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Lightweight elevator

A portable elevator capable of climbing rooftops

TORE MALMSTRÖM

CARL GÖRANSSON

KTH
SKOLAN FÖR INDUSTRIELL TEKNIK OCH MANAGEMENT

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Bachelor's Thesis at ITM
Supervisor:Nihad Subasic
Examiner: Nihad Subasic

TRITA-ITM-EX 2021:53

Abstract

The purpose of this project is to design and construct a portable lightweight elevator for transportation of goods to rooftops. The elevator should be easy to transport, assemble and disassemble, it should also be useful at various heights and for a wide range of roof inclinations.

The elevator contains a railway consisting of four separable modules. A carriage rides the railway and is pulled to the top with a winch powered by a DC-motor. The carriage starts and stops using a Rocker switch and a Hall sensor that detects magnets placed at the end and beginning of the railway. After performing tests with the elevator the conclusion is that the elevator is practical to assemble and transport, but the carriage derails too easily when the railway has angular changes.

Keywords: Mechatronics, elevator, winch, Arduino, DC-motor, Hall sensor, H-bridge.

Referat

Lättviktshiss

Målet med projektet är att designa och konstruera en portabel lättviktshiss som kan transportera gods från marknivå till hustak. Den ska vara lätt att transportera och att montera ner och upp, den ska också gå att använda för olika höjder och på hus med olika taklutningar.

Hissen består av en räls som går att ta isär i fyra olika delar. En vagn åker på fyra hjul uppför rälsen och lyftkraften kommer från en vinsch som drivs av en likströmsmotor. Vagnen kan starta och stanna med hjälp av en knapp, den stannar även automatisk då en hallsensor på vagnen känner av magneter som är placerade vid början och slutet av rälsen. En arduino Uno skickar signaler mellan de elektriska komponenterna och motorn får ström via en H-brygga, vilket gör att den kan rotera i båda riktningarna.

Efter att hissen testats kan det konstateras att konstruktionen är enkel att bygga ihop och smidig att fästa vid olika vinklar och höjder. Däremot spårar vagnen ofta ur då hissen körs med för branta vinklar mellan de olika delarna av rälsen.

Nyckelord: Mekatronik, hiss, vinsch, Arduino, Likströmsmotor, Hall sensor, H-brygga.

Acknowledgements

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List of Abbreviations

3D	Three dimensional
KB	KiloByte
USB	Universal Serial Bus
DC	Direct Current
mm	Millimeter
N cm	Newton centimeter
rpm	Revolutions Per Minute

Chapter 1

Introduction

1.1 Background

Putting up solar panels on roofs has become increasingly popular in Sweden [1]. New technology makes them more efficient and it is a viable option for electricity production. But solar panels are heavy, large and ungainly, and in environments where it is not suitable to bring a crane truck, other solutions might be needed. In this project a lightweight portable elevator will be constructed that could solve this problem and be an even better way to lift solar panels or other goods to roof tops. This work is done with the help of the department of mechatronics at KTH and is inspired by several previous reports written by other students at KTH.

1.2 Purpose

The goal of this project is to design and construct a prototype of a portable elevator. It should be easy to transport and easy to mount on site, it should also be able to lift small objects. It should be able to recognize when it has reached its destination and automatically stop. Although flexibility and being lightweight is the main goal for the elevator, the safety of goods and surrounding people has highest priority. The following scientific questions should be answered during the course of the project:

- How should the elevator be constructed so that it is easy to mount?
- For which roof inclinations is the elevator able to operate?
- How long does it take for the elevator to move from the ground to the roof top?

1.3 Scope

This elevator will only work as a small scale model of a full scale elevator. It will not be able to lift any heavy or large objects, but the results that are acquired in this project should be able to apply on a full scale elevator. To build a full scale elevator, the safety of the construction would have to be assessed further and more time and resources would be needed.

1.4 Demonstrator

Most elevators are constructed by several winches attached to the elevator in one end and a counter weight onto the other end, these two move vertically in opposing directions which saves a lot of energy since the net weight lifted is no more than the difference between the elevator and the counter weight. This construction would be much more difficult on a portable lift that needs to be able to be used in various scenarios. A winch will be used in this project but without the counter weight, the wire end will be attached to the end of the elevator rail. This will be less energy efficient, but easier to construct and install in different environments. The majority of all parts will be 3D-printed in Polylactic acid-plastic. The electronic parts will be provided by the department of Mechatronics with a budget of up to 1000 SEK.

Since the elevator will be used at different angles it needs to be controlled in its horizontal movement in some way. To achieve this, the elevator will ride on four wheels on two parallel rails. The wheels are freewheeling and the only lifting force will come from the winch. The railway consists of modules that can be taken apart during transportation.

Chapter 2

Theory

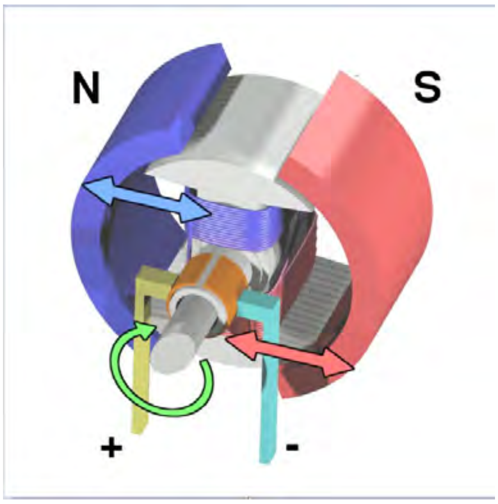
2.1 Winch

A winch is a rotating mechanism that winds up wire, rope or thread on a spool. It can be attached to a motor which makes it rotate, but it is also common to rotate the winch with a manual shaft. The winch used in this project is shown in figure 2.1. The required torque depends on the workload and on the diameter of the spool, a larger diameter increases the required torque but it also reduces the stress on the wire [2], therefore the required torque increases when several layers of wire are rolled up on the spool. With the manual shaft, a long lever can be used to decrease the torque, but when a motor is used, the workload and the number of added layers of wire must be controlled so that the winch does not lack power to successfully rotate throughout the whole process.

Figure 2.1. The winch used in this project

2.2 DC Motor

A DC motor uses direct current to convert electrical energy into mechanical energy. Inside the motor, a coil is located between magnets, and when current is passed through the coil it causes the magnets to spin which creates a rotating movement on a shaft[3]. Unlike the stepper motor, it does not rotate a specified amount of radians, instead it keeps rotating until it is ordered to stop. This is advantageous due to the modular design that allows the length of the railway to vary. A simple setup of a DC-motor is shown in figure 2.2.



[4]

Figure 2.2. Inside the DC motor

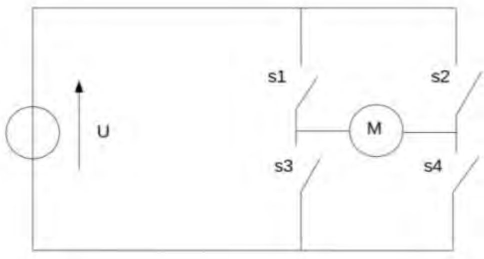
2.3 Arduino Uno

Arduino Uno, shown in Figure 2.3, is an electronic platform with software and hardware that is invented and produced by the company Arduino. The platform can read several inputs such as light, sound or button pushes and turn them into output according to a code that the user writes. The Arduino platform contains 14 digital output or input pins and six analog pins. It has a 32 KB of flash memory and can be plugged in to a computer via USB. The Arduino is programmed with a C-based language and the code is uploaded from a computer to the Arduino platform via an USB port [5].

Figure 2.3. The Arduino Uno platform.

2.4 H-Bridge

An H-Bridge is an electronic device that can change the direction of current passing through it. By closing the circuit through s1 and s4 shown in figure 2.4, the current passes through M in the opposing direction of what it would be if s2 and s3 were closed instead. With this device a DC motor can be allowed to rotate in both directions [6]. In this project this feature will be needed so that the winch can rotate in both directions and move the elevator up and down the railway.

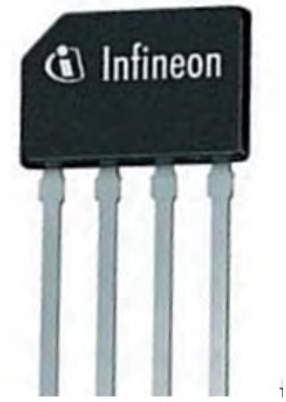


[6]

Figure 2.4. The setup inside an H-bridge.

2.5 Hall sensor

A Hall sensor uses the Hall effect to detect the presence of an external magnetic field [7], it changes its output voltage depending on the magnetic field. There are both analogue and digital Hall sensors, the analogue sends an output voltage proportional to the magnetic field that it detects, while the digital Hall sensors only only has two outputs, on and off. A digital Hall sensor, similar the one shown in figure 2.5, will be used in this project.



[8]

Figure 2.5. Hall sensor.

Chapter 3

Demonstrator

3.1 Construction of hardware

The elevator consists of a carriage riding on two parallel rails, these parts are almost exclusively made in a 3D-printer. A winch powered a DC-motor, mounted on the carriage, pulls the carriage to the top. The parts are shown in figure 3.1 and CAD-models can be found in appendix C.

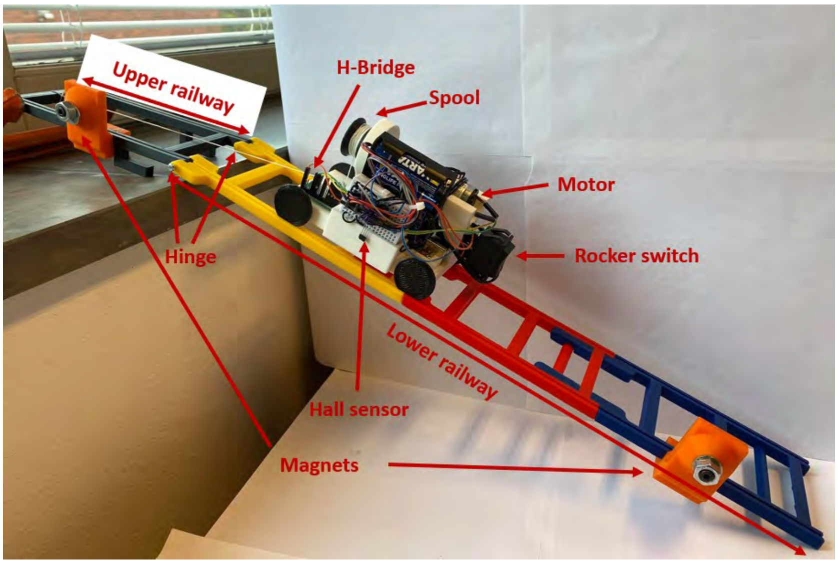


Figure 3.1. A summary of all components.

3.1.1 Carriage

The carriage is a rectangular platform that rides on four freewheeling wheels, the lifting force solely comes from the winch that is mounted on the front end of the platform. The winch consists of a spool mounted on the motor using a friction joint. The spool is 3D-printed and the wire is made of reinforced sewing thread. The end of the wire is attached to the top of the railway, so that the carriage reaches the end of its ride when the wire is completely rolled up. The carriage is shown in figure 3.2.

