results, select the smallest IDRIVE and TDRIVE that meet the above conditions.

Example:

If the gate charge is 15 nC and the desired rise time is 400 ns, then select:

IDRIVEP = 50 mA, IDRIVEN = 100 mA

TDRIVEP = TDRIVEN = 1 µs

7.3.9 External FET Selection

In a typical setup, the DRV8711 can support external FETs over 50 nC each. However, this capacity can be lower or higher based on the device operation. For an accurate calculation of FET driving capacity, use the following equation.

$$Q < \frac{20mA \bullet (2 \bullet DTIME + TBLANK + TOFF)}{4} \quad (3)$$

Example:

If a DTIME is set to 0 (400 ns), TBLANK is set to 0 (1 µs), and TOFF is set to 0 (500 ns), then the DRV8711 will support Q < 11.5 nC FETs (this is an absolute worst-case scenario with a PWM frequency approximately 430 kHz).

If a DTIME is set to 0 (400 ns), TBLANK is set to 0 (1 µs), and TOFF is set to 0x14 (10 µs), then the DRV8711 will support Q < 59 nC FETs (PWM frequency approximately 85 kHz).

If a DTIME is set to 0 (400 ns), TBLANK is set to 0 (1 µs), and TOFF is set to 0x60 (48 µs), then the DRV8711 will support Q < 249 nC FETs (PWM frequency approximately 20 kHz).

7.3.10 Stall Detection

The DRV8711 implements a back EMF monitoring scheme that is capable of detecting a stall during stepper motor motion. This stall detection is intended to be used to get an indication when a motor is run into a mechanical stop, or when an increased torque load on the motor causes it to stall.

To determine that a stall has occurred, a drop in motor back EMF is detected. The DRV8711 supports two methods of this detection: an automatic internal stall detection circuit, or the ability to use an external microcontroller to monitor back EMF.

During a zero-current step, one side of the H-bridge is placed in a high impedance state, and the opposite low-side FET is turned on for a brief duration defined by TORQUE register SMPLTH bit [10:8]. This allows the current to decay quickly through the low-side FET and the opposite body diode. Which side of the bridge is tri-state and which one is driven low depends on the current direction on the previous step. The bridge with the high side that has been actively PWMed (at the beginning of the PWM cycle during blank time) before entering the zero-current step will be held low and the opposite side will be tri-stated.

Back EMF is sampled on the tri-stated output pin at the end of SMPLTH time (TORQUE register bit [10:8]). The back EMF from the selected pin is divided by 4, 8, 16, or 32, depending on the setting of the VDIV bits in the STALL register. The voltage is buffered and held on an external capacitor placed on the BEMF pin. The signal on the BEMF output pin can be further processed by a microcontroller to implement more advanced control and stall detection algorithms.

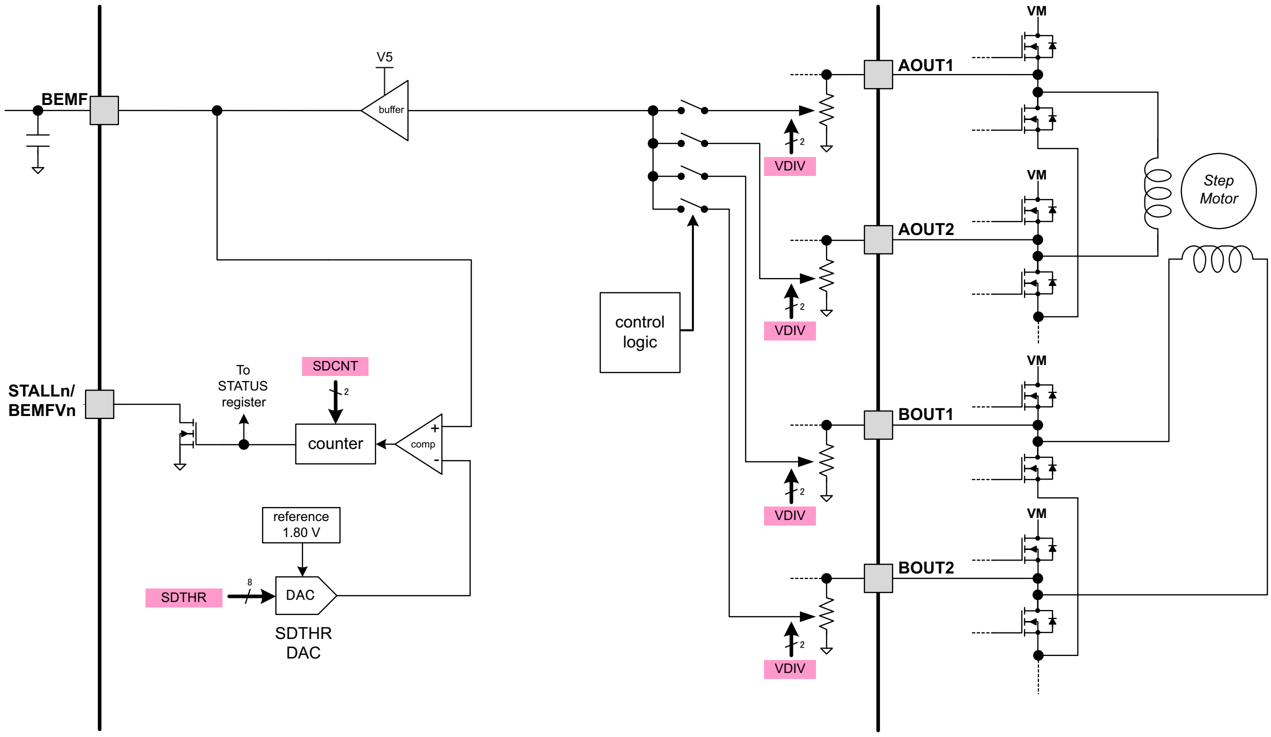


Figure 15. Stall Detection

7.3.10.1 Internal Stall Detection

To use internal stall detection, the EXSTALL bit in the CTRL register is set to 0. In this mode, the STALLn/BEMFVn output pin is used to signal a valid stall condition.

Step time, or rate at which step input is applied to DRV8711, has to be greater than SMPLTH time for back EMF sampling.

Using internal stall detection, a stall is detected when the sampled back EMF drops below the value set by the SDTHR bits in the STALL register. A programmable counter circuit allows the assertion of the STALLn output to be delayed until the back EMF has been sampled below the SDTHR value for more than one zero-current step. The counter is programmed by the SDCNT bits in the STALL register, and provides selections of 1, 2, 4, or 8 steps.

When the stall is detected (at the end of a SMPLTH interval), the STALLn/BEMFVn pin is driven active low, and the STD bit and the STDLAT bit in the STATUS register are set. The STALLn/BEMFVn pin will deassert and the STD bit will automatically clear at the next zero-current step if a stall condition is not detected, while the STDLAT bit will remain set until a 0 is written to it. The STDLAT is reset when the STD bit clears after the first zero-cross step that does not detect a stall condition.

This stall detection scheme is only effective when the motor is stalled while running at or above some minimum speed. Because it relies on detecting a drop in motor back EMF, the motor must be rotating with sufficient speed to generate a detectable back EMF. During motor start-up, and at very slow step rates, the stall detection is not reliable.

Because back EMF can only be sampled during a zero-current state, stall detection is not possible in full step mode. During full-step operation, the stall detect circuit is gated off to prevent false signaling of a stall.

The correct setting of the SDTHR bits needs to be determined experimentally. It is dependent on many factors, including the electrical and mechanical characteristics of the load, the peak current setting, and the supply voltage.

7.3.10.2 External Stall Detection

To use an external microcontroller to manage stall detection, the EXSTALL bit in the CTRL register is set to 1. In this mode, the STALLn / BEMFVn output pin is used to signal a valid back EMF measurement is ready. In addition, the SDT and SDTLAT bits are also set at this time.

BEMFVn and BEMF are still valid outputs in this mode even if the step time is smaller than SMPLTH time.

When the BEMFVn pin goes active low, it is an indication that a valid back EMF voltage measurement is available. This signal could be used, for example, to trigger an interrupt on a microcontroller. The microcontroller can then sample the voltage present (using an A/D converter) on the BEMF pin.

After sampling the back EMF voltage, the microcontroller writes a 0 to the SDTLAT bit to clear the SDT bit and BEMFVn pin, in preparation for the next back EMF sample. If the SDTLAT bit is not cleared by the microcontroller, it will automatically be cleared in the next zero-current step.

For either internal or external stall detection, at very high motor speeds when the PWM duty cycle approaches 100%, the inductance of the motor and the short duration of each step may cause the time required for current recirculation to exceed the step time. In this case, back EMF will not be correctly sampled, and stall detection cannot function. This condition occurs most at high degrees of micro-stepping, because the zero current step lasts for a shorter duration. It is advisable to run the motor at lower degrees of micro-stepping at higher speeds to allow time for current recirculation if stall detection is needed in this condition.

7.3.11 Protection Circuits

The DRV8711 is fully protected against undervoltage, overcurrent and overtemperature events.

7.3.11.1 Overcurrent Protection (OCP)

Overcurrent is sensed by monitoring the voltage drop across the external FETs. If the voltage across a driven FET exceeds the value programmed by the OCPTH bits in the DRIVE register for more than the time period specified by the OCPDEG bits in the DRIVE register, an OCP event is recognized. When operating in direct PWM mode, during an OCP event, the H-bridge experiencing the OCP event is disabled; if operating in indexer mode, both H-bridges will be disabled. In addition, the corresponding xOCP bit in the STATUS register is set, and the FAULTn pin is driven low. The H-bridge(s) will remain off, and the xOCP bit will remain set, until it is written to 0, or the device is reset.

7.3.11.2 Predriver Fault

In PWM mode, if excessive current is detected on the gate drive outputs (which would be indicative of a failed/shorted output FET or PCB fault), the H-bridge experiencing the fault is disabled, the xPDF bit in the STATUS register is set, and the FAULTn pin is driven low. The H-bridge will remain off, and the xPDF bit will remain set until it is written to 0 or the device is reset.

When in indexer mode, both H-bridges are disabled, the xPDF bit in the STATUS register is set, and the FAULTn pin is driven low. The H-bridges will remain off, and the xPDF bit will remain set until it is written to 0 or the device is reset.

7.3.11.3 Thermal Shutdown (TSD)

If the die temperature exceeds safe limits, all FETs in the H-bridge will be disabled, the OTS bit in the STATUS register will be set, and the FAULTn pin will be driven low. Once the die temperature has fallen to a safe level operation will automatically resume and the OTS bit will reset. The FAULTn pin will be released after operation has resumed.

7.3.11.4 Undervoltage Lockout (UVLO)

If at any time the voltage on the VM pin falls below the undervoltage lockout threshold voltage, all FETs in the H-bridge will be disabled, the UVLO bit in the STATUS register will be set, and the FAULTn pin will be driven low. Operation will resume and the UVLO bit will reset when VM rises above the UVLO threshold. The FAULTn pin will be released after operation has resumed.

During any of these fault conditions, the STEP input pin will be ignored.

7.4 Device Functional Modes

7.4.1 RESET and SLEEPn Operation

An internal power-up reset circuit monitors the voltage applied to the VM pin. If VM falls below the VM undervoltage lockout voltage, the part is reset, as described below for the case of asserting the RESET pin.

If the RESET pin is asserted, all internal logic including the indexer is reset. All registers are returned to their initial default conditions. The power stage will be disabled, and all inputs, including STEP and the serial interface, are ignored when RESET is active.

On exiting reset state, some time (approximately 1 mS) needs to pass before the part is fully functional.

Applying an active low input to the SLEEPn input pin will place the device into a low power state. In sleep mode, the motor driver circuitry is disabled, the gate drive regulator and charge pump are disabled, and all analog circuitry is placed into a low power state. The digital circuitry in the device still operates, so the device registers can still be accessed via the serial interface.

When SLEEPn is active, the RESET pin does not function. SLEEPn must be exited before RESET will take effect.

When exiting from sleep mode, some time (approximately 1 mS) needs to pass before applying a STEP input, to allow the internal circuitry to stabilize.

7.4.2 Microstepping Drive Current

Figure 16 shows examples of stepper motor current in one of the windings. Because these waveforms are dependent on DRV8711 register settings as well as the external FETs, sense resistor, and stepper motor, they should only be used as a reference.

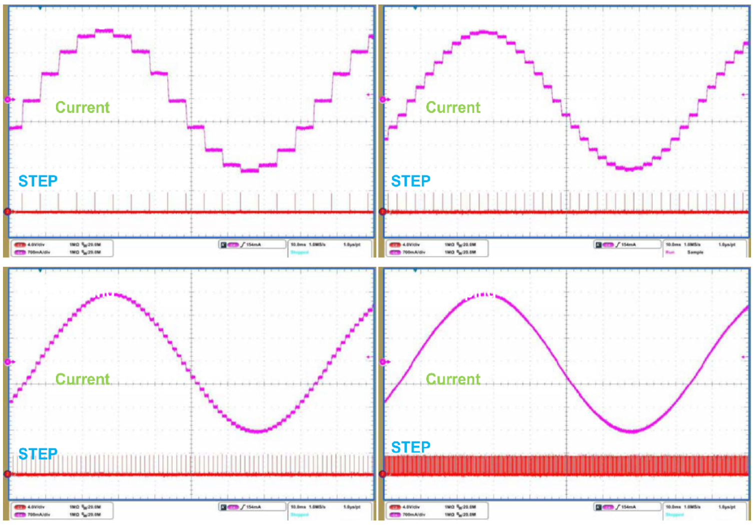


Figure 16. Microstepping Drive Current

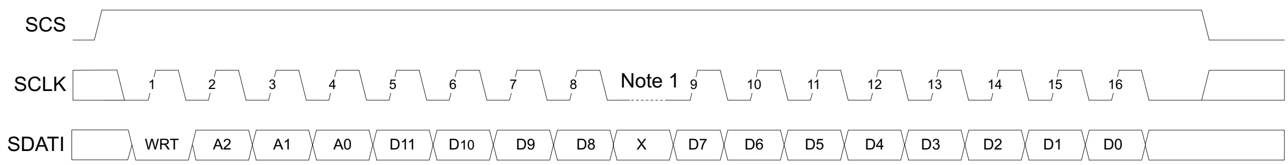
7.5 Programming

7.5.1 Serial Data Format

The serial data consists of a 16-bit serial write, with a read/write bit, 3 address bits and 12 data bits. The 3 address bits identify one of the registers defined in the register section above. To complete the read or write transaction, SCS must be set to a logic 0.

To write to a register, data is shifted in after the address as shown in the timing diagram below. The first bit at the beginning of the access must be logic low for a write operation.

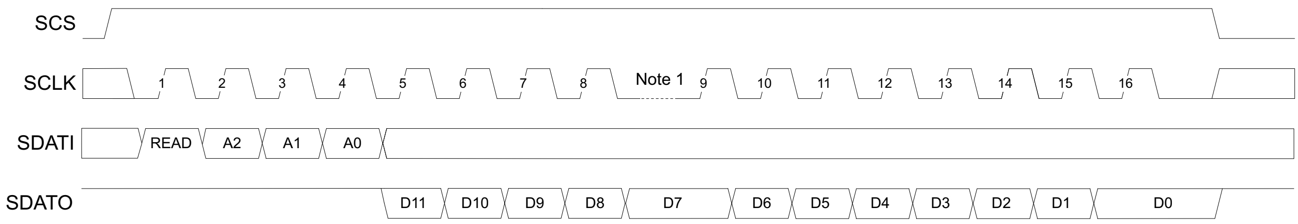
Programming (continued)



A. Any amount of time may pass between bits, as long as SCS stays active high. This allows two 8-bit writes to be used.

Figure 17. Write Operation

Data may be read from the registers through the SDATO pin. During a read operation, only the address is used form the SDATI pin; the data bits following are ignored. The first bit at the beginning of the access must be logic high for a read operation.



(1) Any amount of time may pass between bits, as long as SCS stays active high. This allows two 8-bit writes to be used.

Figure 18. Read Operation

7.6 Register Maps

7.6.1 Control Registers

The DRV8711 uses internal registers to control the operation of the motor. The registers are programmed through a serial SPI communications interface. At power up or reset, the registers will be preloaded with default values as shown in *CTRL Register Address = 0x0h* to *STATUS Register Address = 0x7h*.

Figure 19 is a map of the DRV8711 registers.

Individual register contents are defined in *CTRL Register Address = 0x0h* to *STATUS Register Address = 0x7h*.

DRV8711 REGISTER MAP														
Name	11	10	9	8	7	6	5	4	3	2	1	0		**Address Hex**
CTRL	DTIME		ISGAIN		EXSTALL	MODE				RSTEP	RDIR	ENBL	RW	**00**
TORQUE	Reserved	SMPLTH			TORQUE								RW	**01**
OFF	Reserved			PWMMODE	TOFF								RW	**02**
BLANK	Reserved			ABT	TBLANK								RW	**03**
DECAY	Reserved	DECMOD			TDECAY								RW	**04**
STALL	VDIV		SDCNT		SDTHR								RW	**05**
DRIVE	IDRIVEP		IDRIVEN		TDRIVEP		TDRIVEN		OCPDEG		OCPTH		RW	**06**
STATUS	Reserved				STDLAT	STD	UVLO	BPDF	APDF	BOCP	AOCP	OTS	RW	**07**
Name	11	10	9	8	7	6	5	4	3	2	1	0		**Address Hex**

Figure 19. DRV8711 Register Map

Register Maps (continued)

7.6.2 CTRL Register Address = 0x0h

BIT	NAME	SIZE	R/W	DEFAULT	DESCRIPTION
0	ENBL	1	R/W	0	**0: Disable motor** 1: Enable motor
1	RDIR	1	R/W	0	**0: Direction set by DIR pin** 1: Direction set by inverse of DIR pin
2	RSTEP	1	W	0	0: No action 1: Indexer will advance one step; automatically cleared after write
6-3	MODE	4	R/W	0010	0000: Full-step, 71% current 0001: Half step **0010: 1/4 step** 0011: 1/8 step 0100: 1/16 step 0101: 1/32 step 0110: 1/64 step 0111: 1/128 step 1000: 1/256 step 1001 – 1111: Reserved
7	EXSTALL	1	R/W	0	**0: Internal stall detect** 1: External stall detect
9-8	ISGAIN	2	R/W	00	ISENSE amplifier gain set **00: Gain of 5** 01: Gain of 10 10: Gain of 20 11: Gain of 40
11-10	DTIME	2	R/W	11	Dead time set 00: 400 ns dead time 01: 450 ns dead time 10: 650 ns dead time **11: 850 ns dead time**

7.6.3 TORQUE Register Address = 0x1h

BIT	NAME	SIZE	R/W	DEFAULT	DESCRIPTION
7-0	TORQUE	8	R/W	0xFFh	Sets full-scale output current for both H-bridges
10-8	SMPLTH	3	R/W	001	Back EMF sample threshold 000: 50 μs **001: 100 μs** 010: 200 μs 011: 300 μs 100: 400 μs 101: 600 μs 110: 800 μs 111: 1000 μs
11	Reserved	1	-	-	Reserved

7.6.4 OFF Register Address = 0x2h

BIT	NAME	SIZE	R/W	DEFAULT	DESCRIPTION
7-0	TOFF	8	R/W	0x30h	Sets fixed off time, in increments of 500 ns 0x00h: 500 ns 0xFFh: 128 μs
8	PWMMODE	1	R/W	0	**0: Use internal indexer** 1: Bypass indexer, use xINx inputs to control outputs
11-9	Reserved	3	-	-	Reserved

7.6.5 BLANK Register Address = 0x3h

BIT	NAME	SIZE	R/W	DEFAULT	DESCRIPTION
7-0	TBLANK	8	R/W	0x80h	Sets current trip blanking time, in increments of 20 ns 0x00h: 1 µs 0x32h: 1 µs 0x33h: 1.02 µs 0xFEh: 5.10 µs 0xFFh: 5.12 µs Also sets minimum on-time of PWM
8	ABT	1	R/W	0	**0: Disable adaptive blanking time** 1: Enable adaptive blanking time
11-9	Reserved	3	-	-	Reserved

7.6.6 DECAY Register Address = 0x4h

BIT	NAME	SIZE	R/W	DEFAULT	DESCRIPTION
7-0	TDECAY	8	R/W	0x10h	Sets mixed decay transition time, in increments of 500 ns
10-8	DECMOD	3	R/W	001	000: Force slow decay at all times **001: Slow decay for increasing current, mixed decay for decreasing current (indexer mode only)** 010: Force fast decay at all times 011: Use mixed decay at all times 100: Slow decay for increasing current, auto mixed decay for decreasing current (indexer mode only) 101: Use auto mixed decay at all times 110 – 111: Reserved
11	Reserved	1	-	-	Reserved

7.6.7 STALL Register Address = 0x5h

BIT	NAME	SIZE	R/W	DEFAULT	DESCRIPTION
7-0	SDTHR	8	R/W	0x40h	Sets stall detect threshold The correct setting needs to be determined experimentally
9-8	SDCNT	2	R/W	00	**00: STALLn asserted on first step with back EMF below SDTHR** 01: STALLn asserted after 2 steps 10: STALLn asserted after 4 steps 11: STALLn asserted after 8 steps
11-10	VDIV	2	R/W	00	**00: Back EMF is divided by 32** 01: Back EMF is divided by 16 10: Back EMF is divided by 8 11: Back EMF is divided by 4

7.6.8 DRIVE Register Address = 0x6h

BIT	NAME	SIZE	R/W	DEFAULT	DESCRIPTION
1-0	OCPTH	2	R/W	00	OCP threshold **00: 250 mV** 01: 500 mV 10: 750 mV 11: 1000 mV
3-2	OCPDEG	2	R/W	01	OCP deglitch time 00: 1 µs **01: 2 µs** 10: 4 µs 11: 8 µs
5-4	TDRIVEN	2	R/W	01	Low-side gate drive time 00: 250 ns **01: 500 ns** 10: 1 µs 11: 2 µs

BIT	NAME	SIZE	R/W	DEFAULT	DESCRIPTION
7-6	TDRIVEP	2	R/W	01	High-side gate drive time 00: 250 ns **01: 500 ns** 10: 1 µs 11: 2 µs
9-8	IDRIVEN	2	R/W	00	Low-side gate drive peak current **00: 100 mA peak (sink)** 01: 200 mA peak (sink) 10: 300 mA peak (sink) 11: 400 mA peak (sink)
11-10	IDRIVEP	2	R/W	00	High-side gate drive peak current **00: 50 mA peak (source)** 01: 100 mA peak (source) 10: 150 mA peak (source) 11: 200 mA peak (source)

7.6.9 STATUS Register Address = 0x7h

BIT	NAME	SIZE	R/W	DEFAULT	DESCRIPTION
0	OTS	1	R	0	0: Normal operation 1: Device has entered overtemperature shutdown OTS bit will clear once temperature has fallen to safe levels
1	AOCP	1	R/W	0	0: Normal operation 1: Channel A overcurrent shutdown Write a ‘0’ to this bit to clear the fault and resume operation
2	BOCP	1	R/W	0	0: Normal operation 1: Channel B overcurrent shutdown Write a ‘0’ to this bit to clear the fault and resume operation
3	APDF	1	R/W	0	0: Normal operation 1: Channel A predriver fault Write a ‘0’ to this bit to clear the fault and resume operation
4	BPDF	1	R/W	0	0: Normal operation 1: Channel B predriver fault Write a ‘0’ to this bit to clear the fault and resume operation
5	UVLO	1	R	0	0: Normal operation 1: Undervoltage lockout UVLO bit will clear after VM has increased over V_{UVLO}
6	STD	1	R	0	0: Normal operation 1: Stall detected
7	STDLAT	1	R/W	0	0: Normal operation 1: Latched stall detect Write a ‘0’ to this bit to clear the fault and resume operation
11-8	Reserved	4	-	-	Reserved

8 Applications and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The DRV8711 is used in bipolar stepper control. The microstepping motor predriver provides additional precision and a smooth rotation from the stepper motor.

8.1.1 Sense Resistor

For optimal performance, it is important for the sense resistor to be:

- Surface-mount
- Low inductance
- Rated for high enough power
- Placed closely to the motor driver

The power dissipated by the sense resistor equals $I_{RMS}^2 \times R$. For example, if peak motor current is 3 A, RMS motor current is 2 A, and a 0.05-Ω sense resistor is used, the resistor will dissipate $2\ A^2 \times 0.05\ \Omega = 0.2\ W$. The power quickly increases with higher current levels.

Resistors typically have a rated power within some ambient temperature range, along with a derated power curve for high ambient temperatures. When a PCB is shared with other components generating heat, margin should be added. It is always best to measure the actual sense resistor temperature in a final system, along with the power MOSFETs, as those are often the hottest components.

Because power resistors are larger and more expensive than standard resistors, it is common practice to use multiple standard resistors in parallel, between the sense node and ground. This distributes the current and heat dissipation.

8.1.2 Optional Series Gate Resistor

In high current or high voltage applications, the low side predriver fault may assert due to noise in the system. In this application, TI recommends placing a 47 to 120-Ω resistor in series with the low side output and the gate of the low side FET. TI also recommends setting the dead time to 850 ns when adding a series resistor.

8.2 Typical Application

The following design is a common application of the DRV8711.

Typical Application (continued)

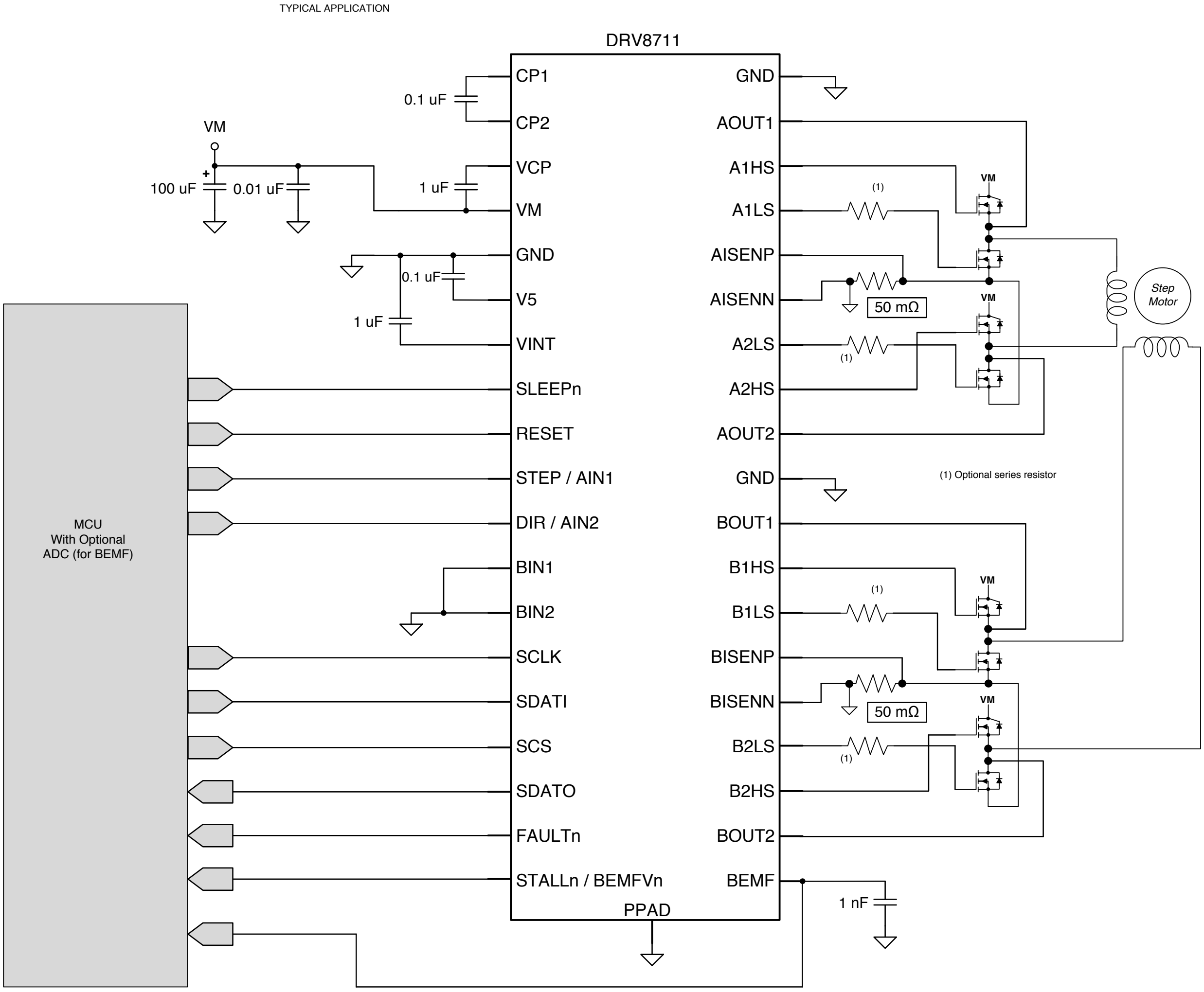


Figure 20. Typical Application Schematic

8.2.1 Design Requirements

For this design example, use the parameters listed in Table 5 as the input parameters.

Table 5. Design Parameters

DESIGN PARAMETER	REFERENCE	EXAMPLE VALUE
Supply Voltage	VM	24 V
Motor Winding Resistance	R_L	3.9 Ω
Motor Winding Inductance	I_L	2.9 mH
Motor Full Step Angle	$θ_{step}$	1.8°/step
Target Microstepping Level	n_m	8 μsteps per step
Target Motor Speed	v	120 RPM
Target Full-Scale Current	I_{FS}	1.25 A

8.2.2 Detailed Design Procedure

8.2.2.1 Stepper Motor Speed

The first step in configuring the DRV8711 requires the desired motor speed and microstepping level. If the target application requires a constant speed, then a square wave with frequency f_{step} must be applied to the STEP pin.

If the target motor start-up speed is too high, the motor will not spin. Make sure that the motor can support the target speed or implement an acceleration profile to bring the motor up to speed.

For a desired motor speed (V), microstepping level (n_m), and motor full step angle (θ_{step}),

$$f_{step}\left(\mu\text{steps/second}\right) = \frac{v\left(\frac{\text{rotations}}{\text{minute}}\right) \times 360\left(\frac{°}{\text{rotation}}\right) \times n_m\left(\frac{\mu\text{steps}}{\text{step}}\right)}{60\left(\frac{\text{seconds}}{\text{minute}}\right) \times \theta_{step}\left(\frac{°}{\text{step}}\right)} \tag{4}$$

$$f_{step}\left(\mu\text{steps/second}\right) = \frac{120\left(\frac{\text{rotations}}{\text{minute}}\right) \times 360\left(\frac{°}{\text{rotation}}\right) \times 8\left(\frac{\mu\text{steps}}{\text{step}}\right)}{60\left(\frac{\text{seconds}}{\text{minute}}\right) \times 1.8\left(\frac{°}{\text{step}}\right)} \tag{5}$$

θ_{step} can be found in the stepper motor data sheet or written on the motor itself.

For the DRV8711, the microstepping level is set by the MODE bits in the CTRL register. Higher microstepping will mean a smoother motor motion and less audible noise, but will increase switching losses and require a higher f_{step} to achieve the same motor speed.

8.2.2.2 Current Regulation

In a stepper motor, the set full-scale current (I_{FS}) is the maximum current driven through either winding. For the DRV8711, this quantity will depend on the analog voltage, the programmed torque and gain values, and the sense resistor value (R_{SENSE}). During stepping, IFS defines the current chopping threshold (I_{TRIP}) for the maximum current step. The gain of DRV8711 is set for 5 V/V.

$$I_{FS}(A) = \frac{2.75(V) \times \text{TORQUE}}{256 \times \text{ISGAIN} \times R_{SENSE}(\Omega)} \tag{6}$$

To achieve I_{FS} = 1.25 A with R_{SENSE} of 0.2 Ω with a gain of 5, TORQUE should be set to 116(dec).

8.2.2.3 Decay Modes

The DRV8711 supports three different decay modes: slow decay, fast decay, and mixed decay. The DRV8711 also supports automatic mixed decay mode, which minimizes current ripple. The current through the motor windings is regulated using programmable settings for blanking, decay and off time. This means that after any drive phase, when a motor winding current has hit the current chopping threshold (I_{TRIP}), the DRV8711 will place the winding in the programmed decay modes until the cycle has expired. Afterward, a new drive phase starts.

The blanking time T_{BLANK} defines the minimum drive time for the current chopping. I_{TRIP} is ignored during T_{BLANK}, so the winding current may overshoot the trip level.

8.2.3 Application Curves

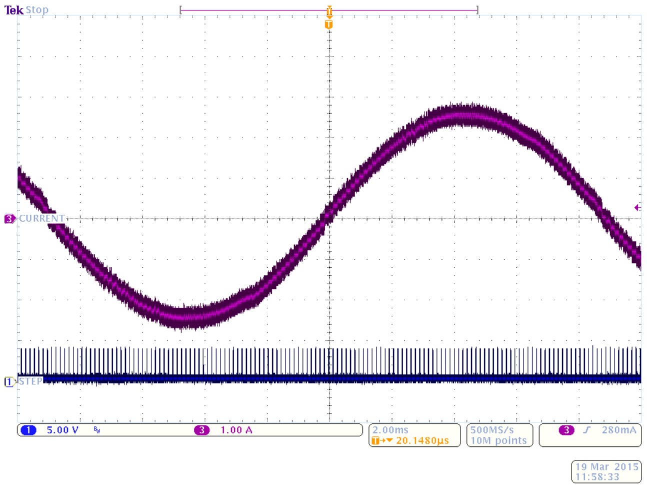


Figure 21. 1/32 Microstepping Drive Current

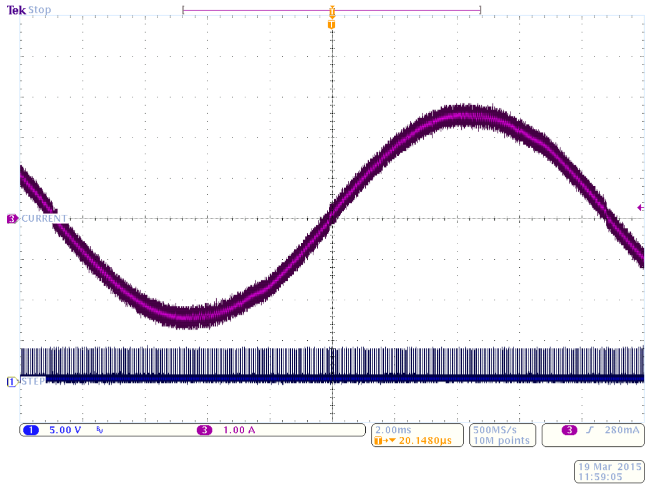


Figure 22. 1/64 Microstepping Drive Current

9 Power Supply Recommendations

9.1 Bulk Capacitance

Having an appropriate local bulk capacitance is an important factor in motor drive system design. It is generally beneficial to have more bulk capacitance, while the disadvantages are increased cost and physical size.

The amount of local capacitance needed depends on a variety of factors, including:

- The highest current required by the motor system
- The power supply's capacitance and ability to source current
- The amount of parasitic inductance between the power supply and motor system
- The acceptable voltage ripple
- The type of motor used (Brushed DC, Brushless DC, Stepper)
- The motor braking method

The inductance between the power supply and the motor drive system limits the rate current can change from the power supply. If the local bulk capacitance is too small, the system responds to excessive current demands or dumps from the motor with a change in voltage. When adequate bulk capacitance is used, the motor voltage remains stable and high current can be quickly supplied.

The data sheet generally provides a recommended value, but system-level testing is required to determine the appropriate sized bulk capacitor.

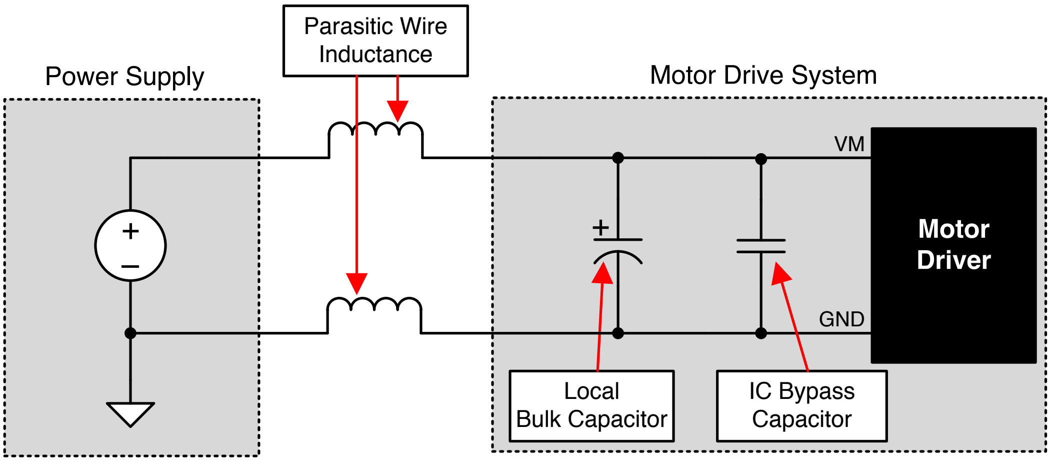


Figure 23. Example Setup of Motor Drive System With External Power Supply

The voltage rating for bulk capacitors should be higher than the operating voltage, to provide margin for cases when the motor transfers energy to the supply.

10 Layout

10.1 Layout Guidelines

The VM pin should be bypassed to GND using low-ESR ceramic bypass capacitors with a recommended value of 0.01-µF rated for VM. This capacitor should be placed as close to the VM pin as possible with a thick trace or ground plane connection to the device GND pin. The VM pin must be bypassed to ground using an appropriate bulk capacitor. This component may be an electrolytic and should be located close to the DRV8711.

A low-ESR ceramic capacitor must be placed in between the VM and VCP pins. TI recommends a value of 1 µF rated for 16 V. Place this component as close to the pins as possible.

A low-ESR ceramic capacitor must be placed in between the CP1 and CP2 pins. TI recommends a value of 0.1 µF rated for VM. Place this component as close to the pins as possible.

Bypass VINT to ground with a 1-µF ceramic capacitor rated 6.3 V. Place this bypass capacitor as close to the pin as possible.

Bypass V5 to ground with a 1-µF ceramic capacitor rated 10 V. Place this bypass capacitor as close to the pin as possible.

