# DC Motor Control HAT with TLE94112ES

Complies with the Raspberry Pi HAT specification

## About this document

### Scope and purpose

**This user manual describes the DC motor control HAT equipped with the TLE94112ES, a twelve-fold half-bridge driver with integrated power stages. This document provides detailed information on the board's content, layout and use. It should be used in conjunction with the TLE94112ES datasheet, which contains full technical details on the device specification and operation.**

### Intended audience

**Engineers, hobbyists and students who want to add a powerful motor control to their projects.**

### Related information

**Table 1 Supplementary links and document references**

| Reference | Description |
|---|---|
| **TLE94112ES datasheet** | Product page which contains reference information for the multiple half-bridge driver TLE94112ES |
| **TLE941xy SPI interface** | Application note for the SPI interface of the multiple half-bridge driver family TLE941xy |
| **DC motor HAT with TLE94112ES** | Information page for DC Motor Control HAT with TLE94112ES |
| **Library for TLE94112ES on GitHub** | Software library for TLE94112ES including examples |



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# 1 Introduction

## 1.1 DC Motor Control HAT overview

**The DC Motor Control HAT with TLE94112ES makes it easy to control up to six independent or eleven cascaded bidirectional DC motors.**

**The HAT can be controlled by a compatible Raspberry Pi via the SPI interface of the TLE94112ES.**

**The board features an Infineon TLE94112ES, a twelve-fold half-bridge driver with integrated MOSFETs. Each half-bridge can drive peak currents up to 0.9 A and DC current in the range of 200 mA to 500 mA, depending on the application conditions and the number of activated outputs.**

**The DC Motor Control HAT has an active reverse polarity protection with the p-channel MOSFET IPD50P04P4L-11.**

**The HAT can power the Raspberry Pi using Infineon's OPTIREG™ DC/DC converter TLS4125D0EPV50.**

**The DC Motor Control HAT can be easily connected to a Raspberry Pi via its 40-pin header.**

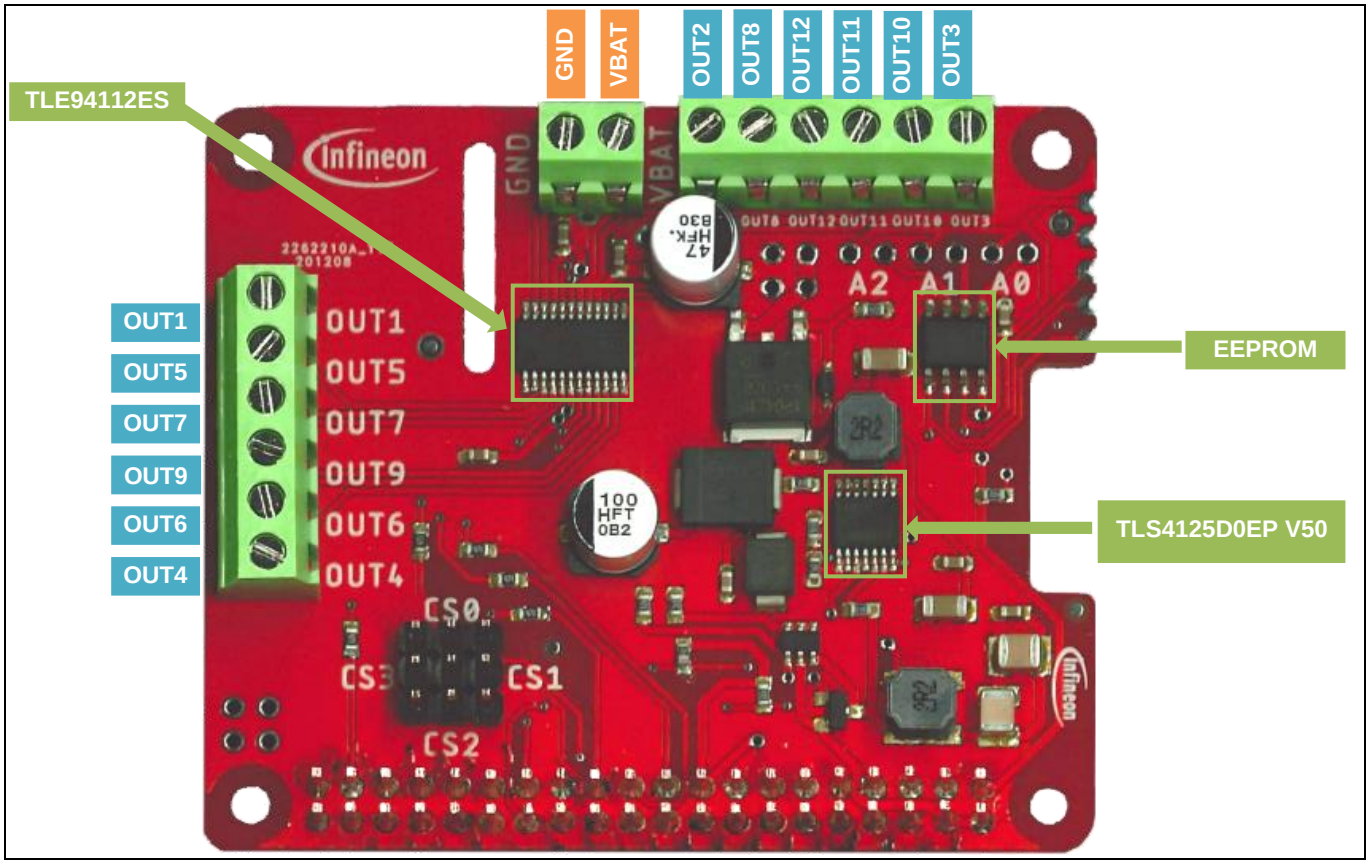



**Figure 1 DC Motor Control HAT with TLE94112ES**



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## 1.2 Key features

**The DC Motor Control HAT has the following features:**

- **Can be controlled by compatible Raspberry Pis:**
  - **1 Mod. A+, 1 Mod. B+, 2 Mod. B, 2 Mod. B v1.2, 3 Mod. A+, 3 Mod. B, 3 Mod. B+, 4 Mod. B**
  - **Zero, Zero W**
- **Brushed DC Motor Control up to 0.9 A peak**
  - **5.5 – 18 V normal operating input voltage**
  - **18 – 20 V extended operating input voltage**
- **Control of:**
  - **Six independent bidirectional DC motors**
  - **Eleven cascaded bidirectional DC motors**
- **SPI interface for high configurability and detailed diagnosis**
- **Protections:**
  - **Overtemperature**
  - **Overcurrent**
  - **Undervoltage**
  - **Overvoltage**
- **Detailed diagnosis per MOSFET:**
  - **Individual open load detection**
  - **Individual overcurrent detection**
- **Paralleling outputs for higher current capability (up to 3.6 A)**
- **Motor speed control by PWM**
  - **Three independent PWM generators**
  - **PWM frequency: 80 Hz, 100 Hz or 200 Hz**
  - **8-bit resolution, 0.5% duty cycle steps**
  - **Active freewheeling for lower power dissipation**
- **Multiple HATs can be stacked to control an increased number of motors**
- **Reverse polarity protection with IPD50P04P4L-11**
- **Powering of Raspberry Pi with up to 2.5A with TLS4125D0EPV50**
- **EEPROM containing HAT information**



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## 1.3 Application diagram for bi-directional DC motor applications