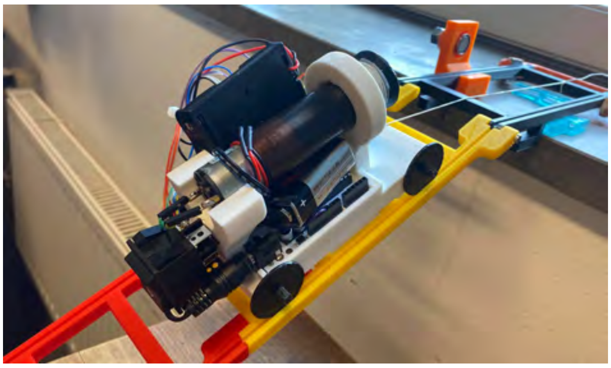


Figure 3.2. The carriage on its way up the rail.

3.1.2 Railway

With four modules combined the railway has a total length of 56 cm. The lower parts are assembled with a hooking mechanism shown in figure 3.3 and are always concentric and parallel to each other when mounted. The lower and upper parts are assembled with a hinge mechanism and can theoretically be at any angle in relation to each other. In reality the carriage will only be able to operate at a certain range of angles, since it can derail, or the winch could fail to pull it up to the roof. With this construction the elevator is able to be used for different heights and also for different roof inclinations, since the railway can be tilted.

Figure 3.3. The hooking mechanism between the lower parts of the railway.

3.1.3 Magnets

Two 20 x 13mm magnets are placed at the beginning and the end of the railway, the carriage detects either of these to know that it has reached its destination. To attach the magnets to the railway two holders, shown in figure 3.4 are constructed. The holders are mounted so that they can easily be moved along the railway if necessary.

Figure 3.4. One of the magnets attached to the railway.

3.2 Electronics and Software

To facilitate wiring, all the electronic parts are placed on the carriage. The Arduino board is powered by a 9 Volt battery and the H-bridge and DC-motor are powered by four AA-batteries.

3.2.1 Arduino

An Arduino Uno is used in this project. It directs digital signals from the sensor and the rocker switch to the DC-motor. The motor rotates the winch according to an Arduino code, the code can be found in appendix A.

3.2.2 Rocker switch

A double pole rocker switch is connected to the Arduino. It has three different states which orders the motor to rotate forward, backwards or to stop. The stop mode is not needed to make the carriage stop when it reaches the magnets, but it can be useful if a stop is needed in the middle of the railway. The Rocker switch is shown in figure 3.5.

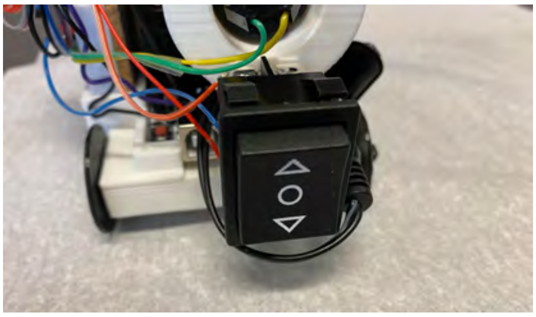


Figure 3.5. The double pole rocker switch mounted on the back of the carriage.

3.2.3 Hall sensor

A digital Hall sensor is placed on the side of the carriage, when it detects one of the magnets that are placed at the beginning and at the end of the railway it sends a signal to the Arduino board which orders the winch to stop rotating. To function the hall sensor had to be connected to two capacitors and one resistor according to figure 3.6.

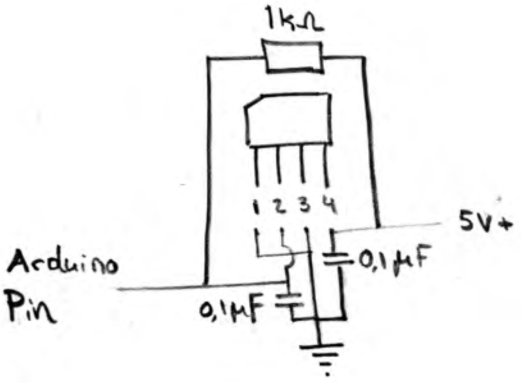


Figure 3.6. Wiring of the Hall sensor.

3.2.4 Motor

The winch is powered by a DC motor connected to the H-bridge. The motor can power the winch with a torque of up to 51 N cm, which is theoretically more than enough to lift the carriage vertically. It rotates with a speed of 7.8 rpm and no gearing is used. The data sheet for the motor can be found in appendix D.

3.2.5 H-Bridge

The H-Bridge is mounted on the carriage using a screw and two bolts, the first bolt elevates the H-bridge from the surface and the second one is used to lock the H-bridge to the carriage as seen in figure 3.7.

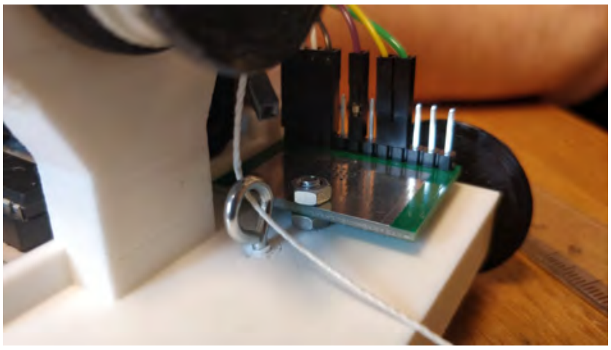


Figure 3.7. The H-bridge mounted to the carriage.

The H-Bridge consists of 12 (8 unique) pins according to figure 3.8 which are connected as described in table 3.1. To engage the motor the EN-pin and either IN1 or IN2 must receive a HIGH signal (5V) and the other IN-pin must receive a LOW signal (0V). Changing HIGH and LOW between the two inputs will change the motors direction of rotation.

Figure 3.8. The H-bridge mounted on the front of the carriage.

Table 3.1. Connections between the pins of the H-bridge.

Pin	Usage and connection (pin)
DIAG	5V Logic - connected to the 5V pin on the arduino board (5V).
EN	Enable - connected to a digital port on the arduino board (12).
IN1	Input 1 - connected to a digital port on the arduino board (11).
IN2	Input 2 - connected to a digital port on the arduino board (10).
GND	Ground - connected to the ground pin on the arduino board (GND).
OUT1	Output 1 - connected to one of the motor pins.
OUT2	Output 2 - connected to the other motor pin.
VS	Supply voltage - connected to the plus side of the battery pack.

Chapter 4

Results

4.1 Climbing the railway

The elevators ability to climb the railway was tested repeatedly at different angles α. The time for the carriage to reach the top at each angle are listed in table 4.1, the angle α was measured according to figure 4.1.

Figure 4.1. Measuring angle α.

At the angles below 163 degrees, the wheels were elevated from the railway when it reached the upper rail due to contact between the bottom of the carriage and the railway. The carriage could however function as intended if the wire was fixed straight in front of the loop. At angles below 145 degrees, the carriage derailed consistently and the conditions were deemed insufficient.

Table 4.1. Results of tests when operating the elevator at different angles.

Angle α between the upper and lower railway (degrees)	Time for the carriage to reach the top (seconds)
180	40.2
170	40.5
165	40.1
160	40.3
155	40.3
150	40.7
145	39.9
140	-

4.2 Descending the railway

The carriage successfully descended the railway without derailing for angles α 180-145 degrees. When the inclination β of the upper rail, measured as shown in figure 4.2, undercut 5 degrees, the carriage stood still and would not descend from the top.

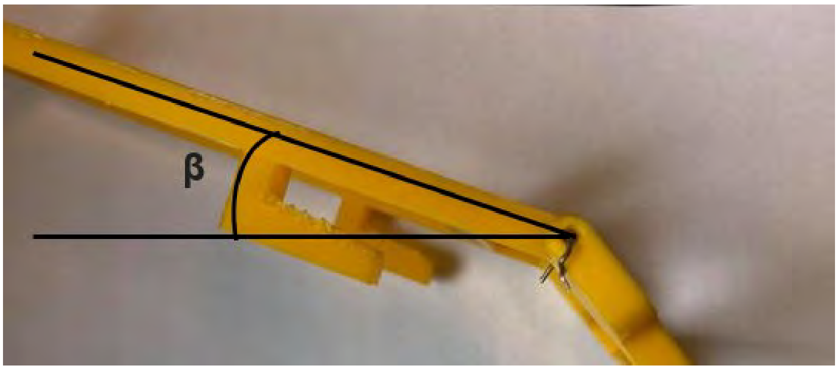


Figure 4.2. Measuring angle β.

4.3 Construction of railway

The construction consists of a modular design utilizing a hook mechanism to interlock each module making it very easy to assemble and disassemble. Each module was built in a 3D-printer with an infill of 20% making it lightweight as well as being able to support a load at least three times the weight of the elevator.

Chapter 5

Discussion and conclusions

5.1 Winch

A winch with its wire fixed to the top of the railway could only force the elevator to move upwards, on the way down it relied solely on gravity. This became an issue when the inclination of the upper railway was lower than 5 degrees, at which point the carriage would not descend. To avoid this the motor could be used to power the wheels instead, or a winch that can be winded up in both ends of the railway.

It took the carriage 40 seconds to reach the top regardless of the angle of the railway, presuming that it did not derail. If the speed needs to be increased, the diameter of the spool would have to be increased, or a motor with a higher angular velocity could be used.

5.2 Carriage

When the angle between the upper and lower railways were less than 163 degrees, the bottom of the carriage made contact with the railway which resulted in the wheels elevating off the railway, which often made the carriage derail. To increase the range of angles at which the elevator could operate without derailing, the wheels would have to have a larger diameter to increase the distance between the carriage and the railway. A third pair of wheels could also be added to make sure two pairs are always in contact with the rail. For the current design of the carriage there was no room to increase this diameter or to add a third pair of wheels, as the platform for the Hall sensor was in the way. Another solution would be to construct the railway so that the inclination occurs at several locations instead of just one, and thereby making the angle less steep.

5.3 Conclusion

The construction of separable modules proved to be a practical way to disassemble and assemble the railway at various angles and height differences. The range of angles at which the elevator could successfully operate without derailing was fairly low, approximately 17 degrees. Due to its tendency to derail, the elevator can not be deemed safe to use in an up scaled version. The time to complete the ride from bottom to top was 40 seconds. The Hall-Sensor reliably detected the magnets and stopped the carriage at the desired locations.

5.4 Future work

For the next version of this elevator the safety should be improved, foremost by avoiding any derailing by adding a pair of wheels or increasing their diameter. These changes will require moving the hall sensor as the wheels will create too much space between the sensor and the magnets. Solutions where the magnets are placed beneath the carriage should be considered.

The purpose of the elevator is to transport things but with the current construction there is no room for that. This would have to be solved by building a larger carriage since the electronic parts require much room as it is. During an attempt to climb the rail at a difficult angle the friction joint could not transfer enough torque to pull the carriage over the top, if the carriage were to transport something at an unfavorable angle it is very likely that the friction joint would have to be improved with a screw into the motor axis.

