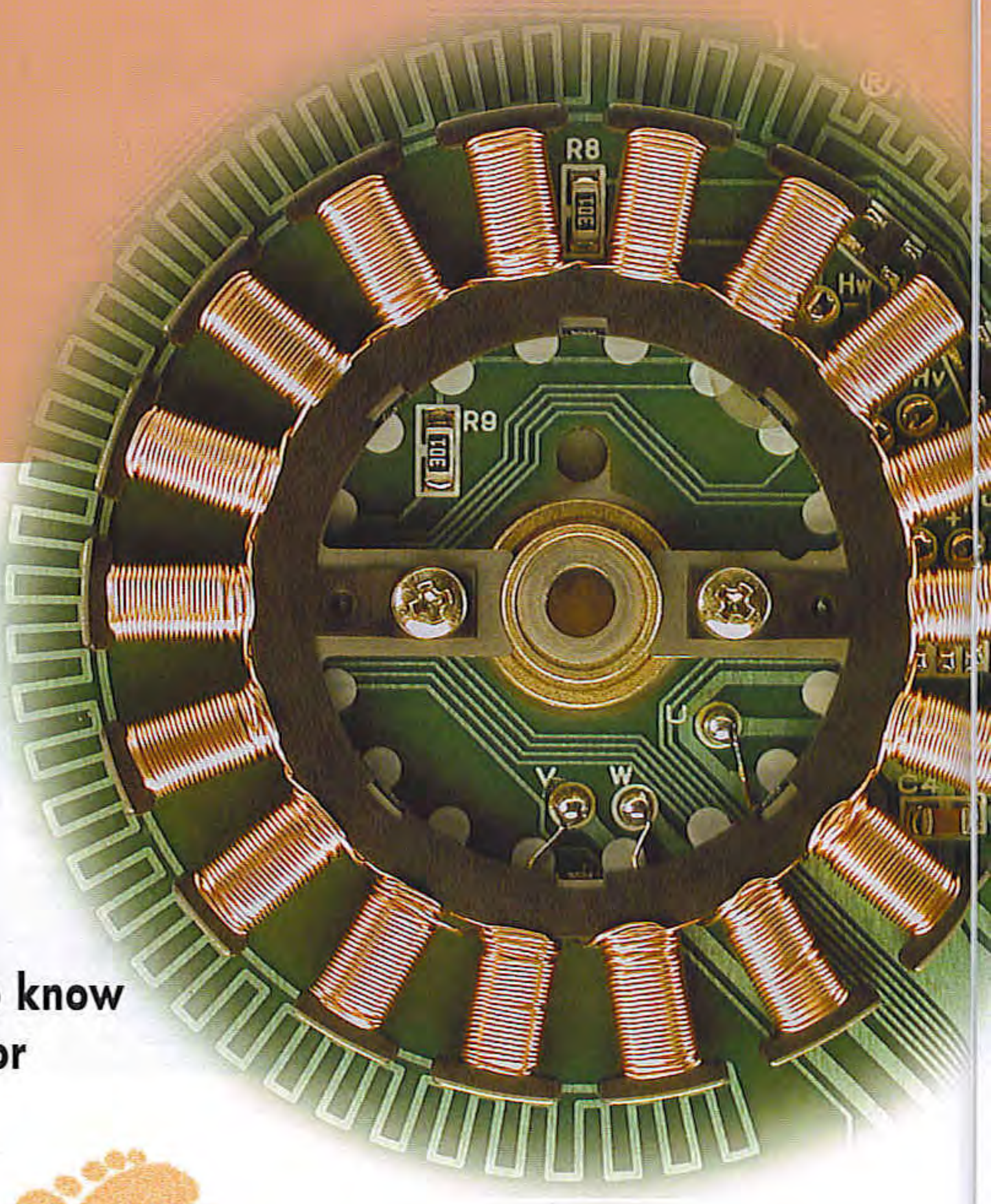

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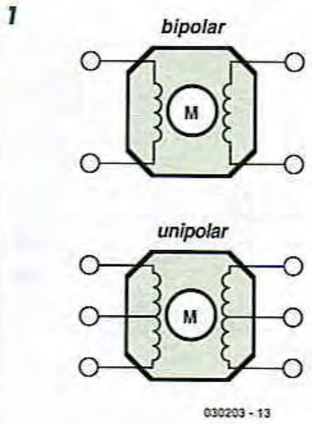
Everything you need to know to drive a stepper motor

First Steps

Stepper motors have found their way into *Elektor Electronics* many times, most recently in the November and December 2003 issues. In contrast to previous articles, we'll keep it practical and won't go into the theory. If you want to know more about the background, have a look at some previous articles (listed in the reference section at the end of this article).