10.2 Layout Example

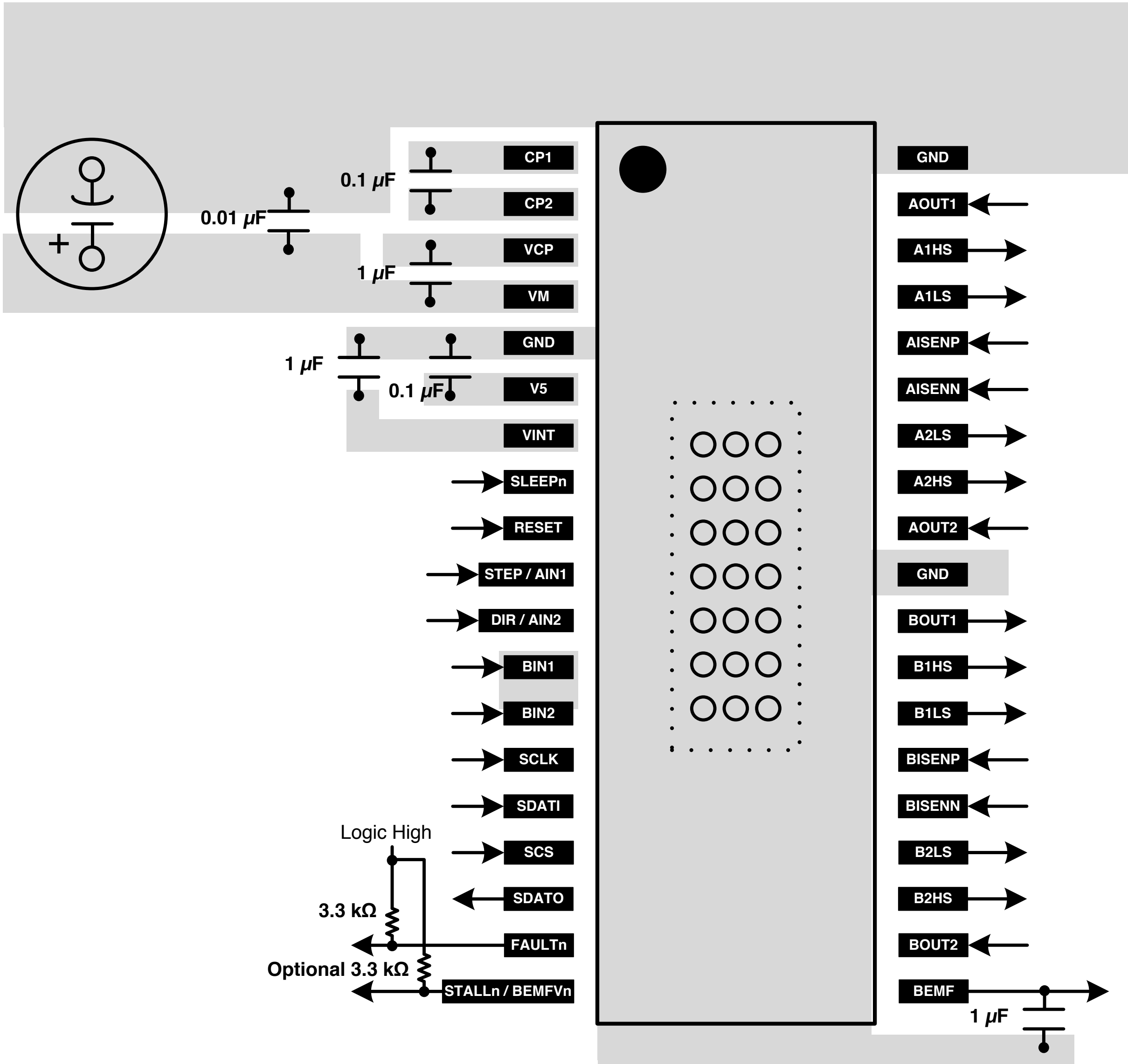


Figure 24. Recommended Layout Example

11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation

For related documentation see the following:

- *DRV8711 Decay Mode Setting Optimization*, SLVA637
- *DRV8711 Quick Spin and Tuning Guide*, SLVA632
- *PowerPAD™ Thermally Enhanced Package*, SLMA002
- *PowerPAD™ Made Easy*, SLMA004

11.2 Trademarks

PowerPAD is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

11.3 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

11.4 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
DRV8711DCP	ACTIVE	HTSSOP	DCP	38	50	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	DRV8711	Samples
DRV8711DCPR	ACTIVE	HTSSOP	DCP	38	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	DRV8711	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

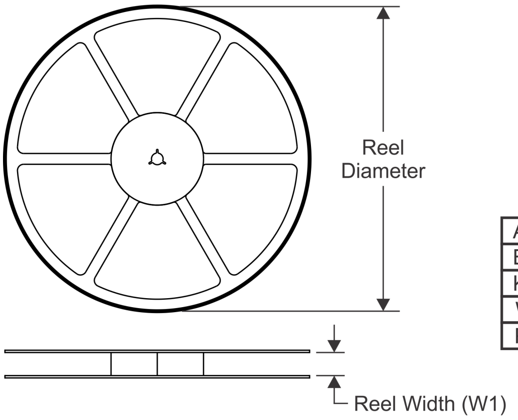
(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

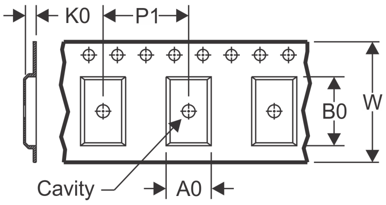
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

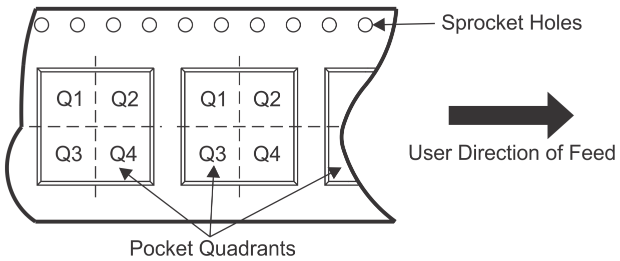


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

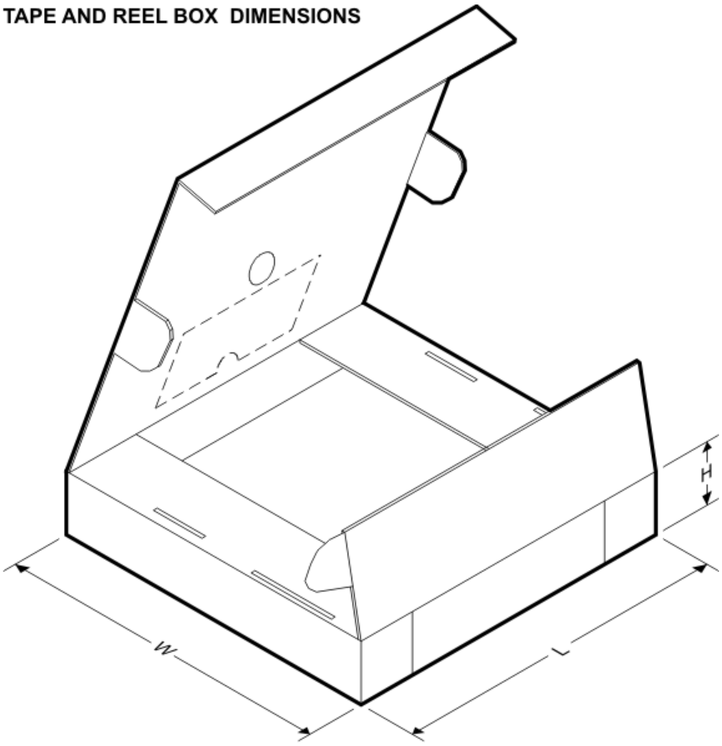
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
DRV8711DCPR	HTSSOP	DCP	38	2000	330.0	16.4	6.9	10.2	1.8	12.0	16.0	Q1

TAPE AND REEL BOX DIMENSIONS

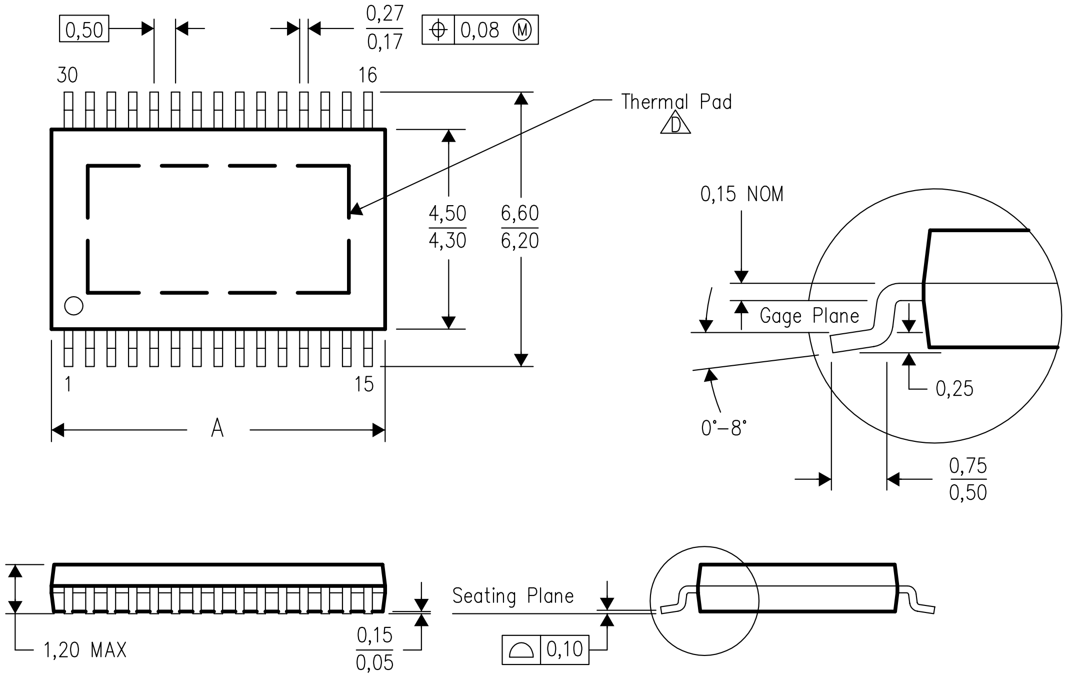


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
DRV8711DCPR	HTSSOP	DCP	38	2000	367.0	367.0	38.0

DCP (R–PDSO–G**) PowerPAD™ PLASTIC SMALL–OUTLINE PACKAGE

30 PIN SHOWN



PINS ** / DIM	28	30	38	44	50
A MAX	7,90	7,90	9,80	11,40	12,60
A MIN	7,70	7,70	9,60	11,20	12,40

4073267/C 03/05

NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protusions, mold flash not to exceed 0.15mm.
- D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding recommended board layout. This document is available at www.ti.com. See the product data sheet for details regarding the exposed thermal pad dimensions.
- E. Falls within JEDEC MO–153

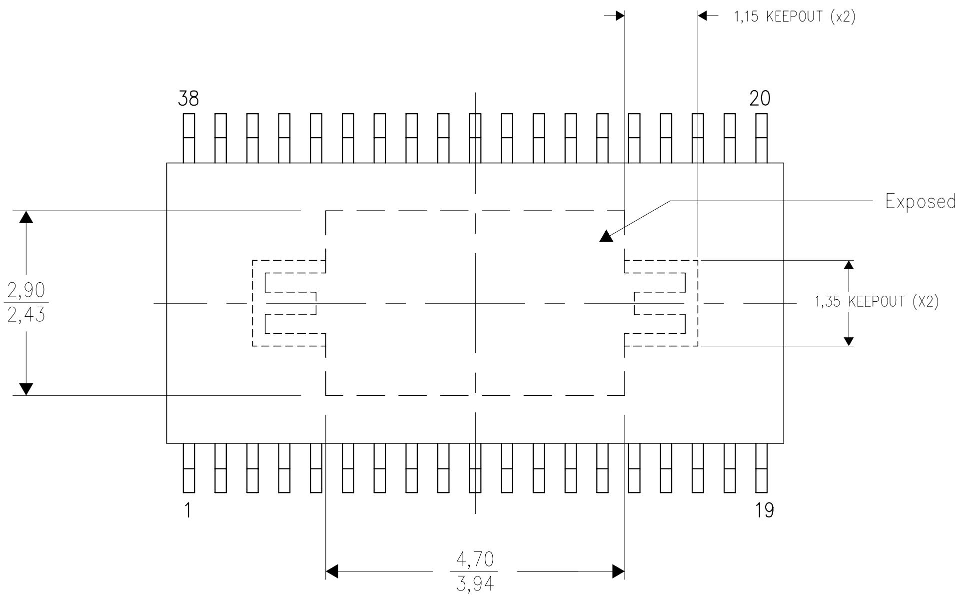
PowerPAD is a trademark of Texas Instruments.

THERMAL INFORMATION

This PowerPAD™ package incorporates an exposed thermal pad that is designed to be attached to a printed circuit board (PCB). The thermal pad must be soldered directly to the PCB. After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.

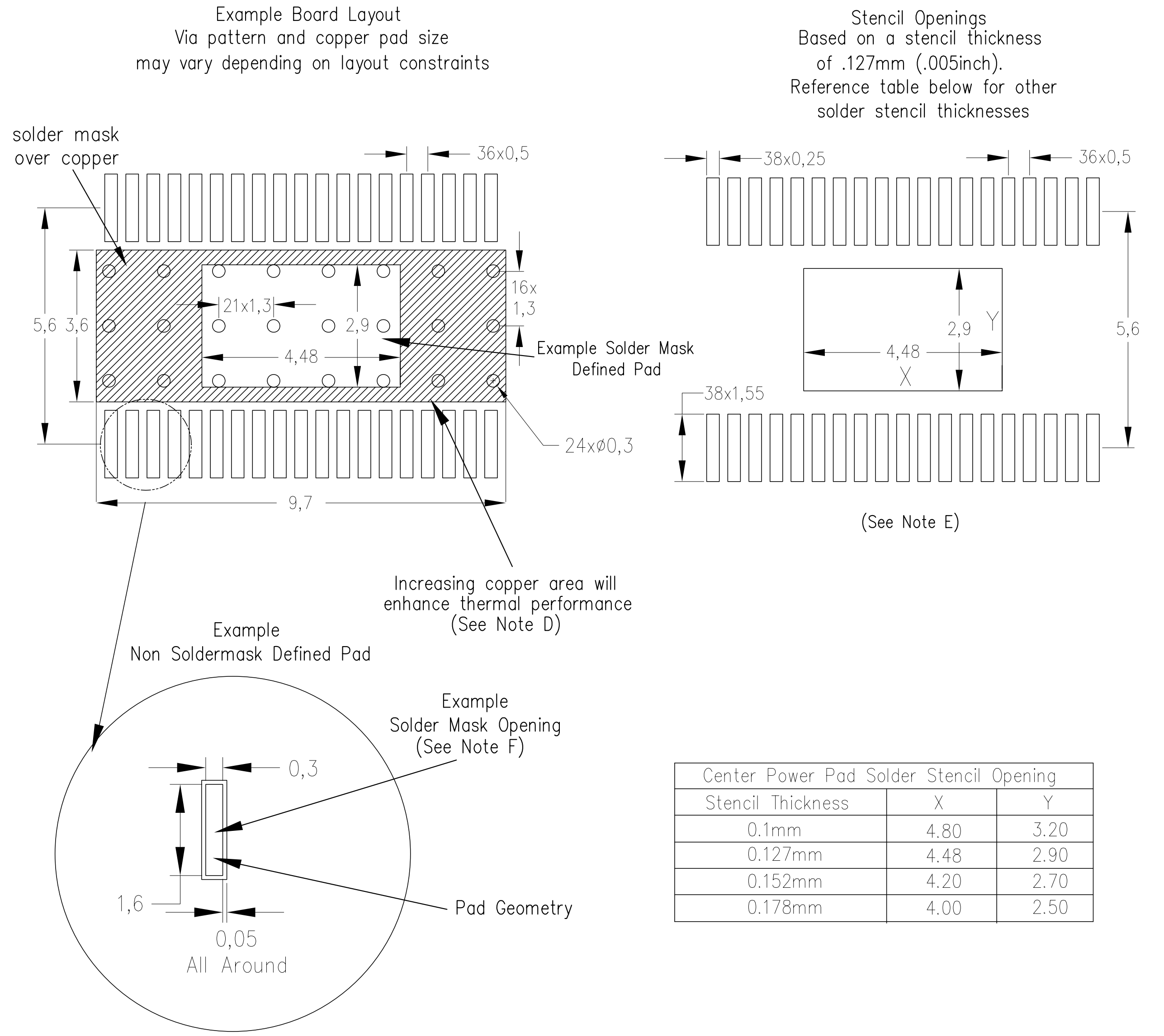


Top View

NOTE: All linear dimensions are in millimeters

Exposed Thermal Pad Dimensions

DCP (R–PDSO–G38) PowerPAD™



Center Power Pad Solder Stencil Opening		
Stencil Thickness	X	Y
0.1mm	4.80	3.20
0.127mm	4.48	2.90
0.152mm	4.20	2.70
0.178mm	4.00	2.50

4207875–3/B 11/09

NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
- D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002, SLMA004, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <http: //www.ti.com>. Publication IPC–7351 is recommended for alternate designs.
- E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC–7525 for other stencil recommendations.
- F. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

IMPORTANT NOTICE

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

B.3. MOSFET IRF520

9.2A, 100V, 0.270 Ohm, N-Channel Power MOSFET

This N-Channel enhancement mode silicon gate power field effect transistor is an advanced power MOSFET designed, tested, and guaranteed to withstand a specified level of energy in the breakdown avalanche mode of operation. All of these power MOSFETs are designed for applications such as switching regulators, switching convertors, motor drivers, relay drivers, and drivers for high power bipolar switching transistors requiring high speed and low gate drive power. These types can be operated directly from integrated circuits.

Formerly developmental type TA09594.

Ordering Information

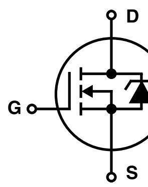
PART NUMBER	PACKAGE	BRAND
IRF520	TO-220AB	IRF520

NOTE: When ordering, use the entire part number.

Features

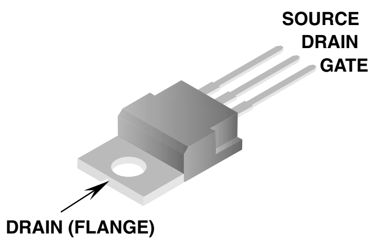
- 9.2A, 100V
- $r_{DS(ON)} = 0.270\Omega$
- SOA is Power Dissipation Limited
- Single Pulse Avalanche Energy Rated
- Nanosecond Switching Speeds
- Linear Transfer Characteristics
- High Input Impedance
- Related Literature
  - TB334 “Guidelines for Soldering Surface Mount Components to PC Boards”

Symbol



Packaging

JEDEC TO-220AB



Absolute Maximum Ratings $T_C = 25^oC$, Unless Otherwise Specified

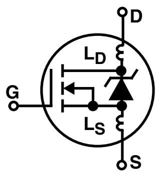
		IRF520	UNITS
Drain to Source Breakdown Voltage (Note 1)	V_{DS}	100	V
Drain to Gate Voltage (R_{GS} = 20kΩ) (Note 1)	V_{DGR}	100	V
Continuous Drain Current	I_D	9.2	A
$T_C = 100^oC$	I_D	6.5	A
Pulsed Drain Current (Note 3)	I_{DM}	37	A
Gate to Source Voltage	V_{GS}	±20	V
Maximum Power Dissipation	P_D	60	W
Dissipation Derating Factor		0.4	$W/^oC$
Single Pulse Avalanche Energy Rating (Note 4)	E_{AS}	36	mJ
Operating and Storage Temperature	T_J, T_{STG}	-55 to 175	^oC
Maximum Temperature for Soldering			
Leads at 0.063in (1.6mm) from Case for 10s	T_L	300	^oC
Package Body for 10s, See Techbrief 334	T_{pkg}	260	^oC

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

NOTE:

1. $T_J = 25^oC$ to 150^oC.

Electrical Specifications $T_C = 25^oC$, Unless Otherwise Specified

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Drain to Source Breakdown Voltage	BV_{DSS}	I_D = 250μA, V_{GS} = 0V (Figure 10)	100	-	-	V
Gate to Threshold Voltage	$V_{GS(TH)}$	$V_{GS} = V_{DS}$, I_D = 250μA	2.0	-	4.0	V
Zero Gate Voltage Drain Current	I_{DSS}	V_{DS} = 95V, V_{GS} = 0V	-	-	250	μA
		V_{DS} = 0.8 x Rated BV_{DSS}, V_{GS} = 0V, $T_J = 150^oC$	-	-	1000	μA
On-State Drain Current (Note 2)	$I_{D(ON)}$	$V_{DS} > I_{D(ON)} \times r_{DS(ON)MAX}$, V_{GS} = 10V (Figure 7)	9.2	-	-	A
Gate to Source Leakage Current	I_{GSS}	V_{GS} = ±20V	-	-	±100	nA
Drain to Source On Resistance (Note 2)	$r_{DS(ON)}$	I_D = 5.6A, V_{GS} = 10V (Figure 8, 9)	-	0.25	0.27	Ω
Forward Transconductance (Note 2)	g_{fs}	$V_{DS} \geq$ 50V, I_D = 5.6A (Figure 12)	2.7	4.1	-	S
Turn-On Delay Time	$t_{d(ON)}$	V_{DD} = 50V, $I_D \approx$ 9.2A, R_G = 18Ω, R_L = 5.5Ω MOSFET Switching Times are Essentially Independent of Operating Temperature	-	9	13	ns
Rise Time	t_r		-	30	63	ns
Turn-Off Delay Time	$t_{d(OFF)}$		-	18	70	ns
Fall Time	t_f		-	20	59	ns
Total Gate Charge (Gate to Source + Gate to Drain)	$Q_{g(TOT)}$	V_{GS} = 10V, I_D = 9.2A, V_{DS} = 0.8 x Rated BV_{DSS}, $I_{g(REF)}$ = 1.5mA (Figure 14) Gate Charge is Essentially Independent of Operating Temperature	-	10	30	nC
Gate to Source Charge	Q_{gs}		-	2.5	-	nC
Gate to Drain "Miller" Charge	Q_{gd}		-	2.5	-	nC
Input Capacitance	C_{ISS}	V_{DS} = 25V, V_{GS} = 0V, f = 1MHz (Figure 11)	-	350	-	pF
Output Capacitance	C_{OSS}		-	130	-	pF
Reverse Transfer Capacitance	C_{RSS}		-	25	-	pF
Internal Drain Inductance	L_D	Measured From the Contact Screw On Tab To Center of Die / Modified MOSFET Symbol Showing the Internal Devices Inductances 	-	3.5	-	nH
		Measured From the Drain Lead, 6mm (0.25in) From Package to Center of Die	-	4.5	-	nH
Internal Source Inductance	L_S	Measured From the Source Lead, 6mm (0.25in) From Header to Source Bonding Pad	-	7.5	-	nH
Thermal Resistance Junction to Case	$R_{\theta JC}$		-	-	2.5	$^oC/W$
Thermal Resistance Junction to Ambient	$R_{\theta JA}$	Free Air Operation	-	-	80	$^oC/W$

Test Circuits and Waveforms

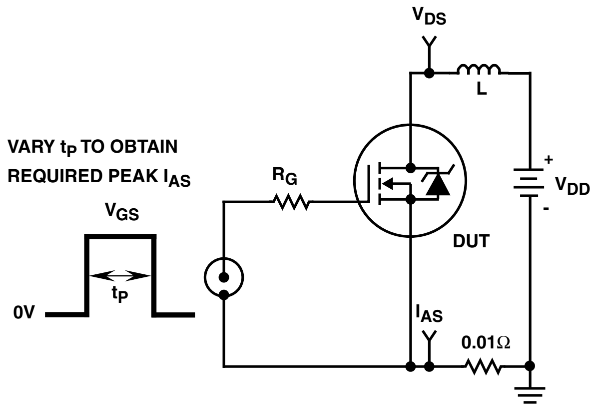


FIGURE 15. UNCLAMPED ENERGY TEST CIRCUIT

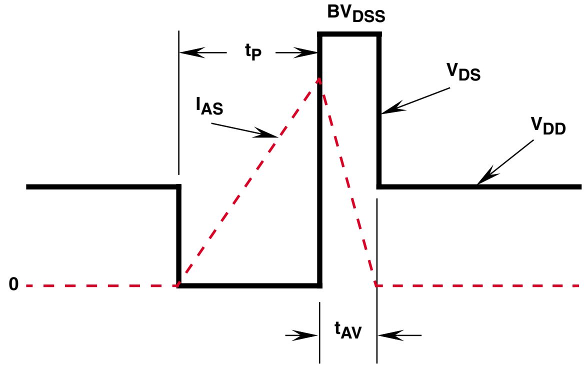


FIGURE 16. UNCLAMPED ENERGY WAVEFORMS

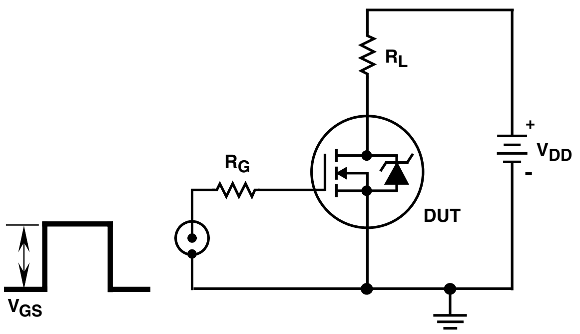


FIGURE 17. SWITCHING TIME TEST CIRCUIT

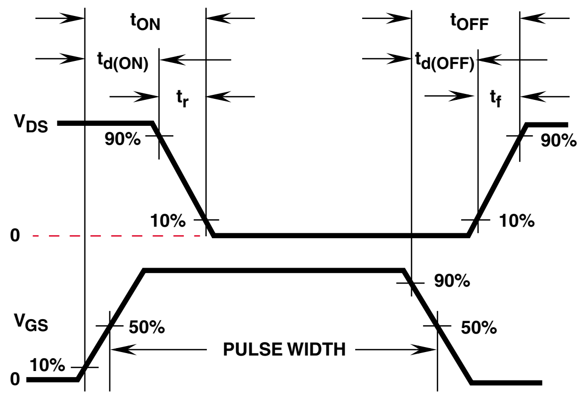


FIGURE 18. RESISTIVE SWITCHING WAVEFORMS

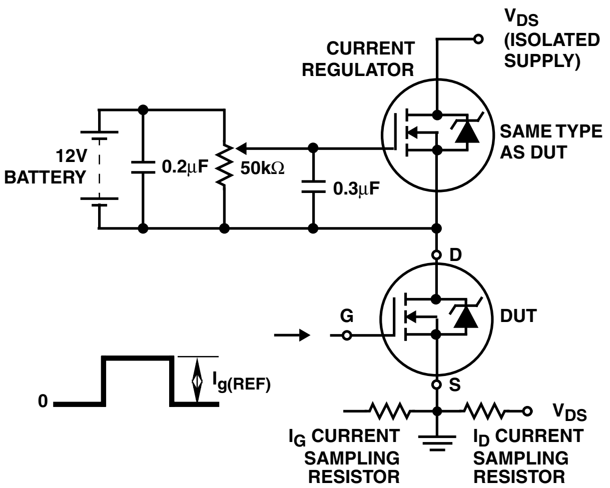


FIGURE 19. GATE CHARGE TEST CIRCUIT

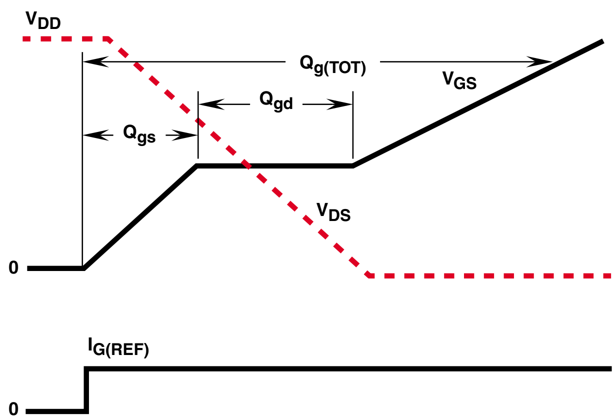
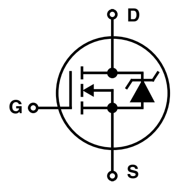


FIGURE 20. GATE CHARGE WAVEFORMS

Source to Drain Diode Specifications

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Continuous Source to Drain Current	I_{SD}	Modified MOSFET Symbol Showing the Integral Reverse P-N Junction Diode 	-	-	9.2	A
Pulse Source to Drain Current (Note 3)	I_{SDM}		-	-	37	A
Source to Drain Diode Voltage (Note 2)	V_{SD}	$T_J = 25^oC$, $I_{SD} = 9.2A$, $V_{GS} = 0V$ (Figure 13)	-	-	2.5	V
Reverse Recovery Time	t_{rr}	$T_J = 25^oC$, $I_{SD} = 9.2A$, $dI_{SD}/dt = 100A/\mu s$	5.5	100	240	ns
Reverse Recovered Charge	Q_{RR}	$T_J = 25^oC$, $I_{SD} = 9.2A$, $dI_{SD}/dt = 100A/\mu s$	0.17	0.5	1.1	μC

NOTES:

2. Pulse test: pulse width ≤ 300μs, duty cycle ≤ 2%.
3. Repetitive rating: pulse width limited by Max junction temperature. See Transient Thermal Impedance curve (Figure 3).
4. $V_{DD} = 25V$, starting $T_J = 25^oC$, L = 640mH, $R_G = 25\Omega$, peak $I_{AS} = 9.2A$.

Typical Performance Curves Unless Otherwise Specified

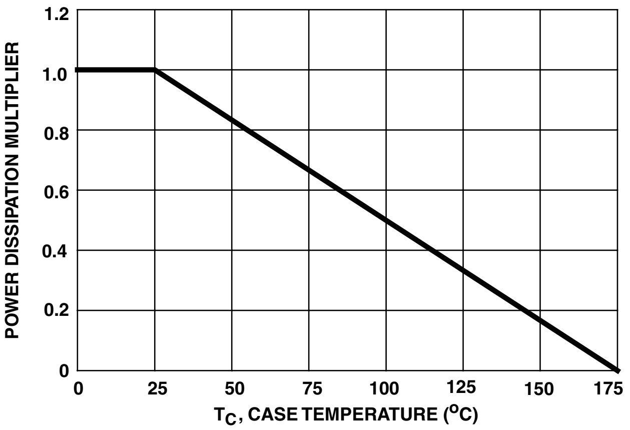


FIGURE 1. NORMALIZED POWER DISSIPATION vs CASE TEMPERATURE

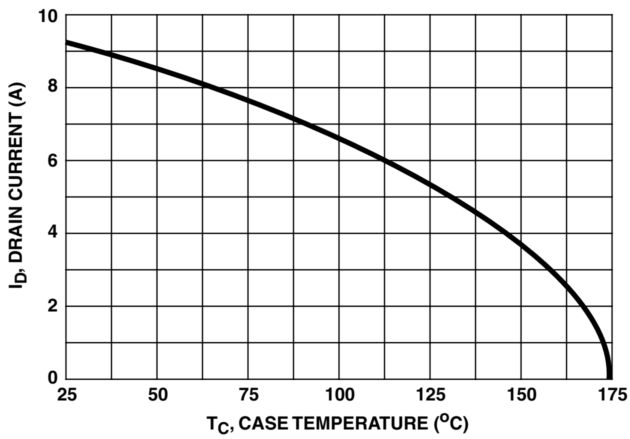


FIGURE 2. MAXIMUM CONTINUOUS DRAIN CURRENT vs CASE TEMPERATURE

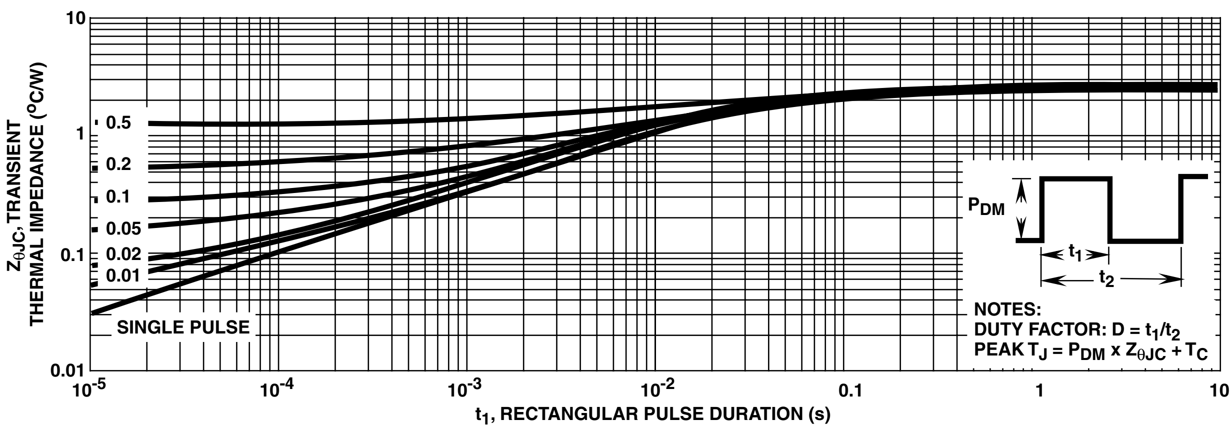


FIGURE 3. MAXIMUM TRANSIENT THERMAL IMPEDANCE

Typical Performance Curves Unless Otherwise Specified (Continued)