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Appendix A

Arduino code

```
//Project name: Lightweight elevator
//Course: MF133X FiM VT21-1 Bachelor’s Thesis at ITM
//Authors: Tore Malmström & Carl Göransson
//TRITA ITM EX 2021-53
//Date: 2021-05-22
//The program i used to run an elevator. The elevator should, when the forward
// button is pressed, start running forward/up until it reaches it’s destination
//(magnet sensor detects a magnet) and stop there. And when the reverse/down
//button is pressed it should start running in reverse until it reaches it’s original
//position.

int in1 = 11; //Pin connected to the in1-pin of the H-bridge
int in2 = 10; //Pin connected to the in2-pin of the H-bridge
int en = 12; //Pin connected to the en-pin of the H-bridge
int STATE = 0; //starting STATE
int prevSTATE = 0; //startvalue for previous STATE
int HALT = 5; //Pin for a stop button (not used in this application of the program)
int UP = 6; //Pin connected to up button (rocker switch)
int DOWN = 7; //Pin connected to down button (rocker switch)
int BREAK = 0; //STATE 0 (0 on the rocker switch)
int sensorSTOP = 1; //STATE 1 (Hall sensor senses a magnet)
int FORWARD = 2; //STATE 2 (Up on the rocker switch)
int REVERSE = 3; //STATE 3 (Down on the rocker switch)
int SENSOR = 8; //Pin connected to the output of the hall sensor
int READY = 0; //READY-variable == 1 means that motor can start even though
//the hall sensor senses a magnet


void setup() {
Serial.begin(9600);
```

```
pinMode(en, OUTPUT); //en, in1, in2 is outputs connected to the H-bridge
pinMode(in1, OUTPUT);
pinMode(in2, OUTPUT);
pinMode(SENSOR, INPUT); //input from the sensor
pinMode(HALT, INPUT); //input from the STOP button
pinMode(UP, INPUT); //input from the UP button
pinMode(DOWN, INPUT); //input from the DOWN button
}

void loop() {
delay(100); //Stability

//——————————————————————————

//Component and code testing. Prints inputs from buttons, STATE, READY:

/* Serial.print(”SENSOR = ”);
Serial.print(digitalRead(SENSOR));
Serial.print(”, UP = ”);
Serial.print(digitalRead(UP));
Serial.print(”, DOWN = ”);
Serial.print(digitalRead(DOWN));
Serial.print(”, READY = ”);
Serial.print(READY);
*/
//——————————————————————————

if ((digitalRead(UP) == 0 && digitalRead(DOWN) == 0)){ //If no button is pushed, can be replaced with a stop button
STATE = BREAK;
READY = 1;
}
else if (digitalRead(SENSOR) == 0 && READY == 0){ //Must be adjusted to sensor depending on output signal
STATE = sensorSTOP; //If sensor senses magnet and READY == 0 motor stops
}
else if (digitalRead(UP) == 1){ //If UP-button is pressed it moves up/forward
STATE = FORWARD;
READY = 0; //READY = 0 to make it stop when it reaches a magnet
}
else if (digitalRead(DOWN) == 1){ //If DOWN-button is pressed it moves down/in reverse
STATE = REVERSE;
READY = 0; //READY = 0 to make it stop when it reaches a magnet
```

```
}
else{
Serial.println(”No STATE, contact your local programmer”); //Error message
}

Serial.print(”, STATE: ”); //Print to serial monitor, follows by print in active case

switch(STATE){

case 0: //BREAK Motor stops
digitalWrite(en, LOW);
digitalWrite(in1, LOW);
digitalWrite(in2, LOW);
Serial.println(”0”); //prints CASE
delay(50); //stability
break;

case 1: //sensorSTOP Motor stops
digitalWrite(en, LOW);
digitalWrite(in1, LOW);
digitalWrite(in2, LOW);
Serial.println(”1”); //prints CASE
delay(50); //stability
break;

case 2: //FORWARD Motor runs forward/up
digitalWrite(en, HIGH);
digitalWrite(in1, HIGH);
digitalWrite(in2, LOW);
Serial.println(”2”); //prints CASE
delay(50); //stability
break;

case 3: //REVERSE Motor runs in reverse
digitalWrite(en, HIGH);
digitalWrite(in1, LOW);
digitalWrite(in2, HIGH);
Serial.println(”3”); //prints CASE
delay(50); //stability
break;
}

if (prevSTATE == BREAK && prevSTATE = STATE){ //If program has entered a new state after being in BREAK-STATE
```

```
delay(1000); //Delay for 1 second to let the elevator get out of the magnetic field
READY = 0;
}

    prevSTATE = STATE; //Save STATE as prevSTATE for next loop
}
```

Appendix B

Acumen simulation

```
//Project name: Lightweight elevator
//Course: MF133X FiM VT21-1 Bachelor's Thesis at ITM
//Authors: Tore Malmström & Carl Göransson
//TRITA ITM EX 2021-53
//Date: 2021-05-22
//This is a simulation of how the wheels of the carriage will roll down the rails

//Creates the base and sides of the rail
model plane (x,y,z) =
initially
_3D = ()
always
_3D = (Box center=(x,y+0.318,z-0.318) size=(12,1.5,0.9)
color=(0.5,0.5,0.1) rotation=(0,-pi/4,pi/2)
Box center=(x+0.45,y-0.106,z+0.106) size=(12,0.6,0.3)
color=(0.1,0.1,1.0) rotation=(0,-pi/4,pi/2)
Box center=(x-0.45,y-0.106,z+0.106) size=(12,0.6,0.3)
color=(0.1,0.1,1.0) rotation=(0,-pi/4,pi/2))

    // the cylinder model with squares as rotational markers =
model fancy_cyl (x,y,z,a,D) =
initially
_3D = ()
always
_3D = (Cylinder center=(x,y,z)+D
radius=3 length=0.3 color=(0.2,1.0,0.2)
rotation=(-1*pi/2,1*pi/2,0),
Box center=(x+1,y,z)+D
size=(0.02,3,3) color=(0.9,0.1,0.1)
rotation=(a,0,0),
```

```
Box center=(x-1,y,z)+D
size=(0.02,3,3) color=(0.9,0.1,0.1)
rotation=(a,0,0))

model Main(simulator) =
initially
// declaring the graphical objects
b = create plane(0,-1.5,-5.4),
c = create fancy_cyl(0,2.2,2.5,0,(0,0,0)),
// declaring the constants
t = 0, t’ = 0, // time starts at zero and does not accelerate
p = 0, p’ = 0,
a = 0, a’ = 0
always
t’ = 0,
a’ = 1, //a is the rotation angle, a’ = angular speed
p’ = a’, // displacement, linear speed, function of time
c.a = a, // rotational speed
c.D = (0,-p,-p) // the displacement from the original position
```

Appendix C

CAD designs

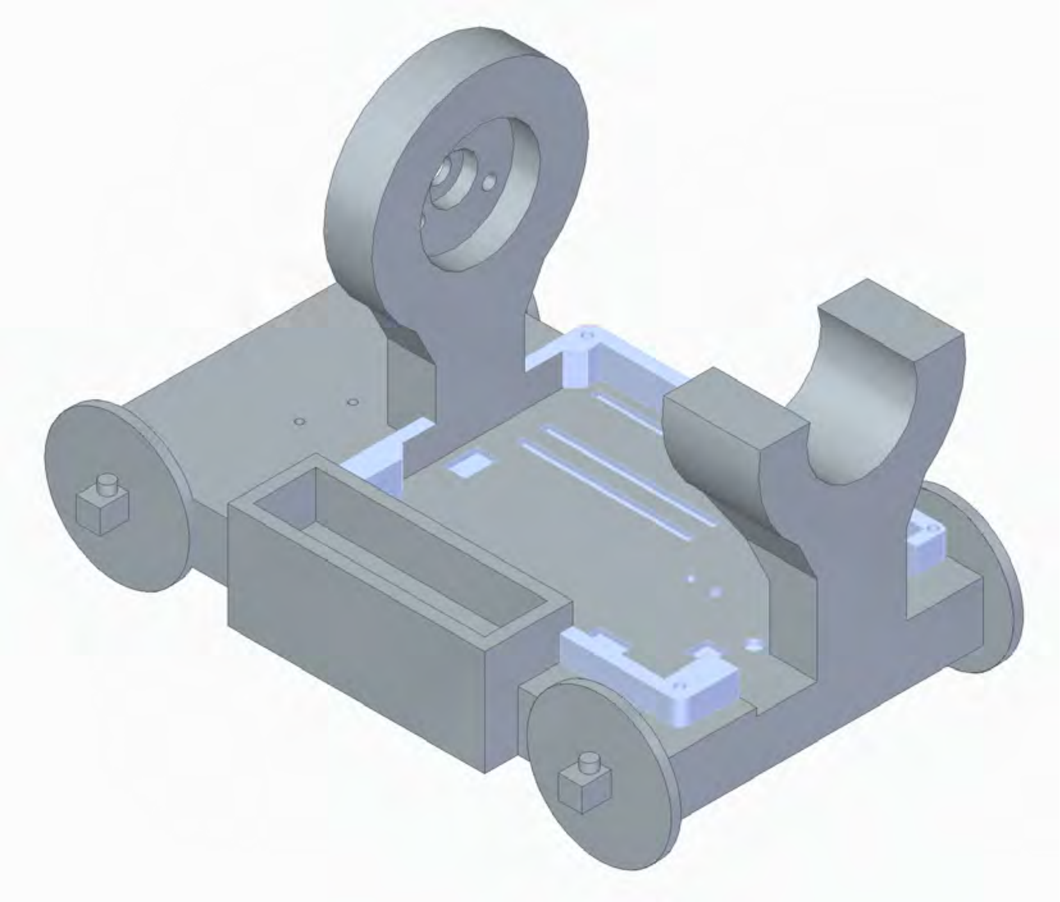


Figure C.1. Carriage.