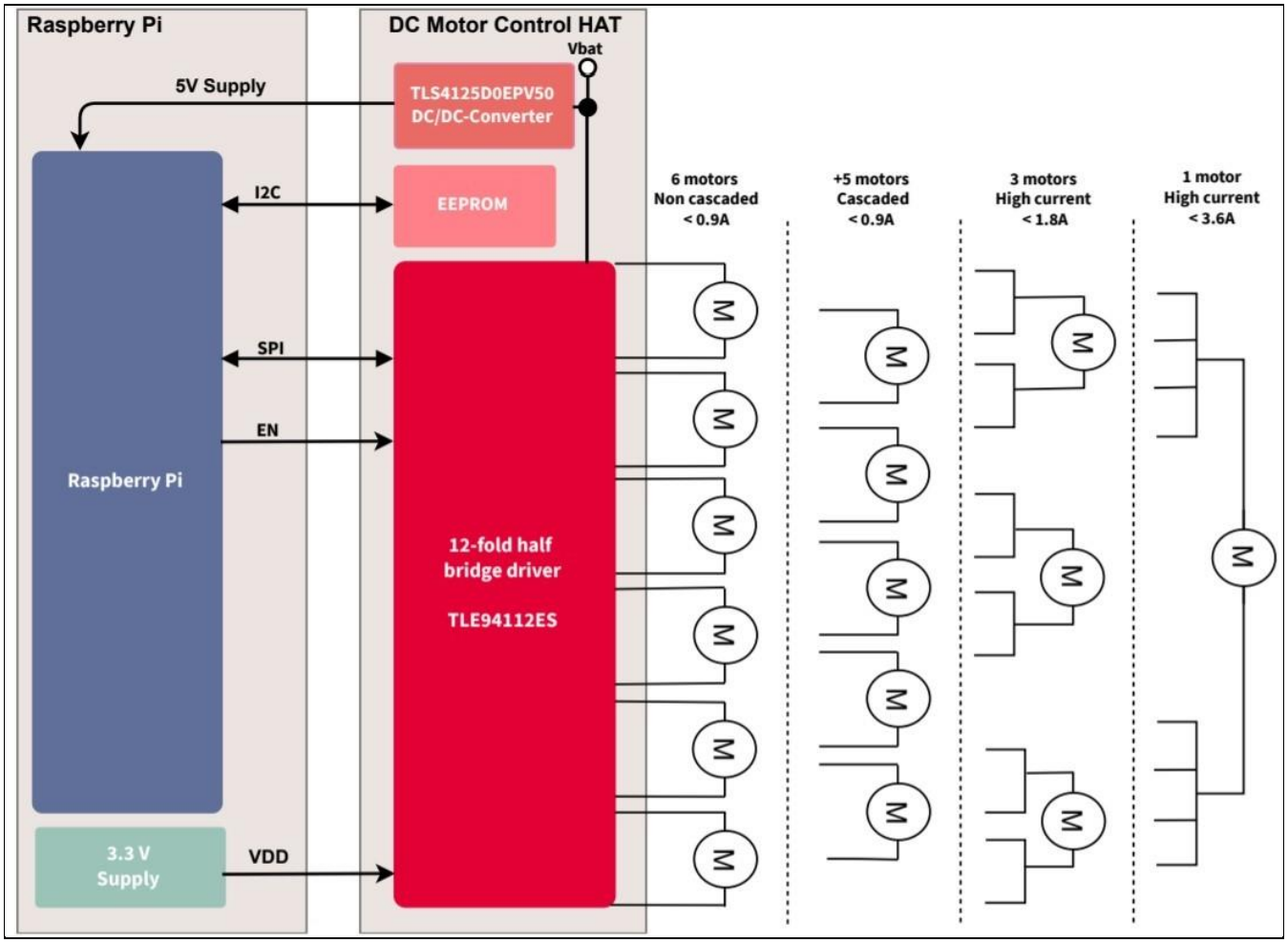



**Figure 2 Simplified application diagram with TLE94112ES driving DC motors**

**Refer to the TLE94112ES datasheet for more information.**



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# 2 DC Motor Control HAT description

**For a safe and optimized motor control design, some discrete components are needed.**

**Figure 4, Figure , Figure  and Figure 7 show the schematics and the corresponding layout of the DC Motor Control Shield with TLE94112ES.**

## 2.1 Overview

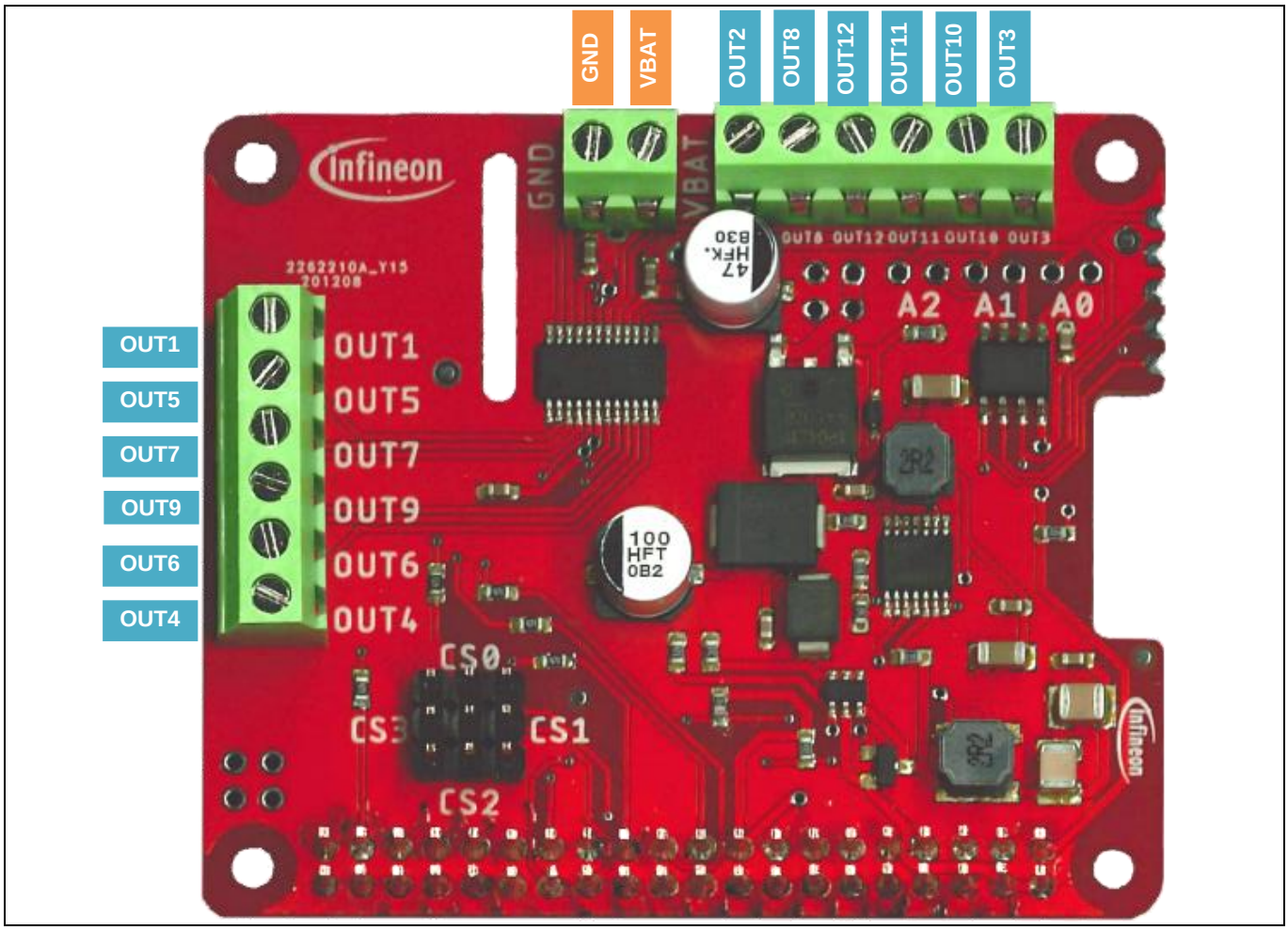



**Figure 3 DC Motor Control HAT connectors**

**TLE94112ES**

The input of the TLE is connected to different capacitors. C11 is there to smooth VCC, the input voltage, C13 to smooth VDD, the 3.3V supply, so glitches do not influence the functionality of the motor driver. C14 and C12 are included to stabilize the input voltage.

**TLS4125**

The DC/DC converter, the TLS4125D0EPV50 is connected to multiple capacitors and inductors on the input and the output side of the chip. C_IN compensates possible drops in the supply voltage. C56 is there to smooth the input voltage, so glitches cannot disturb the functionality of the converter. L_IN combined with C52, C53, C54 and C55 create an EMI filter. This filter protects the TLS against electromagnetic interference. At the output of the chip L_OUT with C58 and C59 are there to support the voltage conversion and C57 is responsible for stabilizing the output voltage.