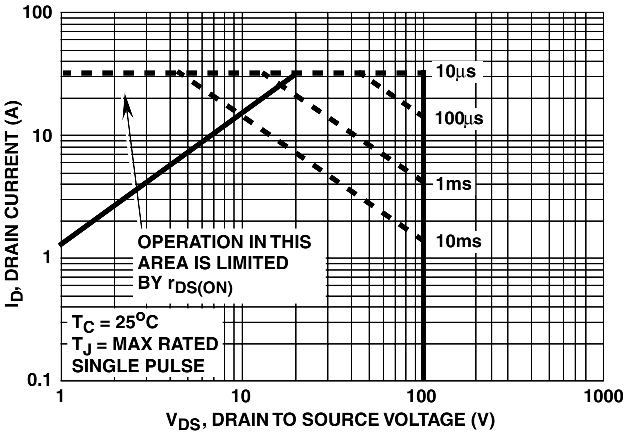


FIGURE 4. FORWARD BIAS SAFE OPERATING AREA

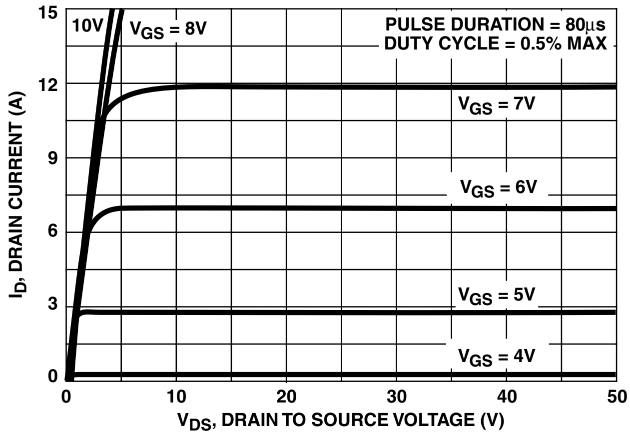


FIGURE 5. OUTPUT CHARACTERISTICS

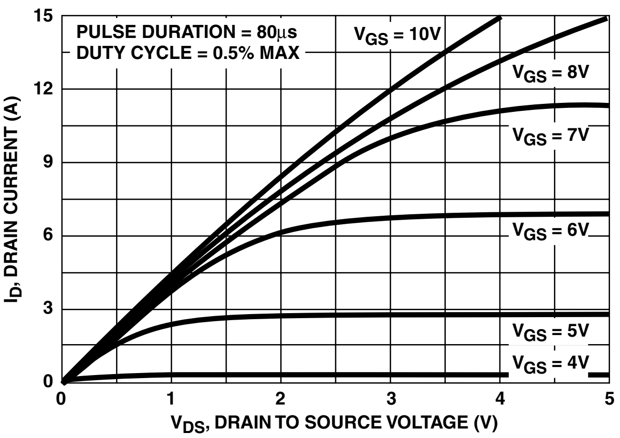


FIGURE 6. SATURATION CHARACTERISTICS

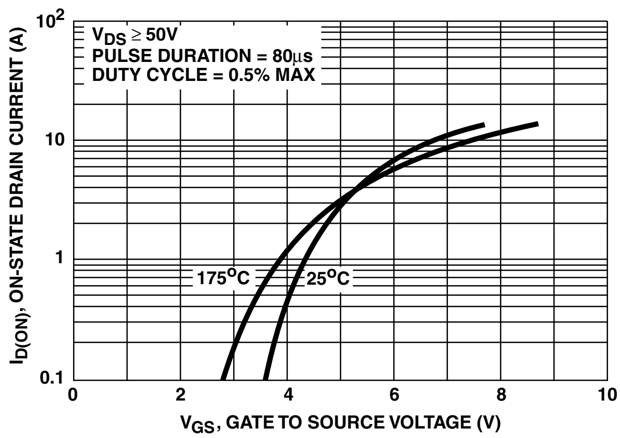


FIGURE 7. TRANSFER CHARACTERISTICS

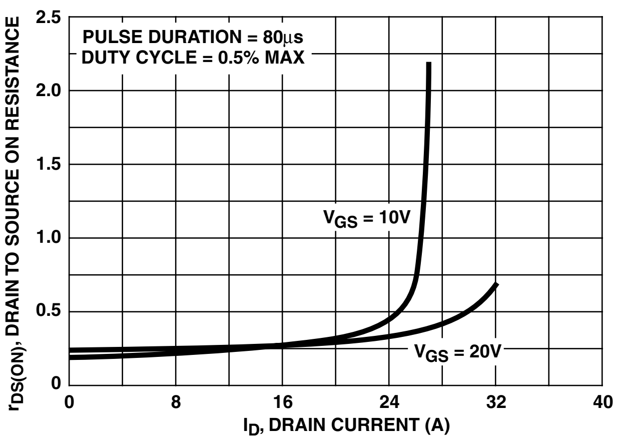


FIGURE 8. DRAIN TO SOURCE ON RESISTANCE vs GATE VOLTAGE AND DRAIN CURRENT

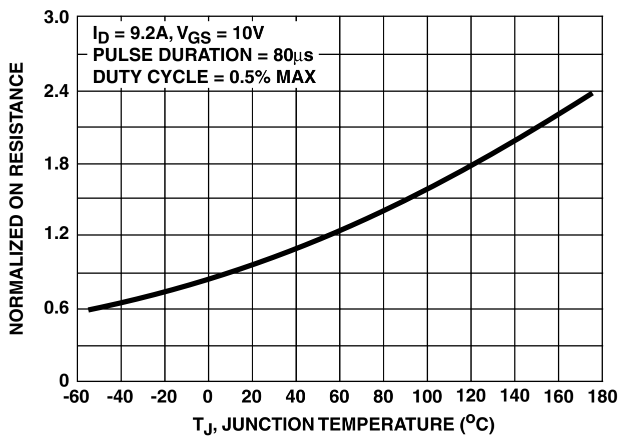


FIGURE 9. NORMALIZED DRAIN TO SOURCE ON RESISTANCE vs JUNCTION TEMPERATURE

Typical Performance Curves Unless Otherwise Specified **(Continued)**

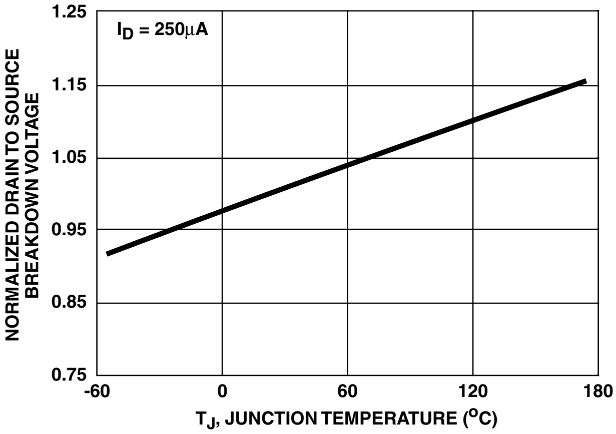


FIGURE 10. NORMALIZED DRAIN TO SOURCE BREAKDOWN VOLTAGE vs JUNCTION TEMPERATURE

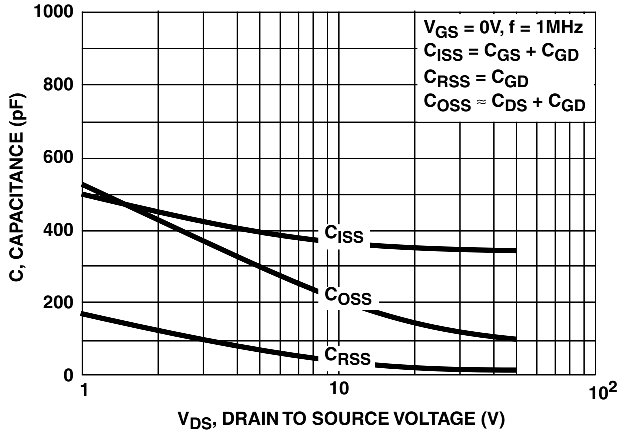


FIGURE 11. CAPACITANCE vs DRAIN TO SOURCE VOLTAGE

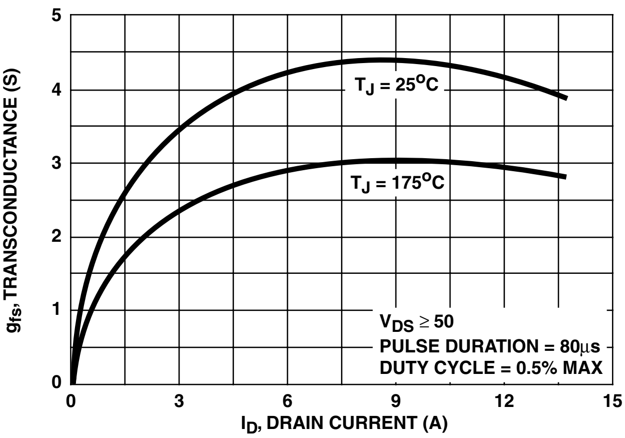


FIGURE 12. TRANSCONDUCTANCE vs DRAIN CURRENT

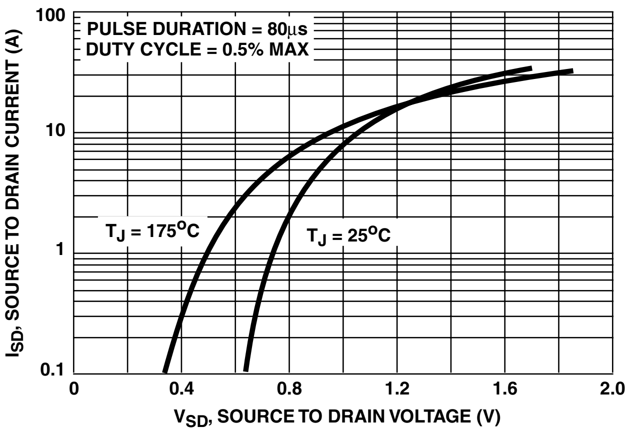


FIGURE 13. SOURCE TO DRAIN DIODE VOLTAGE

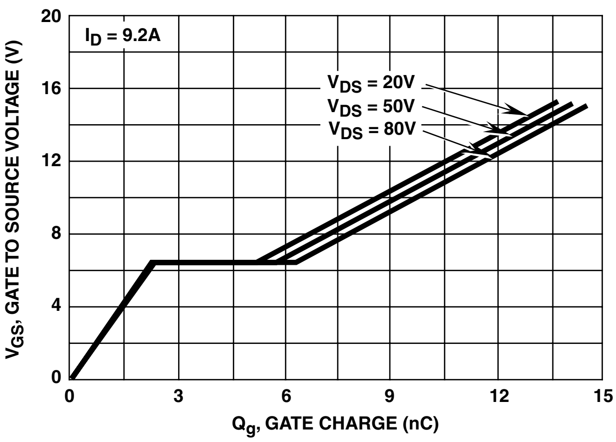


FIGURE 14. GATE TO SOURCE VOLTAGE vs GATE CHARGE

TRADEMARKS

The following are registered and unregistered trademarks Fairchild Semiconductor owns or is authorized to use and is not intended to be an exhaustive list of all such trademarks.

ACEx™	FAST ®	OPTOLOGIC™	SMART START™	VCX™
Bottomless™	FASTr™	OPTOPLANAR™	STAR*POWER™	
CoolFET™	FRFET™	PACMAN™	Stealth™	
CROSSVOLT™	GlobalOptoisolator™	POP™	SuperSOT™-3	
DenseTrench™	GTO™	Power247™	SuperSOT™-6	
DOME™	HiSeC™	PowerTrench ®	SuperSOT™-8	
EcoSPARK™	ISOPLANAR™	QFET™	SyncFET™	
E^{2}CMOS™	LittleFET™	QS™	TinyLogic™	
EnSigna™	MicroFET™	QT Optoelectronics™	TruTranslation™	
FACT™	MicroPak™	Quiet Series™	UHC™	
FACT Quiet Series™	MICROWIRE™	SILENT SWITCHER ®	UltraFET ®	

STAR*POWER is used under license

DISCLAIMER

FAIRCHILD SEMICONDUCTOR RESERVES THE RIGHT TO MAKE CHANGES WITHOUT FURTHER NOTICE TO ANY PRODUCTS HEREIN TO IMPROVE RELIABILITY, FUNCTION OR DESIGN. FAIRCHILD DOES NOT ASSUME ANY LIABILITY ARISING OUT OF THE APPLICATION OR USE OF ANY PRODUCT OR CIRCUIT DESCRIBED HEREIN; NEITHER DOES IT CONVEY ANY LICENSE UNDER ITS PATENT RIGHTS, NOR THE RIGHTS OF OTHERS.

LIFE SUPPORT POLICY

FAIRCHILD'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF FAIRCHILD SEMICONDUCTOR CORPORATION.
As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, or (c) whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in significant injury to the user.

2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

PRODUCT STATUS DEFINITIONS

Definition of Terms

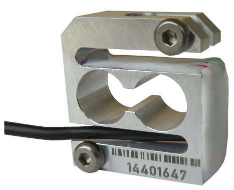
Datasheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This datasheet contains preliminary data, and supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
No Identification Needed	Full Production	This datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
Obsolete	Not In Production	This datasheet contains specifications on a product that has been discontinued by Fairchild semiconductor. The datasheet is printed for reference information only.

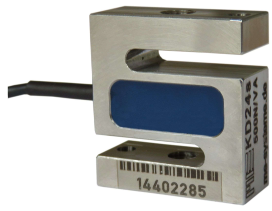
Rev. H4

B.4. Force Sensor

Kraftsensor KD24s / KD24s VA

Nennkraftbereiche: ±2N, ±10N, ±20N, ±50N, ±100N, ±200N, ±100N/VA, ±500N/VA, ±1kN/VA

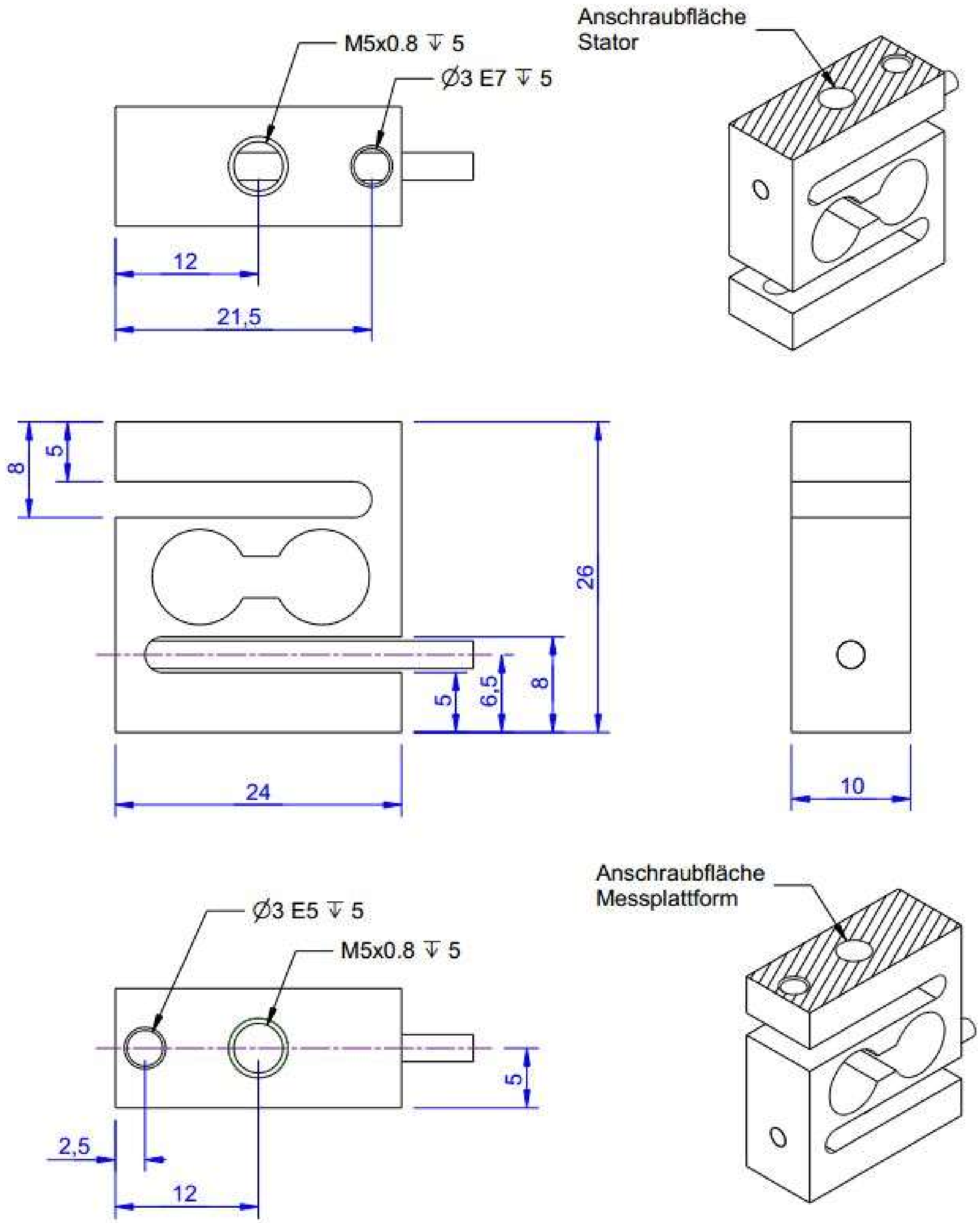




Der Kraftsensor KD24S ist der kleinste Kraftsensor in S-Form. Er eignet sich hervorragend für Prüfaufgaben in der Qualitätssicherung sowie in der Werkstoffprüfung. Krafteinleitung und Kraftausleitung sind zentrisch angeordnet. Die Krafteinleitungsbügel werden bei Belastung parallel verschoben.

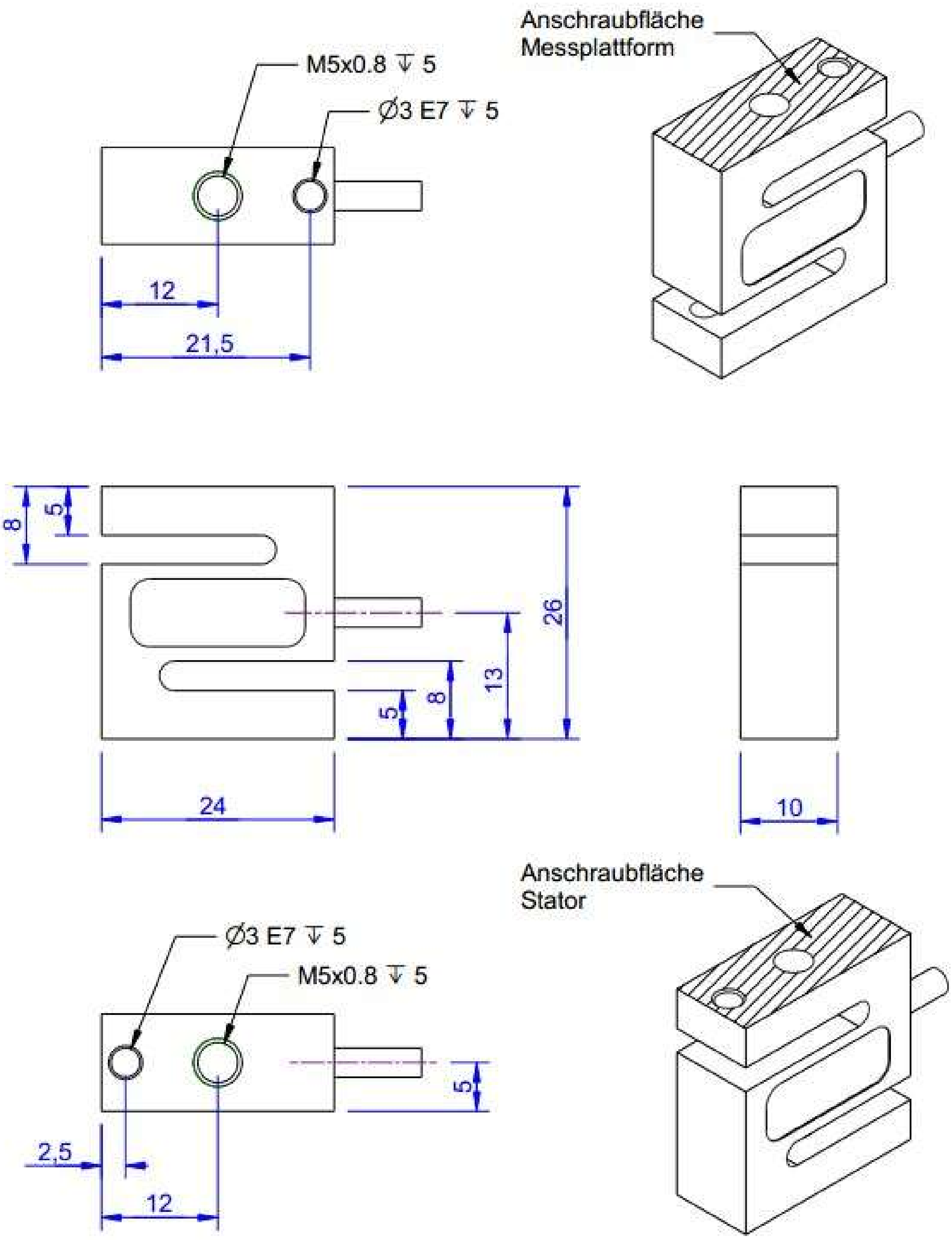
Der Kraftsensor KD24S ist wie der Sensor KD40s als Mehrbereichssensor ausgeführt. Die Genauigkeit von 0,1% wird bereits bei einem Kennwert von 0,5 mV/V erreicht.
Die Sensoren von 2 bis 20N können mit dem 4fachen und von 50 bis 200N mit dem doppelten ihres Nennkraftbereichs betrieben werden.
Bis 200N werden die Sensoren aus Aluminium gefertigt, ab 500N ist der Sensor aus hochfestem Edelstahl 1.4542 gefertigt.
Es wird empfohlen, den Sensor so zu montieren, das die Kabelseite (im Bild unten) an der unbeweglichen Seite, der Krafteinleitung, befestig wird.

Abmessungen KD24s 2N … 20N



ME-Meßsysteme GmbH, Neuendorfstr. 18a, DE-16761 Hennigsdorf
Tel +49 (0)3302 78620 60, Fax +49 (0)3302 78620 69, info@me-systeme.de, www.me-systeme.de

Abmessungen KD24s 50N … 1000N



Technische Daten

Maße / Material		
Material		Aluminium-Legierung
Abmessungen		24 x 26 x 10
Krafteinleitung / Gewinde		2x M5x0,8
mechanische Daten		
Nennkraft(FS)	N	± 2, 10, 20, 50; 100, 200, 500, 1000
Gebrauchskraft	%FS	400% ≤50N, 200% ≤100N, 150% ≥500N
Bruchkraft	%FS	600% ≤50N, 400% ≤100N, 300% ≥500N
Messweg bei FS	mm	0,05...0,1
elektrische Daten		
Nennkennwert 1)	mV/V@FS	0,5
Nullsignaltoleranz	mV/V	0,05
max. Speisespannung	V	5
Eingangswiderstand	Ohm	390±40
Ausgangswiderstand	Ohm	350±1,5
Isolationswiderstand	MOhm	>5 10^9
Anschlusskabel STC-31V-4RWBG	m	3
Genauigkeit		
Genauigkeitsklasse	%	0,1
rel. Linearitätsabweichung	%FS	0,02
rel. Umkehrspanne	%FS	0,02
Temperaturkoeffizient des Nullsignals	%FS/K	0,02
Temperaturkoeffizient des Kennwertes	%RD/K	0,01
Kriechfehler (30 min)	%FS	0,1
Temperatur		
Nenntemperaturbereich	°C	-10… +70
Gebrauchstemperaturbereich	°C	-10 … +85
Lagertemperaturbereich	°C	-10 … +85
Schutzart		IP65

Abkürzungen: RD: Istwert („Reading“); FS: Endwert („Full Scale“);
1) Der exakte Kennwert wird im Prüfprotokoll ausgewiesen.; Druckbelastung: positives Ausgangssignal

Anschlussbelegung

$+U_S$	positive Brückenspeisung	rot
$-U_S$	negative Brückenspeisung	schwarz
$+U_D$	positiver Brückenausgang	grün
$-U_D$	negativer Brückenausgang	weiß
Schirm		transparen

Stand: 26.08.2015

ME-Meßsysteme GmbH, Neuendorfstr. 18a, DE-16761 Hennigsdorf
Tel +49 (0)3302 78620 60, Fax +49 (0)3302 78620 69, info@me-systeme.de, www.me-systeme.de

B.5. LM1086 Linear Voltage Regulator

LM1086 1.5-A Low Dropout Positive Regulators

1 Features

- Available in 1.8-V, 2.5-V, 3.3-V, 5-V and Adjustable Versions
- Current Limiting and Thermal Protection
- Output Current 1.5 A
- Line Regulation 0.015% (Typical)
- Load Regulation 0.1% (Typical)

2 Applications

- High-Efficiency Linear Regulators
- Battery Chargers
- Post Regulation for Switching Supplies
- Constant Current Regulators
- Microprocessor Supplies

3 Description

The LM1086 is a regulator with a maximum dropout of 1.5 V at 1.5 A of load current. The device has the same pin-out as TI's industry standard LM317.

Two resistors are required to set the output voltage of the adjustable output voltage version of the LM1086. Fixed output voltage versions integrate the adjust resistors.

The LM1086 circuit includes a zener trimmed bandgap reference, current limiting, and thermal shutdown.

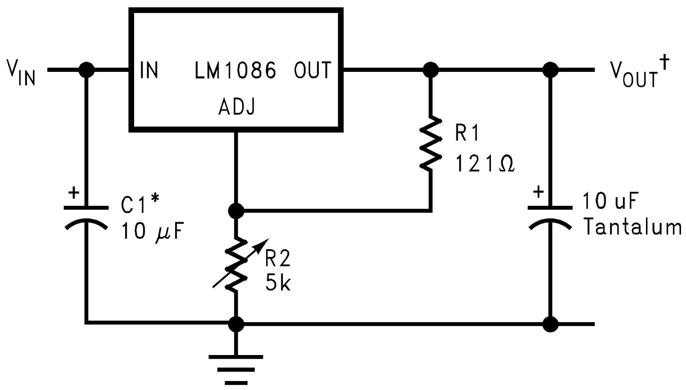
Refer to LM1084 for the 5-A version, and the LM1085 for the 3-A version.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM1086	WSON (8)	4 mm × 4 mm
	DDPAK/TO-263 (3)	10.18 mm × 8.41 mm
	TO-220 (3)	14.986 mm × 10.16 mm

(1) For all available packages, see the orderable addendum at the end of the datasheet.

Typical Application



*NEEDED IF DEVICE IS FAR FROM FILTER CAPACITORS

$$^{\dagger}V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right)$$

Table of Contents

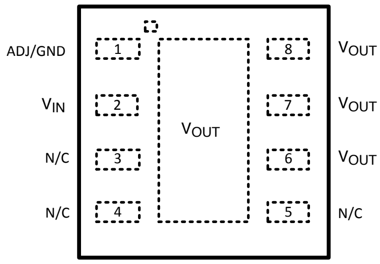
4 Revision History

Changes from Revision I (August 2014) to Revision J	Page
• Added 8-pin WSON pinout drawing and associated device information	3

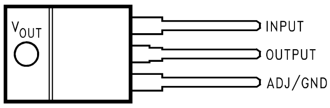
Changes from Revision H (May 2013) to Revision I	Page
• Added *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section	4

5 Pin Configuration and Functions

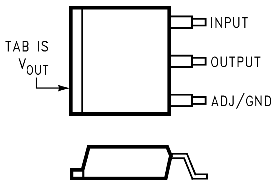
8-Pin WSON
Package NGN
Top View



3-Pin TO-220
Package NDE
Top View



3-Pin DDPAK/TO-263
Package KTT
Top View



Pin Functions

PIN			I/O	DESCRIPTION
NAME	NUMBER			
	KTT/NDE	NGN		
ADJ/GND	1	1	—	Adjust pin for the adjustable output voltage version. Ground pin for the fixed output voltage versions.
V_{OUT}	2, TAB	6, 7, 8, PAD	O	Output voltage pin for the regulator.
V_{IN}	3	2	I	Input voltage pin for the regulator.
N/C		3, 4, 5	—	No Connection

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) (1)(2)

		MIN	MAX	UNIT
Maximum Input to Output Voltage Differential	LM1086-ADJ		29	V
	LM1086-1.8		27	V
	LM1086-2.5		27	V
	LM1086-3.3		27	V
	LM1086-5.0		25	V
Power Dissipation (3)		Internally Limited		
Junction Temperature (T_J) (4)			150	°C
Lead Temperature			260, to 10 sec	°C
Storage temperature, T_{stg}		–65	150	°C

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/Distributors for availability and specifications.
(3) Power dissipation is kept in a safe range by current limiting circuitry. Refer to *Overload Recovery* in *Application and Implementation*. The value θJA for the WSON package is specifically dependent on PCB trace area, trace material, and the number of thermal vias. For improved thermal resistance and power dissipation for the WSON package, refer to Application Note AN-1187 (literature number SNOA401).
(4) The maximum power dissipation is a function of $T_{J(MAX)}$, θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)} – T_A)/\theta_{JA}$. All numbers apply for packages soldered directly into a PC board. Refer to *Thermal Considerations*

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 (1)	±2000	V

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

		MIN	MAX	UNIT
JUNCTION TEMPERATURE RANGE (T_J) (1)				
"C" Grade	Control Section	0	125	°C
	Output Section	0	150	°C
"I" Grade	Control Section	−40	125	°C
	Output Section	−40	150	°C

(1) The maximum power dissipation is a function of $T_{J(MAX)}$, θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)} – T_A)/\theta_{JA}$. All numbers apply for packages soldered directly into a PC board. Refer to *Thermal Considerations*.

6.4 Thermal Information

THERMAL METRIC(1)		LM1086 KTT 3 PINS	LM1086 NDE 3 PINS	LM1086 NGN 8 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	40.8	23.0	35.9	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	42.3	16.1	24.2	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	23.3	4.5	13.2	°C/W
ψ_{JT}	Junction-to-top characterization parameter	10.2	2.4	0.2	°C/W
ψ_{JB}	Junction-to-board characterization parameter	22.3	2.5	13.3	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance: Control Section/Output Section	1.5/4.0	1.5/4.0	2.9	°C/W

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

6.5 Electrical Characteristics

Typicals and limits appearing in normal type apply for T_J = 25°C unless specified otherwise.

PARAMETER		TEST CONDITIONS	T_J = 25°C MIN	T_J = 25°C TYP	T_J = 25°C MAX	T_J over the entire range for operation (see *Recommended Operating Conditions*) MIN(1)	TYP(2)	MAX(1)	UNIT
V_{REF}	Reference Voltage	LM1086-ADJ, I_{OUT} = 10 mA, $V_{IN} - V_{OUT}$ = 3 V, 10 mA ≤ $I_{OUT} \le I_{FULL\ LOAD}$, 1.5 V ≤ $V_{IN} - V_{OUT}$ ≤ 15 V(3)	1.238	1.250	1.262	1.225	1.250	1.270	V
V_{OUT}	Output Voltage(3)	LM1086-1.8, I_{OUT} = 0 mA, V_{IN} = 5 V, 0 ≤ $I_{OUT} \le I_{FULL\ LOAD}$, 3.3 V ≤ V_{IN} ≤ 18 V	1.782	1.8	1.818	1.764	1.8	1.836	V
		LM1086-2.5, I_{OUT} = 0 mA, V_{IN} = 5 V, 0 ≤ $I_{OUT} \le I_{FULL\ LOAD}$, 4.0 V ≤ V_{IN} ≤ 18 V	2.475	2.50	2.525	2.450	2.50	2.55	V
		LM1086-3.3, I_{OUT} = 0 mA, V_{IN} = 5 V, 0 ≤ $I_{OUT} \le I_{FULL\ LOAD}$, 4.75 V ≤ V_{IN} ≤ 18 V	3.267	3.300	3.333	3.235	3.300	3.365	V
		LM1086-5.0, I_{OUT} = 0 mA, V_{IN} = 8 V, 0 ≤ $I_{OUT} \le I_{FULL\ LOAD}$, 6.5 V ≤ V_{IN} ≤ 20 V	4.950	5.000	5.050	4.900	5.000	5.100	V
ΔV_{OUT}	Line Regulation(4)	LM1086-ADJ, I_{OUT} =10 mA, 1.5 V ≤ (V_{IN} - V_{OUT}) ≤ 15 V		0.015%	0.2%		0.035%	0.2%	
		LM1086-1.8, I_{OUT} = 0 mA, 3.3 V ≤ V_{IN} ≤ 18 V		0.3	6		0.6	6	mV
		LM1086-2.5, I_{OUT} = 0 mA, 4.0 V ≤ V_{IN} ≤ 18 V		0.3	6		0.6	6	mV
		LM1086-3.3, I_{OUT} = 0 mA, 4.5 V ≤ V_{IN} ≤ 18 V		0.5	10		1.0	10	mV
		LM1086-5.0, I_{OUT} = 0 mA, 6.5 V ≤ V_{IN} ≤ 20 V		0.5	10		1.0	10	mV

(1) All limits are specified by testing or statistical analysis.
(2) Typical Values represent the most likely parametric norm.
(3) $I_{FULL\ LOAD}$ is defined in the current limit curves. The $I_{FULL\ LOAD}$ Curve defines current limit as a function of input-to-output voltage. Note that 15W power dissipation for the LM1086 is only achievable over a limited range of input-to-output voltage.
(4) Load and line regulation are measured at constant junction temperature, and are specified up to the maximum power dissipation of 15W. Power dissipation is determined by the input/output differential and the output current. Ensured maximum power dissipation will not be available over the full input/output range.

Electrical Characteristics (continued)

Typicals and limits appearing in normal type apply for T_J = 25°C unless specified otherwise.

PARAMETER		TEST CONDITIONS	T_J = 25°C			T_J over the entire range for operation (see *Recommended Operating Conditions*)			UNIT
			MIN	TYP	MAX	MIN [1]	TYP [2]	MAX [1]	
ΔV_{OUT}	Load Regulation [4]	LM1086-ADJ, (V_{IN}-V_{OUT}) = 3 V, 10 mA ≤ I_{OUT} ≤ $I_{FULL\ LOAD}$		0.1%	0.3%		0.2%	0.4%	
		LM1086-1.8, 2.5, V_{IN} = 5 V, 0 ≤ I_{OUT} ≤ $I_{FULL\ LOAD}$		3	12		6	20	mV
		LM1086-3.3, V_{IN} = 5 V, 0 ≤ I_{OUT} ≤ $I_{FULL\ LOAD}$		3	15		7	25	mV
		LM1086-5.0, V_{IN} = 8 V, 0 ≤ I_{OUT} ≤ $I_{FULL\ LOAD}$		5	20		10	35	mV
	Dropout Voltage [5]	LM1086-ADJ, 1.8, 2.5, 3.3, 5, ΔV_{REF}, ΔV_{OUT} = 1%, I_{OUT} = 1.5A					1.3	1.5	V
I_{LIMIT}	Current Limit	LM1086-ADJ, V_{IN} − V_{OUT} = 5 V, V_{IN} − V_{OUT} = 25 V				1.50 0.05	2.7 0.15		A
		LM1086-1.8,2.5, 3.3, V_{IN} = 8 V				1.5	2.7		A
		LM1086-5.0, V_{IN} = 10 V				1.5	2.7		A
	Minimum Load Current [6]	LM1086-ADJ, V_{IN} −V_{OUT} = 25 V					5.0	10.0	mA
	Quiescent Current	LM1086-1.8, 2.5, V_{IN} ≤ 18 V					5.0	10.0	mA
		LM1086-3.3, V_{IN} ≤ 18 V					5.0	10.0	mA
		LM1086-5.0, V_{IN} ≤ 20 V					5.0	10.0	mA
	Thermal Regulation	T_A = 25°C, 30ms Pulse		0.008	0.04				%/W
	Ripple Rejection	f_{RIPPLE} = 120 Hz, C_{OUT} = 25 µF Tantalum, I_{OUT} = 1.5 A LM1086-ADJ, C_{ADJ} = 25 µF, (V_{IN}− V_O) = 3 V				60	75		dB
		LM1086-1.8, 2.5, V_{IN} = 6 V				60	72		dB
		LM1086-3.3, V_{IN}= 6.3 V				60	72		dB
		LM1086-5.0 V_{IN} = 8 V				60	68		dB
	Adjust Pin Current	LM1086		55				120	µA
	Adjust Pin Current Change	10 mA ≤ I_{OUT} ≤ $I_{FULL\ LOAD}$, 1.5 V ≤ (V_{IN}−V_{OUT}) ≤ 15 V					0.2	5	µA
	Temperature Stability						0.5%		
	Long Term Stability	T_A = 125°C, 1000 Hrs		0.3%	1.0%				
	RMS Noise (% of V_{OUT})	10 Hz ≤ f≤ 10 kHz		0.003%					

(5) Dropout voltage is specified over the full output current range of the device.
(6) The minimum output current required to maintain regulation.

6.6 Typical Characteristics

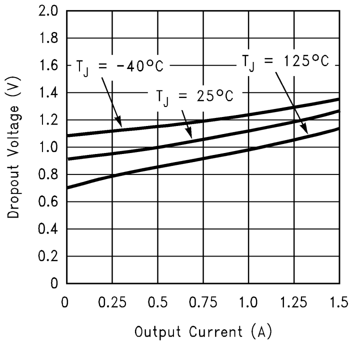


Figure 1. Dropout Voltage vs Output Current

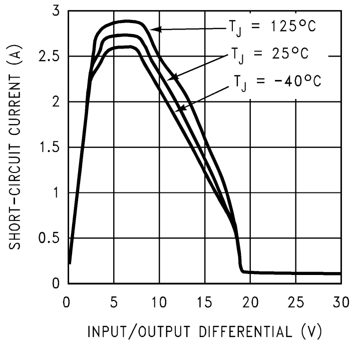


Figure 2. Short-Circuit Current vs Input/Output Difference

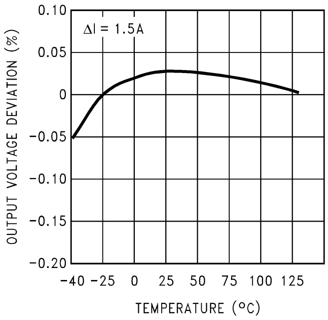


Figure 3. Load Regulation vs Temperature

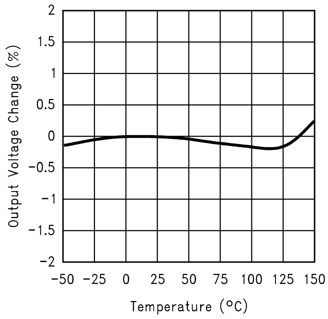


Figure 4. Percent Change in Output Voltage vs Temperature

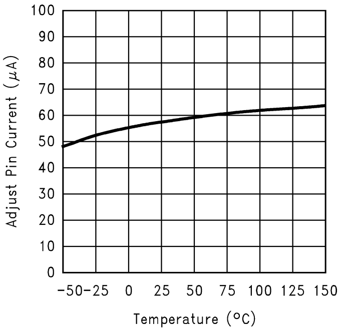


Figure 5. Adjust Pin Current vs Temperature

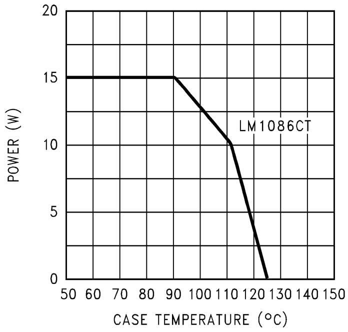


Figure 6. Maximum Power Dissipation vs Temperature

Typical Characteristics (continued)

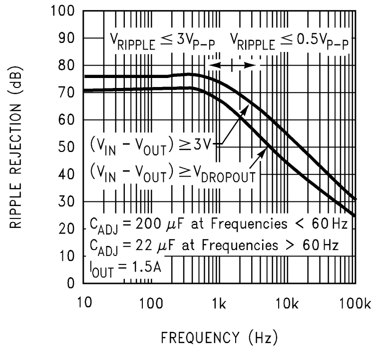


Figure 7. Ripple Rejection vs Frequency (LM1086-ADJ)

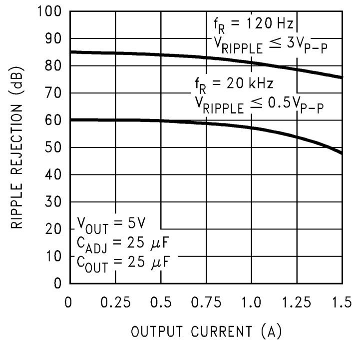


Figure 8. Ripple Rejection vs Output Current (LM1086-ADJ)

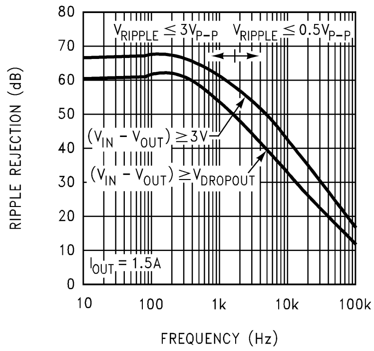


Figure 9. Ripple Rejection vs Frequency (LM1086-5)

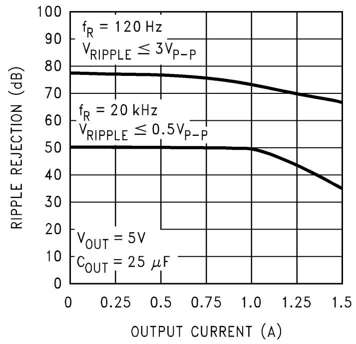


Figure 10. Ripple Rejection vs Output Current (LM1086-5)

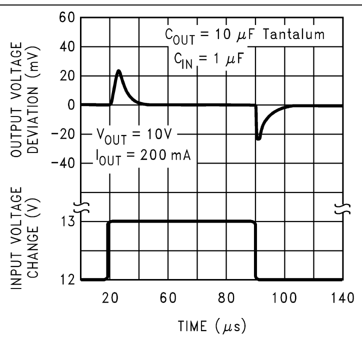


Figure 11. Line Transient Response

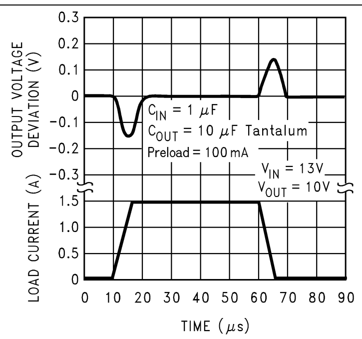


Figure 12. Load Transient Response

7 Detailed Description

7.1 Overview

A basic functional diagram for the LM1086-ADJ (excluding protection circuitry) is shown in Figure 13. The topology is basically that of the LM317 except for the pass transistor. Instead of a Darlingtion NPN with its two diode voltage drop, the LM1086 uses a single NPN. This results in a lower dropout voltage. The structure of the pass transistor is also known as a quasi LDO. The advantage of a quasi LDO over a PNP LDO is its inherently lower quiescent current. The LM1086 is specified to provide a minimum dropout voltage of 1.5V over temperature, at full load.

