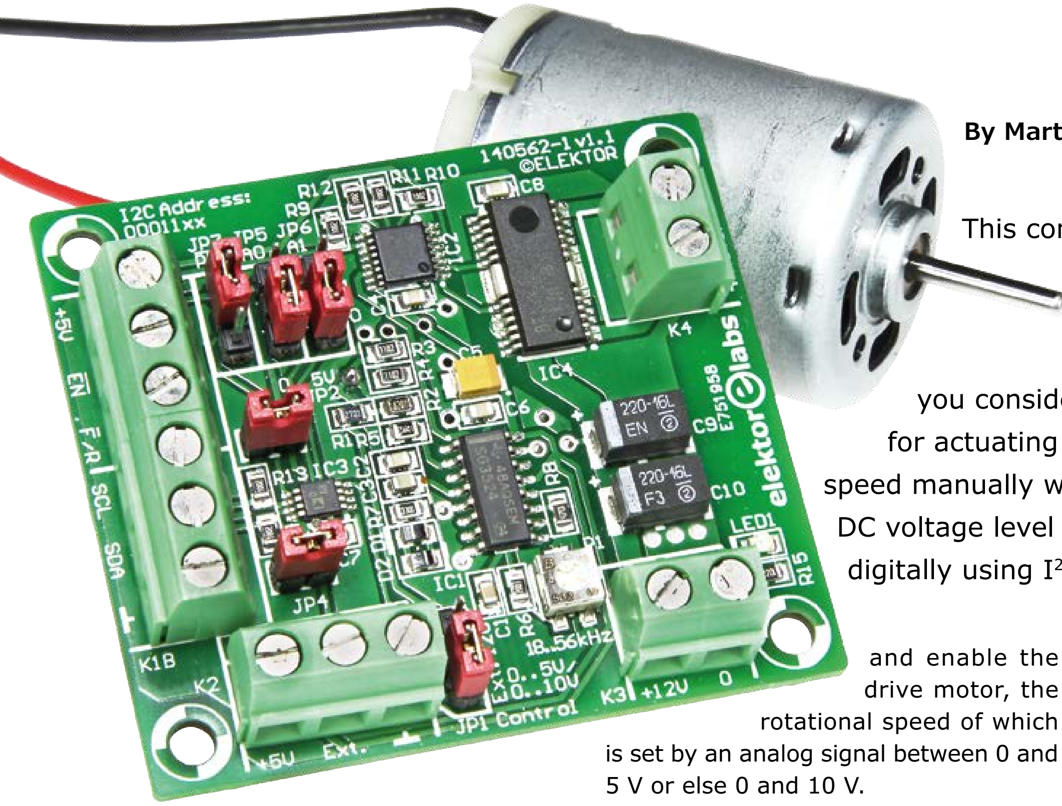
Precision Control for DC Motors

Get the right spin every time!



By Martin Weiss (Germany)

This control circuit will provide the correct rotational speed and direction of a 12-V DC motor. Nothing special in that? But there is definitely, when you consider the multitude of potential options for actuating the motor. You can adjust the speed manually with a potentiometer ('pot'), using a DC voltage level between 0 and 5 (or 10 V) or even digitally using I^{2}C.

In the Department of Fluidics and Aerodynamics at Darmstadt Technical University, Germany, we needed a small circuit for enabling us to calibrate high-sensitivity fluidic sensors using the LabVIEW software from National Instruments (NI). The calibration setup used for this involves actuation by a 12-V drive motor. LabVIEW uses digital signals to specify the rotational direction and enable the drive motor, the rotational speed of which is set by an analog signal between 0 and 5 V or else 0 and 10 V.

National Instruments supply USB modules with analog output signals from 0 to 5 V (inexpensively priced) and from 0 to 10 V (unfortunately not so inexpensively priced!). Naturally controlling the speed of a DC motor using a 0 to 10 V signal is more accurate, but the system also works with the 0 to 5 V signal — admittedly without the same precision but at lower cost. So when we developed this circuit, we kept applications for the NI product line in mind.

The longer we contemplated the design, the more it stuck us that a control circuit of this kind might definitely be useful to many other people too. Plenty of faithful old motor-driven machines and setups could be rendered 'intelligent' thanks to modern software like LabVIEW, enabling motors to be driven to recurring positions as precisely as possible in simple steps.