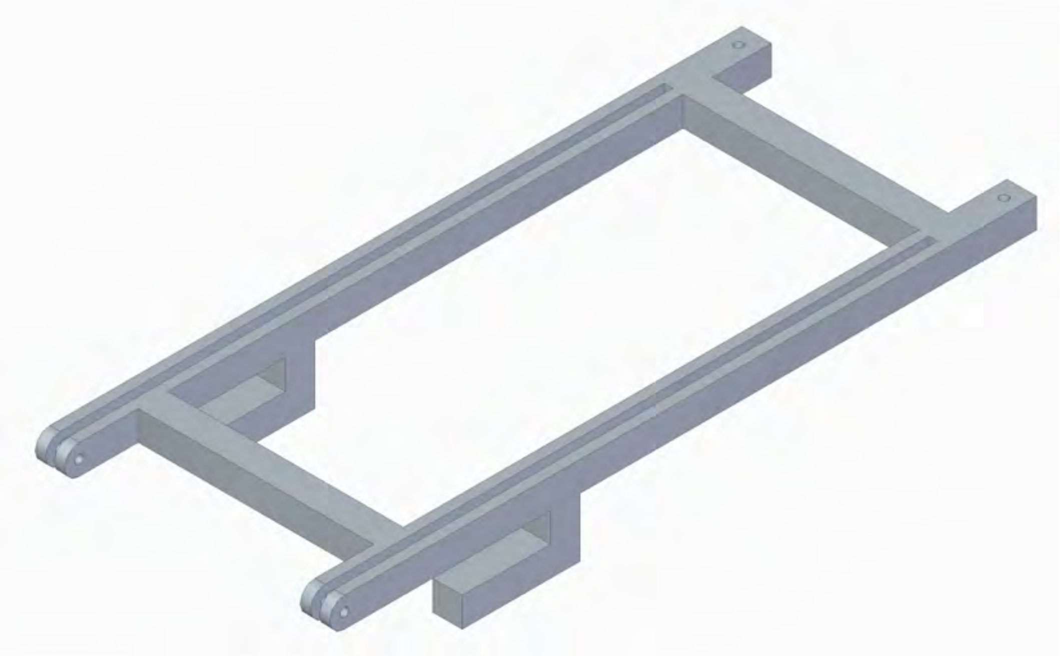


Figure C.2. Upper railway.

Figure C.3. Lower Railway attaching to the upper railway.

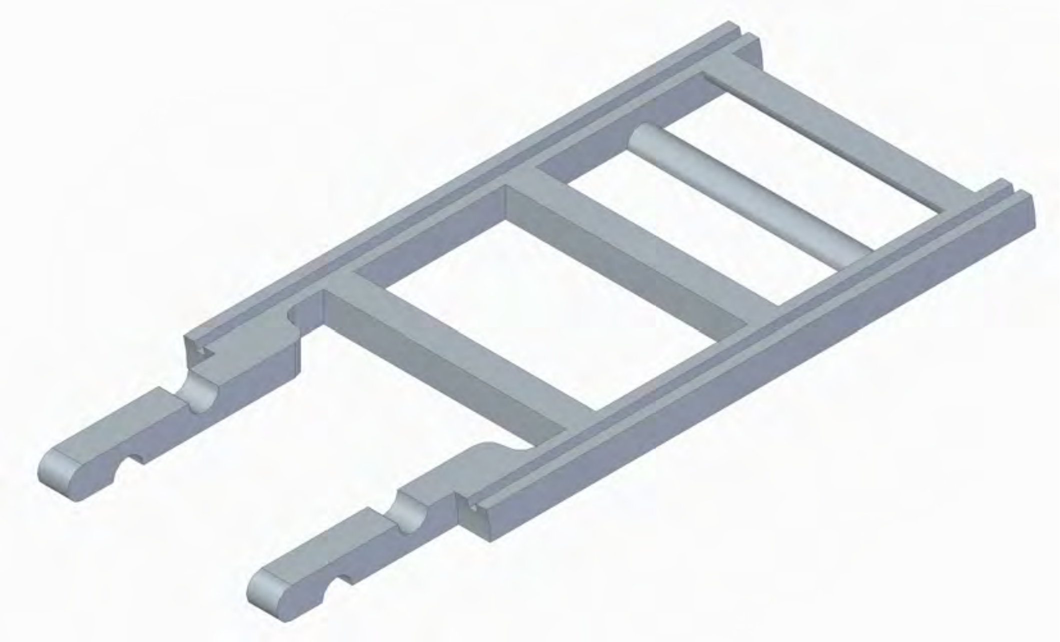


Figure C.4. Lower Railway.

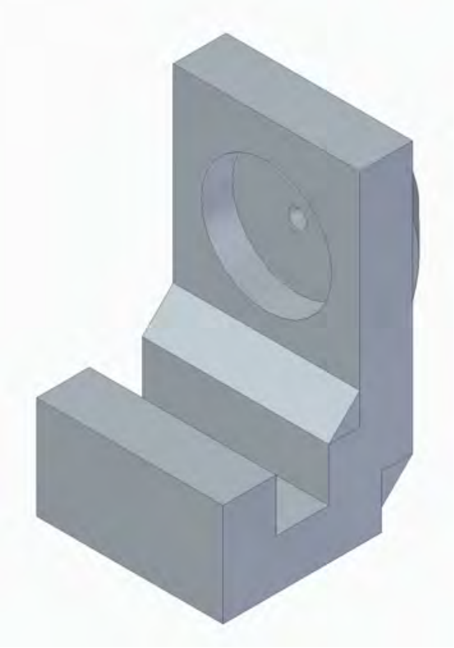


Figure C.5. Magnet holder.

Appendix D

Datasheet Motor

D.C.Motors

Series GR 22.0

Due to their extremely small constructional volume and high output, i.e. high output/volume factor, these classically slotted permanent magnet excited small D.C.motors are suitable for such fields of applications as
- Precision engineering
- Photographic, cinematic, optic
- Measuring and control engineering
- Office and data engineering
- Communications engineering
- Servo engineering etc.

Design

The motors are rigidly built and do not require maintenance during their lifetime.

The chromed housing tube acts simultaneously as the return circuit for two segmented magnets which are manufactured from high quality magnetic material. The advantageous slotted-form of the five part rotor plate guarantees high copper/space factor. Five part copper commutator and graphite brushes comprise the commutating system.

The rotor runs in self-lubricating sinter bearings.

The end-shields are manufactured from black, high quality plastic.

It is possible to combine these motors with gears and actual value generators.

Angle dimensions and angle offset

If angles cannot be shown with individual tolerances on scale drawings, the following applies:
The angle dimensions of individual deviate max. ±1° from the ideal angle.

The max. angle offset of different graduated circles to each other and from the drive side representation to the non-drive side representation is dependent on the model and can be requested if necessary.

Performance data of motor GR 22.0							
Nominal voltage	3	**6**	**12**	15	**24**	30	V
Nominal speed 2)	3700	4000	5400	5600	4700	4500	min^{-1}
Nominal torque 2)	0,46	0,46	0,47	0,47	0,48	0,48	Ncm
Nominal current 2)	≤1,65	≤0,83	≤0,47	≤0,39	≤0,2	≤0,16	A
Rated output power 2)	1,78	1,93	2,66	2,76	2,36	2,26	W
No load speed 1)	8000	7800	9100	9400	8100	8100	min^{-1}
No load current 1)	≤0,35	≤0,17	≤0,1	≤0,09	≤0,05	≤0,04	A
Starting torque 1)	≥1,1	≥1,09	≥1,46	≥1,47	≥1,42	≥1,38	Ncm
Torque constant 1)	0,34	0,72	1,17	1,5	3,0	3,56	Ncm/A
Moment of inertia	2,4	2,4	2,4	2,4	2,4	2,4	gcm^2
Mech. time constant 1)	18,3	18	15,7	16,1	14,3	14,8	ms
Weight	50	50	50	50	50	50	kg

Shaft load capacity axial	4 N max.
Shaft load capacity radial	6 N max. applied 12 mm from mounting surface

All output data are referred to 1) $\partial_R = 20\,°C$ resp. 2) $\Delta\partial_w = 100$ K

Features

- Maximum power with minimum construction volume.
- Stable speed-/torque characteristics.
- High dynamic force due to low mechanical time constant.
- Minimum of pole sensitivity, i.e. lowest possible cogging effect.
- High efficiency.
- Extended mechanical life due to use of long life brushes.
- Low noise levels.
- May be installed in any mounting position, direction of rotation right or left.
- Insulation according to VDE 0530, insulation class E.
- Surface protection.

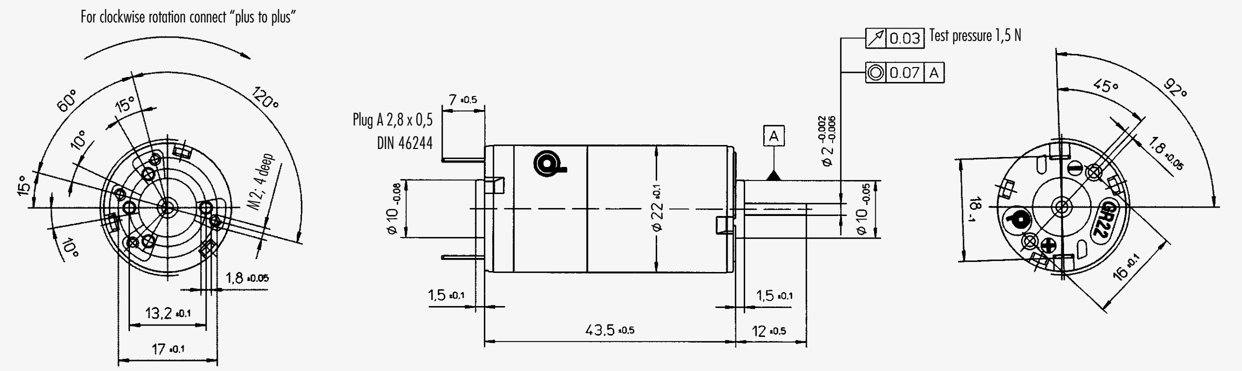
Standard program

Motors with nominal voltages 6 V, 12 V and 24 V represent our standard motor program and should preferably be used.

Load characteristics

The characteristics are examples for the standard program with the possible winding configurations of the motors, type GR 22.0.

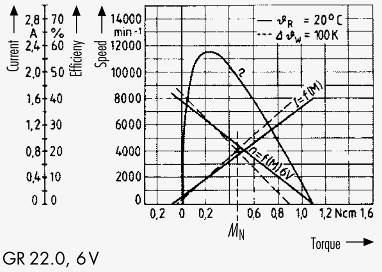
Dimensional drawing · Dimensions in mm



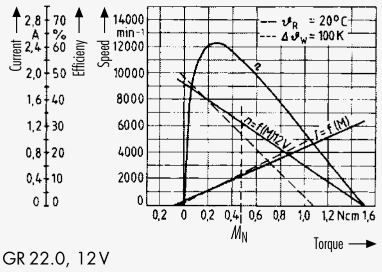
Motor GR 22.0

Please note that differ to the drawing in some cases the rear side shaft may protocle up to 2 mm.
The boss diameter is controled with a cylindrical gauge.

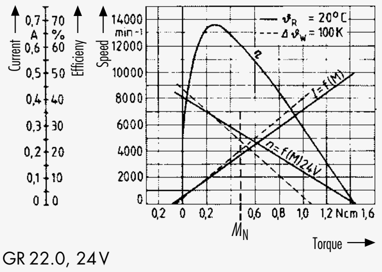
Load characteristics



GR 22.0, 6 V



GR 22.0, 12 V



GR 22.0, 24 V

Appendix E

Datasheet Hall sensor

Data Sheet, V 2.0, May 2004

TLE4990

Programmable
Linear Output Hall Sensor


TLE4990_PHOTO

Advanced Sensors

Never stop thinking.