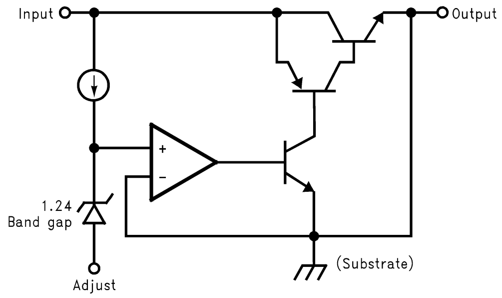
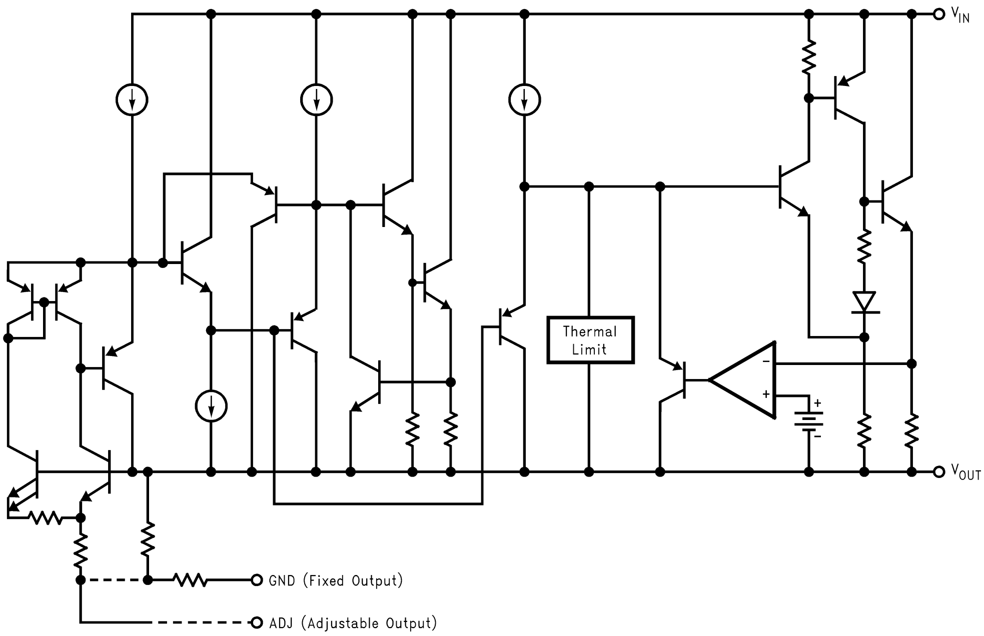


Figure 13. Basic Functional Block Diagram

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Ripple Rejection

Ripple rejection is a function of the open loop gain within the feed-back loop (refer to Figure 13 and Figure 16). The LM1086 exhibits 75dB of ripple rejection (typ.). When adjusted for voltages higher than V_{REF}, the ripple rejection decreases as function of adjustment gain: (1+R1/R2) or V_O/V_{REF}. Therefore a 5-V adjustment decreases ripple rejection by a factor of four (−12dB); Output ripple increases as adjustment voltage increases.

However, the adjustable version allows this degradation of ripple rejection to be compensated. The adjust terminal can be bypassed to ground with a capacitor (C_{ADJ}). The impedance of the C_{ADJ} should be equal to or less than R1 at the desired ripple frequency. This bypass capacitor prevents ripple from being amplified as the output voltage is increased.

$$1/(2\pi * f_{RIPPLE} * C_{ADJ}) \leq R_1 \quad (1)$$

7.3.2 Load Regulation

The LM1086 regulates the voltage that appears between its output and ground pins, or between its output and adjust pins. In some cases, line resistances can introduce errors to the voltage across the load. To obtain the best load regulation, a few precautions are needed.

Figure 14 shows a typical application using a fixed output regulator. Rt1 and Rt2 are the line resistances. V_{LOAD} is less than the V_{OUT} by the sum of the voltage drops along the line resistances. In this case, the load regulation seen at the R_{LOAD} would be degraded from the data sheet specification. To improve this, the load should be tied directly to the output terminal on the positive side and directly tied to the ground terminal on the negative side.

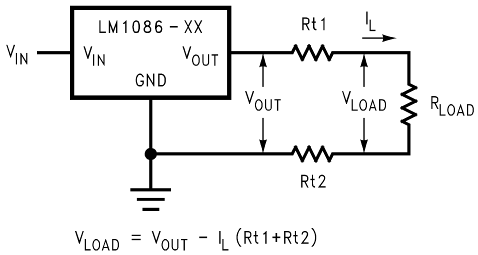


Figure 14. Typical Application Using Fixed Output Regulator

When the adjustable regulator is used (Figure 15), the best performance is obtained with the positive side of the resistor R1 tied directly to the output terminal of the regulator rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 5V regulator with 0.05-Ω resistance between the regulator and load will have a load regulation due to line resistance of 0.05 Ω × I_L. If R1 (=125 Ω) is connected near the load the effective line resistance will be 0.05 Ω (1 + R2/R1) or in this case, it is 4 times worse. In addition, the ground side of the resistor R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

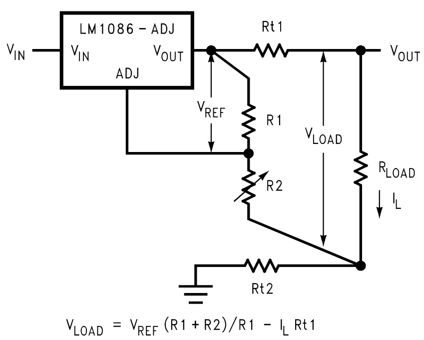


Figure 15. Best Load Regulation Using Adjustable Output Regulator

Feature Description (continued)

7.3.3 Overload Recovery

Overload recovery refers to regulator's ability to recover from a short circuited output. A key factor in the recovery process is the current limiting used to protect the output from drawing too much power. The current limiting circuit reduces the output current as the input to output differential increases. Refer to short circuit curve in the *Typical Characteristics* section.

During normal start-up, the input to output differential is small since the output follows the input. But, if the output is shorted, then the recovery involves a large input to output differential. Sometimes during this condition the current limiting circuit is slow in recovering. If the limited current is too low to develop a voltage at the output, the voltage will stabilize at a lower level. Under these conditions it may be necessary to recycle the power of the regulator in order to get the smaller differential voltage and thus adequate start up conditions. Refer to *Typical Characteristics* section for the short circuit current vs. input differential voltage.

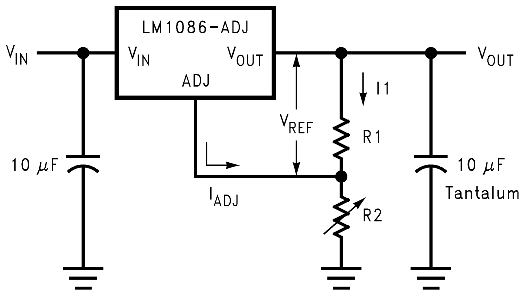
7.4 Device Functional Modes

7.4.1 Output Voltage

The LM1086 adjustable version develops a 1.25-V reference voltage, (V_{REF}), between the output and the adjust terminal. As shown in Figure 16, this voltage is applied across resistor R1 to generate a constant current I1. This constant current then flows through R2. The resulting voltage drop across R2 adds to the reference voltage to sets the desired output voltage.

The current I_{ADJ} from the adjustment terminal introduces an output error . But since it is small (120uA max), it becomes negligible when R1 is in the 100 Ω range.

For fixed voltage devices, R1 and R2 are integrated inside the devices.



$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right) + I_{ADJ}\,R2$$

Figure 16. Basic Adjustable Regulator

7.4.2 Stability Consideration

Stability consideration primarily concerns the phase response of the feedback loop. In order for stable operation, the loop must maintain negative feedback. The LM1086 requires a certain amount series resistance with capacitive loads. This series resistance introduces a zero within the loop to increase phase margin and thus increase stability. The equivalent series resistance (ESR) of solid tantalum or aluminum electrolytic capacitors is used to provide the appropriate zero (approximately 500 kHz).

Aluminum electrolytics are less expensive than tantalums, but their ESR varies exponentially at cold temperatures; therefore requiring close examination when choosing the desired transient response over temperature. Tantalums are a convenient choice because their ESR varies less than 2:1 over temperature.

The recommended load/decoupling capacitance is a 10 uF tantalum or a 50 uF aluminum. These values will assure stability for the majority of applications.

The adjustable versions allows an additional capacitor to be used at the ADJ pin to increase ripple rejection. If this is done the output capacitor should be increased to 22uF for tantalum or to 150 uF for aluminum.

Capacitors other than tantalum or aluminum can be used at the adjust pin and the input pin. A 10 uF capacitor is a reasonable value at the input. See *Ripple Rejection* section regarding the value for the adjust pin capacitor.

Device Functional Modes (continued)

It is desirable to have large output capacitance for applications that entail large changes in load current (microprocessors for example). The higher the capacitance, the larger the available charge per demand. It is also desirable to provide low ESR to reduce the change in output voltage:

$$\Delta V = \Delta I \times ESR \quad (2)$$

It is common practice to use several tantalum and ceramic capacitors in parallel to reduce this change in the output voltage by reducing the overall ESR.

Output capacitance can be increased indefinitely to improve transient response and stability.

7.4.3 Protection Diodes

Under normal operation, the LM1086 regulator does not need any protection diode. With the adjustable device, the internal resistance between the adjustment and output terminals limits the current. No diode is needed to divert the current around the regulator even with a capacitor on the adjustment terminal. The adjust pin can take a transient signal of ±25 V with respect to the output voltage without damaging the device.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and rate of decrease of V_{IN}. In the LM1086 regulator, the internal diode between the output and input pins can withstand microsecond surge currents of 10 A to 20 A. With an extremely large output capacitor (≥1000 µf), and with input instantaneously shorted to ground, the regulator could be damaged. In this case, an external diode is recommended between the output and input pins to protect the regulator, shown in Figure 17.

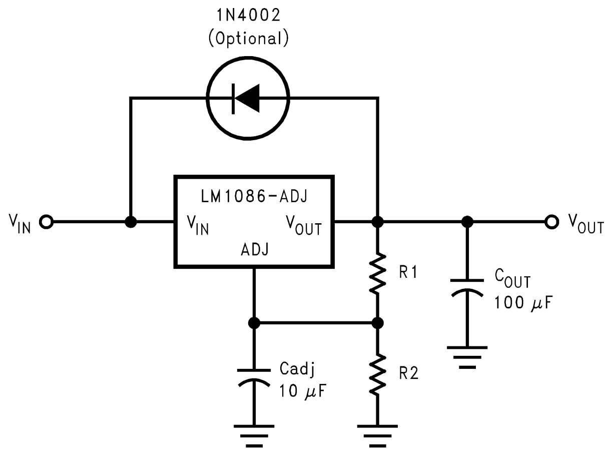


Figure 17. Regulator with Protection Diode

8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

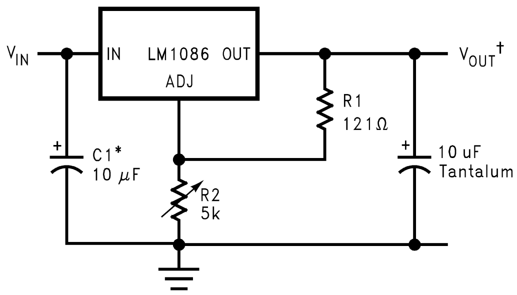
8.1 Application Information

The LM1086 is versatile in its applications, including uses in programmable output regulation and local on-card regulation. Or, by connecting a fixed resistor between the ADJUST and OUTPUT terminals, the LM1086 can function as a precision current regulator. An optional output capacitor can be added to improve transient response. The ADJUST terminal can be bypassed to achieve very high ripple-rejection ratios, which are difficult to achieve with standard three-terminal regulators. Please note, in the following applications, if ADJ is mentioned, it makes use of the adjustable version of the part, however, if GND is mentioned, it is the fixed voltage version of the part.

8.2 Typical Applications

8.2.1 1.2-V to 15-V Adjustable Regulator

This part can be used as a simple low drop out regulator to enable a variety of output voltages needed for demanding applications. By using an adjustable R2 resistor a variety of output voltages can be made possible as shown in Figure 18 based on the LM1086-ADJ.



*NEEDED IF DEVICE IS FAR FROM FILTER CAPACITORS

$^{\dagger}V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right)$

Figure 18. 1.2-V to 15-V Adjustable Regulator

8.2.1.1 Design Requirements

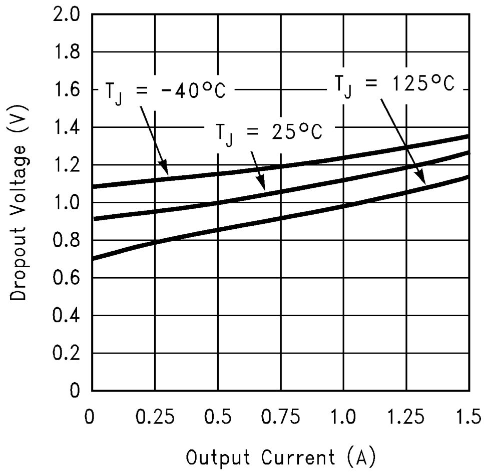
The device component count is very minimal, employing two resistors as part of a voltage divider circuit and an output capacitor for load regulation.

8.2.1.2 Detailed Design Procedure

The voltage divider for this part is set based on the equation shown in Figure 18, where R1 is the upper feedback resistor R2 is the lower feedback resistor.

Typical Applications (continued)

8.2.1.3 Application Curve



8.2.2 Adjustable at 5 V

The application shown in Figure 19 outlines a simple 5-V output application made possible by the LM1086-ADJ. This application can provide 1.5 A at high efficiencies and very low drop-out.

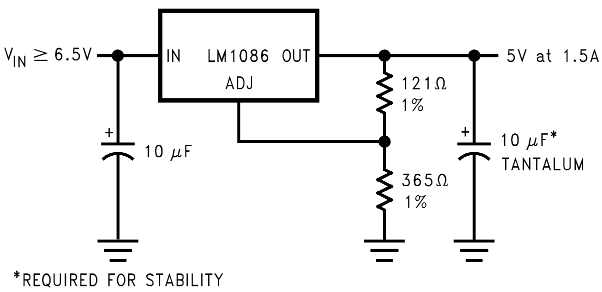


Figure 19. Adjustable at 5 V

8.2.3 5-V Regulator with Shutdown

A variation of the 5-V output regulator application with shutdown control is shown in Figure 20 based on the LM1086-ADJ. It uses a simple NPN transistor on the ADJ pin to block or sink the current on the ADJ pin. If the TTL logic is pulled high, the NPN transistor is activated and the part is disabled, outputting approximately 1.25 V. If the TTL logic is pulled low, the NPN transistor is unbiased and the regulator functions normally.

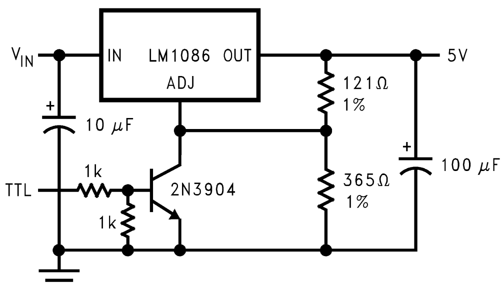


Figure 20. 5-V Regulator with Shutdown

Typical Applications (continued)

8.2.4 Battery Charger

The LM1086-ADJ can be used as a battery charger to regulate the charging current required by the battery bank as shown in Figure 21. In this application the LM1086 acts as a constant voltage, constant current part by sensing the voltage potential across the battery and compensating it to the current voltage. To maintain this voltage, the regulator delivers the maximum charging current required to charge the battery. As the battery approaches the fully charged state, the potential drop across the sense resistor, R_S reduces and the regulator throttles back the current to maintain the float voltage of the battery.

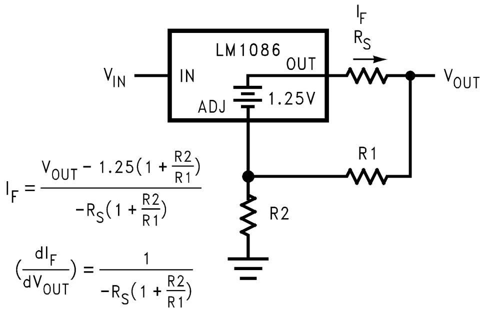


Figure 21. Battery Charger

8.2.5 Adjustable Fixed Regulator

A simple adjustable, fixed range output regulator can be made possible by placing a variable resistor on the ground of the device as shown in Figure 22 based on the fixed output voltage LM1086-5.0. The GND pin has a small quiescent current of 5 mA typical. Increasing the resistance on the GND pin increases the voltage potential across the resistor. This potential is then mirrored on to the output to increase the total output voltage by the potential drop across the GND resistor.

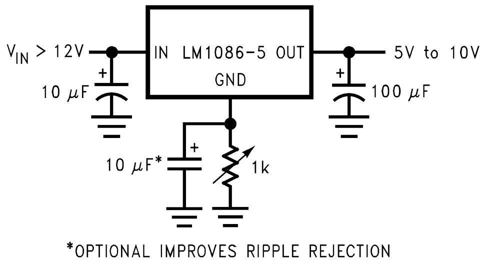


Figure 22. Adjustable Fixed Regulator

8.2.6 Regulator With Reference

A fixed output voltage version of the LM1086-5.0 can be employed to provide an output rail and a reference rail at the same time as shown in Figure 23. This simple application makes use of a reference diode, the LM136-5, to regulate the GND voltage to a fixed 5 V based on the quiescent current generated by the GND pin. This voltage is then added onto the output to generate a total of 10 V out.

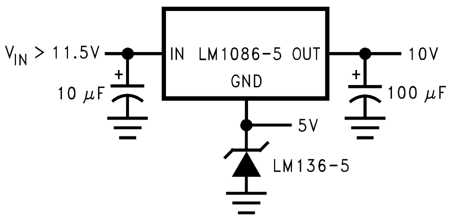


Figure 23. Regulator With Reference

Typical Applications (continued)

8.2.7 High Current Lamp Driver Protection

A simple constant current source with protection can be designed by controlling the impedance between the lamp and ground. The LM1086-ADJ shown in Figure 24 makes use of an external TTL or CMOS input to drive the NPN transistor. This pulls the output of the regulator to a few tenths of a volt and puts the part into current limit. Releasing the logic will reduce the current flow across the lamp into the normal operating current thereby protecting the lamp during startup.

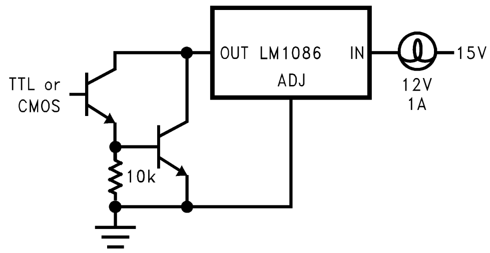


Figure 24. High Current Lamp Driver Protection

8.2.8 Battery Backup Regulated Supply

A regulated battery backup supply can be generated by using two fixed output voltage versions of the part as shown in Figure 25. The top regulator supplies the Line voltage during normal operation, however when the input is not available, the second regulator derives power from the battery backup and regulates it to 5 V based on the LM1086-5.0. The diodes prevent the rails from back feeding into the supply and batteries.

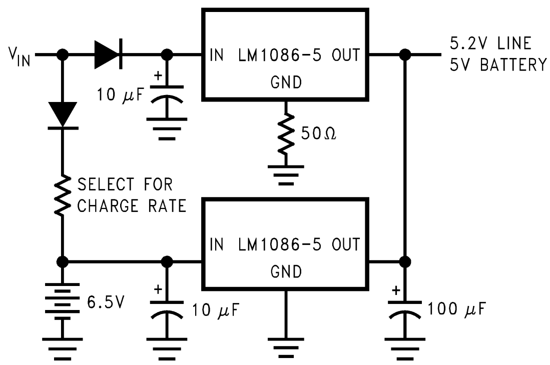


Figure 25. Battery Backup Regulated Supply

Typical Applications (continued)

8.2.9 Ripple Rejection Enhancement

A very simple ripple rejection circuit is shown in Figure 26 using the LM1086-ADJ. The capacitor C1 smooths out the ripple on the output by cleaning up the feedback path and preventing excess noise from feeding back into the regulator. Please remember X_{C1} should be approximately equal to R1 at the ripple frequency.

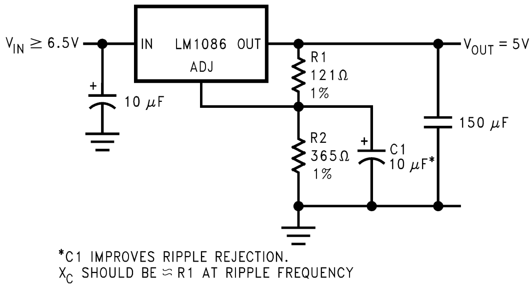


Figure 26. Ripple Rejection Enhancement

8.2.10 Automatic Light Control

A common street light control or automatic light control circuit is designed in Figure 27 based on the LM1086-ADJ. The photo transistor conducts in the presence of light and grounds the ADJ pin preventing the lamp from turning on. However, in the absence of light, the LM1086 regulates the voltage to 1.25 V between OUT and ADJ, ensuring the lamp remains on.

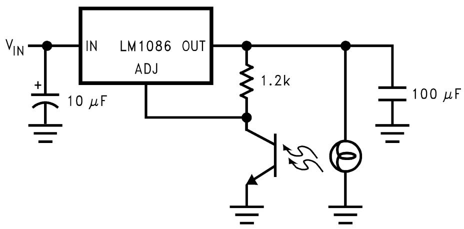


Figure 27. Automatic Light Control

8.2.11 Remote Sensing

Remote sensing is a method of compensating the output voltage to a very precise degree by sensing the output and feeding it back through the feedback. The circuit implementing this is shown in Figure 28 using the LM1086-ADJ. The output of the regulator is fed into a voltage follower to avoid any loading effects and the output of the op-amp is injected into the top of the feedback resistor network. This has the effect of modulating the voltage to a precise degree without additional loading on the output.

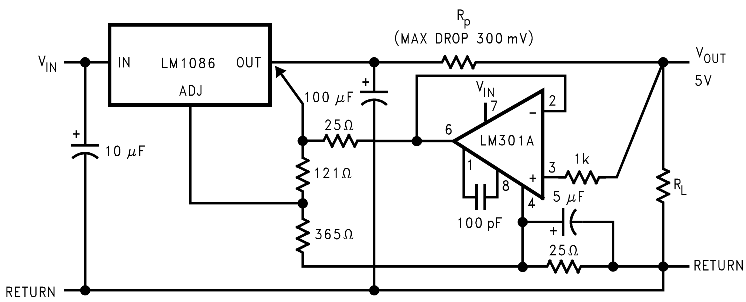


Figure 28. Remote Sensing

9 Power Supply Recommendations

The linear regulator input supply should be well regulated and kept at a voltage level such that the maximum input to output voltage differential allowed by the device is not exceeded. The minimum dropout voltage (V_{IN} – V_{OUT}) should be met with extra headroom when possible in order to keep the output well regulated. A 10 µF or higher capacitor should be placed at the input to bypass noise.

10 Layout

10.1 Layout Guidelines

For the best overall performance, some layout guidelines should be followed. Place all circuit components on the same side of the circuit board and as near as practical to the respective linear regulator pins connections. Traces should be kept short and wide to reduce the amount of parasitic elements into the system. The actual width and thickness of traces will depend on the current carrying capability and heat dissipation required by the end system. An array of plated vias can be placed on the pad area underneath the TAB to conduct heat to any inner plane areas or to a bottom-side copper plane.

10.2 Layout Example

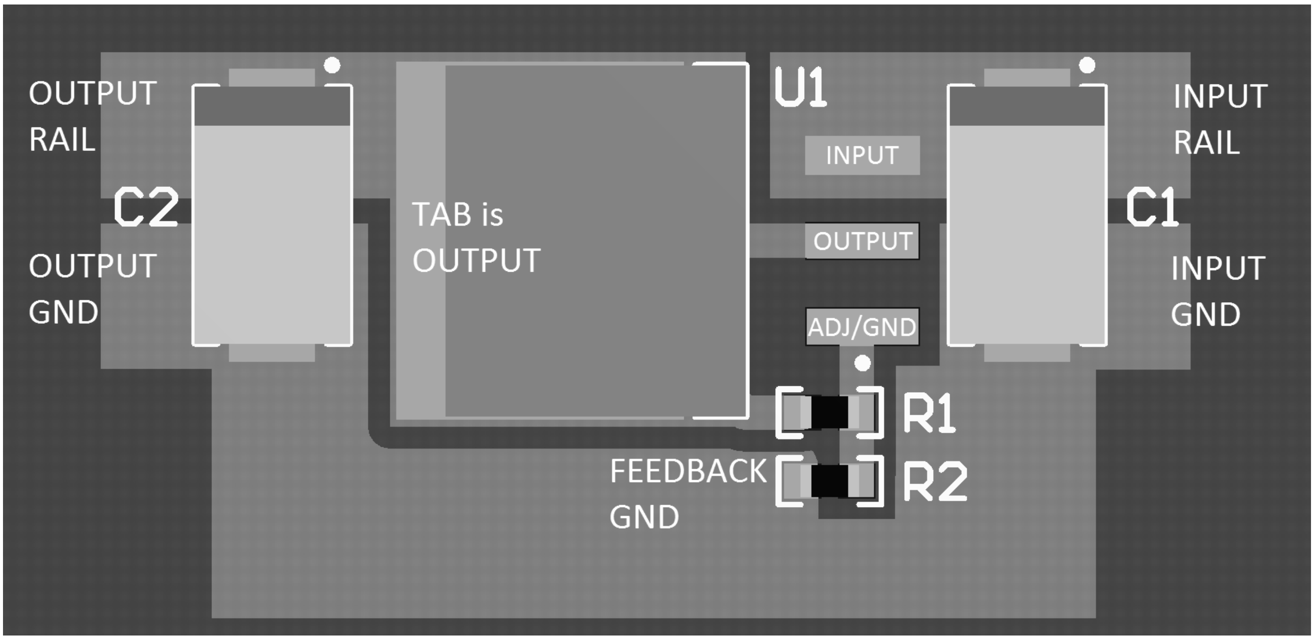


Figure 29. Layout Example

10.3 Thermal Considerations

ICs heats up when in operation, and power consumption is one factor in how hot it gets. The other factor is how well the heat is dissipated. Heat dissipation is predictable by knowing the thermal resistance between the IC and ambient (θ_{JA}). Thermal resistance has units of temperature per power (C/W). The higher the thermal resistance, the hotter the IC.

The LM1086 specifies the thermal resistance for each package as junction to case (θ_{JC}). In order to get the total resistance to ambient (θ_{JA}), two other thermal resistance must be added, one for case to heat-sink (θ_{CH}) and one for heatsink to ambient (θ_{HA}). The junction temperature can be predicted as follows:

$$T_J = T_A + P_D (\theta_{JC} + \theta_{CH} + \theta_{HA}) = T_A + P_D\ \theta_{JA}$$

where

- T_J is junction temperature
- T_A is ambient temperature
- P_D is the power consumption of the device (3)

Device power consumption is calculated as follows:

$$I_{IN} = I_L + I_G \quad (4)$$

$$P_D = (V_{IN}-V_{OUT})\ I_L + V_{IN} I_G \quad (5)$$

Figure 30 shows the voltages and currents which are present in the circuit.

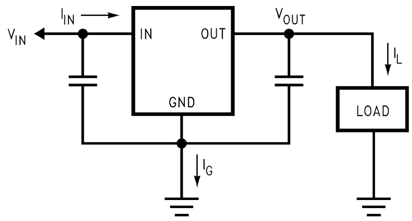


Figure 30. Power Dissipation Diagram

Once the devices power is determined, the maximum allowable ($\theta_{JA\ (max)}$) is calculated as:

$\theta_{JA\ (max)} = T_{R(max)}/P_D = T_{J(max)} - T_{A(max)}/P_D$

The LM1086 has different temperature specifications for two different sections of the IC: the control section and the output section. The *Thermal Information* table shows the junction to case thermal resistances for each of these sections, while the maximum junction temperatures ($T_{J(max)}$) for each section is listed in the *Absolute Maximum Ratings* section of the datasheet. $T_{J(max)}$ is 125°C for the control section, while $T_{J(max)}$ is 150°C for the output section.

$\theta_{JA\ (max)}$ should be calculated separately for each section as follows:

$$\theta_{JA}\ \text{(max, CONTROL SECTION)} = (125°C - T_{A(max)})/P_D \quad (6)$$

$$\theta_{JA}\ \text{(max, OUTPUT SECTION)} = (150°C - T_{A(max)})/P_D \quad (7)$$

The required heat sink is determined by calculating its required thermal resistance ($\theta_{HA\ (max)}$).

$$\theta_{HA\ (max)} = \theta_{JA\ (max)} - (\theta_{JC} + \theta_{CH}) \quad (8)$$

($\theta_{HA\ (max)}$) should also be calculated twice as follows:

$$(\theta_{HA\ (max)}) = \theta_{JA}\ \text{(max, CONTROL SECTION)} - (\theta_{JC}\ \text{(CONTROL SECTION)} + \theta_{CH}) \quad (9)$$

$$(\theta_{HA\ (max)}) = \theta_{JA}\text{(max, OUTPUT SECTION)} - (\theta_{JC}\ \text{(OUTPUT SECTION)} + \theta_{CH}) \quad (10)$$

If thermal compound is used, θ_{CH} can be estimated at 0.2 C/W. If the case is soldered to the heat sink, then a θ_{CH} can be estimated as 0 C/W.

After, $\theta_{HA\ (max)}$ is calculated for each section, choose the lower of the two $\theta_{HA\ (max)}$ values to determine the appropriate heat sink.

Thermal Considerations (continued)

If PC board copper is going to be used as a heat sink, then Figure 31 can be used to determine the appropriate area (size) of copper foil required.

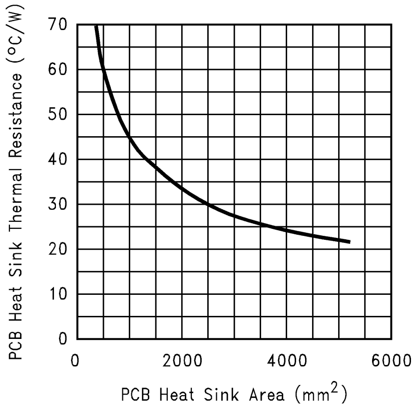


Figure 31. Heat Sink Thermal Resistance vs Area

11 Device and Documentation Support

11.1 Development Support

For additional information, see Texas Instruments' E2E community resources at http://e2e.ti.com.

11.2 Trademarks

All trademarks are the property of their respective owners.

11.3 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

11.4 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM1086CS-2.5/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM1086 CS-2.5	Samples
LM1086CS-3.3/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR		LM1086 CS-3.3	Samples
LM1086CS-5.0/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM1086 CS-5.0	Samples
LM1086CS-ADJ	NRND	DDPAK/ TO-263	KTT	3	45	TBD	Call TI	Call TI		LM1086 CS-ADJ	
LM1086CS-ADJ/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR		LM1086 CS-ADJ	Samples
LM1086CSX-2.5/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM1086 CS-2.5	Samples
LM1086CSX-3.3/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR		LM1086 CS-3.3	Samples
LM1086CSX-ADJ/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR		LM1086 CS-ADJ	Samples
LM1086CT-3.3/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM		LM1086 CT-3.3	Samples
LM1086CT-5.0	NRND	TO-220	NDE	3		TBD	Call TI	Call TI	-40 to 125	LM1086 CT-5.0	
LM1086CT-5.0/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 125	LM1086 CT-5.0	Samples
LM1086CT-ADJ/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM		LM1086 CT-ADJ	Samples
LM1086ILD-3.3/NOPB	ACTIVE	WSON	NGN	8	1000	Green (RoHS & no Sb/Br)	CU SN	Level-3-260C-168 HR	-40 to 125	1086I33	Samples
LM1086IS-1.8/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR		LM1086 IS-1.8	Samples
LM1086IS-3.3	NRND	DDPAK/ TO-263	KTT	3	45	TBD	Call TI	Call TI	-40 to 125	LM1086 IS-3.3	
LM1086IS-3.3/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM1086 IS-3.3	Samples
LM1086IS-5.0	ACTIVE	DDPAK/ TO-263	KTT	3	45	TBD	Call TI	Call TI		LM1086 IS-5.0	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM1086IS-5.0/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM1086 IS-5.0	Samples
LM1086IS-ADJ/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	45	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM1086 IS-ADJ	Samples
LM1086ISX-1.8/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR		LM1086 IS-1.8	Samples
LM1086ISX-3.3/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM1086 IS-3.3	Samples
LM1086ISX-5.0/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM1086 IS-5.0	Samples
LM1086ISX-ADJ/NOPB	ACTIVE	DDPAK/ TO-263	KTT	3	500	Pb-Free (RoHS Exempt)	CU SN	Level-3-245C-168 HR	-40 to 125	LM1086 IS-ADJ	Samples
LM1086IT-3.3/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 125	LM1086 IT-3.3	Samples
LM1086IT-5.0/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 125	LM1086 IT-5.0	Samples
LM1086IT-ADJ/NOPB	ACTIVE	TO-220	NDE	3	45	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 125	LM1086 IT-ADJ	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

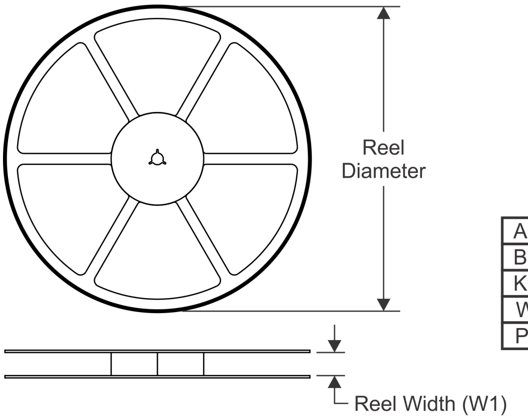
(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

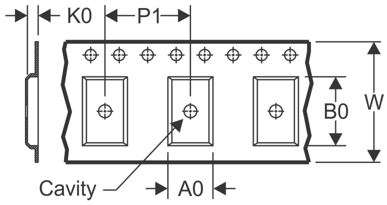
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

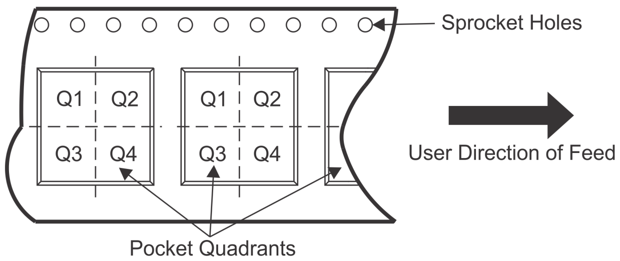


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

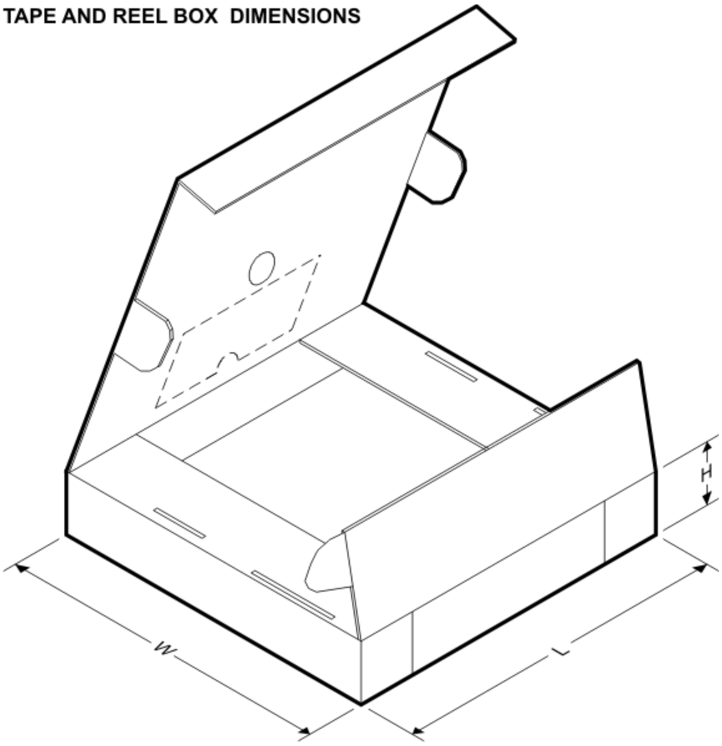
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM1086CSX-2.5/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM1086CSX-3.3/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM1086CSX-ADJ/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM1086ILD-3.3/NOPB	WSON	NGN	8	1000	178.0	12.4	4.3	4.3	1.3	8.0	12.0	Q1
LM1086ISX-1.8/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM1086ISX-3.3/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM1086ISX-5.0/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM1086ISX-ADJ/NOPB	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2

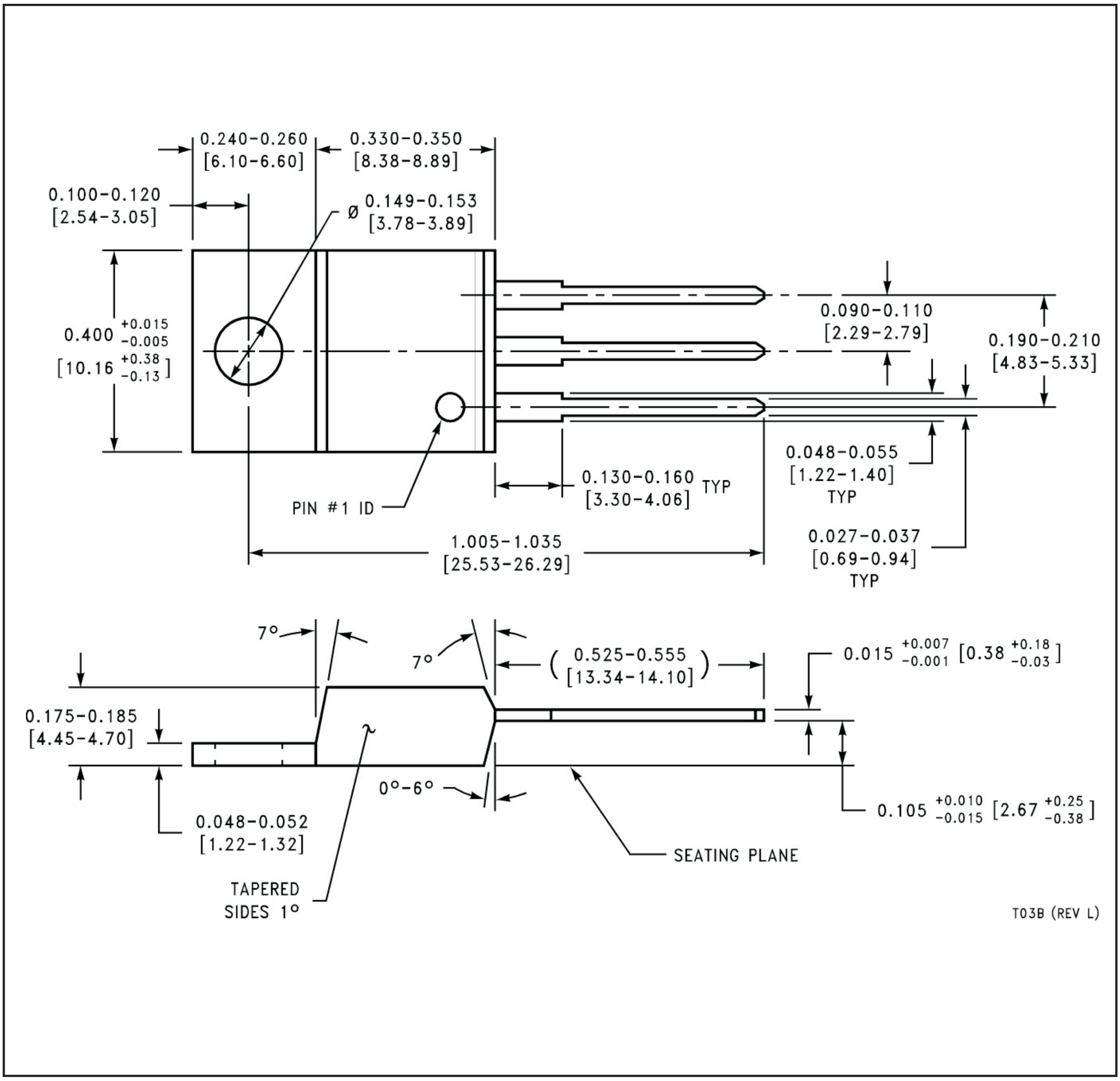
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