We now turned to the Elektor team, in order to develop a universally applicable, 'open design' circuit that would also benefit other users. First stipulation was that the circuit should manage with one (single) voltage source of +12 V. Second, it should be provided with a serial I^{2}C interface, so that a microcontroller could be used to drive it. Third, we would round off the circuit with a manual operation feature (using just a pot and two switches) for basic installations not requiring upstream systems such as LabVIEW or microcontrollers.

All things considered…

Let's take a look at the block diagram in **Figure 1**. The three blocks in the middle represent the module that is common to all control modes. For regulating rotational speed we selected the SG3524D pulse width modulator from Texas Instruments [1]. Nowadays we no longer control the speed of DC motors by voltage level but by the duty cycle of a pulse width modulated (PWM) signal. This task is exactly what the SG3524D is designed for; it uses the analog input voltage to produce a corresponding PWM output signal. The optimum PWM frequency for the motor under control can be set (using pot P1) between 18 kHz and 56 kHz. But the SG3524D has another goodie up its sleeve for us: it uses its 12 V operating voltage to generate a reference voltage of +5 V delivering up to 50 mA that we can use to power all of the components on the board that rely on a 5 V supply rail. For the final amplification stage we looked

Characteristics

(Reference voltage = 4.93 V)

- Supply voltage:12 V
- Maximum output current: 2 A
- Minimum supply current: 11.2 mA
- PWM range: 0 – 100 %
- External control voltage:
  - 0.16 V (PWM 0 %, 0/5 V range)
  - 4.88 V (PWM 100 %, 0/5 V range)
  - 0.27 V (PWM 0 %, 0/10 V range)
  - 9.7 V (PWM 100 %, 0/10 V range)
- Input impedance (Pin 2 of K2):
  - 6.43 kΩ (0/5 V range)
  - 15.36 kΩ (0/10 V range)

About the Author

A state certified technician, Martin Weiss is employed in the Fluidics and Aerodynamics Department of Darmstadt Technical University. The main focus of his work concerns the hardware-based connectivity between various systems and components used for measurement and control technology in the Department's own test rigs. Individual bespoke solutions (electronic circuits) are developed by Martin and implemented for the particular application.
E-Mail: martinweiss-elektronik@gmx.de

around for an H bridge circuit for motors using brushes, whose rotational direction can be set (and reversed) according to user needs with relative simplicity. We settled for a product manufactured by Rohm, the BD6222 [2], whose benchmark data, supply voltage of up to 18 V and output current of up to 2 A will suffice for many types of motor. The frequency range from 20 to 100 kHz is also adequate for our PWM signal (although PWM frequencies from 18 to 20 kHz should be avoided). The bridge driver also features under-voltage lockout (U_{VLO}), over-voltage protection (OVP), over-temperature shutdown (TSD) and current overload protection.

A 74HC4053 triple analog switch is connected between the PWM modulator and the final stage. According to the state of what's on the $\overline{\text{F}}$/R input the 74HC4053 alters the PWM signal on the driver inputs. With a logical zero on the $\overline{\text{F}}$/R input the motor turns forwards; with logical 1, it goes backwards. And there's something else the 74HC4053 can do. When the $\overline{\text{EN}}$ input is not enabled, both switch outputs are high-impedance (with two pull-up resistors taking the inputs of the driver device High). The driver device recognizes this and brakes the motor rapidly. Now for the block at lower left, which we have completely ignored up to now. It contains an AD5301 digital-to-analog converter from Analog Devices [3], which transforms the I²C data into an analog voltage in the range 0 to 5 V. This DAC resolves the signal to 8 Bits but you can substitute the pin-compatible 10-Bit variant AD5311 or the 12-Bitter AD5321, according to your precision requirements and choice of microcontroller. A jumper (JP1) is used to determine whether the analog voltage fed to the PWM modulator is to be taken from the terminal block K2 or from the D-to-A converter.
The block diagram also shows the options for connecting for the Forward/Reverse signal $\overline{\text{F}}$/R and the Enable signal $\overline{\text{EN}}$ (K1A), the I²C signal (K1B), the analog rotational speed voltage (K2), the 12 V power supply (K3) and the motor (K4). To the left of this are the four actuation options: using I²C, using an analog voltage from 0 to 5 V or 0 to 10 V as appropriate or else manually using a pot and switches.