1 Overview

1.1 Summary of Features

- Very linear and ratiometric rail-to-rail output signal with push-pull output
- Temperature compensation
- Low drift of output signal over temperature and lifetime
- Programmable parameters stored in fuse memory:
  - magnetic range and magnetic sensitivity (gain)
  - zero field voltage (offset)
  - clamping option
  - temperature coefficient (calibrated and fused during production)
  - memory lock
- Working over temperatures from -40 °C up to 150 °C
- Single supply voltage 4.5 - 5.5 V
- Continuous measurement ranges between -200 mT and +200 mT or 0 and 400 mT
- Very slim 4-pin package with only 1mm thickness
- Reverse polarity and overvoltage protection for all pins
- Output short circuit protection
- On-board diagnostics (wire breakage detection)
- Individual programming and operation of multiple sensors with common power supply
- Two point calibration of magnetic transfer function

1.2 Target Applications

- Robust replacement of potentiometers
  - No mechanical abrasion
  - Resistant to humidity, temperature, pollution, and vibration
- Linear and angular position sensing in automotive applications like pedal position, suspension control, valve or throttle position, headlight levelling, and steering angle
- High current sensing for battery management, motor control, and electronic fuse

1.3 Ordering Information

Type	Ordering Code	Package
TLE4990	Q62705-K417 1)	P-SSO-4-1
TLE4990-E6782	Q62705-K668 2)	P-SSO-4-1
TLE4990-E6785	Q62705-K741A 3)	P-SSO-4-1

1) Standard type

2) Completely calibrated and fused

3) Temperature coefficient 0 ppm/°C

2 Functional Description

Pin Configuration

Figure 1 shows the location of the hall element in the chip.

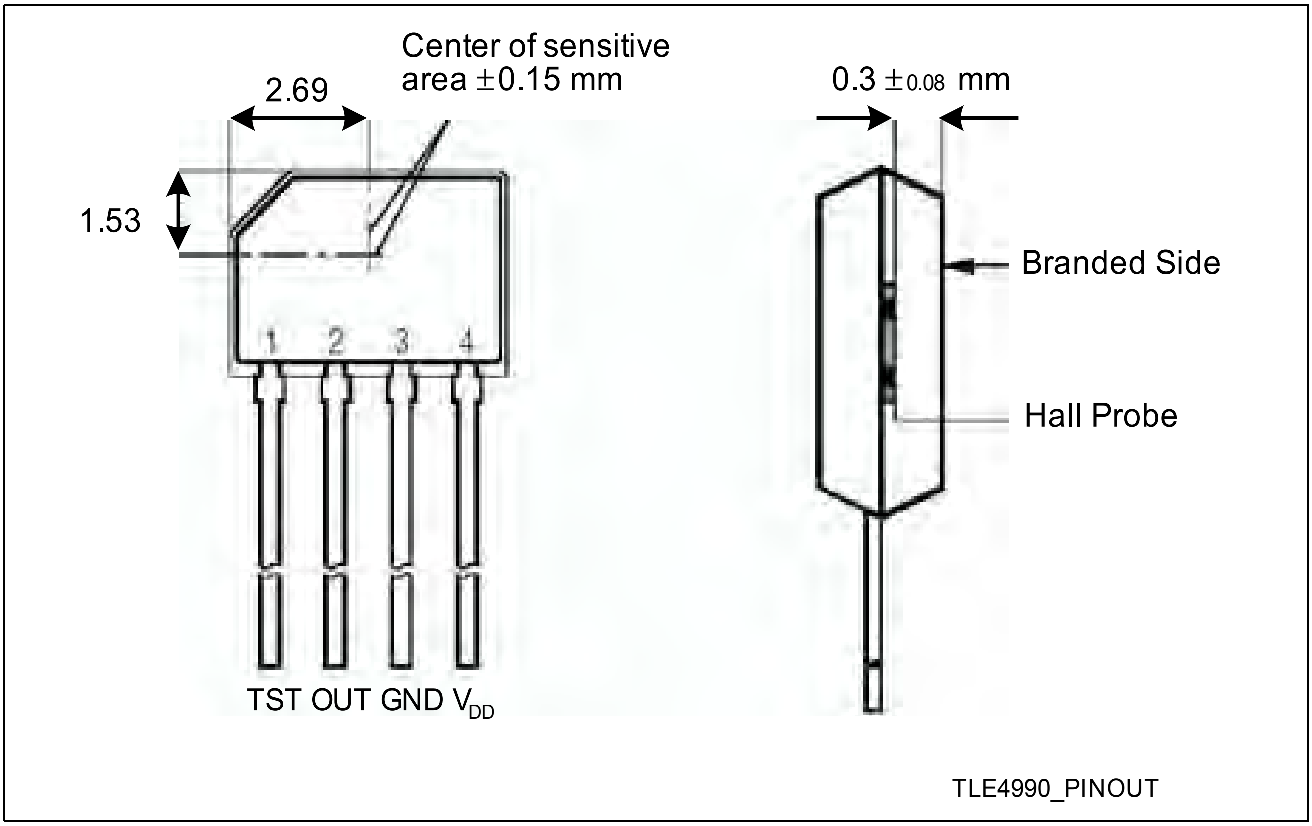


Figure 1 **Pin Configuration and Hall Cell Location**

Table 1 **Pin Definitions and Functions**

Pin No.	Symbol	Function
1	*TST*	Test pin, must be grounded
2	*OUT*	Output voltage / programming interface
3	*GND*	Ground
4	V_{DD}	Supply voltage / programming interface

Block Diagram

Figure 2 shows a simplified block diagram.

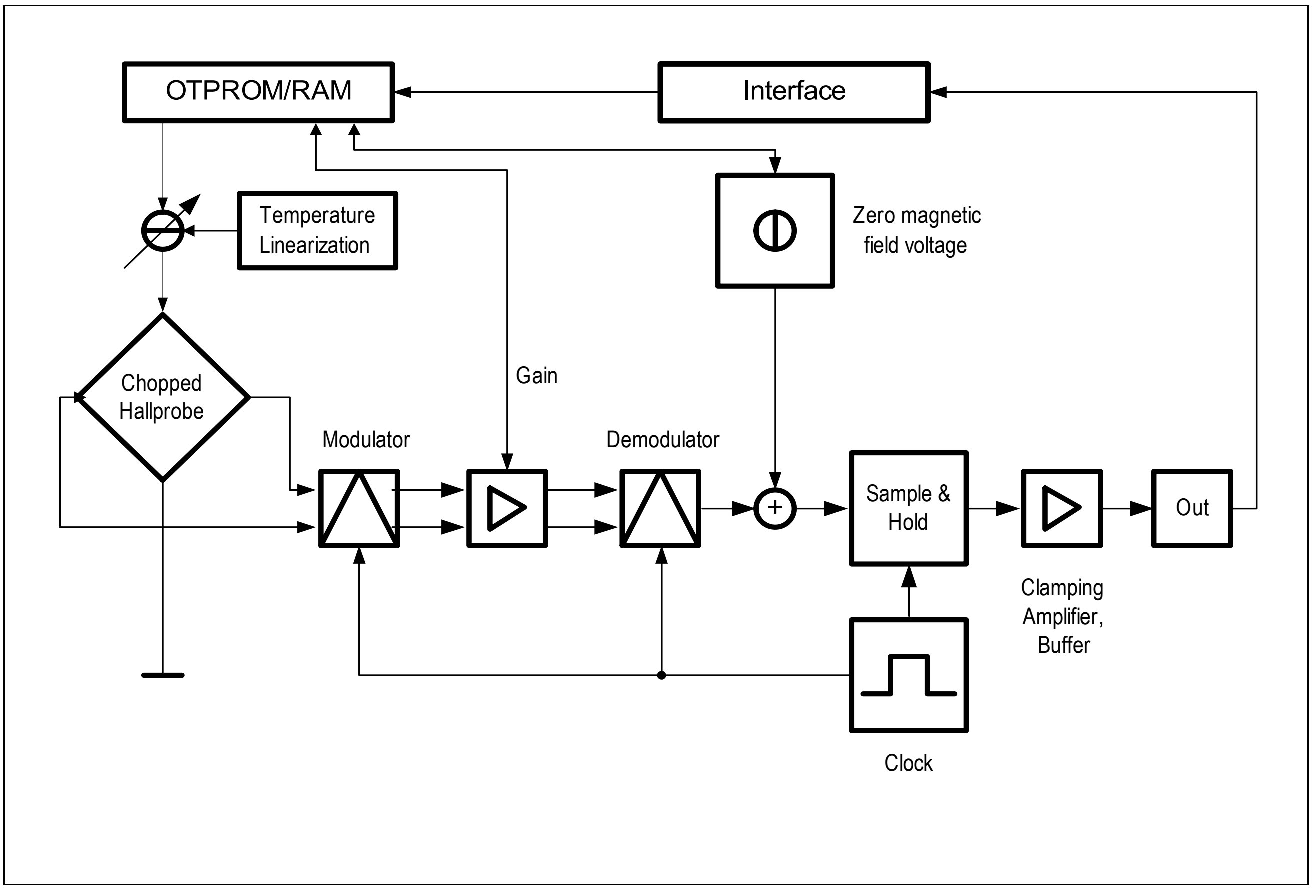


Figure 2 Block Diagram

Principle of Operation

- A magnetic flux is measured by a Hall-Effect cell.
- The Temperature compensation modulates the bias current of the hall cell.
- The output signal from the Hall-Effect cell is amplified.
- A zero field voltage is added.
- The output voltage range can be clamped by limiters.
- The final output value is amplified and buffered.
- The output voltage is proportional to the supply voltage (ratiometric bahaviour).
- An OBD (**O**n **B**oard **D**iagnistics) circuit connects the output to V_{DD} or GND in case of errors.