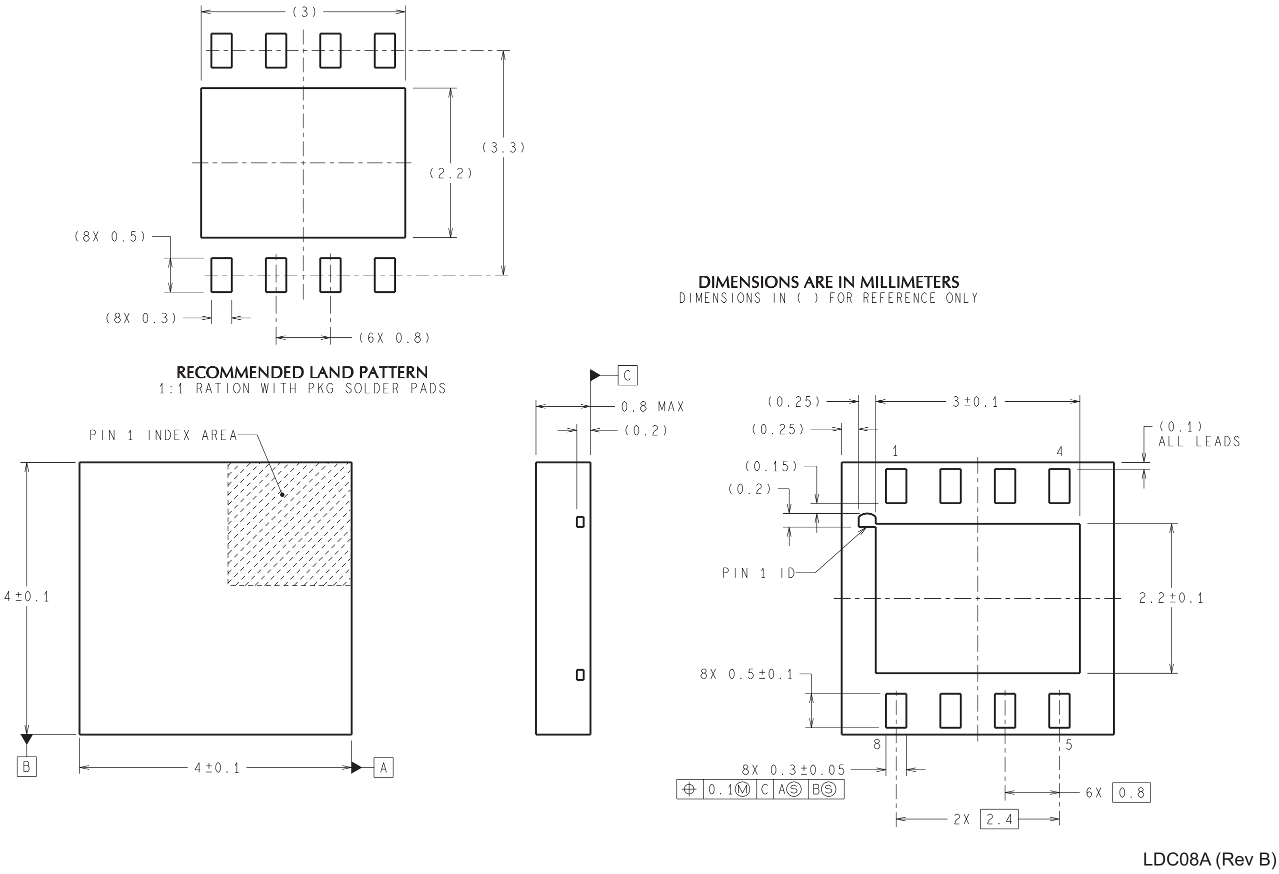
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM1086CSX-2.5/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0
LM1086CSX-3.3/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0
LM1086CSX-ADJ/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0
LM1086ILD-3.3/NOPB	WSON	NGN	8	1000	213.0	191.0	55.0
LM1086ISX-1.8/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0
LM1086ISX-3.3/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0
LM1086ISX-5.0/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0
LM1086ISX-ADJ/NOPB	DDPAK/TO-263	KTT	3	500	367.0	367.0	45.0

NDE0003B

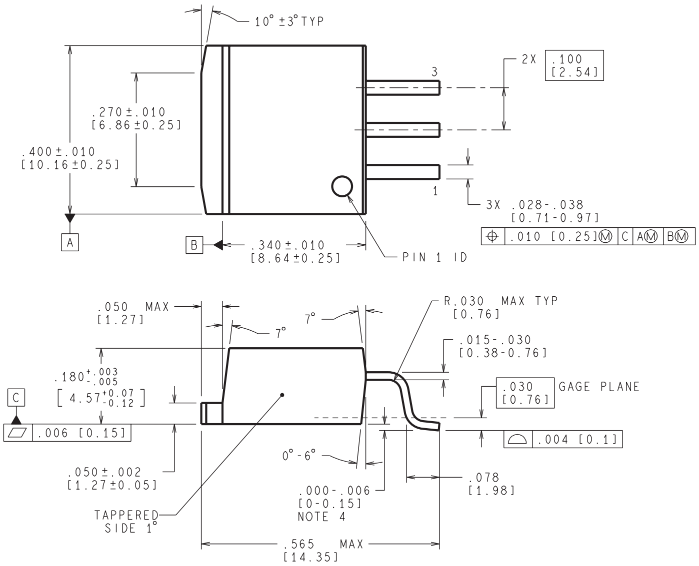


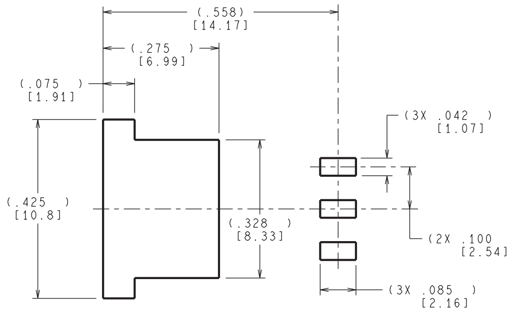
0.240–0.260
[6.10–6.60]
0.330–0.350
[8.38–8.89]
0.100–0.120
[2.54–3.05]
Ø 0.149–0.153
[3.78–3.89]
0.400 +0.015 −0.005
[10.16 +0.38 −0.13]
0.090–0.110
[2.29–2.79]
0.190–0.210
[4.83–5.33]
0.048–0.055
[1.22–1.40]
TYP
0.130–0.160 TYP
[3.30–4.06]
PIN #1 ID
0.027–0.037
[0.69–0.94]
TYP
1.005–1.035
[25.53–26.29]
7°
7°
(0.525–0.555
[13.34–14.10])
0.015 +0.007 −0.001 [0.38 +0.18 −0.03]
0.175–0.185
[4.45–4.70]
0°–6°
0.105 +0.010 −0.015 [2.67 +0.25 −0.38]
0.048–0.052
[1.22–1.32]
SEATING PLANE
TAPERED
SIDES 1°
T03B (REV L)

NGN0008A

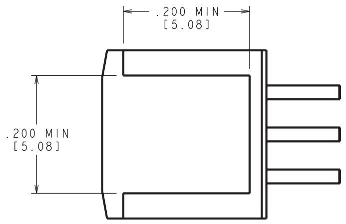

(3)
(3,3)
(2,2)
(8X 0,5)
(8X 0,3)
(6X 0,8)
RECOMMENDED LAND PATTERN
1:1 RATION WITH PKG SOLDER PADS
DIMENSIONS ARE IN MILLIMETERS
DIMENSIONS IN ( ) FOR REFERENCE ONLY
PIN 1 INDEX AREA
4±0,1
4±0,1
B
A
C
0,8 MAX
(0,2)
(0,25)
3±0,1
(0,25)
(0,1)
ALL LEADS
(0,15)
(0,2)
1
4
PIN 1 ID
2,2±0,1
8X 0,5±0,1
8
5
8X 0,3±0,05
0,1 C A B
6X 0,8
2X 2,4
LDC08A (Rev B)

KTT0003B





LAND PATTERN RECOMMENDATION



CONTROLLING DIMENSION IS INCH
VALUES IN [ ] ARE MILLIMETERS
DIMENSIONS IN ( ) FOR REFERENCE ONLY

TS3B (Rev F)

BOTTOM SIDE OF PACKAGE

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

B.6. MAX232 RS232 Level Changer

MAX232x Dual EIA-232 Drivers/Receivers

1 Features

- Meets or Exceeds TIA/EIA-232-F and ITU Recommendation V.28
- Operates From a Single 5-V Power Supply With 1.0-μF Charge-Pump Capacitors
- Operates up to 120 kbit/s
- Two Drivers and Two Receivers
- ±30-V Input Levels
- Low Supply Current: 8 mA Typical
- ESD Protection Exceeds JESD 22
  - 2000-V Human-Body Model (A114-A)
- Upgrade With Improved ESD (15-kV HBM) and 0.1-μF Charge-Pump Capacitors is Available With the MAX202 Device

2 Applications

- TIA/EIA-232-F
- Battery-Powered Systems
- Terminals
- Modems
- Computers

3 Description

The MAX232 device is a dual driver/receiver that includes a capacitive voltage generator to supply TIA/EIA-232-F voltage levels from a single 5-V supply. Each receiver converts TIA/EIA-232-F inputs to 5-V TTL/CMOS levels. These receivers have a typical threshold of 1.3 V, a typical hysteresis of 0.5 V, and can accept ±30-V inputs. Each driver converts TTL/CMOS input levels into TIA/EIA-232-F levels.

Device Information(1)

ORDER NUMBER	PACKAGE (PIN)	BODY SIZE
MAX232x	SOIC (16)	9.90 mm × 3.91 mm
	SOIC (16)	10.30 mm × 7.50 mm
	PDIP (16)	19.30 mm × 6.35 mm
	SOP (16)	10.3 mm × 5.30 mm

(1) For all available packages, see the orderable addendum at the end of the datasheet.

4 Simplified Schematic

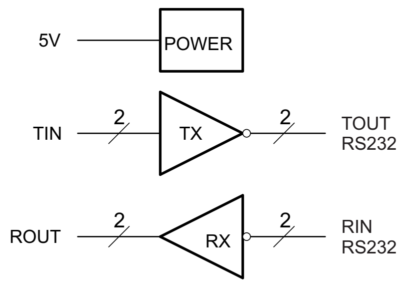


Table of Contents

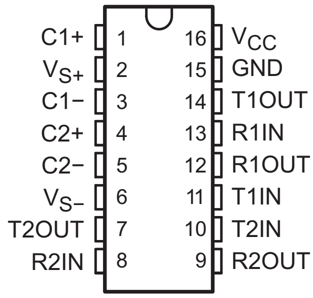
5 Revision History

Changes from Revision L (March 2004) to Revision M	Page
• Removed Ordering Information table.	1
• Added Handling Rating table, Feature Description section, Device Functional Modes, Application and Implementation section, Power Supply Recommendations section, Layout section, Device and Documentation Support section, and Mechanical, Packaging, and Orderable Information section.	1
• Moved T_{stg} to Handling Ratings table.	4

6 Pin Configuration and Functions

Top View

MAX232 . . . D, DW, N, OR NS PACKAGE
MAX232I . . . D, DW, OR N PACKAGE
(TOP VIEW)



Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
C1+	1	—	Positive lead of C1 capacitor
VS+	2	O	Positive charge pump output for storage capacitor only
C1-	3	—	Negative lead of C1 capacitor
C2+	4	—	Positive lead of C2 capacitor
C2-	5	—	Negative lead of C2 capacitor
VS-	6	O	Negative charge pump output for storage capacitor only
T2OUT, T1OUT	7, 14	O	RS232 line data output (to remote RS232 system)
R2IN, R1IN	8, 13	I	RS232 line data input (from remote RS232 system)
R2OUT, R1OUT	9, 12	O	Logic data output (to UART)
T2IN, T1IN	10, 11	I	Logic data input (from UART)
GND	15	—	Ground
V_{CC}	16	—	Supply Voltage, Connect to external 5V power supply

7 Specifications

7.1 Absolute Maximum Ratings(1)

over operating free-air temperature range (unless otherwise noted)

			MIN	MAX	UNIT
V_{CC}	Input Supply voltage range(2)		–0.3	6	V
V_{S+}	Positive output supply voltage range		V_{CC} – 0.3	15	V
V_{S-}	Negative output supply voltage range		–0.3	–15	V
V_I	Input voltage range	T1IN, T2IN	–0.3	V_{CC} + 0.3	V
		R1IN, R2IN		±30	
V_O	Output voltage range	T1OUT, T2OUT	V_{S-} – 0.3	V_{S+} + 0.3	V
		R1OUT, R2OUT	–0.3	V_{CC} + 0.3	
	Short-circuit duration	T1OUT, T2OUT	Unlimited		
T_J	Operating virtual junction temperature			150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltages are with respect to network GND.

7.2 Handling Ratings

			MIN	MAX	UNIT
T_{stg}	Storage temperature range		-65	150	°C
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins(1)	0	2000	V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins(2)	0	1000	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

7.3 Recommended Operating Conditions

			MIN	NOM	MAX	UNIT
V_{CC}	Supply voltage		4.5	5	5.5	V
V_{IH}	High-level input voltage (T1IN,T2IN)		2			V
V_{IL}	Low-level input voltage (T1IN, T2IN)				0.8	V
R1IN, R2IN	Receiver input voltage				±30	V
T_A	Operating free-air temperature	MAX232	0		70	°C
		MAX232I	–40		85	

7.4 Thermal Information

THERMAL METRIC(1)		MAX232xD	MAX232xDW	MAX232xN	MAX232xNS	UNIT
		SOIC	SOIC wide	PDIP	SOP	
		16 PINS	16 PINS	16 PINS	16 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	73	57	67	64	°C/W

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report (SPRA953).

7.5 Electrical Characteristics — Device

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Figure 6)

PARAMETER		TEST CONDITIONS(1)	MIN	TYP(2)	MAX	UNIT
I_{CC}	Supply current	V_{CC} = 5.5V, all outputs open, T_A = 25°C		8	10	mA

(1) Test conditions are C1–C4 = 1 μF at V_{CC} = 5 V ± 0.5 V
(2) All typical values are at V_{CC} = 5 V, and T_A = 25°C.

7.6 Electrical Characteristics — Driver

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

PARAMETER			TEST CONDITIONS(1)	MIN	TYP(2)	MAX	UNIT
V_{OH}	High-level output voltage	T1OUT, T2OUT	R_L = 3 kΩ to GND	5	7		V
V_{OL}	Low-level output voltage(3)	T1OUT, T2OUT	R_L = 3 kΩ to GND		–7	–5	V
r_O	Output resistance	T1OUT, T2OUT	$V_{S+} = V_{S-} = 0$, $V_O = \pm 2$ V	300			Ω
I_{OS}(4)	Short-circuit output current	T1OUT, T2OUT	V_{CC} = 5.5 V, V_O = 0 V		±10		mA
I_{IS}	Short-circuit input current	T1IN, T2IN	V_I = 0			200	µA

(1) Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V
(2) All typical values are at V_{CC} = 5 V, T_A = 25°C.
(3) The algebraic convention, in which the least-positive (most negative) value is designated minimum, is used in this data sheet for logic voltage levels only.
(4) Not more than one output should be shorted at a time.

7.7 Electrical Characteristics — Receiver

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

PARAMETER			TEST CONDITIONS(1)	MIN	TYP(2)	MAX	UNIT
V_{OH}	High-level output voltage	R1OUT, R2OUT	I_{OH} = –1 mA	3.5			V
V_{OL}	Low-level output voltage(3)	R1OUT, R2OUT	I_{OL} = 3.2 mA			0.4	V
V_{IT+}	Receiver positive-going input threshold voltage	R1IN, R2IN	V_{CC} = 5 V, T_A = 25°C		1.7	2.4	V
V_{IT-}	Receiver negative-going input threshold voltage	R1IN, R2IN	V_{CC} = 5 V, T_A = 25°C	0.8	1.2		V
V_{hys}	Input hysteresis voltage	R1IN, R2IN	V_{CC} = 5 V	0.2	0.5	1	V
r_I	Receiver input resistance	R1IN, R2IN	V_{CC} = 5 V, T_A = 25°C	3	5	7	kΩ

(1) Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.
(2) All typical values are at V_{CC} = 5 V, T_A = 25°C.
(3) The algebraic convention, in which the least-positive (most negative) value is designated minimum, is used in this data sheet for logic voltage levels only.

7.8 Switching Characteristics

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

PARAMETER		TEST CONDITIONS(1)	MIN	TYP(1)	MAX	UNIT
SR	Driver slew rate	RL = 3 kΩ to 7 kΩ, see Figure 4			30	V/µs
SR(t)	Driver transition region slew rate	see Figure 5		3		V/µs
	Data rate	One TOUT switching		120		kbit/s
$t_{PLH®)}$	Receiver propagation delay time, low- to high-level output	TTL load, see Figure 3		500		ns
$t_{PHL®)}$	Receiver propagation delay time, high- to low-level output	TTL load, see Figure 3		500		ns

(1) Test conditions are C1–C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

7.9 Typical Characteristics

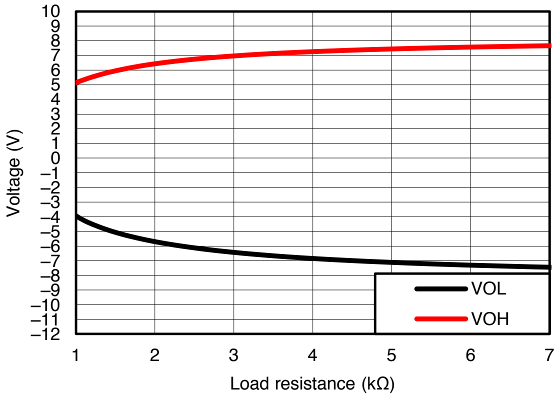


Figure 1. TOUT VOH & VOL vs Load Resistance, Both Drivers Loaded

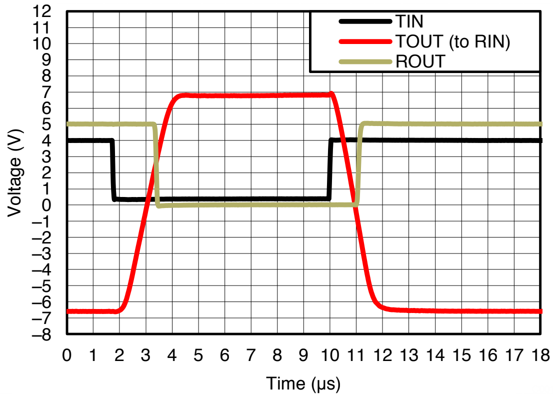
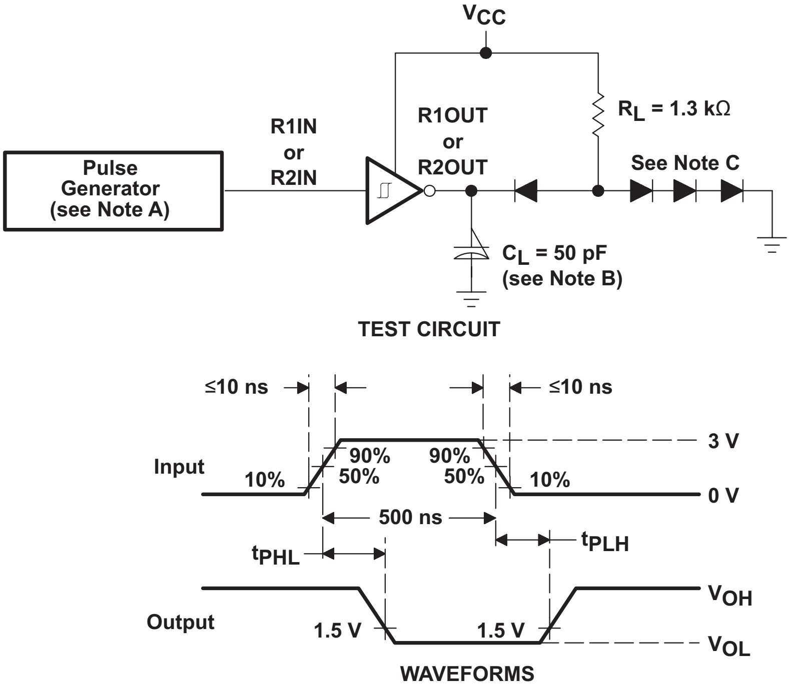


Figure 2. Driver to Receiver Loopback Timing Waveform

8 Parameter Measurement Information



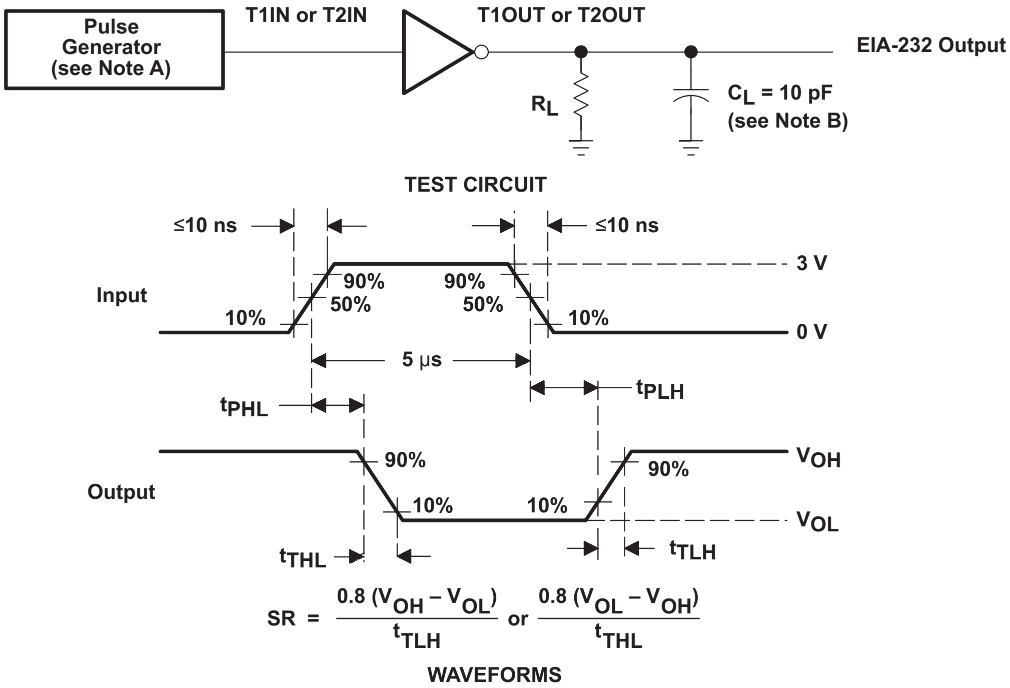
A. The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.

B. C_L includes probe and jig capacitance.

C. All diodes are 1N3064 or equivalent.

Figure 3. Receiver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements

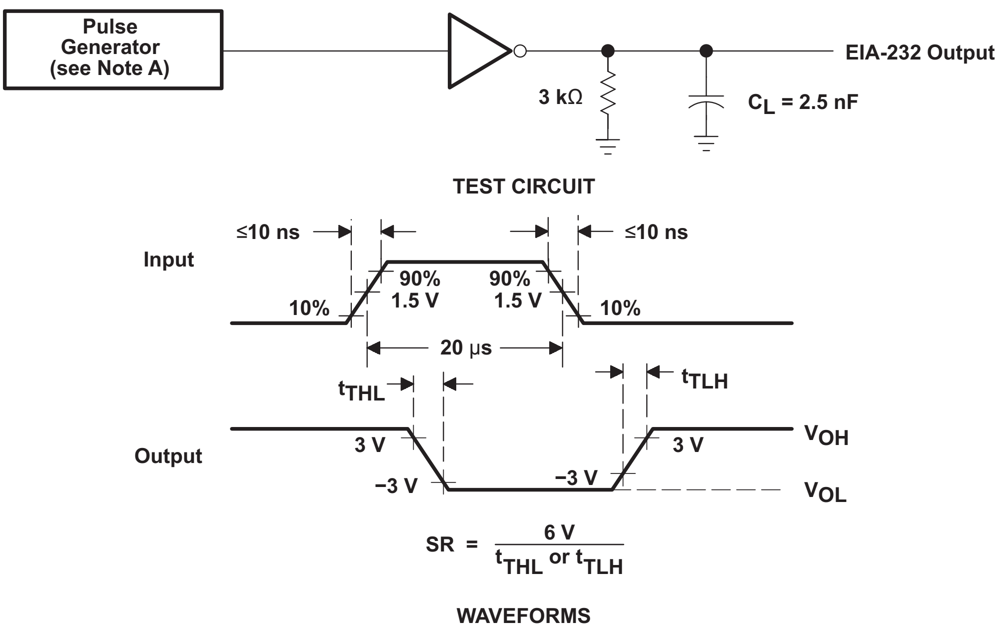
Parameter Measurement Information (continued)



A. The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.

B. C_L includes probe and jig capacitance.

Figure 4. Driver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements (5-μs Input)



A. The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.

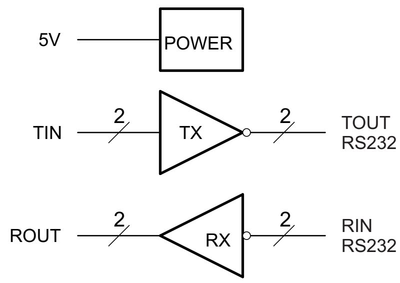
Figure 5. Test Circuit and Waveforms for t_{THL} and t_{TLH} Measurements (20-μs Input)

9 Detailed Description

9.1 Overview

The MAX232 device is a dual driver/receiver that includes a capacitive voltage generator using four capacitors to supply TIA/EIA-232-F voltage levels from a single 5-V supply. Each receiver converts TIA/EIA-232-F inputs to 5-V TTL/CMOS levels. These receivers have a typical threshold of 1.3 V, a typical hysteresis of 0.5 V, and can accept ±30-V inputs. Each driver converts TTL/CMOS input levels into TIA/EIA-232-F levels. The driver, receiver, and voltage-generator functions are available as cells in the Texas Instruments LinASIC™ library. Outputs are protected against shorts to ground.

9.2 Functional Block Diagram



9.3 Feature Description

9.3.1 Power

The power block increases and inverts the 5V supply for the RS232 driver using a charge pump that requires four 1-μF external capacitors.

9.3.2 RS232 Driver

Two drivers interface standard logic level to RS232 levels. Internal pull up resistors on TIN inputs ensures a high input when the line is high impedance.

9.3.3 RS232 Receiver

Two receivers interface RS232 levels to standard logic levels. An open input will result in a high output on ROUT.

9.4 Device Functional Modes

9.4.1 V_{CC} powered by 5V

The device will be in normal operation.

9.4.2 V_{CC} unpowered

When MAX232 is unpowered, it can be safely connected to an active remote RS232 device.

Table 1. Function Table Each Driver(1)

INPUT TIN	OUTPUT TOUT
L	H
H	L

(1) H = high level, L = low level, X = irrelevant, Z = high impedance

Table 2. Function Table Each Receiver(1)

INPUTS RIN	OUTPUT ROUT
L	H
H	L
Open	H

(1) H = high level, L = low level, X = irrelevant, Z = high impedance (off), Open = disconnected input or connected driver off

10 Application and Implementation

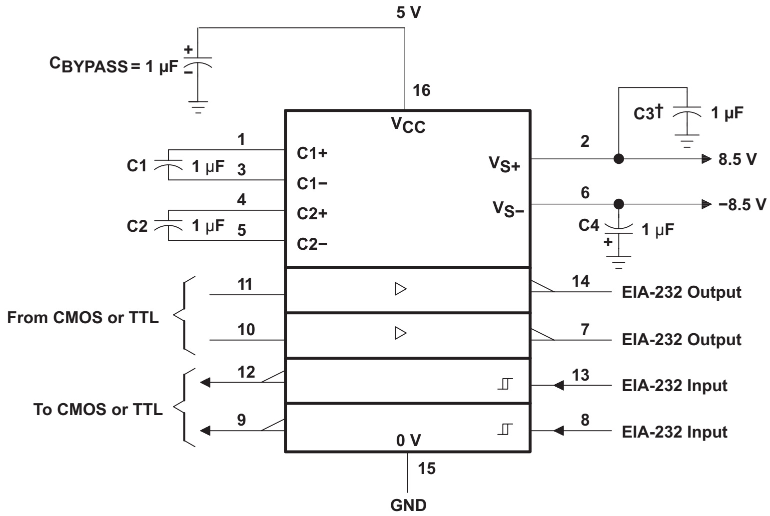
NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

10.1 Application Information

For proper operation add capacitors as shown in Figure 6. Pins 9 through 12 connect to UART or general purpose logic lines. EIA-232 lines will connect to a connector or cable.

10.2 Typical Application



† C3 can be connected to V_{CC} or GND.

NOTES: A. Resistor values shown are nominal.

B. Nonpolarized ceramic capacitors are acceptable. If polarized tantalum or electrolytic capacitors are used, they should be connected as shown. In addition to the 1-µF capacitors shown, the MAX202 can operate with 0.1-µF capacitors.

Figure 6. Typical Operating Circuit

10.2.1 Design Requirements

- V_{CC} minimum is 4.5 V and maximum is 5.5 V.
- Maximum recommended bit rate is 120 kbps.

10.2.2 Detailed Design Procedure

Use 1 uF tantalum or ceramic capacitors.

Typical Application (continued)

10.2.3 Application Curves

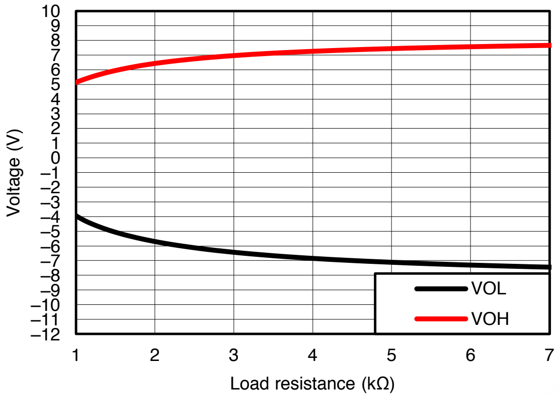


Figure 7. TOUT VOH & VOL vs Load Resistance, Both Drivers Loaded

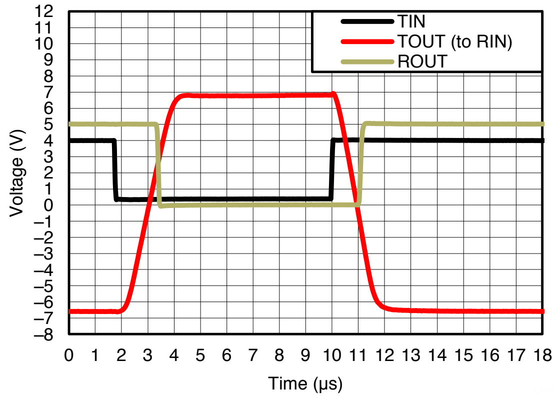


Figure 8. Driver to Receiver Loopback Timing Waveform

11 Power Supply Recommendations

The V_{CC} voltage should be connected to the same power source used for logic device connected to TIN pins. V_{CC} should be between 4.5V and 5.5V.

12 Layout

12.1 Layout Guidelines

Keep the external capacitor traces short. This is more important on C1 and C2 nodes that have the fastest rise and fall times.

12.2 Layout Example

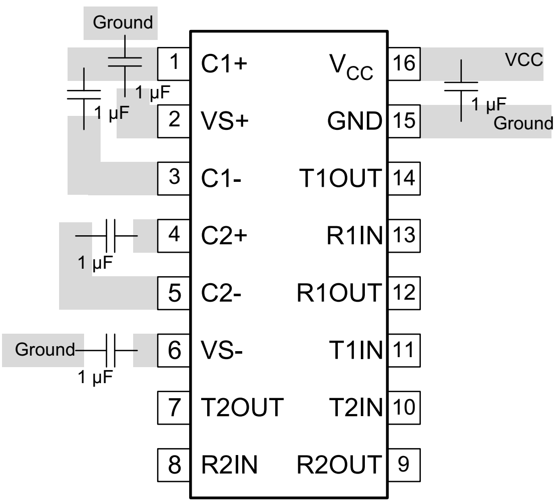


Figure 9. Layout Schematic

13 Device and Documentation Support

13.1 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

Table 3. Related Links

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
MAX232	Click here	Click here	Click here	Click here	Click here
MAX232I	Click here	Click here	Click here	Click here	Click here

13.2 Trademarks

All trademarks are the property of their respective owners.

13.3 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

13.4 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms and definitions.