... and in detail

The schematic in **Figure 2** looks hardly any more complex than the block diagram, although some details are actually quite tricky. For the two control voltages 0 to 5 V and 0 to 10 V you would really expect a simple voltage divider with two resistors at the input of the SG3542D PWM modulator. That's not feasible, however, as the permissible control voltage range on Pin 2 is from about 0.74 V up to 3.58 V. We must therefore apply an offset if the PWM signal is to vary actually between 0 and 100 %. And naturally this offset is different for the two control voltage ranges. Instead of wasting space with two jumpers, we opted on the PCB layout for a 3-way pinheader JP2 that is left open for 0 to 10 V and is closed with a deliberately made solder blob for 0 to 5 V, so that it shunts (bypasses) the two resistors R2 and R4 to make them ineffective. In combination with the setting of the (real) jumper JP1 we can select four actuation modes, as **Table 1** shows.
The second circuitry trick concerns switching the pulse width modulation signal between either the FIN or the RIN pin of the motor driver. An Enable signal $\overline{\text{EN}}$ prevents the motor turning at all in either direction. If $\overline{\text{EN}}$ is logical 1, the outputs of the analog switch are made high-impedance and the inputs FIN and RIN of

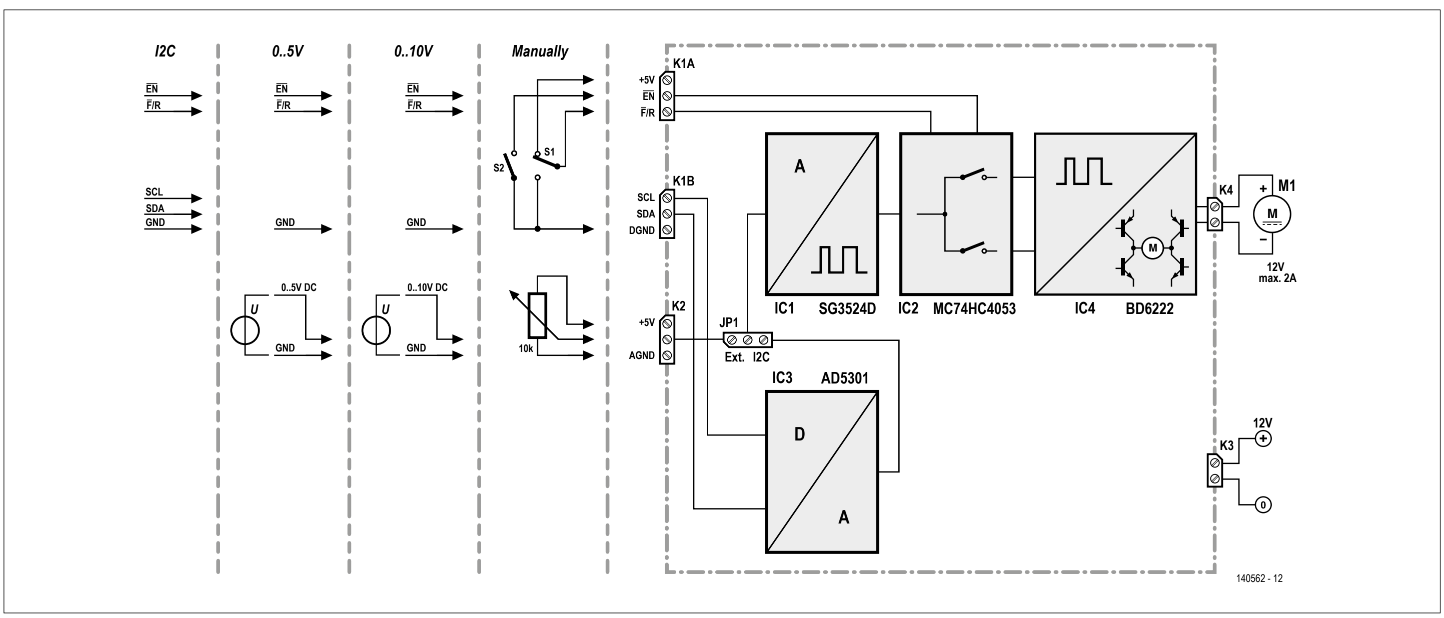
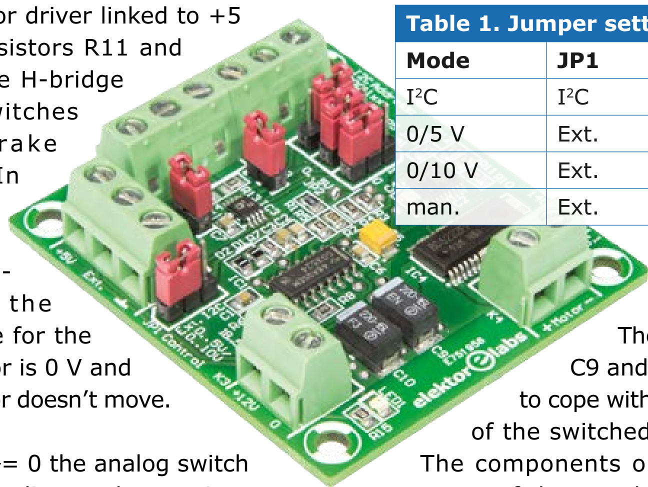