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## 2.2 Schematics

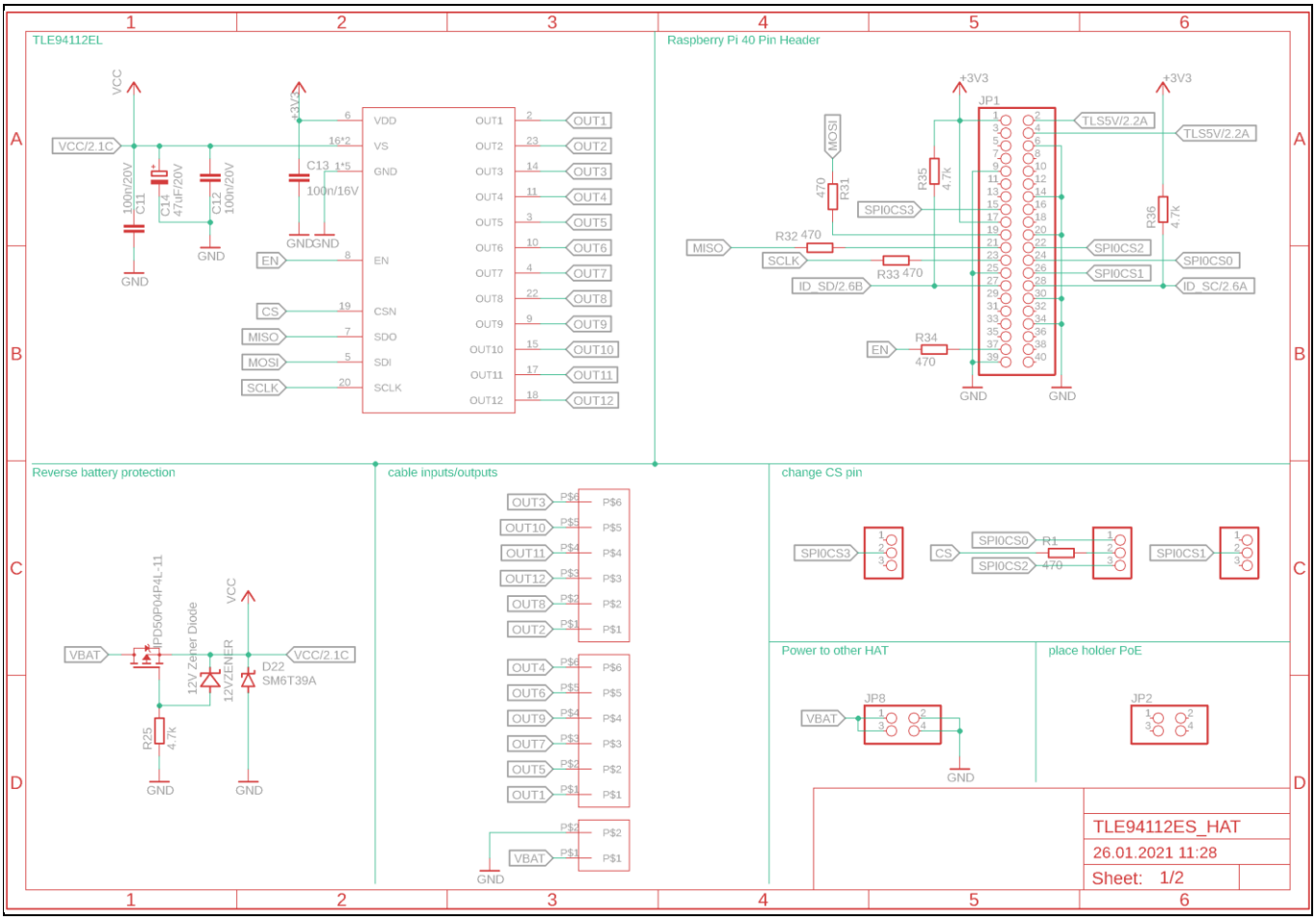



**Figure 4 Schematic Motor Control HAT for Raspberry Pi with TLE94112ES (1/2)**



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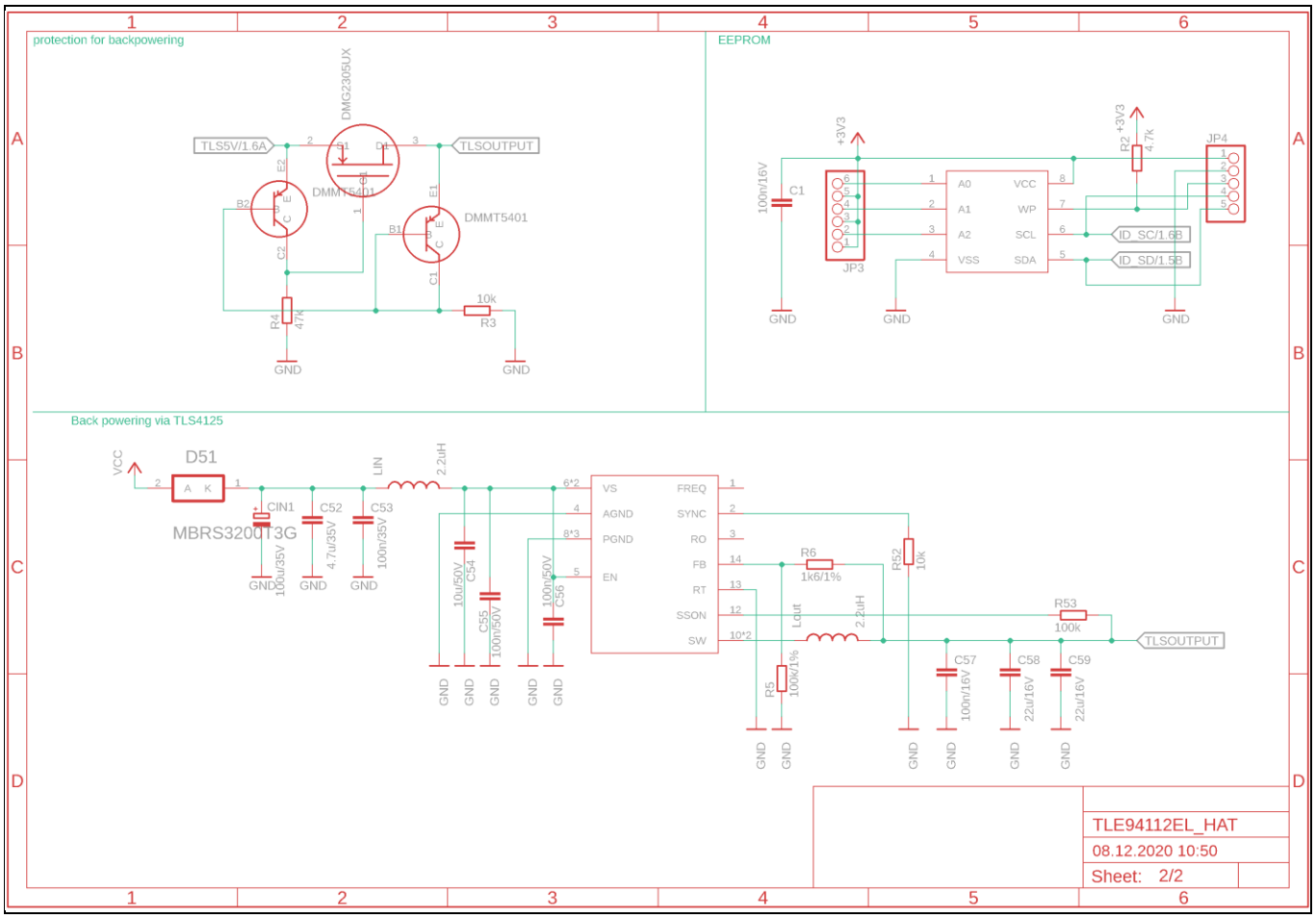