Appendix F

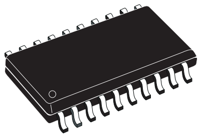
Datasheet H-bridge

L9997ND

DUAL HALF BRIDGE DRIVER

- HALF BRIDGE OUTPUTS WITH TYPICAL $R_{ON} = 0.7\Omega$
- OUTPUT CURRENT CAPABILITY ±1.2A
- OPERATING SUPPLY VOLTAGE RANGE 7V TO 16.5V
- SUPPLY OVERVOLTAGE PROTECTION FUNCTION FOR V_{VS} UP TO 40V
- VERY LOW QUIESCENT CURRENT IN STANDBY MODE < 1µA
- CMOS COMPATIBLE INPUTS WITH HYSTERESIS
- OUTPUT SHORT-CIRCUIT PROTECTION
- THERMAL SHUTDOWN
- REAL TIME DIAGNOSTIC: THERMAL OVERLOAD, OVERVOLTAGE

MULTIPOWER BCD TECHNOLOGY



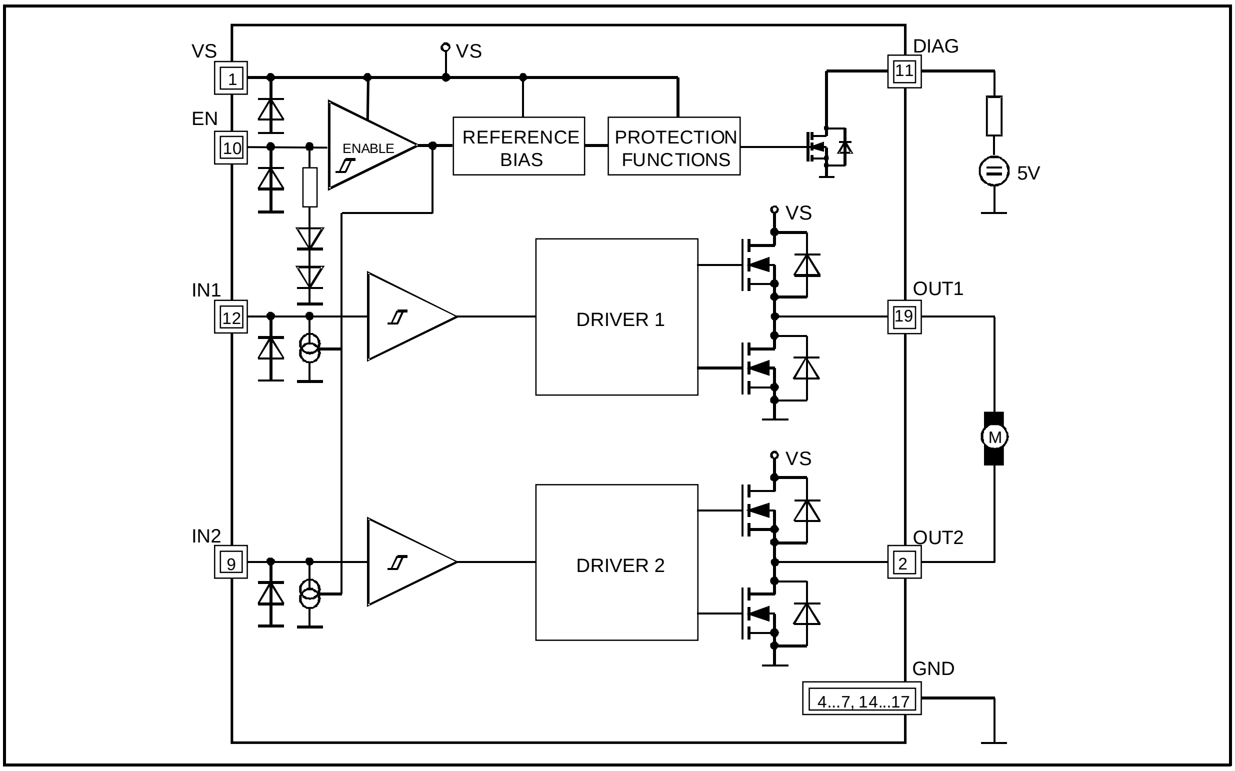
SO20 (12+4+4)

ORDERING NUMBERS: L9997ND
L9997ND013TR

DESCRIPTION

The L9997ND is a monolithic integrated driver, in BCD technology intended to drive various loads, including DC motors. The circuit is optimized for automotive electronics enviromental conditions.

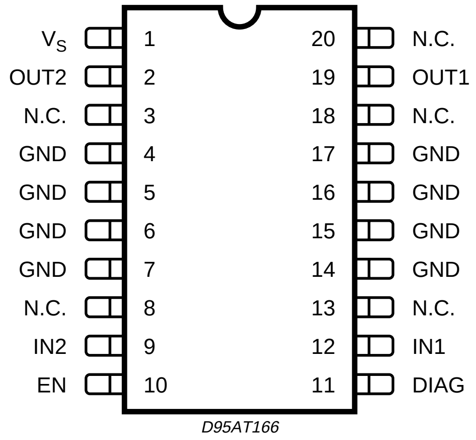
BLOCK DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_{VSDC}	DC Supply Voltage	-0.3 to 26	V
V_{VSP}	Supply Voltage Pulse (T < 400ms)	40	V
I_{OUT}	DC Output Current	±1.8	A
$V_{IN1,2}$	DC Input Voltage	-0.3 to 7	V
V_{EN}	Enable Input Voltage	-0.3 to 7	V
V_{DIAG}	DC Output Voltage	-0.3 to 7	V
I_{OUT}	DC Output Short-circuit Current -0.3V < V_{OUT} < V_S + 0.3V	internally limited	
I_{DIAG}	DC Sink Current -0.3V < V_{DG} < 7V	internally limited	

PIN CONNECTION (Top view)



PIN FUNCTIONS

N.	Name	Function
1	VS	Supply Voltage
2	OUT2	Channel 2: Push-Pull power output with intrinsic body diode
3, 8, 13, 18,20	NC	NC: Not Connected
4 to 7, 14 to 17	GND	Ground: signal - and power - ground, heat sink
9	IN2	Input 2: Schmitt Trigger input with hysteresis (non-inverting signal control)
10	EN	Enable: LOW or not connected on this input switches the device into standby mode and the outputs into tristate
11	DIAG	Diagnostic: Open Drain Output that switches LOW if overvoltage or overtemperature is detected
12	IN1	Input 1: Schmitt Trigger input with hysteresis (non-inverting signal control)

THERMAL DATA

Symbol	Parameter	Value	Unit
T_{jTS}	Thermal Shut-down Junction Temperature	165	°C
T_{jTSH}	Thermal Shut-down Threshold Hysteresis	25	K
$R_{th\ j\text{-}amb}$	Thermal Resistance Junction-Ambient (1)	50	K/W
$R_{th\ j\text{-}pins}$	Thermal Resistance Junction-Pins	15	K/W

(1) With 6cm^2 on board heatsink area.

ELECTRICAL CHARACTERISTICS (7V < V_S < 16.5V; -40°C < T_J < 150°C; unless otherwise specified.)

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
I_{VS_SB}	Quiescent Current in Standby Mode	V_{EN} < 0.3V; V_{VS} <16.5V; T_j < 85°(*) V_{EN} = 0; V_{VS} = 14.5V; T_j = 25°C		<1 <1	90 10	µA µA
I_{VS}	Supply Current	EN = HIGH, $I_{OUT1,2}$ = 0		2	6	mA
V_{ENL}	Low Enable Voltage				1.5	V
V_{ENH}	High Enable Voltage		3.5		6	V
V_{ENthh}	Enable Threshold Hysteresis			1		V
I_{EN}	Enable Input Current	V_{EN} = 5V		85	250	µA
$V_{IN1,2L}$	Low Input Voltage				1.5	V
$V_{IN1,2H}$	High Input Voltage		3.5			V
$V_{IN1,2thh}$	Input Threshold Hysteresis			1		V
$I_{IN1,2}$	Input Bias Current	V_{IN} = 0 V_{IN} = 5V, EN = HIGH	-3 2	0 10	1 50	µA µA
$R_{ON\ OUT1,2}$	ON-Resistance to Supply or GND	I_{OUT} = ±0.8A; V_{VS} = 7V; T_j = 125°C I_{OUT} = ±0.8A; V_{VS} = 12V; T_j = 125°C I_{OUT} = ±0.8A; V_{VS} = 12V; T_j = 25°C		1.2 1.1 0.7	2.8 2.25	Ω Ω Ω
$\|I_{OUT1,2}\|$	Output Current Limitation		1.2	1.6	2.2	A
V_{DIAG}	Diagnostic Output Drop	I_{DIAG} = 0.5mA, EN = HIGH Overvoltage or Thermal Shut-down			0.6	V
V_{VSOVth}	Supply Overvoltage Threshold		17	19	21	V
t_{ONLH}	Turn on Delay Time	See Fig. 2; V_{VS} = 13.5V Measured with 93Ω load		50	150	µs
t_{ONHL}				30	150	µs
t_{OFFHL}	Turn off Delay Time			10	100	µs
t_{OFFLH}				2	20	µs
t_{dHL}	Rising Delay Time			115	250	µs
t_{dLH}	Falling Delay Time			115	250	µs
t_{rHS}	Rise Time			30	100	µs
t_{rLS}				60	150	µs
t_{fHS}	Fall Time			25	100	µs
t_{fLS}				50	150	µs

* Tested at 125°C and guaranteed by correlation

FUNCTIONAL DESCRIPTION

The L9997ND is a motor driver two half-bridge outputs, intended for driving dc motors in automotive systems. The basic function of the device is shown in the Table 1.

Table 1. Table function.

Status	EN	IN1	IN2	OUT1	OUT2	DIAG	NOTE
1	L	X	X	Tristate	Tristate	OFF	Standby Mode
2	H	H	H	SRC	SRC	OFF	Recommended for braking
3	H	H	L	SRC	SNK	OFF	
4	H	L	H	SNK	SRC	OFF	
5	H	L	L	SNK	SNK	OFF	
6	H	X	X	Tristate	Tristate	ON	Overvoltage or Overtemperature

The device is activated with enable input voltage HIGH. For enable input floating (not connected) or LOW the device is in Standby Mode. Very low quiescent current is defined for $V_{EN} < 0.3V$. When activating or disactivating the device by the enable input a wake-up time of 50µs is recommended.

For braking of the motor the status 2 is recommended. The reason for this recommendation is that the device features higher threshold for initialisation of parasitic structures than in state 5.

The inputs IN1, IN2 features internal sink current generators of 10µA, disabled in standby mode. With these input current generators the input level is forced to LOW for inputs open. In this condition the outputs are in SNK state.

The circuit features an overvoltage disable function referred to the supply voltage V_{VS}. This function assures disabling the power outputs, when the supply voltage exceeds the over voltage threshold value of 19V typ. Both outputs are forced to tristate in this condition and the diagnostic output is ON.

The thermal shut-down disables the outputs (tristate) and activates the diagnostic when the junction temperature increases above the thermal shut-down threshold temperature of min. 150°C. For the start of a heavy loaded motor, if the motor current reaches the max. value, it is necessary to respect the dynamical thermal resistance junction to ambient. The outputs OUT1 and OUT2 are protected against short circuit to GND or V_S, for supply voltages up to the overvoltage disable threshold.

The output power DMOS transistors works in linear mode for an output current less than 1.2A. Increasing the output load current (> 1.2A) the output transistor changes in the current regulation mode, see Fig.6, with the typical output current value below 2A. The SRC output power DMOS transistors requires a voltage drop ~3V to activate the current regulation. Below this voltage drop is the device also protected. The output current heat up the power DMOS transistor, the R_{DSON} increases with the junction temperature and decreases the output current. The power dissipation in this condition can activate the thermal shutdown . In the case of output disable due to thermal overload the output remains disabled untill the junction temperature decreases under the thermal enable threshold.

Permanent short circuit condition with power dissipation leading to chip overheating and activation of the thermal shut-down leads to the thermal oscillation. The junction temperature difference between the switch ON and OFF points is the thermal hysteresis of the thermal protection. This hysteresis together with the thermal impedance and ambient temperature determines the frequency of this thermal oscillation, its typical values are in the range of 10kHz.

The open drain diagnostic output needs an external pull-up resistor to a 5V supply. In systems with several L9997ND the diagnostic outputs can be connected together with a common pull-up resistor. The DIAG output current is internally limited.