Figure 1. Simplified block diagram of the motor control device with all actuation options.

the motor driver linked to +5 V via resistors R11 and R12. The H-bridge then switches into Brake mode. In Brake mode the output of the H-bridge for the DC motor is 0 V and the motor doesn't move.



With $\overline{\text{EN}}$ = 0 the analog switch corresponding to the settings on the $\overline{\text{F}}$/R input determining forward or reverse direction and the rotational speed of the motor is conveyed using the analog voltage. If the $\overline{\text{EN}}$ input at K1A is open, pull-up resistor R10 prevents any unintended start of the motor. If you wish to start up the motor gently, this must be handled upstream in the system. Resistors R9 and R10 (and the connections to the unused elements of the analog switches) prevent open (floating) connections occurring when nothing at all is connected to K1A.
At lower left you can see a number of decoupling capacitors for the (stabilized) 12 V supply voltage, along with power indicator LED1. The two electrolytics C9 and C10 are well able to cope with the high currents of the switched H-bridge driver.
The components on the ILIM input are part of the standard wiring for the current-limiting amplifier located in the SG3524D.

Table 1. Jumper settings

Mode	JP1	JP2
I²C	I²C	closed
0/5 V	Ext.	closed
0/10 V	Ext.	open
man.	Ext.	closed

The I²C interface

Pull-up resistors R13 and R14 are connected to the two I²C wires SDA and SCL, which are activated using jumpers JP3 and JP4. Of course these are necessary only when no pull-up resistors of this kind are provided on the I²C Bus of the actuating system. The address of the D-to-A converter can be selected between 0001100 and 0001111 with the help of the two jumpers JP5 and JP6. In this way four DC motors can be controlled independently with one I²C Bus.

The D-to-A converter is permanently enabled when the circuit is powered up. Its current consumption is admittedly only 150 µA but you can reduce this further to as low as 200 nA using three power-down modes. Using a serial data command you can select the defined output resistance of the 'switched-off' voltage outputs to either 1 kΩ, 100 kΩ or tri-state (high impedance). With safety-critical applications, in which no actuation voltage for the PWM modulation is permissible at the input of the SG3524, the variant with 1 kΩ output resistance to GND is recommended. If you wish to use software-based configuration, the $\overline{\text{PD}}$ jumper JP7 must be plugged in the 0 position; otherwise set the jumper in position 1.
The output voltage of the DAC is practically the same as the supply voltage. With a reference voltage from the PWM modulator of 4.934 V the maximum output voltage of the AD5301 amounts to 4.898 V, only 36 mV less. The minimum voltage we measured was 9.28 mV on one of the first prototypes.

Construction and commissioning

In order to keep the size of the PCB (available from the Elektor Store [4]) compact, we specified mainly SMD components (that's just an excuse really;