**Figure 5 Schematic DC Motor Control HAT for Raspberry Pi with TLE94112ES (2/2)**

## 2.3 Layout

**Figure 6 and Figure 7 show the layout of the DC Motor Control HAT with TLE94112ES.**

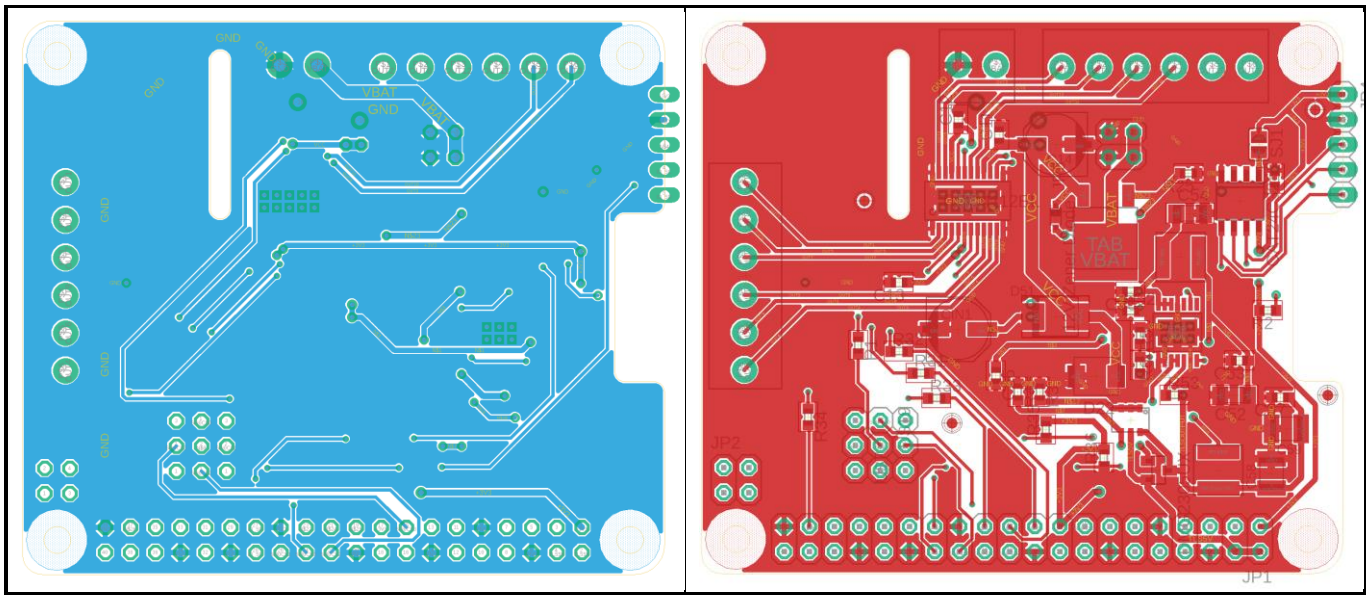



**Figure 6 DC Motor Control HAT – Bottom and top layers**



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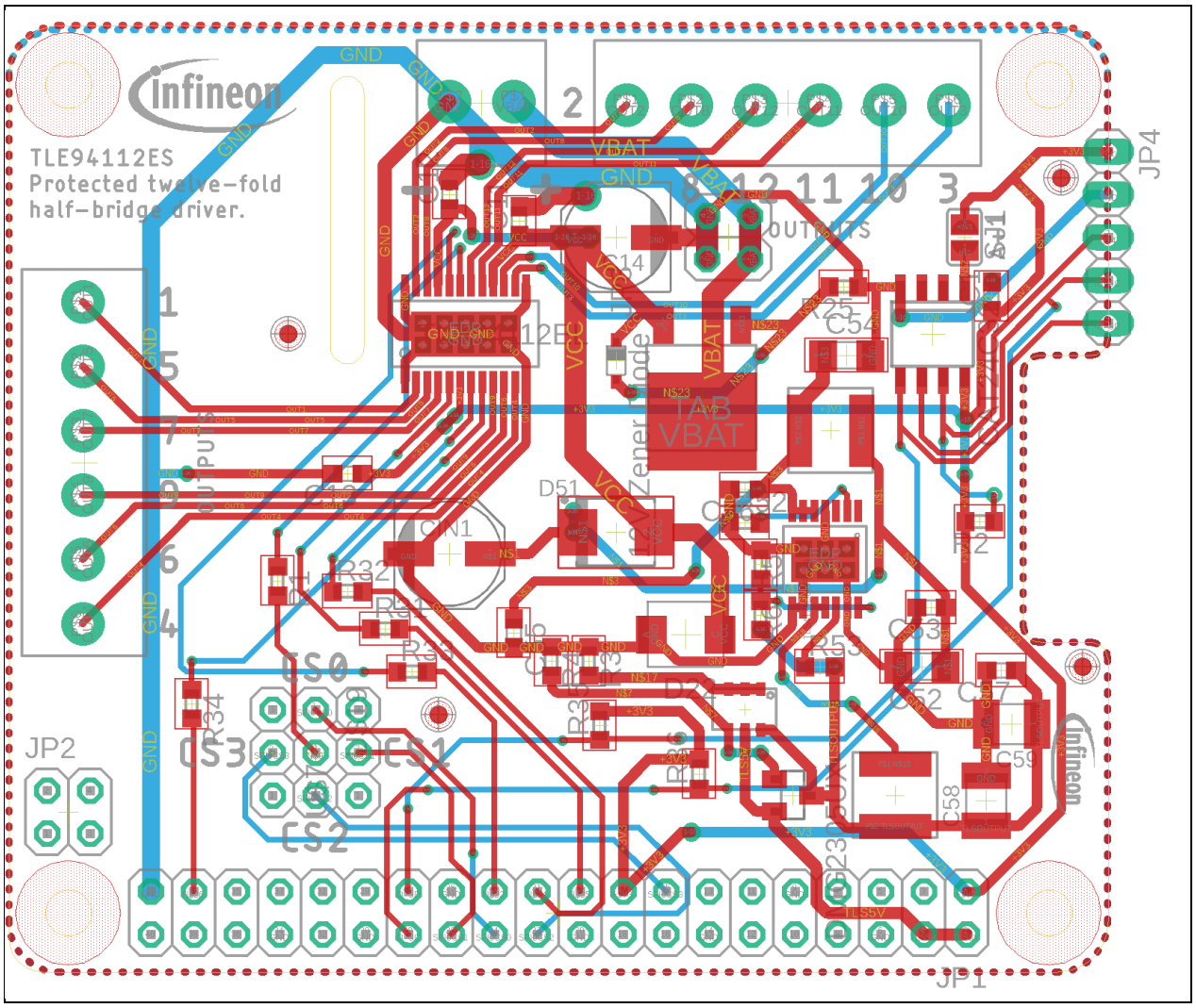



**Figure 7 DC Motor Control HAT for Raspberry Pi with TLE94112ES – Layout**

## 2.4 Bill of Material of the DC Motor Control HAT

| Qty | Value | Device | Package | Parts | Description |
|---|---|---|---|---|---|
| 3 | | PINHD-1X3 | 1X03 | U$7, U$17, U$19 | PIN HEADER |
| 1 | | PINHD-1X5 | 1X05 | JP4 | PIN HEADER |
| 2 | | PINHD-2X2 | 2X02 | JP2, JP8 | PIN HEADER |
| 1 | | PINHD-2X20 | 2X20 | JP1 | PIN HEADER |
| 1 | | SJ | SJ | SJ1 | SMD solder JUMPER |
| 1 | 100k | R-EU_R0603 | R0603 | R53 | RESISTOR, European symbol |
| 1 | 100k/1% | R-EU_R0603 | R0603 | R5 | RESISTOR, European symbol |
| 3 | 100n/16V | C-EUC0603 | C0603 | C1, C13, C57 | CAPACITOR, European symbol |
| 5 | 100n/20V | C-EUC0603 | C0603 | C11, C12, C53, C55, C56 | CAPACITOR, European symbol |