Fig. 1 shows a typical application diagram for the DC motor driving. To assure the safety of the circuit in the reverse battery condition a reverse protection diode D_1 is necessary. The transient protection diode D_2 must assure that the maximal supply voltage V_{VS} during the transients at the V_{BAT} line will be limited to a value lower than the absolute maximum rating for V_{VS}.

Figure 1: Application Circuit Diagram.

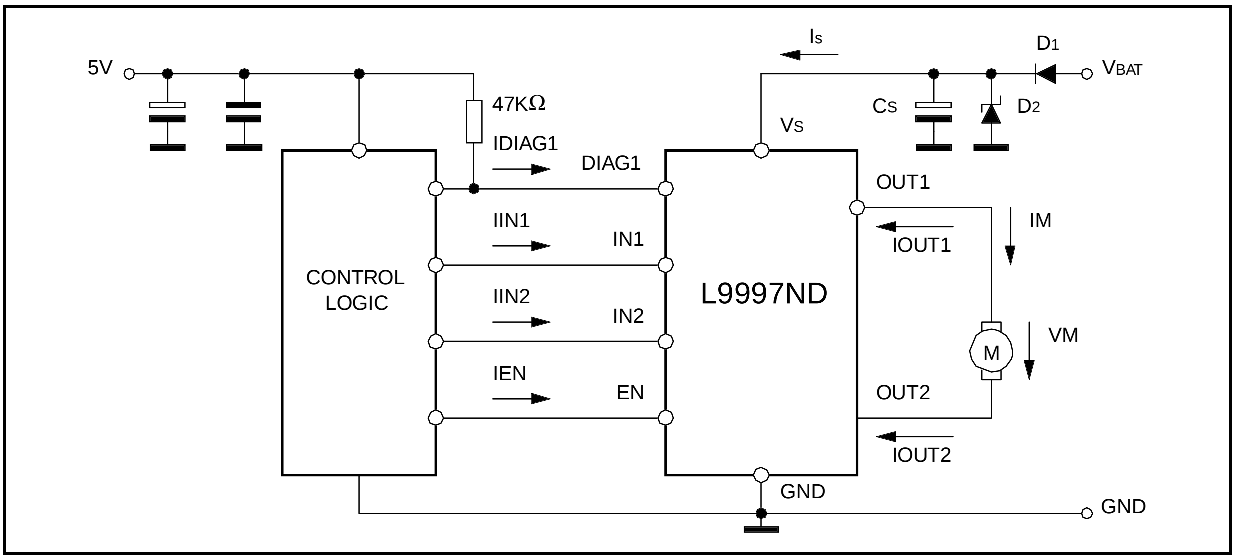


Figure 2. Timing Diagram.

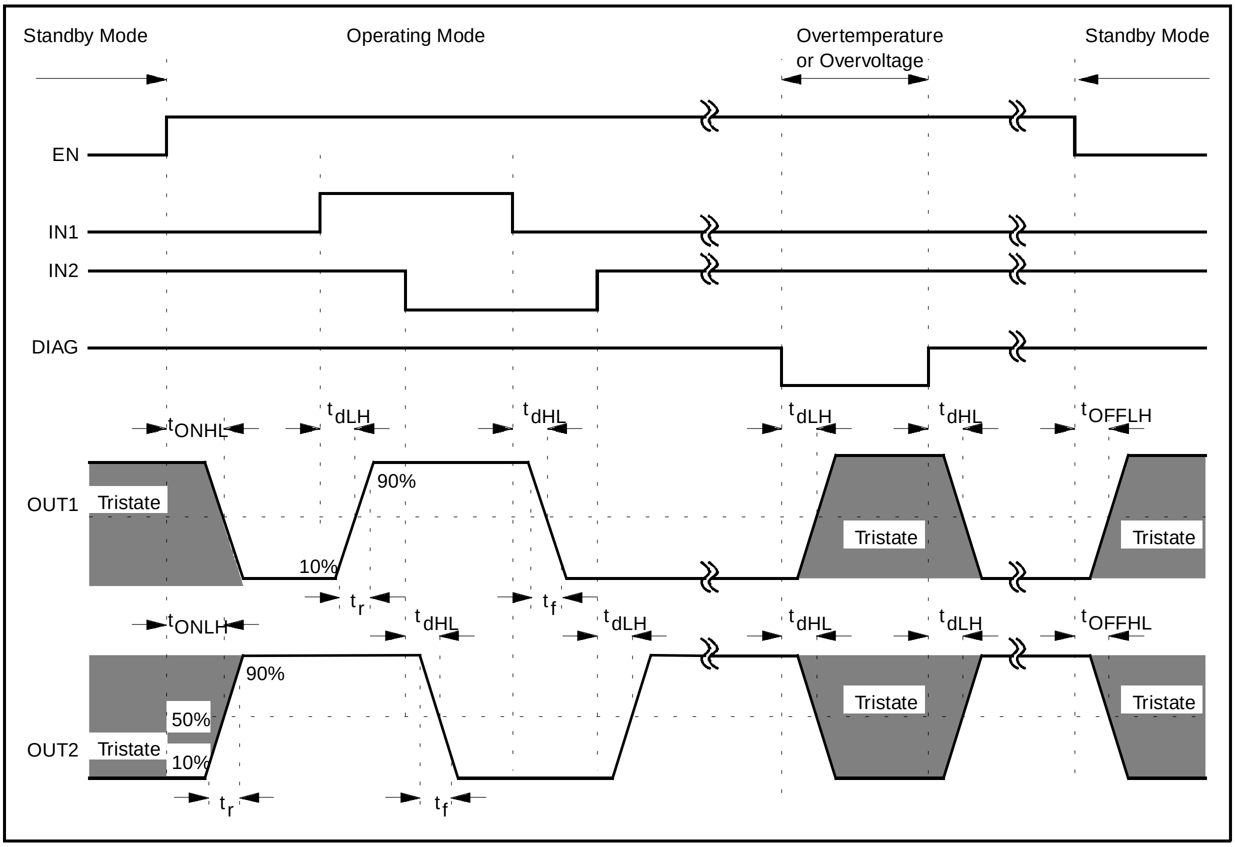


Figure 3. Typical R_{ON} - Characteristics of Source and Sink Stage

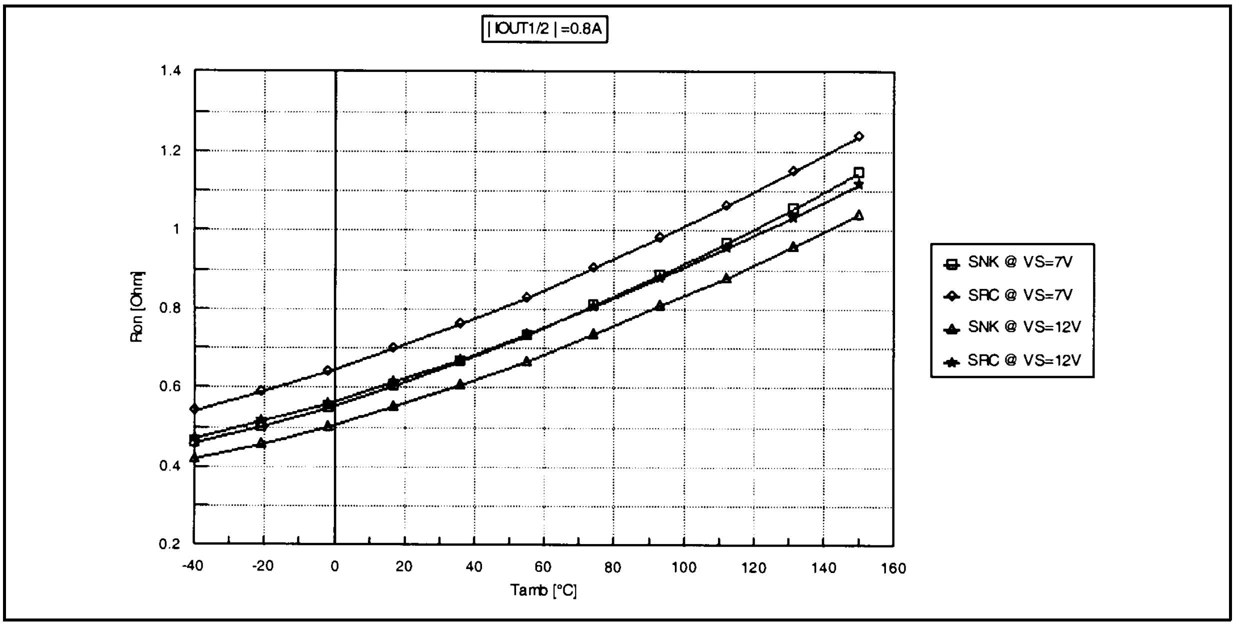


Figure 4. Quiescent current in standby mode versus supply voltage.

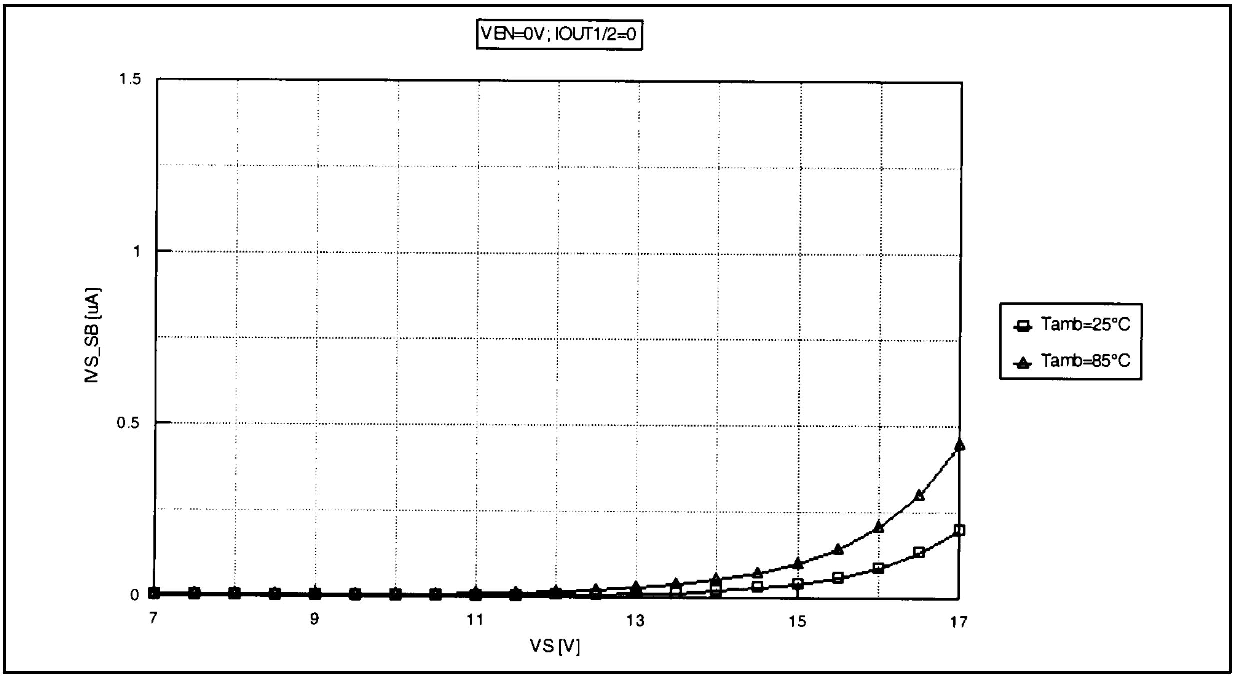


Figure 5. ON-Resistance versus supply voltage.