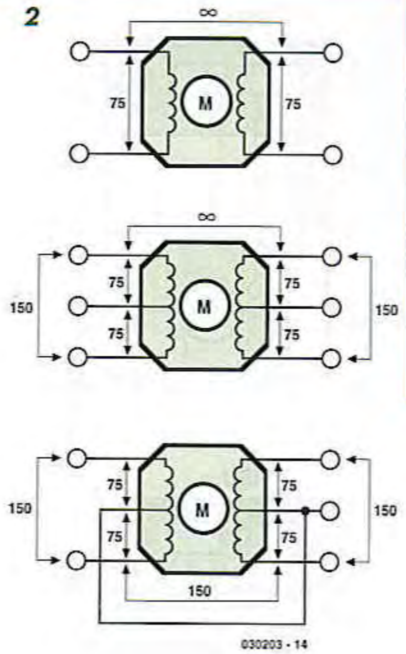


Figure 1. Bipolar or unipolar motor?

Figure 2. Finding out what the connections are.

To get an unknown motor to work you really need to do two things: find out what properties your motor has and choose the right driver electronics. With the help of this article you will find that it's not that difficult. The following three steps will help you discover the most important properties of a motor. The first step helps you determine whether you have a bipolar or unipolar motor.

1. Type of motor

A bipolar motor (**Figure 1**) has windings whereby the current alternately flows in one direction, then in the opposite direction. This creates a magnetic field that also changes direction, causing the motor to turn. The winding of this type of motor has **two** connections. The driver electronics therefore has to continuously reverse the voltage to the winding. This requires a bridge circuit using four transistors.

A unipolar motor has a winding with a centre tap. This winding therefore has **three** connections. The centre tap has to be connected to the positive supply voltage. If we now connect the start connection to ground (and leave the end connection open), there will be a current flow through the first half of the winding. If we connect the end to ground (and the start is left open), there will be a current flow through the second half of the winding. Since the current in the second half of the winding flows in the opposite direction, the magnetic field will also be reversed. The driver electronics can therefore be simpler, since we only need to connect either the start or the end of the winding to ground. Two transistors are sufficient for this.

A stepper motor has at least two pairs of windings, so 2_2 or 2_3 connections. When a motor has four leads it is almost certainly a bipolar type. And when it has five or six leads it is almost certainly a unipolar type. It's as simple as that. Should you find a motor with more leads, then you have a problem. There is nothing left but to open up the motor and hope that you can see what the internal wiring is. This is usually not successful. In that case you'll just have to use a different motor!

2. Connections

Once you have determined what type of motor you have, it's time to find out which leads belong to each of the windings. Measure the resistance between the connections using a multi-meter. Go through all possible combinations and make a note of the results. The resistance between the ends of a winding will be low. Between the centre tap and one of the ends of a winding you'll have half the value measured for the full winding. Between separate windings you'll find an infinite resistance, or at least several megohms. In this way you can determine which two or three connections belong to each winding. When a unipolar motor has a common centre tap (5 leads), it is unfortunately not possible to find out which connections belong to which windings. In that case, the centre tap will have an identical resistance to the remaining four leads. But as you will see later, we have come up with a solution for that as well.

3. Operating voltage

Unless it's written on the motor, there is no way of telling what the operating voltage of the motor is by looking at it. Often you do know what the supply voltage was to the circuit where the motor came from. A stepper motor from a floppy drive will work at either 5 or 12 V. If you have no idea what the voltage was, you can estimate it using the following method. For a bipolar motor connect one of the windings to a variable power supply. For a unipolar motor you connect two of the windings as shown in **Figure 3**. Set the output to a several volts and wait a few minutes. Feel if the motor becomes warm. If not, increase the voltage and check the temperature again after five minutes. Repeat this until the motor becomes almost too hot to touch. This should give you the maximum operating voltage for that particular motor.

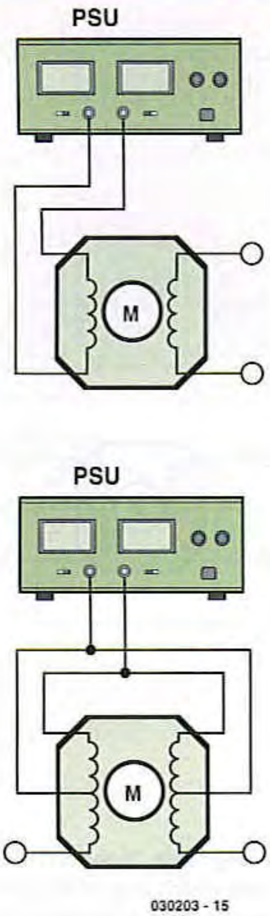


Figure 3. What is the maximum supply voltage?