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| | | | | | |
|---|---|---|---|---|---|
| 1 | 100u/20V | CPOL-EUD | PANASONIC_D | CIN1 | POLARIZED CAPACITOR, European symbol |
| 2 | 10k | R-EU_R0603 | R0603 | R3, R52 | RESISTOR, European symbol |
| 1 | 10u/20V | C-EUC1206 | C1206 | C54 | CAPACITOR, European symbol |
| 1 | 12VZENER | 12VZENER | SOD323_ST | D21 | |
| 1 | 1k6/1% | R-EU_R0603 | R0603 | R6 | RESISTOR, European symbol |
| 2 | 22u/16V | C-EUC1210K | C1210K | C58, C59 | CAPACITOR, European symbol |
| 1 | 2PIN-WTB-CONNECTOR | 2PIN-WTB-CONNECTOR | 2PIN-WTB-CONNECTOR | U$8 | |
| 4 | 4.7k | R-EU_R0603 | R0603 | R2, R25, R35, R36 | RESISTOR, European symbol |
| 1 | 4.7u/20V | C-EUC1206 | C1206 | C52 | CAPACITOR, European symbol |
| 5 | 470 | R-EU_R0603 | R0603 | R1, R31, R32, R33, R34 | RESISTOR, European symbol |
| 1 | 47k | R-EU_R0603 | R0603 | R4 | RESISTOR, European symbol |
| 1 | 47uF/20V | CPOL-EUD | PANASONIC_D | C14 | POLARIZED CAPACITOR, European symbol |
| 2 | 6PIN-WTB-CONNECTOR | 6PIN-WTB-CONNECTOR | 6PIN-WTB-CONNECTOR | U$10, WTB1 | |
| 1 | CAT24C32 | CAT24C32 | SOIC8 | U$2 | |
| 1 | IPD50P04P4L-11 | IPD50P04P4L-11 | PG-TO252-3-313 | U$6 | |
| 1 | MBRS320T3G - 20V PEAK | ON_SEMICONDUCTOR_MBRS3200T3GON_SEMICONDUCTOR_MBRS3200T3G_0_0 | ON_SEMICONDUCTOR_MBRS3200T3G_0 | D51 | ONSC-D-K1A2-2_A |
| 1 | DMG2305UX | DMG2305UX | SOT23 | U$9 | |
| 1 | DMMT5401 | DMMT5401 | SOT26 | U$11 | |
| 1 | SM6T39A | SUPPRESSOR-SMBJ | SMBJ | D22 | Suppressor diode |
| 1 | TLE94112ES | TLE94112ES | SSOP24 | U$1 | |
| 1 | TLS4125D0EPV50 | TLS4125D0EPV50 | TSDSO-14 | U$3 | |
| 2 | TYS50402R2N-10 | TYS50402R2N-10 | 5040 | U$4, U$5 | |

**Figure 8 DC Motor Control HAT with TLE94112ES – Bill of Material (BOM)**



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## 2.5 CS Pin Selection

**The GPIO 8 (CS0) of the Raspberry Pi is used by default to control the CS (Chip Select) input of the TLE94112ES (Figure 9).**

**Alternatively, GPIO 7 (CS1), GPIO 22 (CS2) or GPIO 25 (CS3) of the Raspberry Pi can be used instead to stack multiple HATs (refer to section 2.8). In this case, the jumper on the Pinheader can be changed to the matching CS pin (Figure ).**