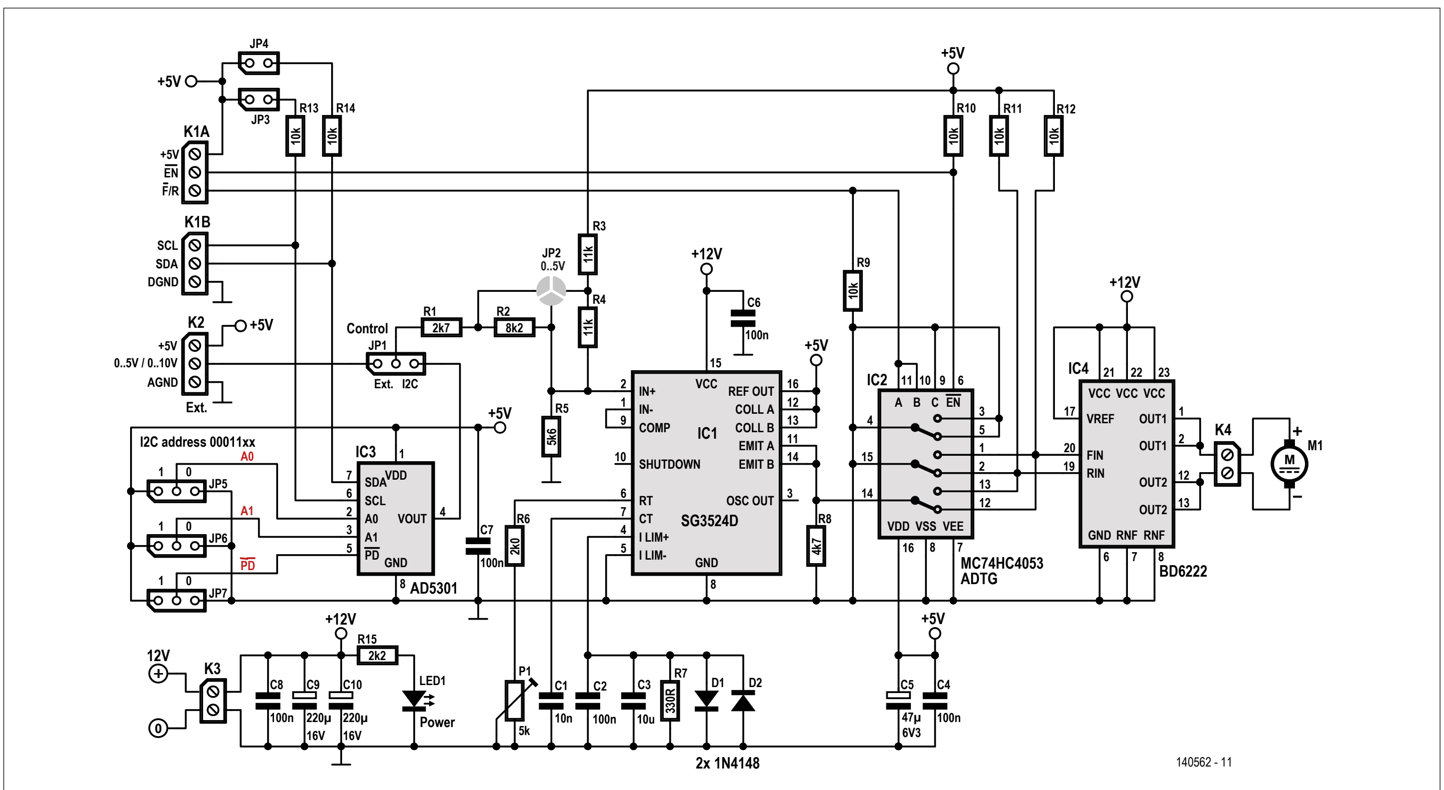


Figure 2. Schematic of the motor control device.

most of the ICs are available only in this subminiature format in any case). Only the five screw-terminal blocks and the six jumpers are soldered into holes and these occupy the bulk of the just 56.5 x 50.2 mm^2 surface of the miniature PCB. You can in fact substitute a wire bridge for jumper JP1 if you do not plan to alter the actuation mode and omit the remaining jumpers altogether if you can manage without I²C control.

Despite all the SMDs, skilled constructors should have no difficulty building this circuit if they keep the placement plan in **Figure 3** and the numbered component list handy. Following construction and a visual check, you can test the circuit without the burden of programming and/or providing additional voltage sources if you hook up a pot (10 to 100 kΩ) and two switches, in line with the manual actuation scheme in Figure 1.

Important warning: the PWM modulator provides its own +5 V voltage! So the +5 V connections at K1A and K2 can be used as OUTPUTS only. Never, ever connect an active supply voltage (taken from a microcontroller circuit for example) to these +5 V pins! On the other hand, if a microcontroller is content with a few milliamps, you can feed it from the actuation circuit.

Alignment for the circuit is confined to setting the PWM modulation frequency. We use trimmer pot P1 to set a (measured) frequency between 16 and 48 kHz. The optimum frequency can be obtained from the data sheet for the motor or — if you cannot rustle up a data sheet — you can establish this by testing. If the motor stutters, the frequency is too low. If it gets hot (buzzing or whistling may be barely audible at these frequencies for people without bats' ears), the frequency selected is too high. In any case, the PWM frequency should lie above 20 kHz, since otherwise the H-bridge will go on strike. In the main, using the pot in a middle setting works well.