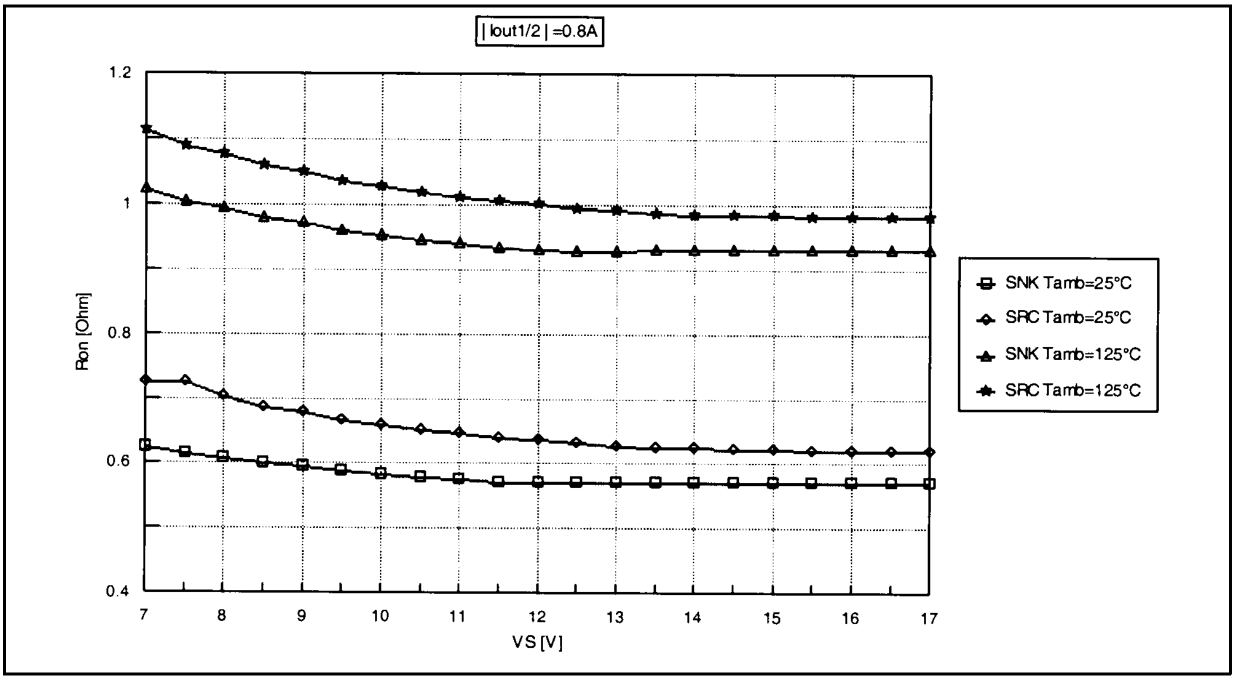


Figure 6. I_{OUT} versus V_{OUT} (pulsed measurement with T_{ON} = 500µs, T_{OFF} = 500ms).

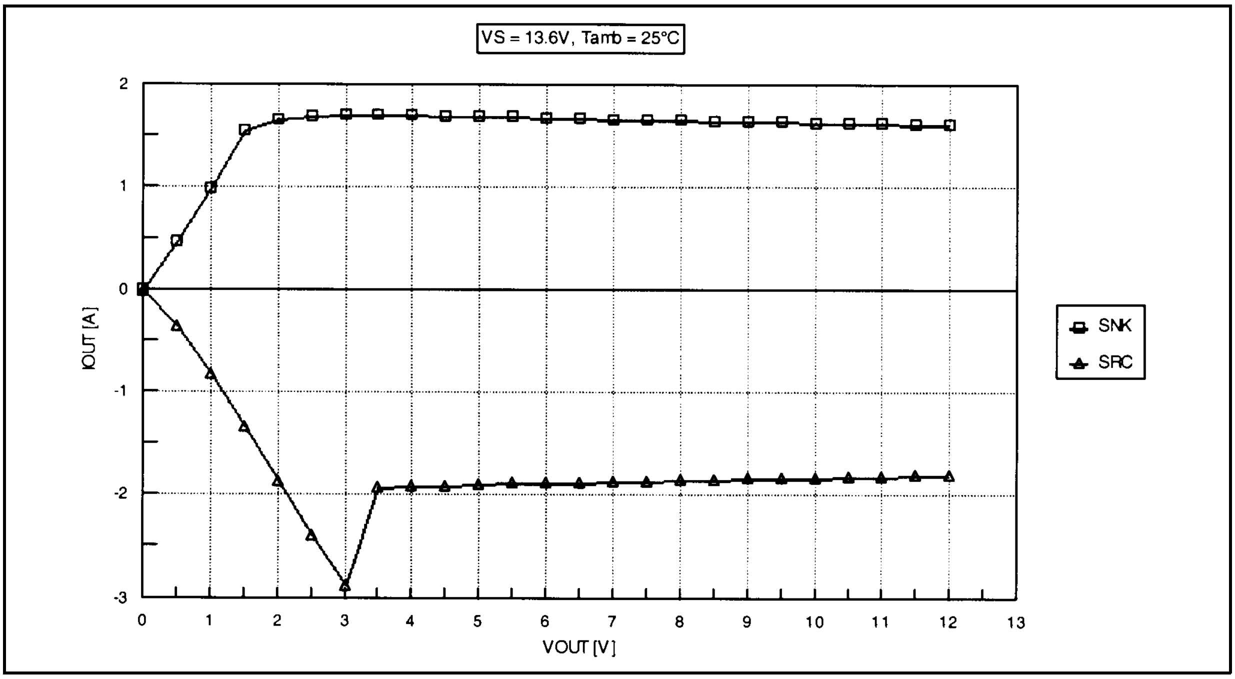
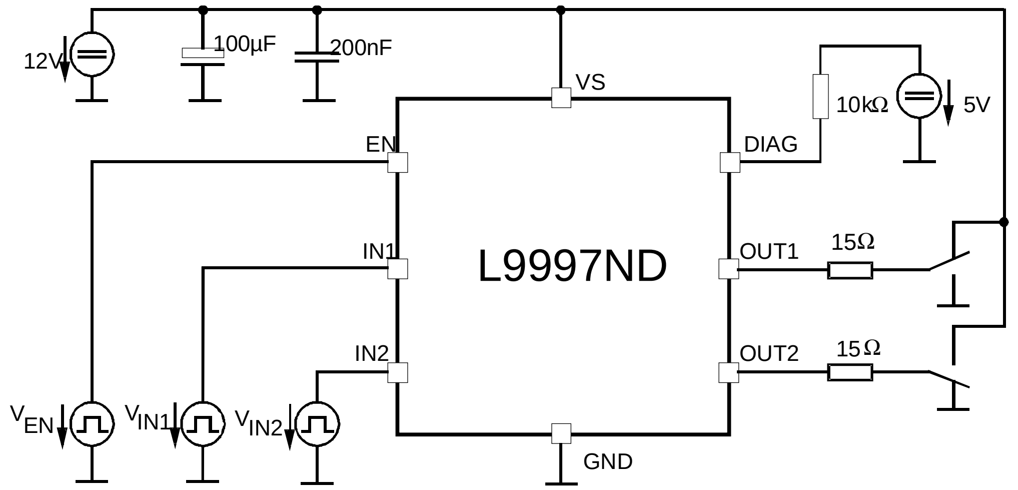
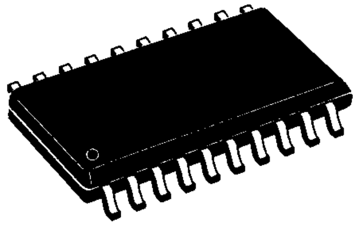


Figure 7. Test circuit.



DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A	2.35		2.65	0.093		0.104
A1	0.1		0.3	0.004		0.012
B	0.33		0.51	0.013		0.020
C	0.23		0.32	0.009		0.013
D	12.6		13	0.496		0.512
E	7.4		7.6	0.291		0.299
e		1.27			0.050	
H	10		10.65	0.394		0.419
h	0.25		0.75	0.010		0.030
L	0.4		1.27	0.016		0.050
K	0° (min.)8° (max.)					

OUTLINE AND MECHANICAL DATA



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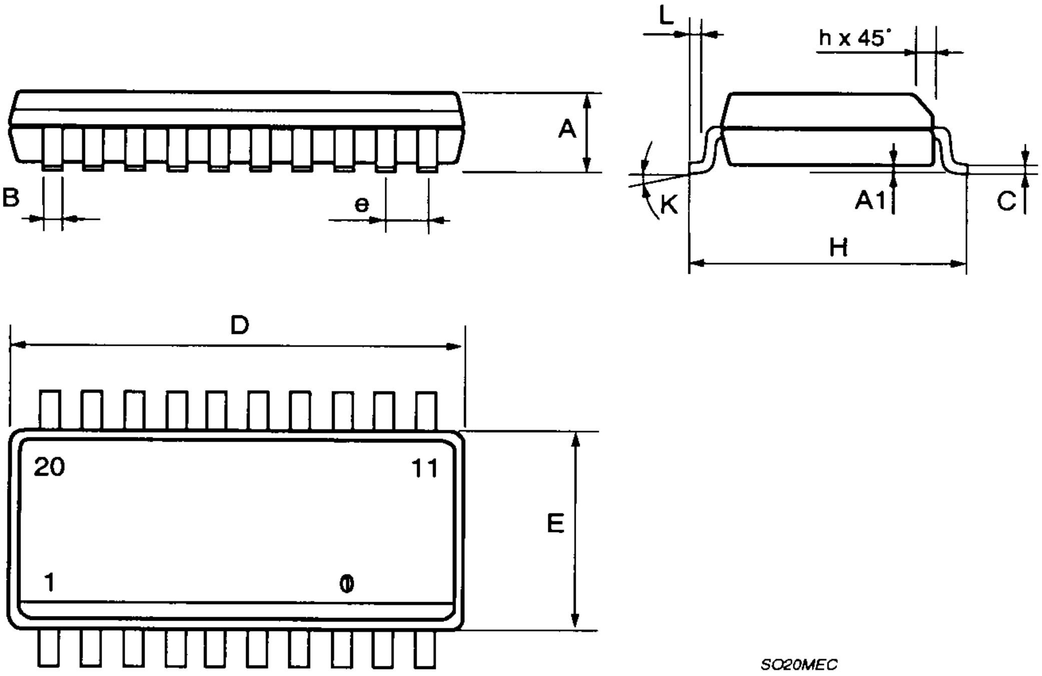

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