14 Mechanical, Packaging, and Orderable Information

The following pages include mechanical packaging and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser based versions of this data sheet, refer to the left hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
MAX232D	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DE4	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DG4	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DR	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU I CU SN	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DRE4	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DRG4	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DW	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DWE4	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DWG4	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DWR	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU I CU SN	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DWRE4	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232DWRG4	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples
MAX232ID	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	MAX232I	Samples
MAX232IDE4	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	MAX232I	Samples
MAX232IDG4	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	MAX232I	Samples
MAX232IDR	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	MAX232I	Samples
MAX232IDRG4	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	MAX232I	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
MAX232IDW	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	MAX232I	Samples
MAX232IDWG4	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	MAX232I	Samples
MAX232IDWR	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU I CU SN	Level-1-260C-UNLIM	-40 to 85	MAX232I	Samples
MAX232IDWRE4	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	MAX232I	Samples
MAX232IDWRG4	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	MAX232I	Samples
MAX232IN	ACTIVE	PDIP	N	16	25	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 85	MAX232IN	Samples
MAX232INE4	ACTIVE	PDIP	N	16	25	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 85	MAX232IN	Samples
MAX232N	ACTIVE	PDIP	N	16	25	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	MAX232N	Samples
MAX232NE4	ACTIVE	PDIP	N	16	25	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	MAX232N	Samples
MAX232NSR	ACTIVE	SO	NS	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	MAX232	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

[3] MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

[4] There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

[5] Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

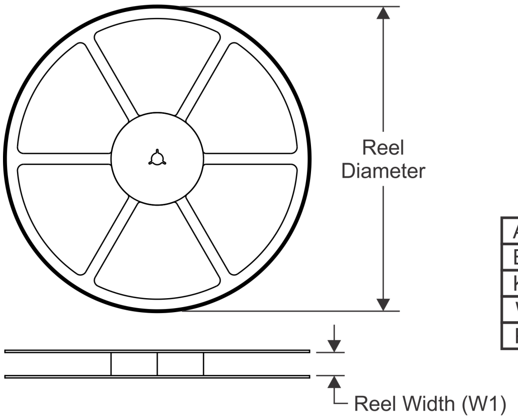
[6] Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

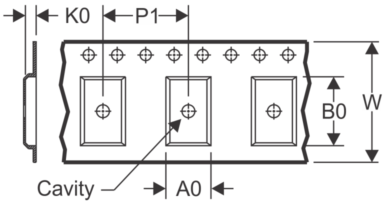
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

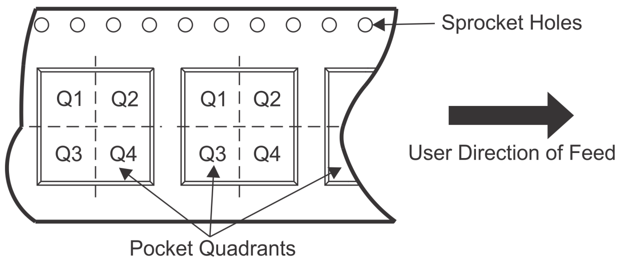


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

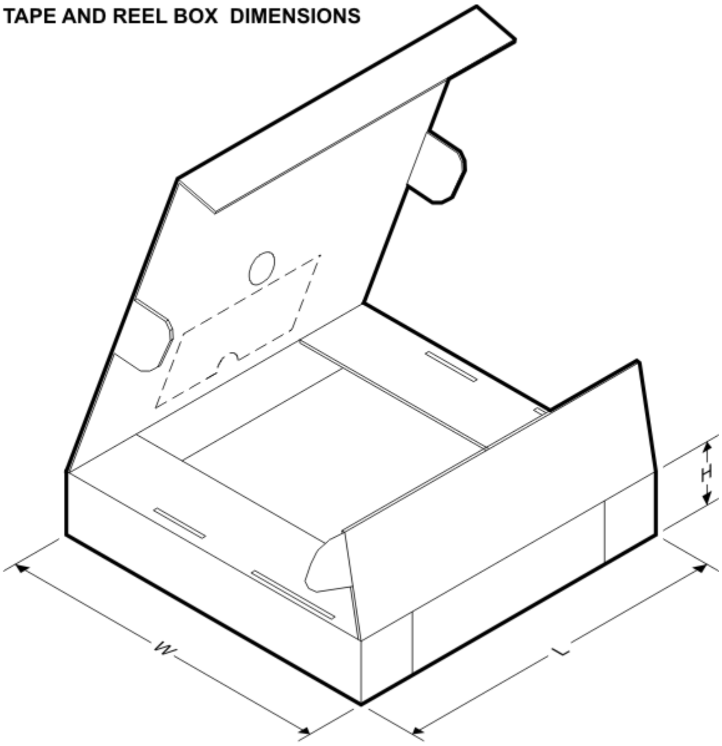
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
MAX232DR	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.1	8.0	16.0	Q1
MAX232DR	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.1	8.0	16.0	Q1
MAX232DRG4	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.1	8.0	16.0	Q1
MAX232DRG4	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.1	8.0	16.0	Q1
MAX232DWR	SOIC	DW	16	2000	330.0	16.4	10.75	10.7	2.7	12.0	16.0	Q1
MAX232DWRG4	SOIC	DW	16	2000	330.0	16.4	10.75	10.7	2.7	12.0	16.0	Q1
MAX232IDR	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.1	8.0	16.0	Q1
MAX232IDWR	SOIC	DW	16	2000	330.0	16.4	10.75	10.7	2.7	12.0	16.0	Q1
MAX232IDWRG4	SOIC	DW	16	2000	330.0	16.4	10.75	10.7	2.7	12.0	16.0	Q1

TAPE AND REEL BOX DIMENSIONS



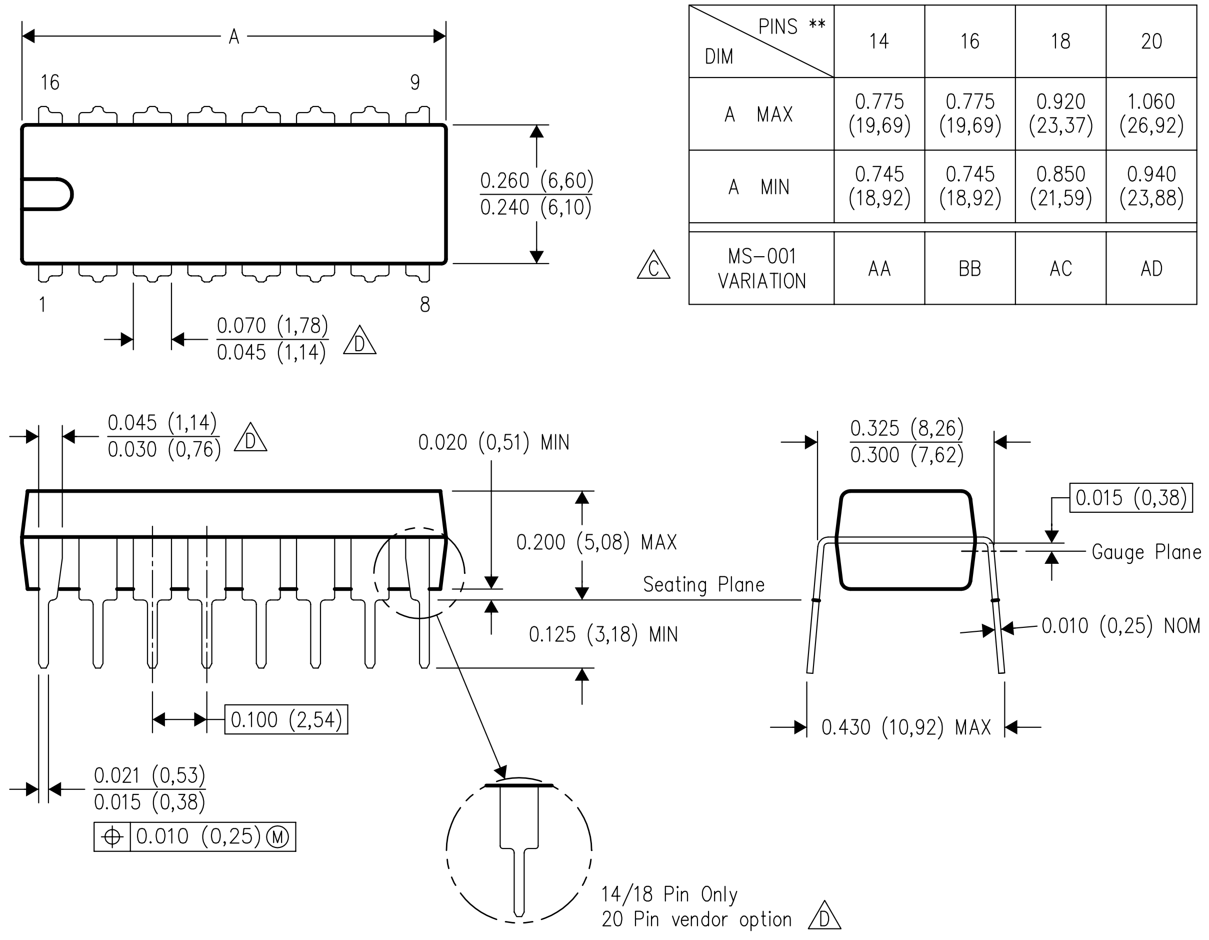
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
MAX232DR	SOIC	D	16	2500	333.2	345.9	28.6
MAX232DR	SOIC	D	16	2500	367.0	367.0	38.0
MAX232DRG4	SOIC	D	16	2500	333.2	345.9	28.6
MAX232DRG4	SOIC	D	16	2500	367.0	367.0	38.0
MAX232DWR	SOIC	DW	16	2000	367.0	367.0	38.0
MAX232DWRG4	SOIC	DW	16	2000	367.0	367.0	38.0
MAX232IDR	SOIC	D	16	2500	333.2	345.9	28.6
MAX232IDWR	SOIC	DW	16	2000	367.0	367.0	38.0
MAX232IDWRG4	SOIC	DW	16	2000	367.0	367.0	38.0

N (R–PDIP–T**) PLASTIC DUAL–IN–LINE PACKAGE

16 PINS SHOWN

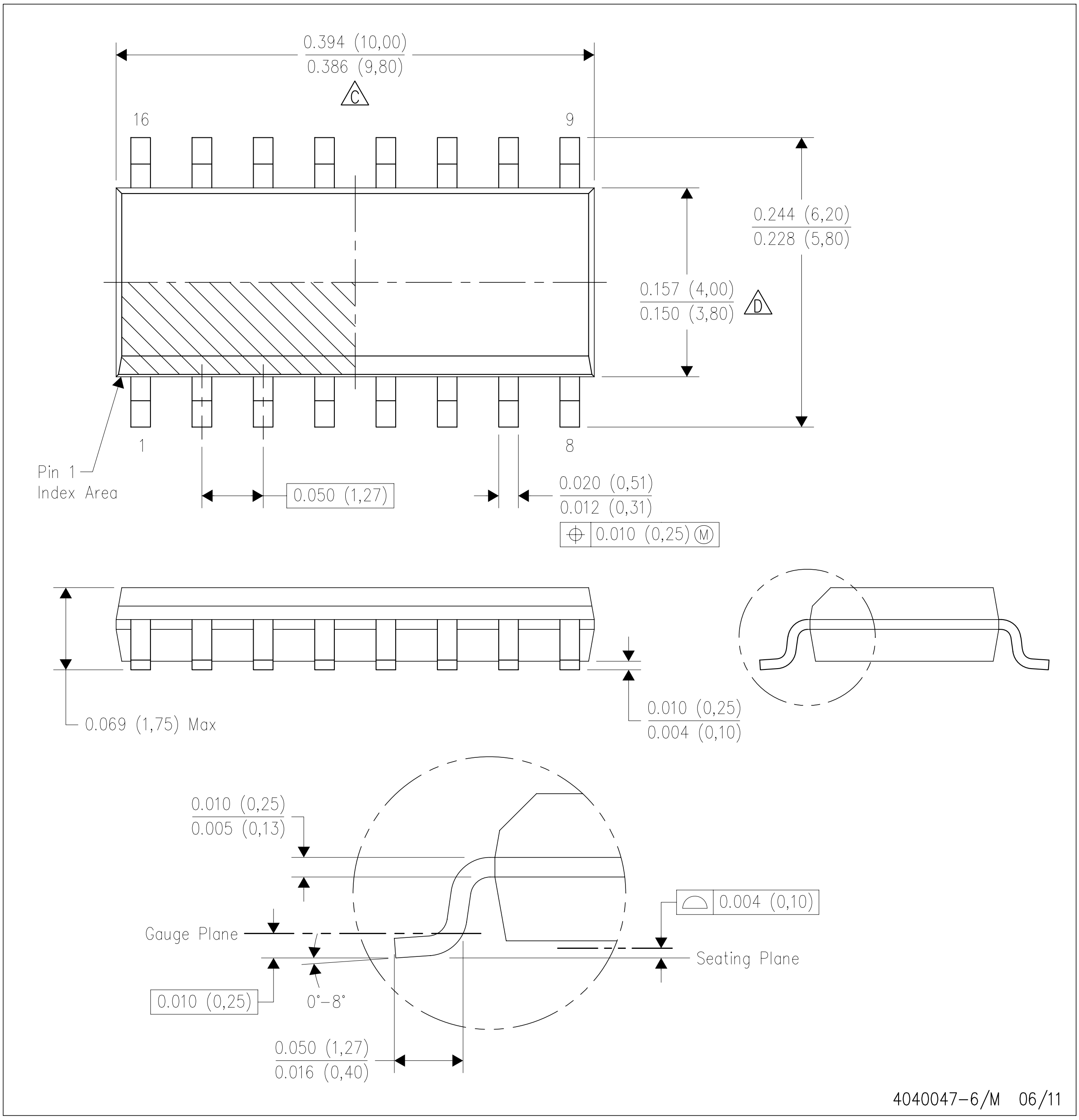
PINS ** / DIM	14	16	18	20
A MAX	0.775 (19,69)	0.775 (19,69)	0.920 (23,37)	1.060 (26,92)
A MIN	0.745 (18,92)	0.745 (18,92)	0.850 (21,59)	0.940 (23,88)
MS–001 VARIATION (C)	AA	BB	AC	AD



4040049/E 12/2002

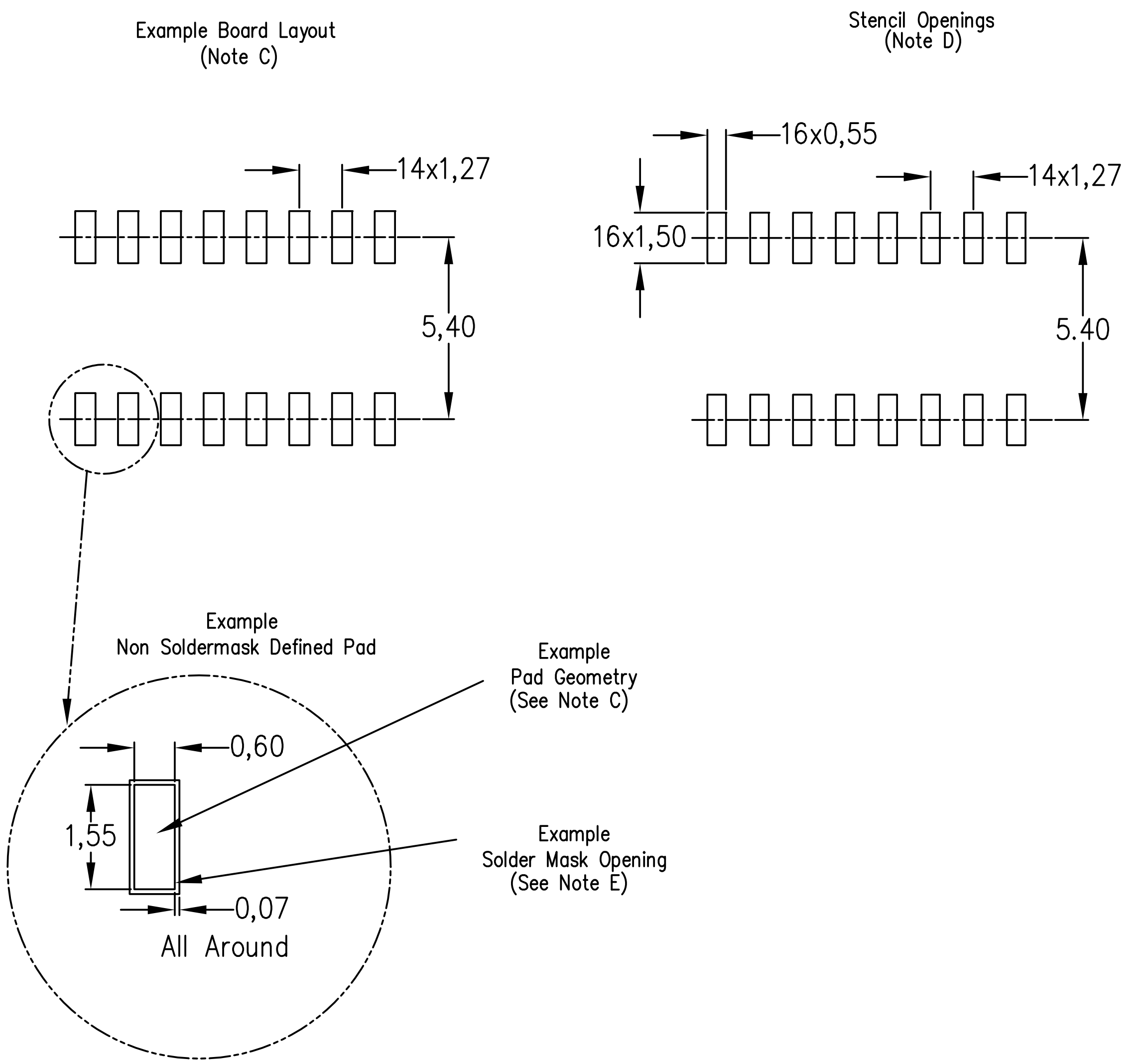
NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Falls within JEDEC MS–001, except 18 and 20 pin minimum body length (Dim A).
- D. The 20 pin end lead shoulder width is a vendor option, either half or full width.

D (R–PDSO–G16) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
E. Reference JEDEC MS–012 variation AC.

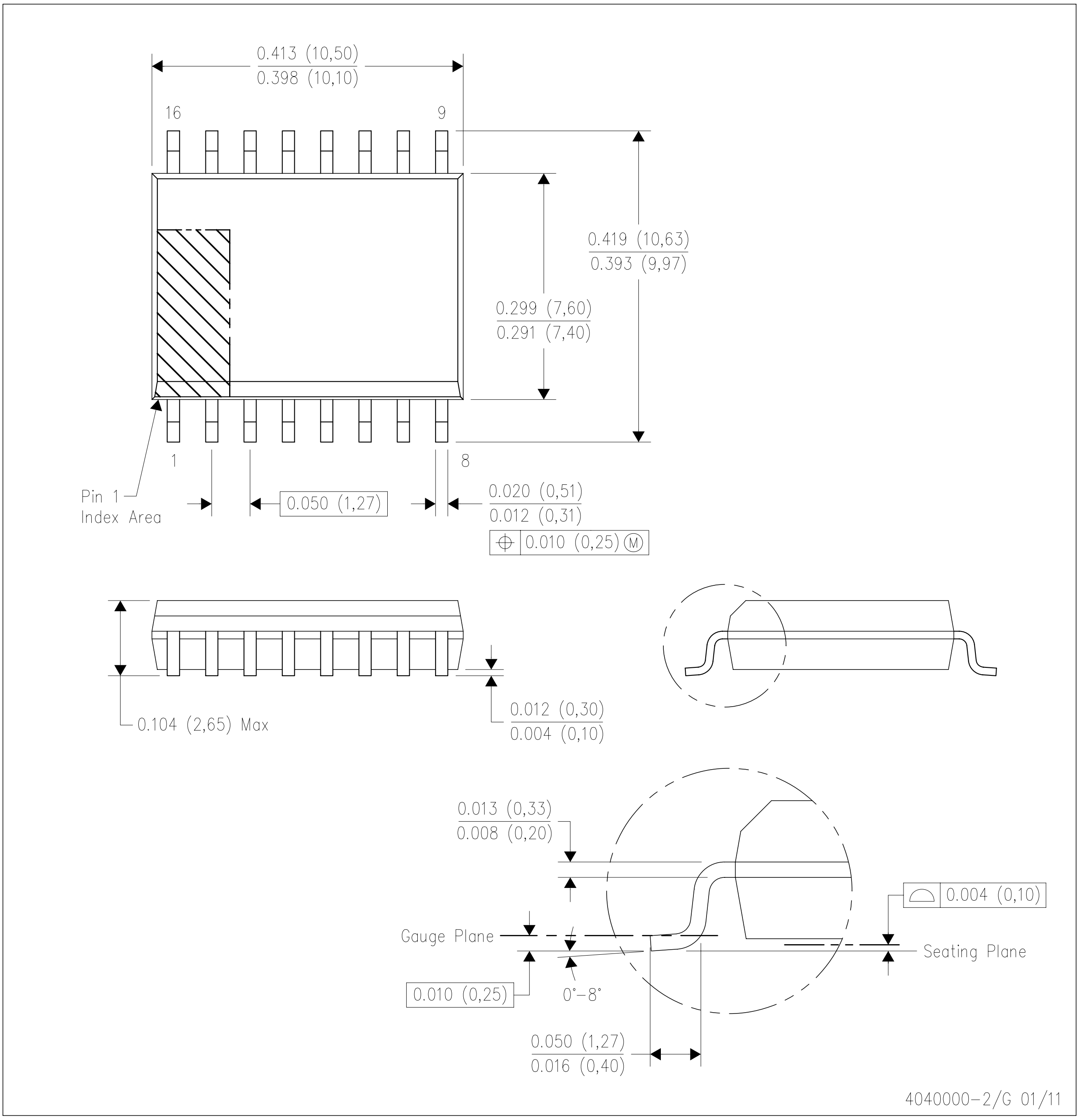
D (R–PDSO–G16) PLASTIC SMALL OUTLINE



4211283–4/E 08/12

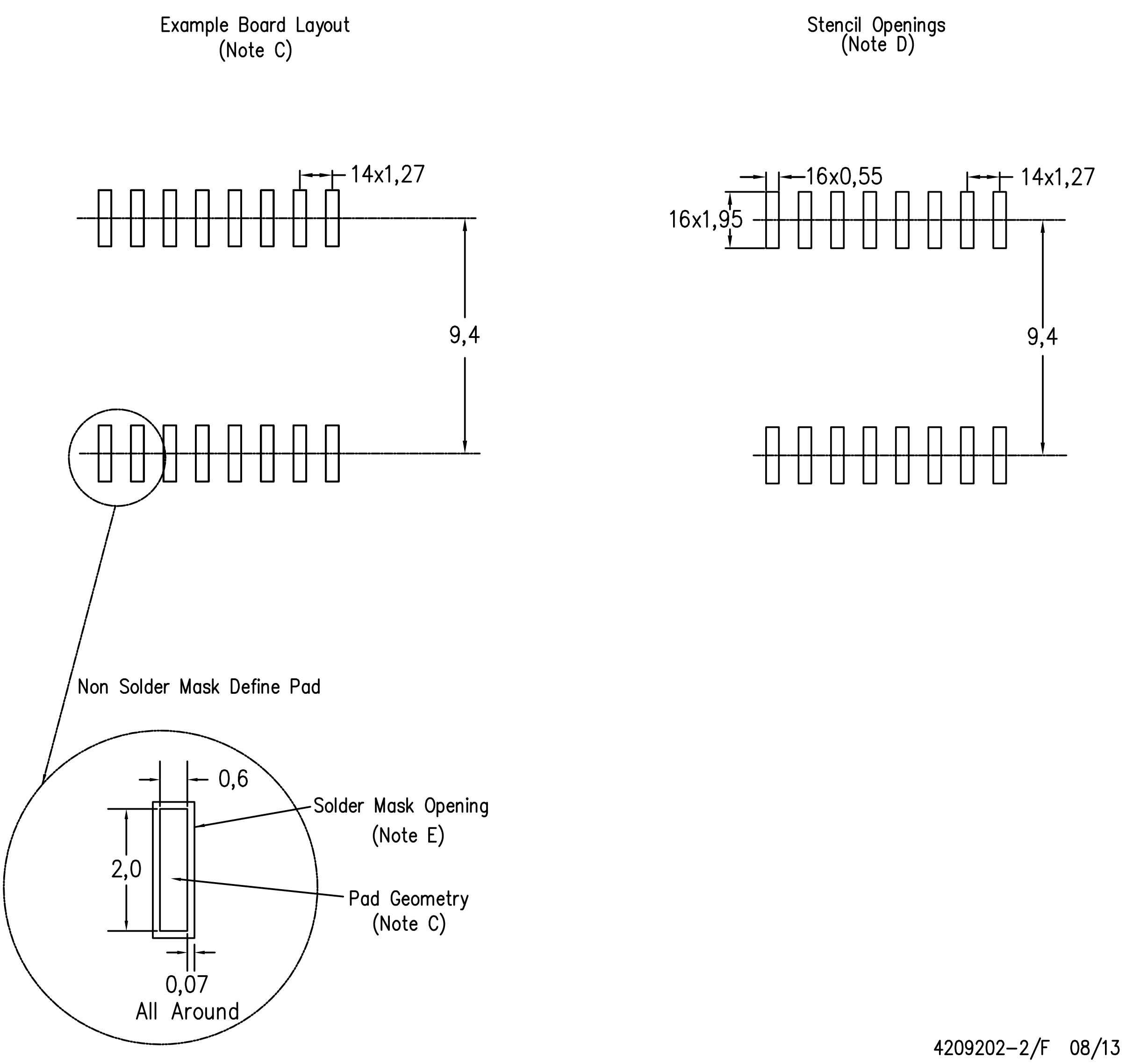
NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

DW (R–PDSO–G16) PLASTIC SMALL OUTLINE



NOTES: A. All linear dimensions are in inches (millimeters). Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion not to exceed 0.006 (0,15).
D. Falls within JEDEC MS–013 variation AA.

DW (R–PDSO–G16) PLASTIC SMALL OUTLINE

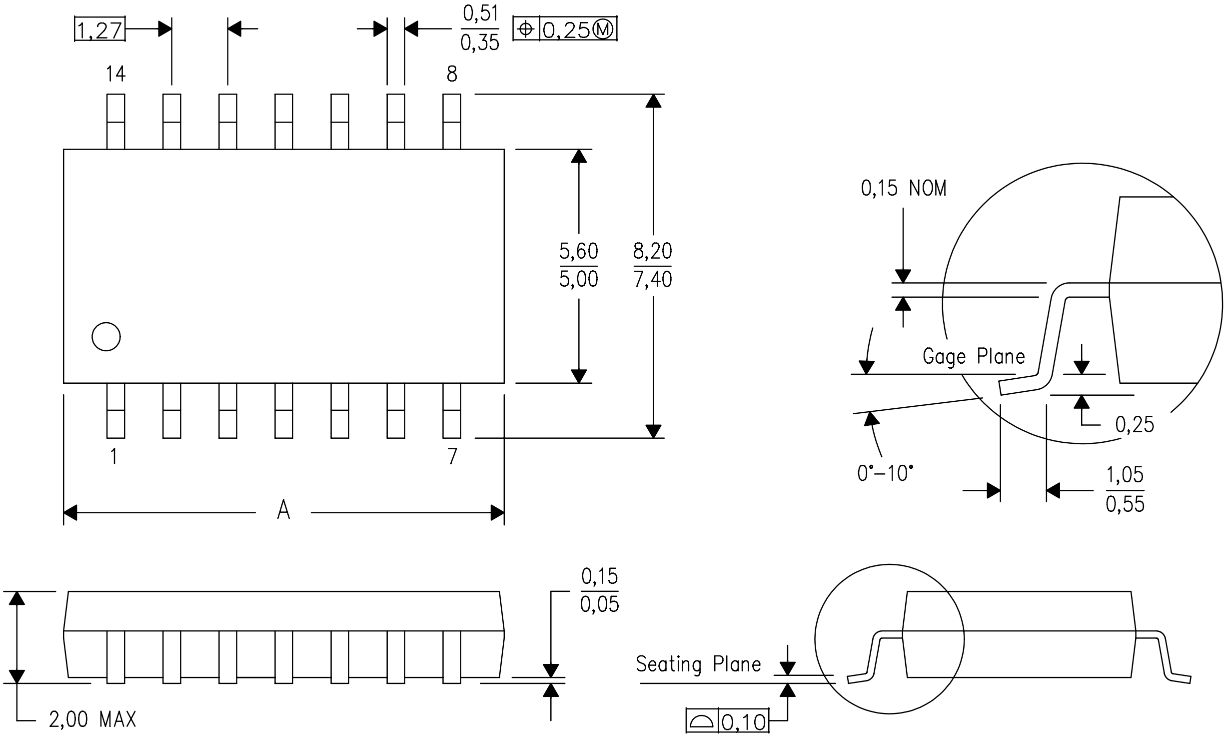


4209202–2/F 08/13

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Refer to IPC7351 for alternate board design.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

NS (R-PDSO-G)** **PLASTIC SMALL-OUTLINE PACKAGE**

14-PINS SHOWN



DIM \ PINS **	14	16	20	24
A MAX	10,50	10,50	12,90	15,30
A MIN	9,90	9,90	12,30	14,70

4040062/C 03/03

NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protrusion, not to exceed 0,15.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

B.7. Schrack Relay

Power PCB Relay RT2

- **2 pole 8A, 2 form C (CO) or 2 form A (NO) contacts**
- **DC or AC coil**
- **5kV/10mm coil-contact, reinforced insulation**
- **Ambient temperature up to 85°C**
- **WG version: product in accordance to IEC60335-1**
- **Reflow version: for THR (Through-Hole Reflow) soldering process**

F0149-C

Typical applications
Boiler control, timers, garage door control, POS automation, interface modules

Approvals

VDE REG.-Nr. 6106, UL E214025, cCSAus 14385
Technical data of approved types on request

Contact Data

Contact arrangement	2 form C (CO) or 2 form A (NO)
Rated voltage	250VAC
Max. switching voltage	400VAC
Rated current	8A, UL: 10A
Limiting continuous current	8A, UL: 10A
Limiting making current, max. 4s, duty factor 10%	15A
Breaking capacity max.	2000VA
Contact material	AgNi 90/10, AgNi 90/10 gold plated, $AgSnO_2$
Frequency of operation, with/without load	
DC coil	360/72000h^{-1}
AC coil	360/36000h^{-1}
Operate/release time max., DC coil	8/6ms
Bounce time max., DC coil, form A/form B	4/10ms
Electrical endurance	see electrical endurance graph1)

Contact ratings

Type	Contact	Load	Cycles
IEC 61810			
RT424 DC coil	C (CO)	8A, 250VAC, cosφ=1, 85°C	$10x10^3$
RT444 AC coil	A (NO)	8A, 250VAC, cosφ=1, 70°C	$50x10^3$
RT424 AC coil	C (CO)	8A, 250VAC, cosφ=1, 70°C	$30x10^3$
UL 508			
RT424 DC coil	A/B (NO/NC)	10A, 250VAC, gen. purpose, 85°C	$20x10^3$
RT424 DC coil	A/B (NO/NC)	1/2hp, 240VAC, 85°C	$1x10^3$
RT424 DC coil	A/B (NO/NC)	Pilot duty, B300, R300, 85°C	$6x10^3$
EN60947-5-1			
RTE24 DC coil	A/B (NO/NC)	AC15, 250VAC, 3A	6.050
RTE24 DC coil	A/B (NO/NC)	DC13, 24VDC, 2A	6.050
RTE24 DC coil	A/B (NO/NC)	DC13, 250VDC, 0.2A	6.050
EN60730-1			
RT424 DC coil	A/B (NO/NC)	6(2)A, 250VAC, 85°C	$100x10^3$

1) For reflow solderable versions: actual contact performance may be influenced by the reflow soldering process.

Contact Data (continued)

Mechanical endurance	
DC coil	>$30x10^6$ operations
DC coil, reflow version	>$10x10^6$ operations
AC coil	>$5x10^6$ operations
AC coil, reflow version	>$2x10^6$ operations

Coil Data

Coil voltage range, DC coil/AC coil	5 to 110VDC / 24 to 230VAC
Operative range, IEC 61810	2
Coil insulation system according UL	class F

Coil versions, DC coil

Coil code	Rated voltage VDC	Operate voltage VDC	Release voltage VDC	Coil resistance Ω±10%2)	Rated coil power mW
005	5	3.5	0.5	62	403
006	6	4.2	0.6	90	400
009	9	6.3	0.9	200	400
012	12	8.4	1.2	360	400
024	24	16.8	2.4	1440	400
048	48	33.6	4.8	5520	417
060	60	42.0	6.0	8570 2)	420
110	110	77.0	11.0	28800 2)	420

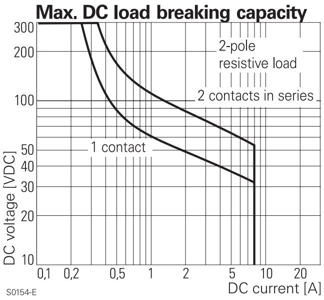
2) Coil resistance ±12%. All figures are given for coil without pre-energization, at ambient temperature +23°C. Other coil voltages on request.

Coil versions, AC coil 50Hz

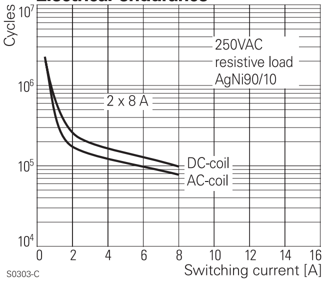
Coil code	Rated voltage VAC	Operate voltage VAC	Release voltage VAC	Coil resistance Ω±15%3)	Rated coil power VA
524	24	18.0	3.6	350 3)	0.76
615	115	86.3	17.3	8100	0.76
620	120	90.0	18.0	8800	0.75
700	200	150.0	30.0	24350	0.76
730	230	172.5	34.5	32500	0.74

3) Coil resistance ±10%. All figures are given for coil without pre-energization, at ambient temperature +23°C, 50Hz. Other coil voltages on request.

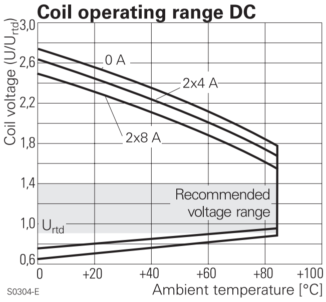
Max. DC load breaking capacity



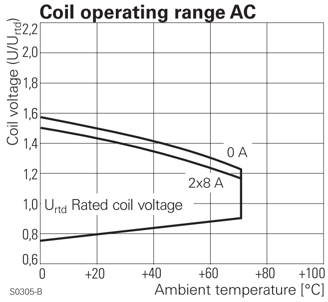
Electrical endurance



Coil operating range DC



Coil operating range AC



Power PCB Relay RT2 (Continued)

Insulation Data

Initial dielectric strength	
between open contacts	1000V_{rms}
between contact and coil	5000V_{rms}
between adjacent contacts	2500V_{rms}
Clearance/creepage	
between contact and coil	≥10/10mm
between adjacent contacts	≥3/4mm
Material group of insulation parts	IIIa
Tracking index of relay base	PTI 250V
reflow version	PTI 175V

Other Data

Material compliance: EU RoHS/ELV, China RoHS, REACH, Halogen content	refer to the Product Compliance Support Center at www.te.com/customersupport/rohssupportcenter
Resistance to heat and fire	
WG version or reflow version	according EN60335, par30
Ambient temperature	
DC coil	-40 to 85°C
AC coil	-40 to 70°C
$AgSnO_2$ contacts	-40 to 70°C
Category of environmental protection, IEC 61810	
standard version	RTII - flux proof, RTIII - wash tight
reflow version	RTII - flux proof
Vibration resistance (functional),	
form A/form B contact, 30 to 300Hz	20g/5g
Shock resistance (destructive)	100g

Other Data (continued)

Terminal type	PCB-THT, plug-in
reflow version	PCB-THR
Mounting distance, AC coil	≥2.5mm
Weight	13g
Resistance to soldering heat THT, IEC 60068-2-20	
RTII	270°C/10s
RTIII	260°C/5s
Resistance to soldering heat THR	
reflow soldering (for reflow version)	forced gas convection 4) or vapour phase 5)
temperature profile	according EN61730
Packaging/unit	tube/20pcs., box/500pcs.

4) infrared heating not allowed
5) recommended fluid LS/230

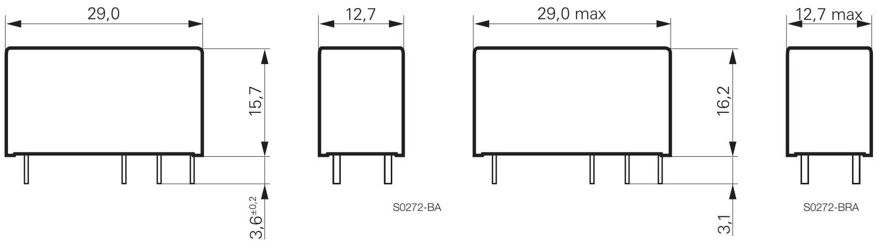
Accessories

For details see datasheet	Accessories Industrial Power Relay RT

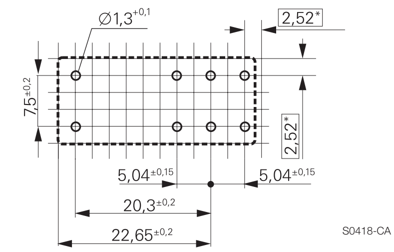
NOTE: indicated contact ratings and electrical endurance data for direct wiring of relays (according IEC 61810-1); for relays mounted on sockets deratings may apply.

Dimensions

THT version THR version (reflow solderable)

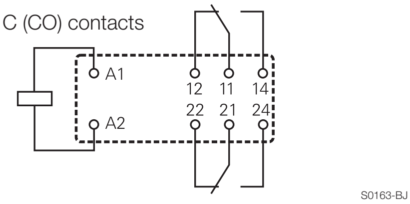


PCB layout / terminal assignment
Bottom view on solder pins

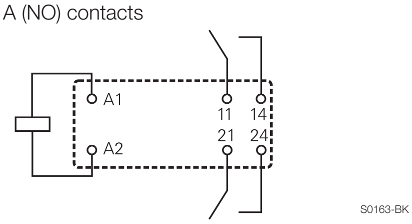


*) With the recommended PCB hole sizes a grid pattern from 2.5mm to 2.54mm can be used.