At Elektor Labs we've determined the circuit's minimum current draw as 11.2 mA when nothing is connected to K1 and Pin 1 of K2, with Pin 2 of K2 and jumper JP7 in Low state. If you remove jumper JP1 altogether, then the input voltage of IC1 (Pin 2) should amount to 1.68 V (in the 0 to 5 V range) or 1 V (in the 0 to 10 V range). Both of these voltages lie within the limits of the control range for the SG3524D, making the current consumption higher, around 14 to 15 mA.

The I²C actuation can be checked out using, for example, the FT311D break-out board [5]. At jumper JP1 on the FT311D board only CFG2 should be closed, in order to transfer the FT311D into I²C mode. The I²C Demo from FTDI is basic but still very useful; you simply set the Device Address of the AD5301 to 0001100 (JP5 and JP6 at 0), the three data fields *device address* (simply the device address of the AD5301), then enter *address* (the most significant bit or MSB part of the data, a Register address) and *write bytes* (the least significant bit or LSB part of the data) and up pops the corresponding voltage at the output of the IC. If you enter 0C, 0F and F0 for instance, the DAC is set to its maximum output voltage.

(140562)

Component List

Resistors

All SMD 0805, 150V, 5%, 0.1W)
R1 = 2.7kΩ
R2 = 8.2kΩ
R3,R4 = 11kΩ
R5 = 5.6kΩ
R6 = 2.00kΩ
R7 = 330Ω
R8 = 4.7kΩ
R9 to R14 = 10kΩ
R15 = 2.2kΩ
P1 = 5k SMD preset, Bourns 3314G-502E

Capacitors

C1 = 10nF 50V, X7R, SMD 0805
C2,C4,C6,C7,C8 = 100nF 50V, X7R, SMD 0805
C3 = 10µF, 16V, X5R, SMD 0805
C5 = 47µF, 6.3V, 0.5Ω, tantalum, SMD case B
C9,C10 = 220µF, 16V, 0.1Ω, tantalum, SMD case

Semiconductors

D1,D2 = TS4148RY, SMD 0805 (Taiwan Semiconductor)
LED1 = LED, green
IC1 = SG3524D, SMD SOIC-16 (Texas Instruments)
IC2 = MC74HC4053ADTG, SMD TSSOP-16 (ON Semiconductor)
IC3 = AD5301BRMZ, SMD MSOP-8, only with I²C populating (Analog Devices)
IC4 = BD6222FP-E2, SMD HSOP-25 (ROHM)

Miscellaneous

K1A,K1B,K2 = 3-way PCB screw terminal block, 5mm pitch
K3,K4 = 2-way PCB screw terminal block, 5mm pitch
JP1,JP5,P6,JP7 = 3-pin pinheader, vertical, 0.1'' pitch
JP3,JP4 = 2-pin pinheader, vertical, 0.1'' pitch
JP1,JP3–JP7 = jumper, 0.1'' pitch
PCB # 140562-1 from Elektor Store

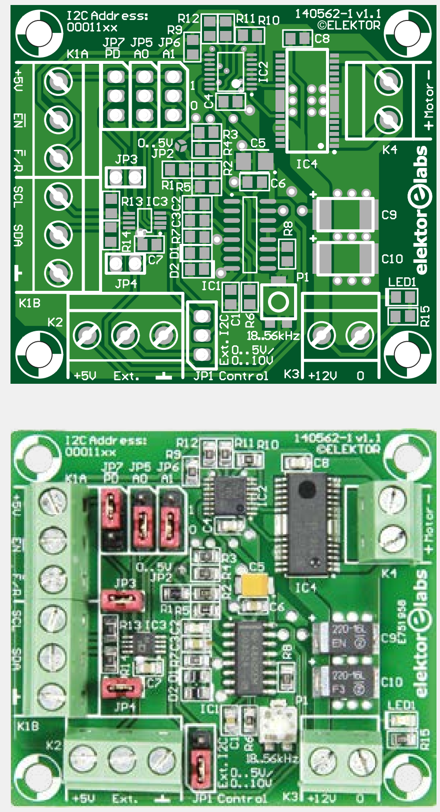


Figure 3. The small PCB for the motor control device: unequipped and constructed.

Web Links

[1] www.ti.com/product/sg3524/description

[2] www.rohm.com/web/global/products/-/product/BD6222FP

[3] www.analog.com/en/products/digital-to-analog-converters/da-converters/ad5301.html

[4] www.elektormagazine.com/140562

[5] www.elektormagazine.com/130516