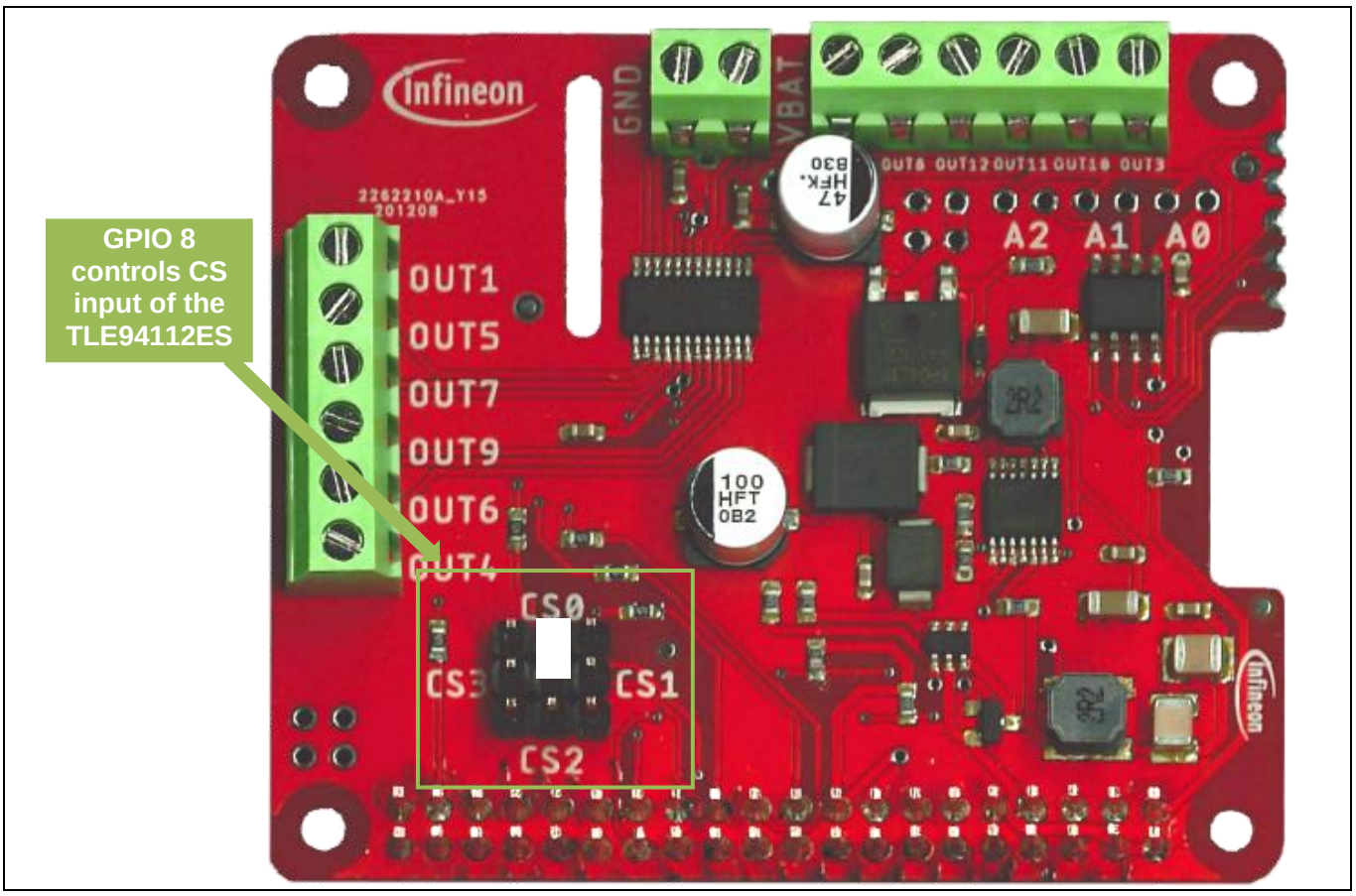



**Figure 9 Control of CSN of TLE94112ES by GPIO 8 (CS0)**



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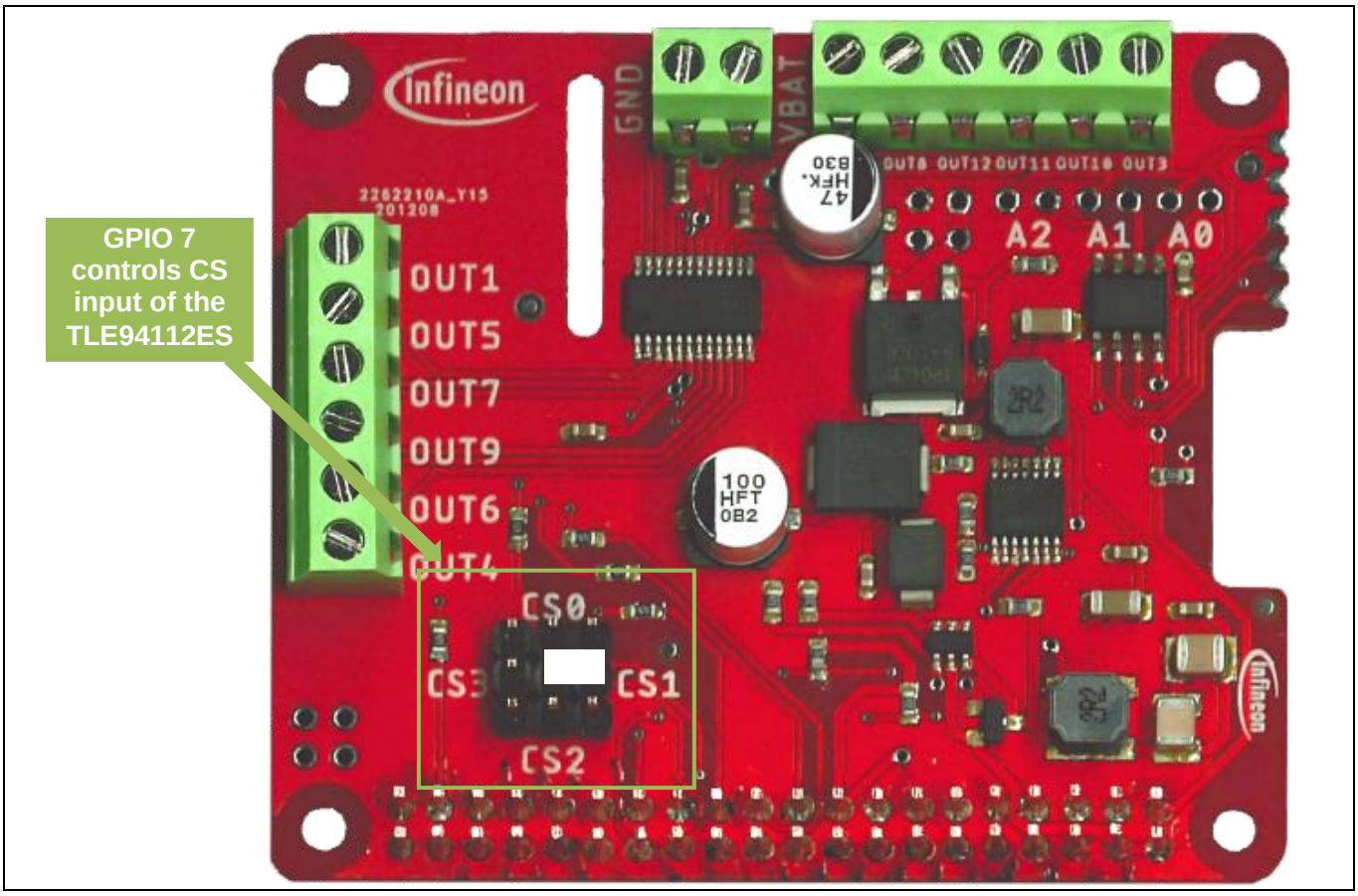



**Figure 10 Control of CS of TLE94112ES by GPIO 7 (CS1)**

## 2.6 EEPROM

**The DC Motor Control HAT also contains an Electrically Erasable Programmable Read-Only Memory (EEPROM). It allows the Raspberry Pi firmware to automatically load the necessary drivers for the HAT. The CAT24C32 communicates via I2C on ID_SD (GPIO 27) and ID_SC (GPIO 28) with the Raspberry Pi.**

**If another HAT with an EEPROM is used concurrently with the DC Motor Control HAT, the address of the EEPROM can be adjusted by closing the solder bridge marked with A+1. If the pin is left open, the I2C address is 0x50 and if the bridge is closed it is 0x51.**

## 2.7 Back-Powering

**This HAT is able to supply the Raspberry Pi (up to 12.5 W) via its input voltage. The input voltage (recommended 12V) is converted to 5V and maximum 2.5A by the DC/DC converter TLS4125D0EPV50 from Infineon. The output of the chip is connected to the 5V pins of the Raspberry Pi. Consequently the power supply unit of the Raspberry Pi is not necessarily needed. In case the Raspberry Pi is powered separately, the TLS is protected against voltage collision by a p-channel MOSFET and a transistor array.**

## 2.8 Stacking multiple DC Motor Control HATs

**It is possible to stack multiple DC Motor Control HATs to increase the number of controlled motors.**

**In this configuration, the CS input of each TLE94112ES must be controlled individually by different microcontroller GPIOs:**

- **The TLE94112ES of one DC Motor Control HAT is controlled by GPIO 8 (default setting, Figure ).**



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- **The TLE94112ES of the other DC Motor Control HAT is controlled by GPIO 7 (Figure ).**

**The combination with different HATs is possible in general, but compatibility depends on pin usage and bus addresses and cannot be guaranteed for every HAT.**

## 2.9 Pin assignment

**To use the DC Motor Control HAT, the necessary control signals can be applied directly at the Raspberry Pi connectors.**

**Figure  shows the pinout/connectors of the DC Motor Control HAT with TLE94112ES.**

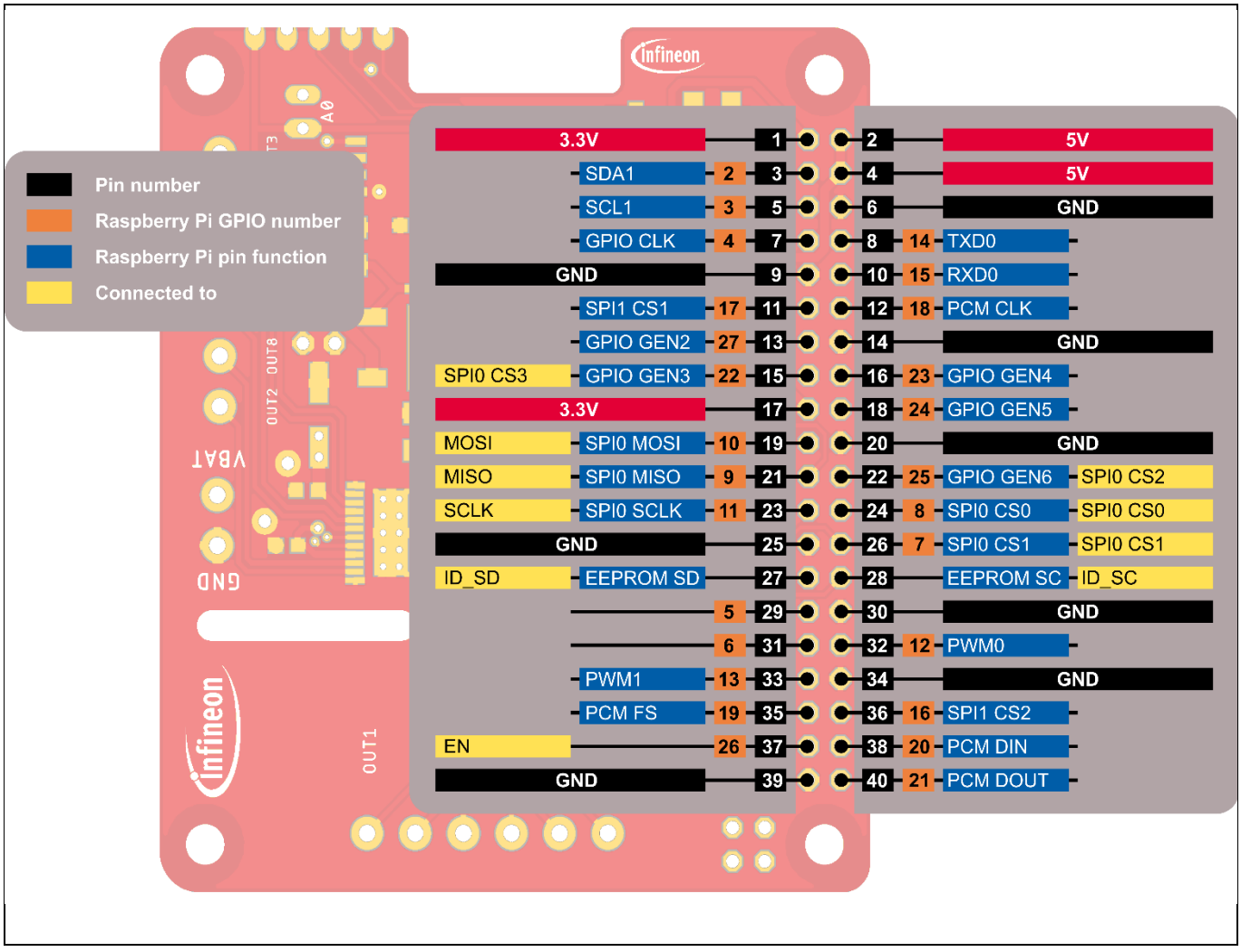



**Figure 13 Connectors of DC Motor Control HAT**



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## 2.10 Pin definitions and functions