2 form C (CO) contacts

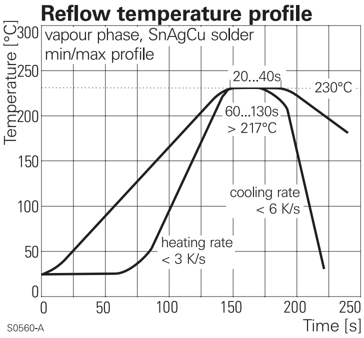


2 form A (NO) contacts

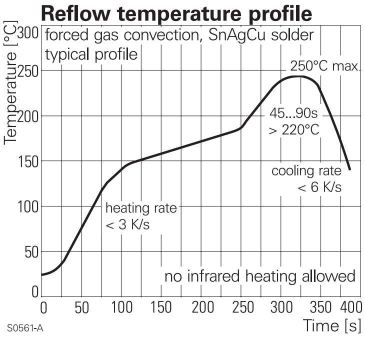


Process conditions for Reflow soldering
according to EN61760-1

Reflow temperature profile



Reflow temperature profile



Power PCB Relay RT2 (Continued)

Product code structure	Typical product code	RT	4	2	4	024

Type
- **RT** Power PCB Relay RT2

Version
- **4** 8A, pinning 5mm, flux proof
- **E** 8A, pinning 5mm, wash tight (not for Reflow version)

Contact arrangement
- **2** 2 form C (CO) contacts
- **4** 2 form A (NO) contacts

Contact material
- **3** AgSnO
- **4** AgNi 90/10
- **5** AgNi 90/10 gold plated

Coil
- Coil code: please refer to coil versions table

Version
- **Blank** Standard version
- **WG** Product in accordance with IEC 60335-1 (domestic appliances)
- **R** Reflow solderable

Product code	Version	Contacts	Contact material	Coil	Version	Part number
RT423730	8A,	2 form C (CO)	AgSnO	230VAC	Standard	4-1393243-3
RT424005	pinning 5mm,	contacts	AgNi 90/10	5VDC		5-1393243-9
RT424006	flux proof			6VDC		6-1393243-1
RT424012				12VDC		6-1393243-3
RT424012WG					IEC60335-1 compliant	7-1415538-8
RT424024				24VDC	Standard	6-1393243-8
RT424024WG					IEC60335-1 compliant	7-1415538-7
RT424048				48VDC	Standard	7-1393243-0
RT424060				60VDC		7-1393243-3
RT424110				110VDC		7-1393243-5
RT424524				24VAC		7-1393243-6
RT424615				115VAC		7-1393243-8
RT424730				230VAC		7-1393243-9
RT425003			AgNi 90/10	3VDC		7-1415525-1
RT425005			gold plated	5VDC		8-1393243-0
RT425012				12VDC		8-1393243-2
RT425024				24VDC		8-1393243-5
RT444012		2 form A (NO)	AgNi 90/10	12VDC		9-1393243-7
RT444024		contacts		24VDC		9-1393243-9
RTE24005	8A,	2 form C (CO)		5VDC		1393243-1
RTE24006	pinning 5mm,	contacts		6VDC		1393243-2
RTE24012	wash tight			12VDC		1393243-4
RTE24024				24VDC		1-1393243-0
RTE24048				48VDC		1-1393243-1
RTE24110				110VDC		1-1393243-4
RTE24524				24VAC		1-1393243-5
RTE24615				115VAC		1-1393243-7
RTE24730				230VAC		1-1393243-8
RTE25005			AgNi 90/10	5VDC		1-1393243-9
RTE25012			gold plated	12VDC		2-1393243-0
RTE25024				24VDC		2-1393243-1
RTE25524						2-1393243-4
RTE43009		2 form A (NO)	AgSnO	9VDC		4-1415535-1
RTE44009		contacts	AgNi 90/10			3-1393243-1
RTE44730				230VAC		3-1393243-5

This list represents the most common types and does not show all variants covered by this datasheet.
Other types on request

C. uC

C.1. Main Loop

Listing C.1: Main

```
#include <conf_quick_start_callback.h>
#include <asf.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>
#include "FHV\config_focus_fhv.h"

/**
 * \brief main programm
 *
 * this program is driving an DRV8711
 * It gets the order from a Beckhoff PLC over RS232
 *
 */
int main(void)
{
  //insertValuesIntoStruct();
  //system_init();
  //delay_init();
  //
  //configure_extint_channel();
  //configure_extint_channel_emergency();
  //configure_extint_callbacks();
  //
  //configure_adc();
  //configure_adc_callbacks();
  //
  //configure_usart();
  //configure_usart_callbacks();
  //
  //configure_tc();
  //configure_tc_callbacks();
  //
  //system_interrupt_enable_global();
  //configure_spi_master();
  //configure_spi_master_callbacks();
  //configure_port_pins();
   initGrabtastic();

  while (true) {

    usart_read_buffer_job(&usart_instance, (uint8_t *) rx_buffer, sizeof(rx_buffer)); /*
        lets read the RS232 */

    executeOrder(); /* execute the order we get from PLC*/

    reposIfInLimitSwitch(); /* if we should init and the limit switch is pressed, repos
        and drive every time from the same direction to reference*/

    finishTheOrder(); /* finish the order on prepare the send status*/

    startRepositioningWhenDown(); /*if z axis reaches down position, it is necesary to
        move 2mm up, because it scratches on the repository*/

    sendTheTelegram(); /* send the telegram */
```

```
  }
}
```

C.2. Library

Listing C.2: Header

```
/*
* This file includes all header files
* And also all programed functions
*/
#include <string.h>
#ifndef CONFIG_FOCUS_FHV_H
#define CONFIG_FOCUS_FHV_H
#define richtung false
#define respond_I "i"
#define respond_H "h"
#define respond_D "d"
#define respond_P "p"
#define respond_ok "ok"
#define respondBussy "bussy"
#define respondUnkown "UNKOWN"
#define respondStartetUp "Started up"
#define respondOK "ok"
#define trennzeichen '/'
//! [definition_DRV8711]
/** definitions commands */
/* setting for the moter, speed and that shit*/
#define trapezSteigung 1.5
/* this are the mm values to drive for target D */
#define targetDinmm 67
//* this are the mm values to drive for target P */
#define targetPinmm 35
#define freifahrenInmm 8
#define forErrorInmm (targetDinmm - 35)
/* this are the mm values to drive after D*/
#define repositioningAfterDownInmm (targetDinmm - 2)
/* it needs 400 spin for one completaly turn at full step */
#define oneSpin 400
#define targetH 1100
#define targetP (int) (targetH + targetPinmm / trapezSteigung * oneSpin)
#define targetD (int) (targetH + targetDinmm / trapezSteigung * oneSpin)
#define targetFreifahren (int) (targetH + freifahrenInmm / trapezSteigung * oneSpin)
#define targetRepositioningAfterDown (int) (targetH + repositioningAfterDownInmm /
    trapezSteigung * oneSpin)
#define targetForError  (int) (targetH + forErrorInmm / trapezSteigung * oneSpin)
#define treshholdAccelerateUp 9500
#define treshholdAccelerateDown 7600
#define accelerationRate 1
#define differenceTreshhold (treshholdAccelerateUp - treshholdAccelerateDown) /
    accelerationRate
#define trehsholdNotMovingError 50
//! [definition_DRV8711]
//! [definition_StrainGauge]
/* things for the strain gauge*/
#define maxN 20000.0
#define scalingFactorForce 2.15
#define offsetIfDRVon  0.0
//! [definition_StrainGauge]
/********** Fuction Prototypes ************/
void delete_buffer(uint8_t *buffer);
void writeToDRV(volatile uint8_t *wr_config, volatile uint8_t *rd_config, uint16_t length
    );
void deleteBuffer(char *arrayBuffer, uint16_t lenght);
```

```c
void addToWriteBuffer(char *arrayInput, const char *arrayCopy);
double calculateMedian(volatile uint16_t *valueBuffer, uint16_t length);
volatile bool targetDirection (int iActualPos, int iTargetPos);
void executeOrder(void);
void reposIfInLimitSwitch(void);
void finishTheOrder(void);
void calculatePosZaxis(void);
void startRepositioningWhenDown(void);
void errorHandling(void);
void sendRestartTelegram(void);
void sendTheTelegram(void);
void deleteRespondBuffer(void);
void sendBusy(void);
void sendInvalidTelegram(void);
void sendOK(void);
void telegramPreparation(void);
void insertValuesIntoStruct(void);
void initGrabtastic(void);
/* protoype port configuration*/
void configure_port_pins(void);
/* prototype Integer to Int */
void reverse(char s[]);
void itoaEigen(int n, char s[]);
/* protoype DRV8711 write and read default values*/
void drv8711enable (bool reference, bool direction);
void DRV8711disable(void);
/* Timter Counter */
void configure_tc(void);
void configure_tc_callbacks(void);
void tc_callback_to_change_duty_cycle(struct tc_module *const module_inst);
/* USART RS232 */
void usart_read_callback(const struct usart_module *const usart_module);
void usart_write_callback(const struct usart_module *const usart_module);
void configure_usart(void);
void configure_usart_callbacks(void);
/* SPI */
void configure_spi_master_callbacks(void);
void configure_spi_master(void);
/* Interrupt Limit Switch */
void configure_extint_channel(void);
void configure_extint_callbacks(void);
void extint_detection_callback(void);
/* Interrupt Emergency Stop */
void configure_extint_channel_emergency(void);
void extint_detection_callback_emergency(void);
/* ADC */
void configure_adc(void);
void configure_adc_callbacks(void);
void adc_complete_callback(struct adc_module *const module);

/* Timter Counter */
struct adc_config config_adc;
struct tc_module tc_instance;
/* USART RS232 */
struct usart_module usart_instance;
#define MAX_RX_BUFFER_LENGTH 1
volatile uint8_t rx_buffer[MAX_RX_BUFFER_LENGTH];
volatile uint8_t  rx_string[MAX_RX_BUFFER_LENGTH] = {0};
/* SPI */
#define BUF_LENGTH 2
#define SLAVE_SELECT_PIN EXT2_PIN_SPI_SS_0
static uint8_t wr_buffer[BUF_LENGTH] = {0x01, 0x02};
static uint8_t rd_buffer[BUF_LENGTH];
struct spi_module spi_master_instance;
struct spi_slave_inst slave;
volatile bool transrev_complete_spi_master = false;
```

```
/* ADC */
#define ADC_SAMPLES 128
volatile uint16_t adc_result_buffer[ADC_SAMPLES];
struct adc_module adc_instance;
volatile bool adc_read_done = false;

/* Program Status */
volatile uint8_t globalOrder = 0;   /*!< received Order to execute */
volatile uint8_t globalSendOK = 0;    /*!< send respond after an order received */
volatile uint8_t globalDrive = 0;   /*!< if movement is executing Drive is 1, if its finished it's 2 */
volatile bool globalSendStatus = false; /*!< after drive gets 2, the status will be send. To get the Status ready */
volatile bool globalActualDirection = false;  /*!< the actual direction of the motor. down=false, up=true */
volatile bool globalInvalidTelegram = false;  /*!< respond to a unknown command */
volatile bool globalBusy = false;       /*!< respond if getting an new order, but there is already executing an order, expects it is a reset command */
volatile bool globalEmergencyPressed = false; /*!< if an emergency stop is detected, this is true */
volatile bool globalLimitSwitchPressed = true;  /*!< if limit switch is pressed the value is true */
volatile bool globalOrderWasDown = false;   /*!< the order before was down */
static uint8_t globalMovingFreeAxis = 0;    /*!< the axis has to move down first, to do the referencing */

char globalRespondTelegram[20]; /*!< is a global buffer for the respond telegram in ASCII */
static bool globalSendRespond = false; /*!< is true, if the respond has to be send */
char globalPositionAxisForTelegram [20] = {0}; /*!< is a global buffer for the position of the Z axis in ASCII */
char globalErrorForTelegram [20] = {0}; /*!< is a global buffer for the error of the Z axis in ASCII */
static bool globalSendRestartTelegram = true; /*!< if the uC has turned on, we want to know it, therefore send something */
double globalResult = 0.0;
/* Measurement */
volatile int globalStepPositionAxis = targetH;
volatile static uint8_t wr_drv8711Defaults[] = {0xF, 0x0, 0x11, 0x64, 0x20, 0xC8, 0x30, 0x64, 0x40, 0x32, 0x50, 0x40, 0x65, 0xA4, 0x70, 0x0};  /*!< uint8 array for send the config of the DRV8711 */
volatile static uint8_t wr_drv8711Read[] = {0x80,  0x00, 0x90, 0x00, 0xA0,  0x00, 0xB0, 0x00, 0xC0,  0x00, 0xD0,  0x00, 0xE0,  0x00, 0x70, 0x00};  /*!< uint8 array for receive the config of the DRV8711 */
volatile static uint8_t rd_drv8711Defaults[sizeof(wr_drv8711Defaults)]={0};  /*!< uint8 array for get the status of the DRV8711 */
volatile static uint8_t rd_drv8711Read[sizeof(wr_drv8711Read)]={0};     /*!< uint8 array for receive the status of the DRV8711 */

/* struct of order */
#define lengt 6
struct index {
  int targetPosition;
  bool direction;
  bool repos;
  int order;
  char receive;
  char respond;
};
struct index positionOfEachOrder[lengt]; /* array number */

/**
* \brief insert values into array of struct
*
* this is an array of struct indes, and carry all necessary values for the order, etc.
*
```

```
*/
void insertValuesIntoStruct(void)
{
  uint8_t j = 1;
  positionOfEachOrder[j].targetPosition=1;
  positionOfEachOrder[j].direction=richtung;
  positionOfEachOrder[j].order = 1;
  positionOfEachOrder[j].repos = 0;
  strcpy(&positionOfEachOrder[j].receive, "I");
  strcpy(&positionOfEachOrder[j].respond, respond_I);

  positionOfEachOrder[++j].targetPosition=targetD;
  positionOfEachOrder[j].direction=!richtung;
  positionOfEachOrder[j].order = 2;
  positionOfEachOrder[j].repos = 1;
  strcpy(&positionOfEachOrder[j].receive, "D");
  strcpy(&positionOfEachOrder[j].respond, respond_D);

  positionOfEachOrder[++j].targetPosition=targetH;
  positionOfEachOrder[j].direction=richtung;
  positionOfEachOrder[j].order = 3;
  positionOfEachOrder[j].repos = 0;
  strcpy(&positionOfEachOrder[j].receive, "H");
  strcpy(&positionOfEachOrder[j].respond, respond_H);

  positionOfEachOrder[++j].targetPosition=targetP;
  positionOfEachOrder[j].direction=richtung;
  positionOfEachOrder[j].order = 4;
  positionOfEachOrder[j].repos = 0;
  strcpy(&positionOfEachOrder[j].receive, "P");
  strcpy(&positionOfEachOrder[j].respond, respond_P);

  positionOfEachOrder[++j].targetPosition=targetRepositioningAfterDown; /* for repos*/
  positionOfEachOrder[j].direction=richtung;
  positionOfEachOrder[j].order = 5;
  positionOfEachOrder[j].repos = 0;
  strcpy(&positionOfEachOrder[j].receive, "");
  strcpy(&positionOfEachOrder[j].respond, respond_D);

}

/**
* \brief calculateOrder
*
* searches from the received command the belonging order struct
*
*/
void calculateOrder(char receivedOrder){
  int localFound;
  volatile int i = 0;
  for (i = 1; i < lengt ; i++) {
    if (positionOfEachOrder[i].receive == receivedOrder) { //matched
      /*init command immer ausfuehren, auch wenn schon ein order da ist*/
      localFound = strncmp(&positionOfEachOrder[i].receive, "I", sizeof(
          positionOfEachOrder[i].receive));
      if(!localFound == 0 && positionOfEachOrder[0].order != 0){
        globalBusy = true;
        break;
      }
      else /*sonst ausfuehren*/
      {
        //globalOrder = positionOfEachOrder[i].order;
        /* save the order in array number 0*/
        positionOfEachOrder[0].targetPosition = positionOfEachOrder[i].targetPosition;
        positionOfEachOrder[0].direction = positionOfEachOrder[i].direction;
        positionOfEachOrder[0].order = positionOfEachOrder[i].order;
```

```
        positionOfEachOrder[0].repos = positionOfEachOrder[i].repos;
        strcpy(&positionOfEachOrder[0].receive, &positionOfEachOrder[i].receive);
        strcpy(&positionOfEachOrder[0].respond, &positionOfEachOrder[i].respond);
        break;
      }
    }
  }
  if(i > lengt)
  {
    globalInvalidTelegram = true; //UNKOWN
  }

}

/**
* \brief callback frequency
*
* changes the frequency and manages the positioning
*
*/
void tc_callback_to_change_duty_cycle(struct tc_module *const module_inst)
{

  static uint16_t i = treshholdAccelerateUp;
  static bool accelerateUp = true;
  static bool accelerateDown = false;
  static int distanceToTarget = 0;
  static bool newOrder = true;
  volatile bool stop = false;
  if (!newOrder)
  {
    i = treshholdAccelerateUp; // reset if new order arrived
    accelerateUp = true;
    accelerateDown = false;
    newOrder = true;
  }

  if (( i < treshholdAccelerateDown ) && accelerateUp)
  {
    accelerateUp = false;

  }
  if (( i > treshholdAccelerateUp ) && accelerateDown)
  {
    accelerateUp = true;
    accelerateDown = false;
  }

  if (accelerateDown && (positionOfEachOrder[0].order != 1))
  {
    i = i + accelerationRate;
  }
  if(accelerateUp && (positionOfEachOrder[0].order != 1))
  {
    i = i - accelerationRate;
  }
  distanceToTarget = globalStepPositionAxis - positionOfEachOrder[0].targetPosition;
  distanceToTarget = abs (distanceToTarget);

  if(differenceTreshhold > distanceToTarget && (positionOfEachOrder[0].order != 1))
  {
    accelerateDown = true;
    accelerateUp = false;
  }
  tc_set_compare_value(module_inst, TC_COMPARE_CAPTURE_CHANNEL_0, i);
  /* count the virtual measurement of distance */
```

```
  if (globalActualDirection)
  {
    globalStepPositionAxis ++; /* down */
  }
  else
  {
    globalStepPositionAxis --;  /* up */
  }

  if((distanceToTarget <= 0 && positionOfEachOrder[0].order != 1))
  {
    stop = true;
  }

  if ((globalResult > 15000.0) | (globalResult < -15000.0))
  {
    globalEmergencyPressed = true;
  }

  if(stop | globalEmergencyPressed) // stop the PWM when Z Axis is down or up
  {
    tc_disable(&tc_instance); // pwm aus
    port_pin_set_output_level(EXT2_PIN_5,false); //sleep on
    globalDrive = 2; //-> send respond
    i = treshholdAccelerateUp;
    accelerateUp = true;
    accelerateDown = false;
    newOrder = false;
    stop = false;
    if (positionOfEachOrder[0].order == 2 && !globalEmergencyPressed) //if order was down
    {
      globalOrderWasDown = true;
    }
  }
}

/**
* \brief configure the TC
*
* configure the TC as frequency match mode
*
*/
void configure_tc(void)
{
  struct tc_config config_tc;
  tc_get_config_defaults(&config_tc);
  config_tc.clock_source = GCLK_GENERATOR_0;
  config_tc.counter_size = TC_COUNTER_SIZE_16BIT;
  config_tc.counter_16_bit.compare_capture_channel[TC_COMPARE_CAPTURE_CHANNEL_0] =
      treshholdAccelerateUp; //650
  config_tc.wave_generation = TC_WAVE_GENERATION_MATCH_FREQ_MODE;
  config_tc.pwm_channel[0].enabled = true;
  config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
  config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;
  tc_init(&tc_instance, PWM_MODULE, &config_tc);
  //tc_enable(&tc_instance);
}

/**
* \brief configure callbacks
*
* the TC callbacks are attached to the interrupt controller
*
*/
void configure_tc_callbacks(void)
{
```

```
  tc_register_callback(&tc_instance,tc_callback_to_change_duty_cycle,
      TC_CALLBACK_CC_CHANNEL0);
  tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL0);
}
/**
* \brief RS232 read callbacks
*
* is called when the PLC sends a command to the uC
* it translates the order into a value stored in globalOrder
*/
void usart_read_callback(const struct usart_module *const usart_module)
{
  //  usart_write_buffer_job(&usart_instance, (uint8_t *) rx_buffer, MAX_RX_BUFFER_LENGTH
      );
  rx_string [0] = rx_buffer [0];
  calculateOrder(rx_buffer [0]);
}
/**
* \brief RS232 write callbacks
*
* is called when, the uC is done with sending to the PLC
*/
void usart_write_callback(const struct usart_module *const usart_module)
{
  globalSendStatus = false;
}
/**
* \brief configure RS232
*
* RS232 is configured as standard
*/
void configure_usart(void)
{
  struct usart_config config_usart;
  usart_get_config_defaults(&config_usart);
  //config_usart.baudrate    = 9600;
  config_usart.baudrate    = 115200;
  config_usart.mux_setting = EXT1_UART_SERCOM_MUX_SETTING;
  config_usart.pinmux_pad0 = EXT1_UART_SERCOM_PINMUX_PAD0;
  config_usart.pinmux_pad1 = EXT1_UART_SERCOM_PINMUX_PAD1;
  config_usart.pinmux_pad2 = EXT1_UART_SERCOM_PINMUX_PAD2;
  config_usart.pinmux_pad3 = EXT1_UART_SERCOM_PINMUX_PAD3;

  while (usart_init(&usart_instance,EXT1_UART_MODULE, &config_usart) != STATUS_OK) {
  }
  usart_enable(&usart_instance);
}

/**
* \brief configure RS232 callbacks
*
* the RS232 callbacks are attached to the interrupt controller
*/
void configure_usart_callbacks(void)
{
  usart_register_callback(&usart_instance, (void*) usart_write_callback,
      USART_CALLBACK_BUFFER_TRANSMITTED);
  usart_register_callback(&usart_instance, (void*) usart_read_callback,
      USART_CALLBACK_BUFFER_RECEIVED);

  usart_enable_callback(&usart_instance, USART_CALLBACK_BUFFER_TRANSMITTED);
  usart_enable_callback(&usart_instance, USART_CALLBACK_BUFFER_RECEIVED);
}
/**
* \brief SPI callbacks
*
```

```c
* is called, when the SPI finished the transmission
*/
static void callback_spi_master( struct spi_module *const module)
{
  transrev_complete_spi_master = true;
}
/**
* \brief configure SPI callbacks
*
* the SPI callbacks are attached to the interrupt controller
*/
void configure_spi_master_callbacks(void)
{
  spi_register_callback(&spi_master_instance, callback_spi_master,
      SPI_CALLBACK_BUFFER_TRANSCEIVED);
  spi_enable_callback(&spi_master_instance, SPI_CALLBACK_BUFFER_TRANSCEIVED);
}
/**
* \brief configure SPI
*
* SPI is configured as standard, but with on EXT2
*/
void configure_spi_master(void)
{
  struct spi_config config_spi_master;
  struct spi_slave_inst_config slave_dev_config;
  spi_slave_inst_get_config_defaults(&slave_dev_config);
  slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
  spi_attach_slave(&slave, &slave_dev_config);
  spi_get_config_defaults(&config_spi_master);
  config_spi_master.mux_setting = EXT2_SPI_SERCOM_MUX_SETTING;
  config_spi_master.pinmux_pad0 = EXT2_SPI_SERCOM_PINMUX_PAD0;
  config_spi_master.pinmux_pad1 = PINMUX_UNUSED;
  config_spi_master.pinmux_pad2 = EXT2_SPI_SERCOM_PINMUX_PAD2;
  config_spi_master.pinmux_pad3 = EXT2_SPI_SERCOM_PINMUX_PAD3;
  config_spi_master.mode_specific.master.baudrate = 100000;
  spi_init(&spi_master_instance, EXT2_SPI_MODULE, &config_spi_master);
  spi_enable(&spi_master_instance);
}
/**
* \brief ADC callbacks
*
* is called, when the ADC finished the conversion
*/
void adc_complete_callback(struct adc_module *const module)
{
  adc_read_done = true;
}
/**
* \brief configure ADC
*
* SPI is configured on EXT1
* GCLK_GENERATOR_2
* ADC_CLOCK_PRESCALER_DIV4
* ADC_REFERENCE_AREFB
* ADC_RESOLUTION_10BIT
*/
void configure_adc(void)
{
  //struct adc_config config_adc;
  adc_get_config_defaults(&config_adc);

  config_adc.clock_source =  GCLK_GENERATOR_0;
  config_adc.clock_prescaler = ADC_CLOCK_PRESCALER_DIV256;
  //  config_adc.reference       = ADC_REFERENCE_INTVCC1;
  config_adc.reference       = ADC_REFERENCE_AREFB;
```

```c
  // PIN setzen bzw auswaehlen!!
  config_adc.positive_input   = ADC_POSITIVE_INPUT_PIN8;
  config_adc.resolution       = ADC_RESOLUTION_10BIT;
  adc_init(&adc_instance, ADC, &config_adc);
  adc_disable_pin_scan_mode(&adc_instance);
  adc_enable(&adc_instance);
}
/**
* \brief configure ADC callbacks
*
* the ADC callbacks are attached to the interrupt controller
*/
void configure_adc_callbacks(void)
{
  adc_register_callback(&adc_instance,adc_complete_callback, ADC_CALLBACK_READ_BUFFER);
  adc_enable_callback(&adc_instance, ADC_CALLBACK_READ_BUFFER);
}
/**
* \brief configure Ports
*
* the used I/O's are configured here
*/
void configure_port_pins(void)
{
  struct port_config config_port_pin;
  port_get_config_defaults(&config_port_pin);
  config_port_pin.input_pull = PORT_PIN_PULL_DOWN;
  config_port_pin.direction = PORT_PIN_DIR_OUTPUT;
  port_pin_set_config(EXT2_PIN_5, &config_port_pin);
  port_pin_set_config(EXT2_PIN_6, &config_port_pin);
  port_pin_set_config(EXT2_PIN_9, &config_port_pin);
  config_port_pin.direction = PORT_PIN_DIR_INPUT;
  //port_pin_set_config(EXT1_IRQ_INPUT, &config_port_pin);
}

/**
* \brief enables DRV8711
*
* Writes all necessary registert to DRV7811
*
* \param[in]  reference   bool if to enable the frequency
* \param[in]  direction   bool in which direction should DRV8711 turn
*/
void drv8711enable (bool reference, bool direction){

  port_pin_set_output_level(EXT2_PIN_5,false); //sleep on
  delay_ms(10);
  port_pin_set_output_level(EXT2_PIN_5,true); //sleep off
  delay_ms(10);

  port_pin_set_output_level(EXT2_PIN_6,true); //reset on
  delay_ms(10);
  port_pin_set_output_level(EXT2_PIN_6,false); //reset off
  delay_ms(10);

  globalActualDirection = direction;
  port_pin_set_output_level(EXT2_PIN_9, direction); // nach oben fahren vorbereiten
  delay_ms(40);

  writeToDRV(wr_drv8711Defaults, rd_drv8711Defaults, sizeof(wr_drv8711Defaults)); //-> write the DRV8711 Default

  wr_buffer [0] = wr_drv8711Defaults[0];
  wr_buffer [1] = wr_drv8711Defaults[1] | (uint8_t) 0b00000001; //enable drv8711
  writeToDRV(wr_buffer, rd_drv8711Read, sizeof(wr_buffer)); //-> write the enable command to DRV8711
```

```
  if (reference)
  {
    tc_enable(&tc_instance);
  }
  delay_ms(10);
}

/**
* \brief disables the DRV8711
*/
void DRV8711disable()
{
  wr_buffer [0] = wr_drv8711Defaults[0];
  wr_buffer [1] = wr_drv8711Defaults[1] | (uint8_t) 0b00000000; //disable drv8711
  writeToDRV( wr_buffer, rd_drv8711Read, sizeof(wr_buffer)); //-> write the enable
      command to DRV8711
  port_pin_set_output_level(EXT2_PIN_5,false); //sleep on
}

/**
* \brief limit switch callbacks
*
* the EXT3_PIN_IRQ is configured as emergency stop
*/
void configure_extint_channel(void)
{
  struct extint_chan_conf config_extint_chan;
  extint_chan_get_config_defaults(&config_extint_chan);
  config_extint_chan.gpio_pin           = EXT3_PIN_IRQ;
  config_extint_chan.gpio_pin_mux       = EXT3_IRQ_MUX;
  config_extint_chan.filter_input_signal = true;
  config_extint_chan.gpio_pin_pull      = EXTINT_PULL_DOWN;
  config_extint_chan.detection_criteria = EXTINT_DETECT_FALLING;
  extint_chan_set_config(EXT3_IRQ_INPUT, &config_extint_chan);
}

/**
* \brief configure Emergency Stop callbacks
*
* the EXT1_PIN_IRQ is configured as emergency stop
*/
void configure_extint_channel_emergency(void)
{
  struct extint_chan_conf config_extint_chan;
  extint_chan_get_config_defaults(&config_extint_chan);
  config_extint_chan.gpio_pin           = EXT1_PIN_IRQ;
  config_extint_chan.gpio_pin_mux       = EXT1_IRQ_MUX;
  config_extint_chan.filter_input_signal = true;
  config_extint_chan.gpio_pin_pull      = EXTINT_PULL_DOWN;
  config_extint_chan.detection_criteria = EXTINT_DETECT_FALLING;
  extint_chan_set_config(EXT1_IRQ_INPUT, &config_extint_chan);
}
/**
* \brief configure extint callbacks
*
* the Emergency Stop and  limit switch callbacks are attached to the interrupt controller
*/
void configure_extint_callbacks(void)
{
  extint_register_callback(extint_detection_callback,EXT3_IRQ_INPUT,
      EXTINT_CALLBACK_TYPE_DETECT);
  extint_chan_enable_callback(EXT3_IRQ_INPUT,EXTINT_CALLBACK_TYPE_DETECT);

  extint_register_callback(extint_detection_callback_emergency,EXT1_IRQ_INPUT,
      EXTINT_CALLBACK_TYPE_DETECT);
```

```
  extint_chan_enable_callback(EXT1_IRQ_INPUT,EXTINT_CALLBACK_TYPE_DETECT);
}
/**
* \brief   limit switch callbacks
*
* here the motor is stoped
*/
void extint_detection_callback(void)
{
  port_pin_toggle_output_level(LED_0_PIN);
  //globalLimitSwitchPressed = true; /*!globalLimitSwitchPressed;*/
  if ((positionOfEachOrder[0].order == 1) | (positionOfEachOrder[0].order == 3)) // if motor drive up and hit the limit switch, we calibrate new.
  {
    globalStepPositionAxis = targetH;
  }
  if(((positionOfEachOrder[0].order == 1) | (positionOfEachOrder[0].order == 3))){
    tc_disable(&tc_instance); // pwm aus
    globalDrive = 2;
    port_pin_set_output_level(EXT2_PIN_5,false); //sleep on
  }

}
/**
* \brief emergency stop callbacks
*
* stop all moving
*/
void extint_detection_callback_emergency(void)
{
  port_pin_toggle_output_level(LED_0_PIN);
  globalEmergencyPressed = true;
  globalDrive = 2;
  tc_disable(&tc_instance);
  port_pin_set_output_level(EXT2_PIN_5,false); //sleep on
}

/**
* \brief   delete buffer
*
* \param[in] buffer   Pointer to data buffer to delete
*/
void delete_buffer(uint8_t *buffer)
{
  for(uint8_t i=0; i<sizeof(buffer); ++i)
  {
    buffer[i] = 0;
  }
}

/**
* \brief write all necessary register over SPI
*
* Writes the register to DRV8711, independently of the length
*
* \param[in] wr_config   Pointer to data buffer to send
* \param[out] rd_config  Pointer to data buffer to receive
* \param[in]  length    Data buffer length
*
*/
void writeToDRV(volatile uint8_t *wr_config, volatile uint8_t *rd_config, uint16_t length){
  for (uint16_t j = 0; j < length; j = j +2){
    wr_buffer [0] = wr_config[j];
    wr_buffer [1] = wr_config[j+1];
    spi_select_slave(&spi_master_instance, &slave, false);      // register schreiben
```

```
    spi_transceive_buffer_job(&spi_master_instance, wr_buffer, rd_buffer,sizeof(wr_buffer
        ));
    while (!transrev_complete_spi_master) {
    }
    transrev_complete_spi_master = false;
    spi_select_slave(&spi_master_instance, &slave, true);
    rd_config[j] = rd_buffer[0];
    rd_config[j+1] = rd_buffer[1];
    //delay_ms(1);
  }
}
/**
* \brief add values and text to the write buffer
*
* \param[in] arrayInput   Pointer to write buffer
* \param[out] arrayCopy  Pointer to data to copy
*
*/
void addToWriteBuffer(char *arrayInput, const char *arrayCopy)
{
  uint8_t returnValueInput = strcspn(arrayInput, "\0");
  uint8_t returnValueCopy = strcspn(arrayCopy, "\0");
  memmove(arrayInput + returnValueInput, arrayCopy, returnValueCopy);
}
/**
* \brief deletes a buffer
*
* \param[in] arrayBuffer   Pointer to the array
* \param[in]  length   Data buffer length
*
*/
void deleteBuffer(char *arrayBuffer, uint16_t length){
  for (uint16_t j = 0; j < length; j++)
  {
    arrayBuffer[j]='\0';
  }
}

/**
* \brief calcualete median
*
* \param[in out] valueBuffer   Pointer to buffer to store the result
* \param[in]  length      Data buffer length
*
*/
double calculateMedian(volatile uint16_t *valueBuffer, uint16_t length)
{
  double  maxDigit = pow (2.0, 10.0) - 1.0; // 2^10
  uint16_t i = 0;
  double result = 0.0;
  for (i = 0; i < length / 2; i ++)
  {
    result = result + valueBuffer[i];
  }
  result = result / ((double) i);
  result = maxN / maxDigit * (double) result;
  result = result - maxN / 2.0;
  return (result);
}
/**
* \brief calculates the direction to drive
*
* calculates the direction depending the actual position
*
* \param[in] iActualPos   actual postion
* \param[in]  iTargetPos    target position
```

```
* \param[out] targetDirection bool if the direction is up or down
*
*/
volatile bool targetDirection (int iActualPos, int iTargetPos)
{
  bool temp = false;
  if ((iActualPos > iTargetPos) & richtung)
  {
    temp = true;
  }
  else
  {
    temp = false;
  }

  if ((iActualPos > iTargetPos) & !richtung)
  {
    temp = false;
  }
  else
  {
    temp = true;
  }
  return(temp);
}
/**
* \brief executes an order
*
* if the RS232 receives an order, this function will start the command
*
*/
double abgleich = 0.0;
void executeOrder(void){
  if ((globalDrive == 0) & (positionOfEachOrder[0].order !=0)) /* if we did not start a
      command */
  {
    globalDrive = 1; //->motor is moving
    if (abgleich==0)
    {
      abgleich = globalResult;
    }

    if (positionOfEachOrder[0].order != 1) /* all other commands */
    {
      globalActualDirection = targetDirection(globalStepPositionAxis, positionOfEachOrder
          [0].targetPosition);
    }
    else
    {
      globalActualDirection = !port_pin_get_input_level(EXT3_PIN_IRQ); /* if init command
           */
      if (globalActualDirection)
      {
        globalMovingFreeAxis = 1;
      }
      globalEmergencyPressed = false;
    }
    if(positionOfEachOrder[0].repos)
    {
      globalOrderWasDown = false;
    }
    drv8711enable(true, globalActualDirection);
    delay_ms(1);
  }
}
void reposIfInLimitSwitch(void){
```

```
  if (globalDrive == 1 && positionOfEachOrder[0].order == 1 && globalStepPositionAxis >
      targetFreifahren && globalMovingFreeAxis  == 1)
  {
    globalActualDirection = richtung;
    globalLimitSwitchPressed = false;
    drv8711enable(true, richtung); //freifahren
    globalMovingFreeAxis = 2;
  }
}
/**
* \brief finish the order
*
* finish the order prepares the sending of the respond telegram and stops the movement
*
*/
void finishTheOrder(void){
  if ((globalDrive == 2)&!globalOrderWasDown){
    if (positionOfEachOrder[0].order != 1) /* if there was the Init command */
    {
      globalMovingFreeAxis = 0;
    }
    if(positionOfEachOrder[0].repos)
    {
      globalOrderWasDown = false;
    }
    strcpy(globalRespondTelegram, &positionOfEachOrder[0].respond);
    /* ready for new orders */
    globalDrive = 0;
    positionOfEachOrder[0].order = 0;
    globalSendRespond = true;
    port_pin_set_output_level(EXT2_PIN_5,false); //sleep on
    DRV8711disable();
    delay_ms(10);
  }
}
/**
* \brief send telegram
*
* if the ADC is finished with the conversion, a new telegram is sent
* with the before prepared position, error and status massage
*
*/
void sendTheTelegram(void)
{
  if (adc_read_done & !globalSendStatus){
    uint16_t returnValue = 0;

    static char writeBufferToPLC [100] = {0};
    char actualForceValue [18] = {0};

    errorHandling(); /*status and error code*/

    telegramPreparation(); /* prepare the different telegrams */

    calculatePosZaxis(); /* calculate the z axis postion in mm*/

    deleteBuffer(actualForceValue, sizeof(actualForceValue));

    globalResult =  calculateMedian(adc_result_buffer, sizeof(adc_result_buffer));

    if (globalDrive == 1)
    {
      globalResult = globalResult + offsetIfDRVon;
    }
    globalResult = globalResult * scalingFactorForce;
```

```
    itoaEigen((int)globalResult, actualForceValue);

    /*do the positiong rigth in the Buffer*/
    memmove( actualForceValue + 1,  actualForceValue, sizeof(actualForceValue) - 1);
    actualForceValue[0] = 35; //35 for #
    /*delete buffer*/
    deleteBuffer(writeBufferToPLC, sizeof(writeBufferToPLC));
    /*write the respond in the buffer*/
    addToWriteBuffer(writeBufferToPLC, globalRespondTelegram);
    /*add delimiter in the buffer*/
    addToWriteBuffer(writeBufferToPLC, "/");
    /*write the force value in the buffer*/
    addToWriteBuffer(writeBufferToPLC, actualForceValue);
    /*add delimiter in the buffer*/
    addToWriteBuffer(writeBufferToPLC, "/"); //add delimiter
    /*add the positon from the z axis in the buffer*/
    addToWriteBuffer(writeBufferToPLC,  globalPositionAxisForTelegram );
    /*add delimiter in the buffer*/
    addToWriteBuffer(writeBufferToPLC, "/");
    /*add the error from the drv8711 in the buffer*/
    addToWriteBuffer(writeBufferToPLC, globalErrorForTelegram);
    /* line break and so shit...*/
    addToWriteBuffer(writeBufferToPLC, "\r\n");
    returnValue = strcspn(writeBufferToPLC, "\0");
    globalSendStatus = true;
    usart_write_buffer_job(&usart_instance, (uint8_t *) writeBufferToPLC, returnValue);
    adc_read_done = false;
    globalSendRespond = false;
  }
  if (!adc_read_done)
  {
    adc_read_buffer_job(&adc_instance, (uint16_t *) adc_result_buffer, ADC_SAMPLES);
  }
}
/**
* \brief error handling
*
* reading the status from the DRV8711 and prepare the globalErrorForTelegram buffer with
    the error status in ASCII
*
*/
void errorHandling(void){

  writeToDRV(wr_drv8711Read, rd_drv8711Read, sizeof(wr_drv8711Read));

  if (((rd_drv8711Read[3] == 255) | (rd_drv8711Read[15] != 0))){  /* if a failure
      happened, the PLC wants to know it*/
    itoaEigen(rd_drv8711Read[15], globalErrorForTelegram); /* the drv8711 resets itself
        sometimes, then the torque register is 255, so we get it*/
    addToWriteBuffer(globalErrorForTelegram, "E");
  }
  else
  {
    addToWriteBuffer(globalErrorForTelegram, "0E");
  }
  if(!port_pin_get_input_level(EXT1_PIN_IRQ))
  {
    DRV8711disable();
    deleteBuffer(globalErrorForTelegram, sizeof(globalErrorForTelegram));
    addToWriteBuffer(globalErrorForTelegram, "1E");
    globalMovingFreeAxis = 0;
    globalOrderWasDown = false;
  }
//  deleteBuffer(globalErrorForTelegram, sizeof(globalErrorForTelegram));
//  itoaEigen((int)(abgleich - globalResult), globalErrorForTelegram); /* the drv8711
    resets itself sometimes, then the torque register is 255, so we get it*/
```

```
//  volatile int temp = abs(abgleich - globalResult);
//  if( (temp < trehsholdNotMovingError) & (globalDrive == 1) & (globalStepPositionAxis <
     targetForError))
//  {
//    deleteBuffer(globalErrorForTelegram, sizeof(globalErrorForTelegram));
//    addToWriteBuffer(globalErrorForTelegram, "2E");
//  }

}
/**
* \brief calculate position into ASCII
*
* reading the position from the motor and prepare the globalPositionAxisForTelegram
    buffer with the position in ASCII status
*
*/
void calculatePosZaxis(void)
{
  int posZ = (double) globalStepPositionAxis / (double) oneSpin * (double) trapezSteigung
      ;
  itoaEigen(posZ , globalPositionAxisForTelegram);
}
/**
* \brief repositioning when down
*
* if the snapper is down, it is necessary to repos, because otherwise
*the disk will scratch on the repository and at the next cycle the
* possibility is high, that there is a crash
*
*/
void startRepositioningWhenDown(void)
{
  if ((globalDrive == 2)& globalOrderWasDown) //lets start repositioning
  {
    positionOfEachOrder[0].order = 5;
    positionOfEachOrder[0].targetPosition = positionOfEachOrder[5].targetPosition=
        targetRepositioningAfterDown; /* for repos*/
    positionOfEachOrder[0].order = positionOfEachOrder[5].order = 5;
    strcpy(&positionOfEachOrder[0].receive, &positionOfEachOrder[5].receive);
    strcpy(&positionOfEachOrder[0].respond, &positionOfEachOrder[5].respond);
    globalDrive = 0;
  }
}
/**
* \brief send restart telegram
*
* prepare the globalRespondTelegram buffer with the restart message in ASCII
*
*/
void sendRestartTelegram(void){

  if (globalSendRestartTelegram & !globalSendRespond)
  {
    memmove(globalRespondTelegram,  respondStartetUp, sizeof(respondStartetUp));
    globalSendRestartTelegram = false;
    globalSendRespond = true;
  }
}
/**
* \brief delete the respond buffer
*
* deletes the respond buffer afterwards a respond is send
*
*/
void deleteRespondBuffer(void)
{
```

```
  if (!globalSendRespond)
  {
    deleteBuffer(globalRespondTelegram, sizeof(globalRespondTelegram));
    addToWriteBuffer(globalRespondTelegram, "00");
  }
}
/**
* \brief send busy telegram
*
* prepare the globalRespondTelegram buffer with the busy message in ASCII
*
*/
void sendBusy(void)
{

  if (globalBusy & !globalSendRespond) {// bussy
    memmove(globalRespondTelegram,  respondBussy, sizeof(respondBussy));
    globalSendRespond = true;
    globalBusy = false;
  }
}
/**
* \brief send invalid telegram
*
* prepare the globalRespondTelegram buffer with the invalid message in ASCII
*
*/
void sendInvalidTelegram(void)
{
  if (globalInvalidTelegram & !globalSendRespond)
  {
    memmove(globalRespondTelegram,  respondUnkown, sizeof(respondUnkown));
    globalSendRespond = true;
    globalInvalidTelegram = false;
  }
}
/**
* \brief send OK telegram
*
* prepare the globalRespondTelegram buffer with the OK message in ASCII
*
*/
void sendOK(void)
{
  if ((globalSendOK == 1) & !globalSendRespond){
    memmove(globalRespondTelegram,  respondOK, sizeof(respondOK));
    globalSendRespond = true;
    globalSendOK = 0;
  }
}
/**
* \brief prepares all the telegrams
*
* prepare the globalRespondTelegram buffer with the necessary message in ASCII
*
*/
void telegramPreparation(void)
{
  deleteRespondBuffer();
  sendBusy();
  sendInvalidTelegram();
  sendOK();
  sendRestartTelegram();
}
void initGrabtastic(void)
{
```

```
    insertValuesIntoStruct();
    system_init();
    delay_init();

    configure_extint_channel();
    configure_extint_channel_emergency();
    configure_extint_callbacks();

    configure_adc();
    configure_adc_callbacks();

    configure_usart();
    configure_usart_callbacks();

    configure_tc();
    configure_tc_callbacks();

    system_interrupt_enable_global();
    configure_spi_master();
    configure_spi_master_callbacks();
    configure_port_pins();
}
#endif
```