| Pin | I/O [1] | Function |
|---|---|---|
| GND | - | **GND**<br>**Common 0V reference for all components on the DC Motor Control HAT.** |
| VBAT | - | **Battery supply (5.5 – 18V normal, 18-20V extended)**<br>Connected to the battery voltage of the HAT |
| VDD | - | Logic supply (3.3V from Raspberry Pi) |
| VCC | - | Supply for Backpowering (5V for Raspberry) |
| SCLK | I | Serial Clock Input [2] |
| MOSI | I | Master Output Slave Input [2] |
| MISO | O | Master Input Slave Output [2] |
| CS0 | I | Chip Select 0 [2, Error! Bookmark not defined.] |
| CS1 | I | Chip Select 1 [2, Error! Bookmark not defined.] |
| CS2 | I | Chip Select 2 [2, Error! Bookmark not defined.] |
| CS3 | I | Chip Select 3 [2, Error! Bookmark not defined.] |
| EN | I | **Enable Input**<br>Connected to GPIO 26 of the Raspberry Pi. When set to low device goes in sleep mode with low current consumption. |
| OUT1-12 | O | Connectors for outputs of the half-bridges 1-12 |
| ID_SD | I | Connected to the EEPROM |
| ID_SC | I | Connected to the EEPROM |

**[1] With respect to the TLE94112ES**

**[2] Connected to the SPI interface of the Raspberry Pi**

**[3] Refer to chapter 2.5**



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# 3 TLE94112ES overview

The TLE94112ES is a protected twelve-fold half-bridge driver designed especially for automotive motion control applications such as heating, ventilation and air conditioning (HVAC) flap DC motor control. It is part of a larger family offering half-bridge drivers from three outputs to twelve outputs with direct interface or SPI interface.

The half bridge drivers are designed to drive DC motor loads in sequential or parallel operation. Operation modes forward, reverse, brake and high impedance are controlled from a 16-bit SPI interface. It offers diagnosis features such as short circuit, open load, power supply failure and overtemperature detection.

In combination with its low quiescent current, this device is attractive among others for automotive applications. The small fine pitch exposed pad package, PG-TSDSO-24, provides a good thermal performance and reduces PCB-board space and costs.

## 3.1 Key features of the TLE94112ES

- Twelve half-bridge power outputs
- Optimized EMC behavior
- Very low power consumption in sleep mode
- 3.3V / 5V compatible inputs with hysteresis
- All outputs with overload and short circuit protection
- Independently diagnosable outputs (overcurrent, open load)
- Open load diagnostics in ON-state for all high-side and low-side
- Outputs with selectable open load thresholds (HS1, HS2)
- 16-bit Standard SPI interface with daisy chain and in-frame response capability for control and diagnosis
- Fast diagnosis with the global error flag
- PWM capable outputs for frequencies 80Hz, 100Hz and 200Hz with 8-bit duty cycle resolution
- Overtemperature pre-warning and protection
- Over- and Undervoltage lockout
- Cross-current protection
- AEC-100 Qualified

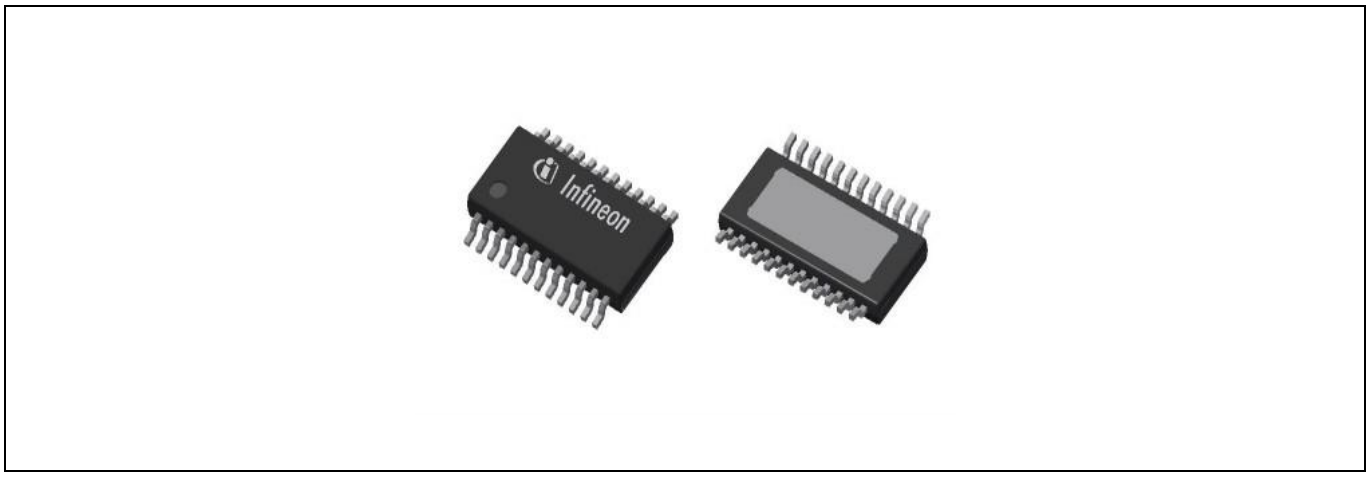



**Figure 14 PG-TSDSO-24 Package**



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## 3.2 Block diagram

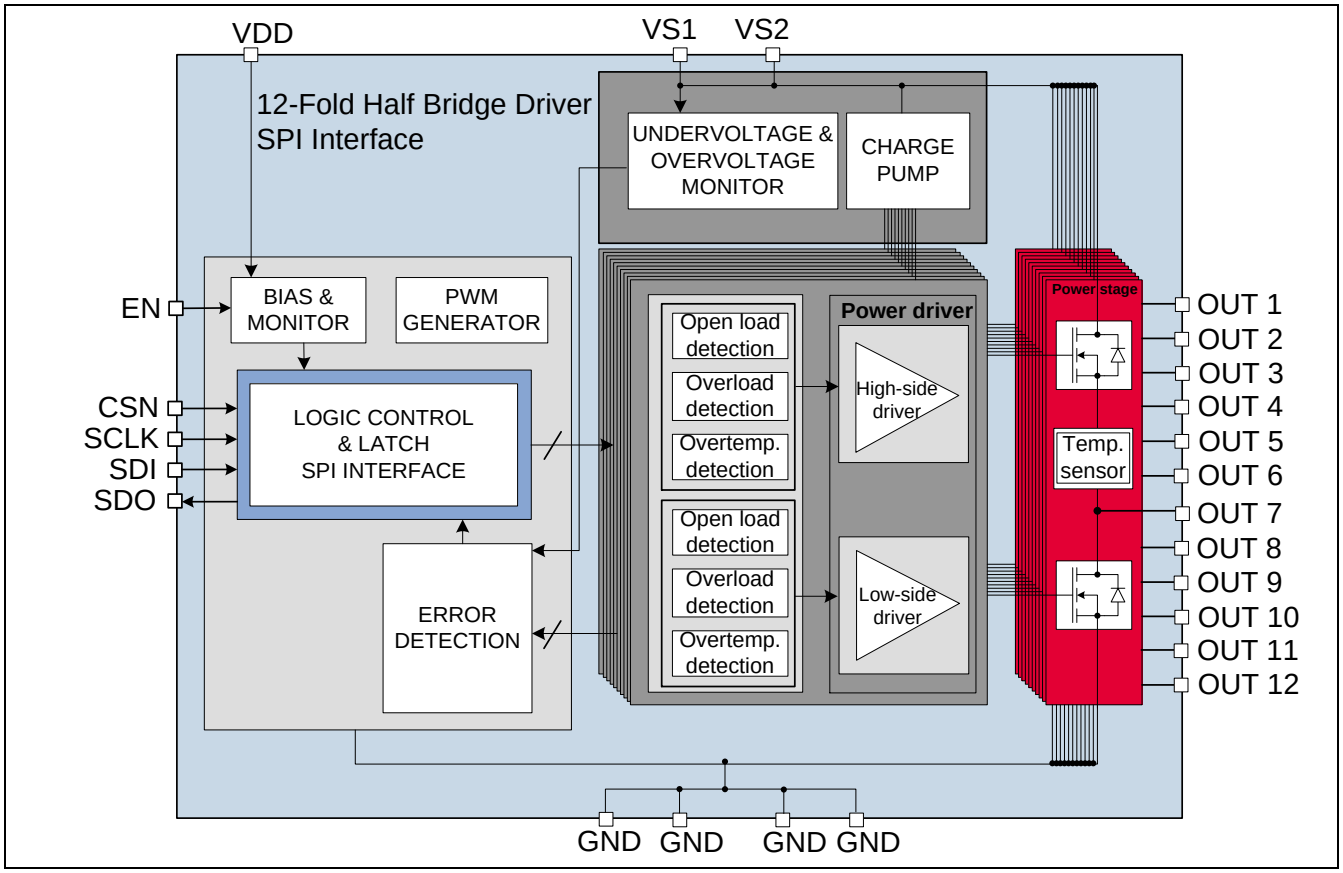



**Figure 15 Block diagram TLE94112ES**



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## 3.3 Pin assignment

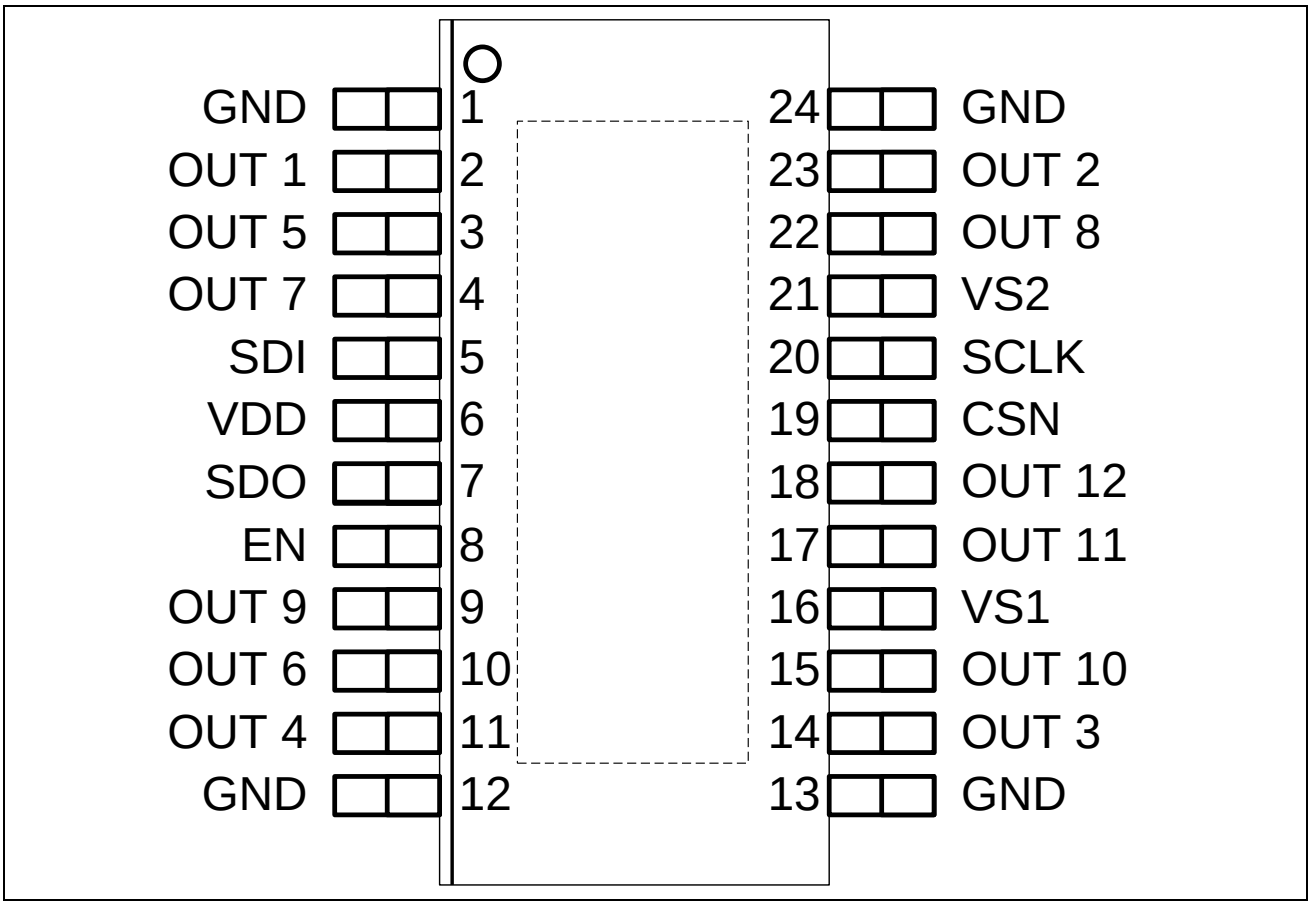



**Figure 16 Pin assignment TLE94112ES (top view)**



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## 3.4 Pin definitions and functions

| Pin | Symbol | Function |
|---|---|---|
| 1 | GND | Ground. All ground pins should be externally connected together. |
| 2 | OUT 1 | Power half-bridge 1 |
| 3 | OUT 5 | Power half-bridge 5 |
| 4 | OUT 7 | Power half-bridge 7 |
| 5 | SDI | Serial data input with internal pull down |
| 6 | VDD | Logic supply voltage |
| 7 | SDO | Serial data output |
| 8 | EN | Enable with internal pull-down; Places device in standby mode by pulling the EN line Low |
| 9 | OUT 9 | Power half-bridge 9 |
| 10 | OUT 6 | Power half-bridge 6 |
| 11 | OUT 4 | Power half-bridge 4 |
| 12 | GND | Ground. All ground pins should be externally connected together. |
| 13 | GND | Ground. All ground pins should be externally connected together. |
| 14 | OUT 3 | Power half-bridge 3 |
| 15 | OUT 10 | Power half-bridge 10 |
| 16 | VS1 | Main supply voltage for power half bridges. VS1 should be externally connected to VS2. |
| 17 | OUT11 | Power half-bridge 11 |
| 18 | OUT12 | Power half-bridge 12 |
| 19 | CSN | Chip select Not input with internal pull up |
| 20 | SCLK | Serial clock input with internal pull down |
| 21 | VS2 | Main supply voltage for power half bridges. VS1 should be externally connected to VS1. |
| 22 | OUT 8 | Power half-bridge 8 |
| 23 | OUT 2 | Power half-bridge 2 |
| 24 | GND | Ground. All ground pins should be externally connected together. |
| EDP | - | Exposed Die Pad; For cooling purpose only - not usable as electrical ground. Electrical ground must be provided by pins 1, 12, 13, 24 |



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# 4 Getting started

**For a quick and easy set up check out the Quick Start Guide available on the website and on github.com/Infineon/multi-half-bridge.**



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# 5 Revision History

**Major changes since the last revision**

| Page or Reference | Description of change |
|---|---|
| V1.0, 2021-03-10 | First release |
| | |
| | |



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