C.3. ASF Library

Atmel ASF

C.4. Register Settings Atmel

Atmel SAM D20 Register Settings

D. PLC

D.1. Program

D.1.1. Allgemein

Listing D.1: Allgemein

```
(*safe the min and max value of the force*)
IF maxForceValuePos < acutalForceValue THEN
  maxForceValuePos := acutalForceValue;
END_IF
IF maxForceValueNeg > acutalForceValue THEN
  maxForceValueNeg := acutalForceValue;
END_IF
```

D.1.2. Main

Listing D.2: Main

```
VAR CONSTANT
  BufStart:INT:=  1;       // Start-Index
  BufEnd:INT:=  100;    // End-Index
END_VAR

VAR
  diX, diY AT %I* : BOOL;
  (*boole variables*)
  bStart :BOOL := FALSE;
  bMoveHome : BOOL := FALSE;
  bDauerlauf : BOOL := FALSE;
  i: INT;
  btest : BOOL;
  btestZwei : bool;
  btesDrei: BOOL;
END_VAR

posAxisX(Axis:= axisX, Enable:= TRUE , Valid=> , Busy=> , Error=> , ErrorID=> , Position
    => );
posAxisY(Axis:= axisY, Enable:= TRUE, Valid=> , Busy=> , Error=> , ErrorID=> , Position=>
     );

powerX(Axis:= axisX, Enable:= bEnable, Enable_Positive:= bEnable, Enable_Negative:=
    bEnable, Override:= 100, BufferMode:= , Options:= , Status=> , Busy=> , Active=> ,
    Error=> , ErrorID=> );
powerY(Axis:= axisY, Enable:= bEnable, Enable_Positive:= bEnable, Enable_Negative:=
    bEnable, Override:= 100, BufferMode:= , Options:= , Status=> , Busy=> , Active=> ,
    Error=> , ErrorID=> );

resetX(Axis:= axisX, Execute:= , Done=> , Busy=> , Error=> , ErrorID=> );
resetY(Axis:= axisY, Execute:= , Done=> , Busy=> , Error=> , ErrorID=> );

homeX(Axis:= axisX, Execute:= , Position:= 0 , HomingMode:= , BufferMode:= , Options:= ,
    bCalibrationCam:= NOT diX, Done=> , Busy=> , Active=> , CommandAborted=> , Error=> ,
    ErrorID=> );
homeY(Axis:= axisY, Execute:= , Position:= 0 , HomingMode:= , BufferMode:= , Options:= ,
    bCalibrationCam:= NOT diY, Done=> , Busy=> , Active=> , CommandAborted=> , Error=> ,
    ErrorID=> );

moveAbsX(Axis:= axisX, Execute:= , Position:= , Velocity:= , Acceleration:= ,
    Deceleration:= , Jerk:= , BufferMode:= , Options:= , Done=> , Busy=> , Active=> ,
    CommandAborted=> , Error=> , ErrorID=> );

moveAbsY(Axis:= axisY, Execute:= , Position:= , Velocity:= , Acceleration:= ,
    Deceleration:= , Jerk:= , BufferMode:= buffermoveAbsY, Options:= , Done=> , Busy=> ,
    Active=> , CommandAborted=> , Error=> , ErrorID=> );
```

```
moveAbsNewY(Axis:= axisY, Execute:= , Position:= , Velocity:= , Acceleration:= ,
    Deceleration:= , Jerk:= , BufferMode:= buffermoveAbsY, Options:= , Done=> , Busy=> ,
    Active=> , CommandAborted=> , Error=> , ErrorID=> );

SCL(Crtl:= , bSend:= , ReceivedString=> , bNewString=> , bSendBusy=> , bStringReceived=>
    );

  rTrigStartCycle(CLK:= bStart , Q=> );
  CASE iState OF

  0:  IF (*rTrig.Q AND *)powerX.Status AND powerY.Status THEN
        iState := iState + 1;
      END_IF

  1:  SCL.Crtl := 'I';
      SCL.bSend := TRUE;
      respondOfORder := '';
      istate := 2;

  2:  IF NOT SCL.bSendBusy THEN
        SCL.bSend := FALSE;
        istate := 3;
      END_IF

  3:  IF waitToLongForRespond.Q THEN
        istate := 1;
      END_IF
      IF respondI.Q1 THEN
        respondI.RESET := TRUE;
        respondI.SET1 := FALSE;
        istate := 5;
      END_IF

  5:    resetX.Execute :=TRUE;
        resetY.Execute :=TRUE;
        iState := 10;

  10: IF resetX.Done AND resetY.Done THEN
        resetX.Execute := FALSE;
        resetY.Execute := FALSE;
        iState :=  iState + 5;
      END_IF

  15: IF NOT readInfoAxisX.Status.Homed or NOT readInfoAxisY.Status.Homed THEN
      homeX.Execute := TRUE;
      homeY.Execute := TRUE;
      iState := 20;
      ELSE
        iState := 21; //--> if already referenced, go home position
      END_IF
  20: IF homeX.Done AND homeY.Done THEN
        homeX.Execute := FALSE;
        homeY.Execute := FALSE;
        NotHomed.RESET := FALSE;
        iState := 21;
      END_IF
  21:     moveAbsY.Velocity := posHomeVelocityY;
          moveAbsY.Position := posHomeY;
          moveAbsY.Execute := TRUE;

        IF posAxisY.Position > posPrepositioningY THEN
          moveAbsX.Velocity := posHomeVelocityX;
          moveAbsX.Position := posHomeX;
          moveAbsX.Execute := TRUE;
          iState :=  25;
        END_IF
```

```
25: IF  moveAbsX.Done AND moveAbsY.Done THEN
    moveAbsX.Execute:= FALSE;
    moveAbsY.Execute:= FALSE;
    respondH.RESET := TRUE;
    respondH.SET1 := FALSE;
    iState :=  26;
  END_IF

(*this starts a new cycle, depending on the load*)
26: IF rTrigStartCycle.Q OR bDauerlauf THEN
    IF bLoaded THEN
      iState :=  125;
    ELSE
      iState :=  27;
    END_IF
    respondD.RESET := TRUE;
    respondD.SET1 := FALSE;
    respondH.RESET := TRUE;
    respondH.SET1 := FALSE;
    respondP.RESET := TRUE;
    respondP.SET1 := FALSE;
    cycleFinished := FALSE;
  END_IF

27:   moveAbsX.Velocity := posRepositoryVelocityX;
    moveAbsX.Position := posRepositoryX;
    moveAbsX.Execute := TRUE;
    moveAbsY.Velocity := posRepositoryVelocityY;
    moveAbsY.Position :=posRepositoryY;
    moveAbsY.Execute := TRUE;
    iState :=  28;
    maxForceValuePos := 0;
    maxForceValueNeg := 0;

28:   SCL.Crtl := 'P'; // vorpositionieren
    SCL.bSend := TRUE;
    iState :=  29;

29: IF NOT SCL.bSendBusy THEN
    SCL.bSend := FALSE;
    SCL.Crtl := '';
    istate := 30;
  END_IF

30: IF waitToLongForRespond.Q THEN
    istate := 28;
    END_IF
  IF  moveAbsX.Done AND moveAbsY.Done AND respondP.Q1 THEN
    moveAbsX.Execute:= FALSE;
    moveAbsY.Execute:= FALSE;
    respondP.RESET := TRUE;
    respondP.SET1 := FALSE;
    iState := 31;
  END_IF

31: SCL.Crtl := 'D';
  SCL.bSend := TRUE;
  istate := 32;

32: IF NOT SCL.bSendBusy THEN
    SCL.bSend := FALSE;
    SCL.Crtl := '';
    istate := 33;
  END_IF
```

```
33: IF waitToLongForRespond.Q THEN
      istate := 31;
      END_IF
    IF respondD.Q1 THEN //Move Down
      respondD.RESET := TRUE;
      respondD.SET1 := FALSE;
      bLoaded := TRUE;
      cycleFinished :=TRUE;
      istate := 35;
    END_IF

35:   IF NOT respondD.Q1 THEN
        moveAbsY.Velocity := posHomeVelocityY;
        moveAbsY.Position :=posHomeY;
        moveAbsY.Execute := TRUE;
      IF posAxisY.Position > posPrepositioningY THEN //über dem weg drausen, dan darf er
          fahren
        moveAbsX.Velocity := posHomeVelocityX;
        moveAbsX.Position := posHomeX;
        moveAbsX.Execute := TRUE;
        iState :=  40;
      END_IF

    END_IF
40: IF  moveAbsX.Done AND moveAbsY.Done THEN
      moveAbsX.Execute:= FALSE;
      moveAbsY.Execute:= FALSE;
      iState := 26;
    END_IF

125:  moveAbsX.Velocity := 5;
      moveAbsX.Position := posPrepositioningX;
      moveAbsX.Execute := TRUE;
      moveAbsY.Velocity := posPrepositioningVelocityY;
      moveAbsY.Position :=posPrepositioningY;
      moveAbsY.Execute := TRUE;
      iState :=  130;
      maxForceValuePos := 0;
      maxForceValueNeg := 0;

130:  IF moveAbsX.Done THEN
        moveAbsNewY.Execute:= TRUE;
        moveAbsNewY.Velocity := posRepositoryVelocityY;
        moveAbsNewY.Position := posRepositoryY;
        moveAbsY.Execute:= FALSE;
        moveAbsX.Execute:= FALSE;
      END_IF
      IF moveAbsNewY.Done THEN
        iState := 140;
    END_IF

(*135:  moveAbsX.Velocity :=  posRepositoryVelocityX;
      moveAbsX.Position :=  posRepositoryX;
      moveAbsX.Execute :=   TRUE;
      moveAbsY.Velocity :=  posRepositoryVelocityY;
      moveAbsY.Position :=  posRepositoryY;
      moveAbsY.Execute := TRUE;
      iState :=  140;*)

140:  IF  (*moveAbsX.Done AND*) moveAbsNewY.Done THEN
      moveAbsNewY.Execute:= FALSE;
      iState :=  141;
      END_IF

141:  SCL.Crtl := 'P'; //Move Up
      SCL.bSend := TRUE;
```

```
        istate := 142;

    142:  IF NOT SCL.bSendBusy THEN
        SCL.bSend := FALSE;
        SCL.Crtl := '';
        istate := 143;
      END_IF

    143:  IF waitToLongForRespond.Q THEN
          istate := 141;
        END_IF
        IF respondP.Q1 THEN
          respondP.RESET := TRUE;
          respondP.SET1 := FALSE;
          bLoaded := FALSE;
          cycleFinished :=TRUE;
          iState := 145;
        END_IF

    145:  SCL.Crtl := 'H'; // Home pos anfahren
        SCL.bSend := TRUE;
        iState :=  150;

    150:  IF NOT SCL.bSendBusy THEN
          SCL.bSend := FALSE;
          SCL.Crtl := '';
          istate := 155;
        END_IF

    155:  moveAbsY.Velocity := posHomeVelocityY;
          moveAbsY.Position := posHomeY;
          moveAbsY.Execute := TRUE;

        IF posAxisY.Position > posPrepositioningY THEN
          moveAbsX.Velocity := posHomeVelocityX;
          moveAbsX.Position := posHomeX;
          moveAbsX.Execute := TRUE;
          iState :=  160;
        END_IF

    160:  IF waitToLongForRespond.Q THEN
          istate := 145;
        END_IF
        IF  moveAbsX.Done AND moveAbsY.Done AND respondH.Q1 THEN
        moveAbsX.Execute:= FALSE;
        moveAbsY.Execute:= FALSE;
        respondH.RESET := TRUE;
        respondH.SET1 := FALSE;
        iState :=  26;
      END_IF

    END_CASE

    resetErrorHandling();
    visu();
```

D.1.3. Error and Reset

Listing D.3: Error and Reset

```
VAR
  reset: INT := 0; //reset state machine
END_VAR

VAR CONSTANT
```

```
  toMuchForcePositive : INT := 15000;
  toMuchForceNegative : INT := -15000;
END_VAR

respondD(SET1:= , RESET:= , Q1=> );
respondH(SET1:= , RESET:= , Q1=> );
respondI(SET1:= , RESET:= , Q1=> );
respondP(SET1:= , RESET:= , Q1=> );
respondOk(SET1:= , RESET:= , Q1=> );
respondStartetUp(SET1:= , RESET:= , Q1=> );
emergencyStopToMuchForce(SET1:= , RESET:= , Q1=> );
motorXYNoPower(SET1:= , RESET:= , Q1=> );
errorNoSignalFromUc(SET1:= , RESET:= , Q1=> );
unequalLoadThanExpected(SET1:= , RESET:= , Q1=> );
zAxisNotMoving(SET1:= , RESET:= , Q1=> );

rTrigStartViewPressed(CLK:= bStartViewPressed , Q=> );

IF respondI.Q1 THEN
    respondI.SET1 := FALSE;
END_IF

respondD.RESET := FALSE;
respondH.RESET := FALSE;
respondI.RESET := FALSE;
respondP.RESET := FALSE;
respondOK.RESET := FALSE;
respondStartetUp.RESET := FALSE;
emergencyStopToMuchForce.RESET := FALSE;
motorXYNoPower.RESET := FALSE;
errorNoSignalFromUc.RESET := FALSE;
unequalLoadThanExpected.RESET := FALSE;
zAxisNotMoving.RESET:=FALSE;

(*read status from x and y*)
readInfoAxisX(Axis:= axisX, Enable:= TRUE, Valid=> , Busy=> , Error=> , ErrorID=> ,
    ErrorStop=> , Disabled=> , Stopping=> , StandStill=> , DiscreteMotion=> ,
    ContinuousMotion=> , SynchronizedMotion=> , Homing=> , ConstantVelocity=> ,
    Accelerating=> , Decelerating=> , Status=> );
readInfoAxisY(Axis:= axisY, Enable:= TRUE, Valid=> , Busy=> , Error=> , ErrorID=> ,
    ErrorStop=> , Disabled=> , Stopping=> , StandStill=> , DiscreteMotion=> ,
    ContinuousMotion=> , SynchronizedMotion=> , Homing=> , ConstantVelocity=> ,
    Accelerating=> , Decelerating=> , Status=> );

(* wait to seconds to give the stepper motor drivers a little time to built DC link*)
waitWithEnable(IN:= bEmergencyPressed, PT:= T#2S, Q=> , ET=> );

(* if no respond from the uC in a little time, the nsend command again*)
waitToLongForRespond(IN:=   iState = 33  OR iState = 143 OR iState =3 OR iState = 30, PT
    := T#10S, Q=> , ET=> );

zAxisNotMoving.SET1:= (globalErrorFromUC = '2E');

(* Ungleich soll beladung *)
IF (iState = 23 OR iState = 0) AND ((acutalForceValue > -200 AND bLoaded) OR (
    acutalForceValue < -700 AND NOT bLoaded))THEN
  unequalLoadThanExpected.SET1:=TRUE;
END_IF

(* error if no respond from uC*)
errorNoSignalFromUc.SET1 := NOT noSiganlFromU.Q;

(* trigger after restart from emergency *)
fTrigReset(CLK:= waitWithEnable.Q, Q=> );

(* set if we ar not homed*)
```

```
NotHomed(SET1:= NOT readInfoAxisX.Status.Homed OR NOT readInfoAxisY.Status.Homed, RESET:= , Q1=> );
motorXYNoPower.SET1 :=  readInfoAxisY.ErrorStop OR readInfoAxisX.ErrorStop;
(* Status not ok but Emergency is ok*)
globalErrorDetect := motorXYNoPower.Q1 OR respondStartetUp.Q1 OR emergencyStopToMuchForce.Q1 OR bEmergencyPressed OR errorNoSignalFromUc.Q1 OR unequalLoadThanExpected.Q1 OR zAxisNotMoving.Q1;
(* set error *)
setError(SET1:=globalErrorDetect, RESET:= , Q1=> );

CASE reset OF
0:  IF fTrigReset.Q OR ((setError.Q1 OR NotHomed.SET1) AND (bReset OR rTrigStartViewPressed.Q)) THEN
    reset := 5;
    iState := 0;
    bEnable := FALSE;
    globalErrorDetect := FALSE;
    setError.RESET :=TRUE;
    respondStartetUp.RESET := TRUE;
    bLoaded := FALSE;
    respondStartetUp.SET1 := FALSE;
    emergencyStopToMuchForce.RESET := TRUE;
    emergencyStopToMuchForce.SET1 := FALSE;
    motorXYNoPower.SET1 := FALSE;
    motorXYNoPower.RESET := TRUE;
    errorNoSignalFromUc.SET1 := FALSE;
    errorNoSignalFromUc.RESET := TRUE;
    unequalLoadThanExpected.SET1:= FALSE;
    unequalLoadThanExpected.RESET := TRUE;
    zAxisNotMoving.SET1 := FALSE;
    zAxisNotMoving.RESET := TRUE;
    respondI.RESET := TRUE;
    respondI.SET1 := FALSE;
    respondD.RESET := TRUE;
    respondD.SET1 := FALSE;
    respondH.RESET := TRUE;
    respondH.SET1 := FALSE;
    maxForceValuePos := 0;
    maxForceValueNeg := 0;
  END_IF
5:  resetX.Execute :=TRUE;
  resetY.Execute :=TRUE;
  setError.RESET :=FALSE;
  reset := 10;

10: IF resetX.Done AND resetY.Done THEN
    resetX.Execute := FALSE;
    resetY.Execute := FALSE;
    reset :=  15;
  END_IF
15: bEnable := TRUE;
  reset  := 0;
END_CASE

(* if to much force --> emergency stop!*)
IF (acutalForceValue > toMuchForcePositive) OR (acutalForceValue < toMuchForceNegative) THEN
  emergencyStopToMuchForce.SET1 := TRUE;
END_IF



(*reset all movements and sending*)
IF setError.Q1 THEN
  iState := 0;
  homeX.Execute := FALSE;
```

```
  homeY.Execute := FALSE;
  moveAbsX.Execute:= FALSE;
  moveAbsY.Execute:= FALSE;
  moveAbsNewY.Execute:= FALSE;
  bEnable := FALSE;
  SCL.bSend := FALSE;
  SCL.Crtl := '';
END_IF

\begin{lstlisting}[language=pascal]
```

D.1.4. Serial Com

Listing D.4: Serial Communication

```
VAR_INPUT
  Crtl: STRING;
  bSend: BOOL;
END_VAR
VAR_OUTPUT
  ReceivedString: STRING;
  bNewString: BOOL;
  bSendBusy: BOOL;
  bStringReceived: BOOL;
END_VAR
(*VAR_IN_OUT
  IOrespondOfORder: STRING;
END_VAR*)
VAR
  //DataIn AT %I*: EL6inData22B;
  //DataOut AT %Q*: EL6outData22B;
  SerialLineCtrl: SerialLineControl;
  //BuffTX: ComBuffer;
  //BuffRX: ComBuffer;
  clearbuff: ClearComBuffer;
  SendString: SendString;
  RecString: ReceiveString;
  istate: INT;
  rtrig: r_trig;
  test: ReceiveByte;
  bTest: BYTE;
  bByteReceived : BOOL := FALSE;
  bBuffer: BYTE;
  arrForceValues : ARRAY [1..1000] OF INT;

  lengtOfReceivedString: INT;
  strTemp : STRING(255);
  posSuffix: INT;
  stest :STRING;

  posFirstSlash: INT;
  posSecondSlash: INT;
  posThirdSlash: INT;
  posHash: INT;
END_VAR


SendString(SendString:= , Busy=> , Error=> , TXbuffer:= BuffTX);
RecString(Prefix:= , Suffix:= '$N', Timeout:= T#2S, Reset:= , StringReceived=> , Busy=> , Error=> , RxTimeout=> , ReceivedString:= ReceivedString, RXbuffer:= BuffRX);
posHash := FIND (ReceivedString,'#');
posSuffix := FIND (ReceivedString,'$R');
posFirstSlash := FIND (ReceivedString,'/');
strTemp := MID (ReceivedString,posSuffix - posFirstSlash-1,posFirstSlash+1);
posSecondSlash := FIND (strTemp,'/') + posFirstSlash;
```

```
strTemp := MID (ReceivedString,posSuffix - posSecondSlash-1,posSecondSlash+1);
posThirdSlash := FIND (strTemp,'/') + posSecondSlash;

lengtOfReceivedString:=LEN(STR:= ReceivedString);

IF RecString.StringReceived THEN
  strTemp := MID (ReceivedString,posSecondSlash - posHash-1,posHash+1);
  acutalForceValue := STRING_TO_INT (strTemp);

  strTemp := MID (ReceivedString,posThirdSlash - posSecondSlash-1,posSecondSlash+1);
  posAxisZ := STRING_TO_INT (strTemp);

  globalErrorFromUC := MID (ReceivedString,posSuffix - posThirdSlash-1,posThirdSlash+1);

  globalForceValueArrived := TRUE;
  RecString.Reset := TRUE;

  respondOfORder := MID (ReceivedString,posFirstSlash-1,1); (* else its a respond of the
      Order*)
  RecString.Reset := TRUE;
  respondI.SET1 := respondOfORder = 'i';
  respondH.SET1 := respondOfORder = 'h';
  respondD.SET1 := respondOfORder = 'd';
  respondP.SET1 := respondOfORder = 'p';
  respondOK.SET1 := respondOfORder = 'ok';
  respondStartetUp.SET1 :=  respondOfORder  = 'Started up';
  respondOfORder := '';
  counterSerialCom := counterSerialCom+1;
END_IF


(* no isgnal from uC *)
noSiganlFromU(IN:= RecString.StringReceived, PT:= T#2S, Q=> , ET=> );


rtrig(CLK:= bSend, Q=> );
CASE istate OF

0:  RecString.Reset := FALSE;
  bStringReceived := FALSE;
  IF rtrig.Q THEN
    SendString.SendString := Crtl;
    bSendBusy := TRUE;
    istate := istate  + 1;
  END_IF

1:  IF NOT SendString.Busy THEN
      SendString.SendString := '';
      (*clearbuff(Buffer:= BuffTX );*)
      istate := istate + 1;
      ReceivedString := '';
      bSendBusy := FALSE;
  END_IF

2:  IF RecString.StringReceived THEN
    bStringReceived := TRUE;
    RecString.Reset := TRUE;
    istate := 0;
  END_IF

END_CASE
```

D.1.5. Visualization

Listing D.5: Visualization

```
VAR
  //stringErrorText : WSTRING; //error texts for visu
  //stringMessageText : WSTRING;
  //stringDebugText : WSTRING;
  stringErrorText: ARRAY [1..20] OF STRING;
  stringMessageText: ARRAY [1..20] OF STRING;
  stringDebugText: ARRAY [1..20] OF STRING;
  forceMemoryDrop: writeInArray;
  forceMemoryPick: writeInArray;
  zaehl: INT := 1;
END_VAR

forceMemoryDrop(i_iState:= iState, i_actualForceValue:= acutalForceValue, i_bLoaded:=
    TRUE, io_ValueArrived:= globalForceValueArrived);
forceMemoryPick(i_iState:= iState, i_actualForceValue:= acutalForceValue, i_bLoaded:=
    FALSE, io_ValueArrived:= globalForceValueArrived);
//cycleFinished(SET1:= , RESET:= , Q1=> );

(* pos of x and y for the visu*)
IF readInfoAxisX.Status.Homed AND readInfoAxisY.Status.Homed  THEN
realVisuPosX := posAxisX.Position * 1.5;
realVisuPosY := (posAxisY.Position * (-1.0) + 10) *1.7;
//realVisuPosX := ABS (realVisuPosX);
ELSE
realVisuPosX := 0.0;
realVisuPosY := 0.0;
END_IF

IF bLoaded THEN
  realVisuDiskX := realVisuPosX; (* - posRepositoryX * 1.5;*)
  realVisuDiskY := realVisuPosY; (*- (posRepositoryY * (-1.0) + 10) *2.0; *)
ELSE
  realVisuDiskX := posRepositoryX * 1.5;
  realVisuDiskY := (posRepositoryY * (-1.0) + 10) *2.0;
END_IF

IF iState > 3 THEN
intVisuPosZ := (posAxisZ) *2;
ELSE
intVisuPosZ := 0;
END_IF

(*prepare cycle finished*)

(* visu texts *)

MEMSET(ADR(stringErrorText), 0, SIZEOF(stringErrorText));
MEMSET(ADR(stringMessageText), 0, SIZEOF(stringMessageText));
MEMSET(ADR(stringDebugText), 0, SIZEOF(stringDebugText));

zaehl := 1;
(* error messages *)
IF NOT readInfoAxisX.Status.Homed OR NOT readInfoAxisY.Status.Homed THEN
  stringErrorText[zaehl]:= CONCAT(STR1:= stringErrorText[zaehl], STR2:= 'Not referenced
      in X/Y');
  zaehl := zaehl + 1;
END_IF

IF  globalErrorDetect THEN
  stringErrorText[zaehl]:= CONCAT(STR1:= stringErrorText[zaehl], STR2:= 'Failure');
  zaehl := zaehl + 1;
END_IF

IF  bEmergencyPressed THEN
```

```
  stringErrorText[zaehl]:= CONCAT(STR1:= stringErrorText[zaehl], STR2:= 'Emergency Stop');
  zaehl := zaehl + 1;
END_IF

IF  emergencyStopToMuchForce.Q1 THEN
  stringErrorText[zaehl]:= CONCAT(STR1:= stringErrorText[zaehl], STR2:= 'too much Force');
  zaehl := zaehl + 1;
END_IF

IF motorXYNoPower.Q1 THEN
  stringErrorText[zaehl]:= CONCAT(STR1:= stringErrorText[zaehl], STR2:= 'Not referenced in X/Y');
  zaehl := zaehl + 1;
END_IF

IF errorNoSignalFromUc.Q1 THEN
  stringErrorText[zaehl]:= CONCAT(STR1:= stringErrorText[zaehl], STR2:= 'error connection lost to uC');
  zaehl := zaehl + 1;
END_IF

IF unequalLoadThanExpected.Q1 THEN
  stringErrorText[zaehl]:= CONCAT(STR1:= stringErrorText[zaehl], STR2:= 'load unequal than expected');
  zaehl := zaehl + 1;
END_IF

IF zAxisNotMoving.Q1 THEN
  stringErrorText[zaehl]:= CONCAT(STR1:= stringErrorText[zaehl], STR2:= 'z-axis Error');
  zaehl := zaehl + 1;
END_IF

(* massage textes *)
  zaehl := 1;
IF acutalForceValue > -200  THEN
  stringMessageText[zaehl]:= CONCAT(STR1:= stringMessageText[zaehl], STR2:= 'The object is successfully dropped');
  zaehl := zaehl + 1;
END_IF

IF acutalForceValue < -700 THEN
  stringMessageText[zaehl]:= CONCAT(STR1:= stringMessageText[zaehl], STR2:= 'The object is successfully grabbed');
  zaehl := zaehl + 1;
END_IF


IF iState = 26 AND cycleFinished THEN
  stringMessageText[zaehl]:= CONCAT(STR1:= stringMessageText[zaehl], STR2:= 'Cycle successfully finished');
  zaehl := zaehl + 1;
END_IF

(* debug messages *)
  zaehl := 1;
IF bLoaded THEN
  stringDebugText[zaehl]:= CONCAT(STR1:= stringDebugText[zaehl], STR2:= 'Load');
  zaehl := zaehl + 1;
ELSE
  stringDebugText[zaehl]:= CONCAT(STR1:= stringDebugText[zaehl], STR2:= 'No Load');
  zaehl := zaehl + 1;
END_IF

stringDebugText[zaehl]:= CONCAT(STR1:= stringDebugText[zaehl], STR2:= 'State PLC: ');
```

```
stringDebugText[zaehl]:= CONCAT(STR1:= stringDebugText[zaehl], STR2:= INT_TO_STRING (
    iState));
zaehl := zaehl + 1;
stringDebugText[zaehl]:= CONCAT(STR1:= stringDebugText[zaehl], STR2:= 'Error from uC:');
stringDebugText[zaehl]:= CONCAT(STR1:= stringDebugText[zaehl], STR2:= globalErrorFromUC);
zaehl := zaehl + 1;
```

D.1.6. Write in Array

Listing D.6: Write in Array

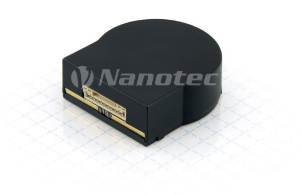
```
VAR CONSTANT
  BufStart:INT:=  1;      // Start-Index
  BufEnd:INT:=  100;   // End-Index
END_VAR

VAR_INPUT
  i_iState : INT;
  i_actualForceValue : INT;
  i_bLoaded : BOOL;
END_VAR
VAR_OUTPUT

END_VAR
VAR
  sTemp : INT;
  sArrForceValue: ARRAY [BufStart..BufEnd] OF INT;
END_VAR

VAR_IN_OUT
  io_ValueArrived : BOOL;
END_VAR


IF io_ValueArrived AND ((NOT i_bLoaded AND (iState = 33) AND (posAxisZ > 60 )) OR (
    i_bLoaded AND (iState = 143) AND (posAxisZ > 57 ))) THEN
    sTemp := sTemp + 1;
    IF sTemp > BufEnd THEN
      sTemp:=1;
    END_IF
    sArrForceValue[sTemp] := i_actualForceValue;
    io_ValueArrived := FALSE;
  END_IF

  IF  (((i_iState = 27 AND NOT i_bLoaded) OR (i_iState = 125 AND i_bLoaded)) ) THEN //
      delet Buffer Begin from new
    MEMSET(ADR(sArrForceValue), 0, SIZEOF(sArrForceValue));
    sTemp:=1;
  END_IF
```

D.2. Datasheets

NOE2

Optical 3-Channel Encoder

Nanotec®



TECHNICAL DATA

	NOE2-05	NOE2-24
Resolution	1000, 2000, 4000 pulses/revolution	1000, 2000, 4000 pulses/revolution
Signal form	Square wave signal	Square wave signal
Output signals	Phase A, A\, B, B\, I, I\	Phase A, A\, B, B\, I, I\
Operating voltage	DC 4.5 V to 5.5 V	24 VDC
Current consumption	typical 30 mA	typical 15 mA
Limit frequency	60 KHz (1000 CPR), 120 KHz (2000 CPR), 240 KHz (4000 CPR)	60 KHz (1000 CPR), 120 KHz (2000 CPR), 240 KHz (4000 CPR)
Limit speed	3600 rpm	3600 rpm
Pulse width	180 ° ± 30 °e	180 ° ± 30 °e
Phase shift	90 ° ± 18 °e	90 ° ± 18 °e
Signal level	Low: 0 V; high: +3,5 V (±10 %, without lead), +3 V (±10 %, with lead 20 mA)	Low: 0 V, high: Vcc-0.5 V
Max. output current per channel	150 mA	200 mA
Working temperature	-20 to 85 °C	-20 to 85 °C
Storage temperature	-40 to 85 °C	-40 to 85 °C
Humidity	Max. 90%, non-condensing	Max. 90%, non-condensing

VERSIONS

Type	Index	Line Driver	Signal Voltage V	Cycles per Revolution
NOE2-05-B	Yes	Yes	5	1000
NOE2-05-K	Yes	Yes	5	4000
NOE2-24-B	Yes	Yes	24	1000
NOE2-24-K	Yes	Yes	24	4000

NOE2

Optical 3-Channel Encoder

Nanotec®

ORDER IDENTIFIER

NOE2-05-B

14 = 5 mm Shaft Diameter

06 = 6.35 mm Shaft Diameter

10 = 10 mm, Type Hollow Shaft

15 = 15 mm, Type Hollow Shaft

ACCESSORIES

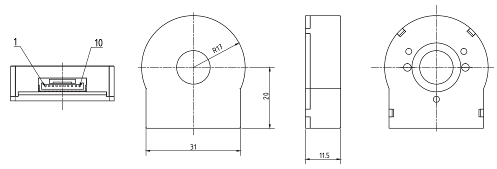
ZK-NOE1-10-500-S Encoder Cable

CAUTION

Please note that the NOE1 encoders are only available together with a motor and must be mounted by Nanotec.

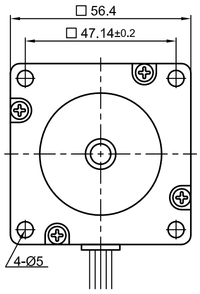
DIMENSIONS (IN MM)

NOE2

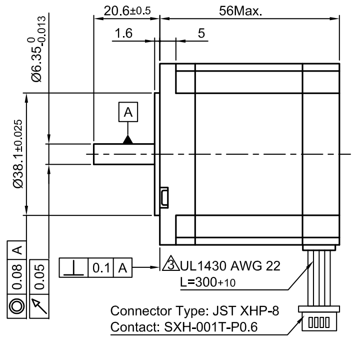


OPTIONS

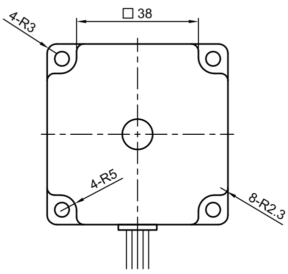
Front view and mounting



Side view



Rear view



SPECIFICATION \ CONNECTION	UNIPOLAR OR BIPOLAR–1 WINDING	BIPOLAR SERIAL	BIPOLAR PARALLEL
VOLTAGE (VDC)	2.1		
AMPS/PHASE	3.0	2.12	4.24
RESISTANCE/PHASE (Ohms)@25°C	0.7±10%	1.4±10%	0.35±10%
INDUCTANCE/PHASE (mH) @1KHz	1.3±20%	5.2±20%	1.3±20%
HOLDING TORQUE (Nm) [lb–in]	0.88 [7.8] △4	△4 1.24 [10.98]	△4 1.24 [10.98]
DETENT TORQUE (Nm) [lb–in]	0.04 [0.354]		
STEP ANGLE (°)	1.8		
ACCURACY(NON–ACCUM)	±5%		
ROTOR INERTIA (Kg–m²) [lb–in²]	3.0x10⁻⁵ [0.102]		
WEIGHT (Kg) [lb]	0.7 [1.54]		

TEMPERATURE RISE: MAX.80°C (MOTOR STANDSTILL; FOR 2 PHASE ENERGIZED)

AMBIENT TEMPERATURE –10°~ 50°C [14°F ~ 122°F]

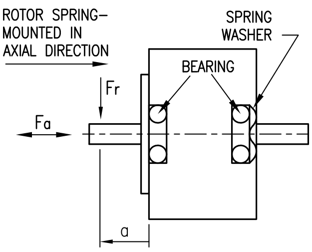
INSULATION RESISTANCE 100 MOhm (UNDER NORMAL TEMPERATURE AND HUMIDITY)

INSULATION CLASS B 130° [266°F]

DIELECTRIC STRENGTH 500VAC FOR 1 MIN. (BETWEEN THE MOTOR COILS AND THE MOTOR CASE)

AMBIENT HUMIDITY MAX. 85% (NO CONDENSATION)

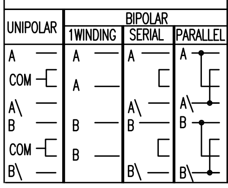
PERMISSIBLE RADIAL+AXIAL FORCE



AXIAL–FORCE Fa (N)	Fa=15			
DISTANCE a (mm)	5	10	15	20
RADIAL–FORCE Fr (N)	130	90	70	52

	AXIAL	RADIAL
SHAFT PLAY (mm)	0.08	0.02
AT LOAD MAX: (N)	4.5	4.5

TYPE OF CONNECTION (EXTERN)



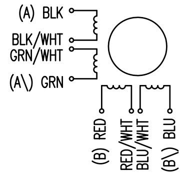
MOTOR

CONNECTOR PIN NO. △2	LEADS	WINDING
1	BLK	A
3	BLK/WHT	
2	GRN/WHT	A\
4	GRN	
5	RED	B
7	RED/WHT	
6	BLU/WHT	B\
8	BLU	

FULL STEP 2 PHASE–Ex.,
WHEN FACING MOUNTING END (X)

STEP	A	B	A\	B\	CW ↓	CCW ↑
1	+	+	–	–		
2	–	+	+	–		
3	–	–	+	+		
4	+	–	–	+		

WIRING DIAGRAM



REV	DESCRIPTION	DATE	APVD
4	HOLD.TOR.+DELE. BACK–EMF	18.10.13	J.D.
3	NEW UL NO.	28.07.09	J.W.
2	PIN–ASSIGNMENT	08.01.08	J.W.

Nanotec® PLUG & DRIVE

ST5918M3008–A

SCALE FREE	
X	±0.5
1PL	±0.2
2PL	±0.1
ANGLE	±30'

	SIGNATURE	DATE
APVD	S.Ha.	19.03.07
CHKD		
DRN	J.W.	21.11.06

STEPPING MOTOR

DWG.NO

ST5918M3008–A