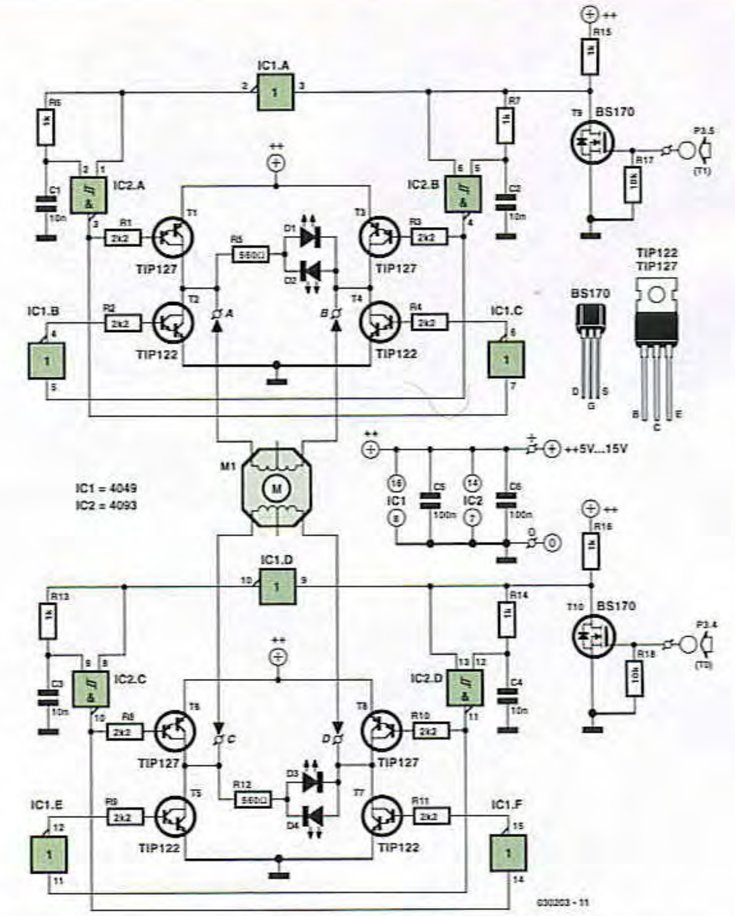


Figure 4a. Circuit diagram of the stepper motor driver.

Hardware

Now that we have determined what the properties of the motor are, we have to choose the right hardware. But don't panic, we'll work through this in a few simple steps as well.

Our driver stage has several limitations. The maximum operating voltage is 18 V (preferably a bit less, such as 15 V) and the maximum motor current is 2 Amps. If your motor requires a higher voltage or current then this circuit won't be suitable. The current consumption of the motor can be read from the power supply during the previous test, or calculated by dividing the motor voltage by the resistance of the winding.
The supply voltage chosen for the circuit should be the same as the required motor voltage.

The circuit in **Figure 4a** consists of a bridge, so that it can drive bipolar motors. It is also possible to use the same board to drive unipolar motors. In that case the 'top' transistors aren't mounted. Instead of these, a reverse biased diode is put between the collector of the remaining transistors and the positive supply. That means that the cathode, the side with the line, goes to the positive. The other sides go to motor connectors A, B, C and D.
Remember to connect the centre tap to the positive supply for a unipolar motor. The complete circuit diagram can be downloaded from the *Elektor Electronics* website (**Figure 4b**).

The next question is which type of semiconductor to use. It happens that both transistors and FETs are suitable. Transistors are often cheaper and more robust, but have greater losses. In fact, we don't use ordinary transistors, but darlingtons. These consist of two transistors after each other in one case. They behave just like ordinary transistors, but with a much greater gain, usually about 1,000 times. Their disadvantage is that they have a greater voltage drop of about 0.8 V.

FETs are usually a better choice, but take note: P-FETs (for the 'top' semiconductors in the bridge) are a bit harder to find. Their voltage drop is minimal, which makes the FET version particularly suitable for 5 V motors. In the transistor version there would only be

$$5 - 0.8 - 0.8 = 3.4\ \text{V}$$

left for the motor.

It may be that you're told to buy so-called logic FETs. These FETs can function with a lower driving voltage on the gate. You can use logic FETs, but they're not strictly necessary, as can be seen from **Figure 5**. With a 5 V supply even a 'normal' FET can switch over 5 A, which is more than enough. In case of a 9530 type P-FET this is less favourable, but 2 A should still be possible.

The choice of either the darlingtons or the FETs isn't critical. If you can't find

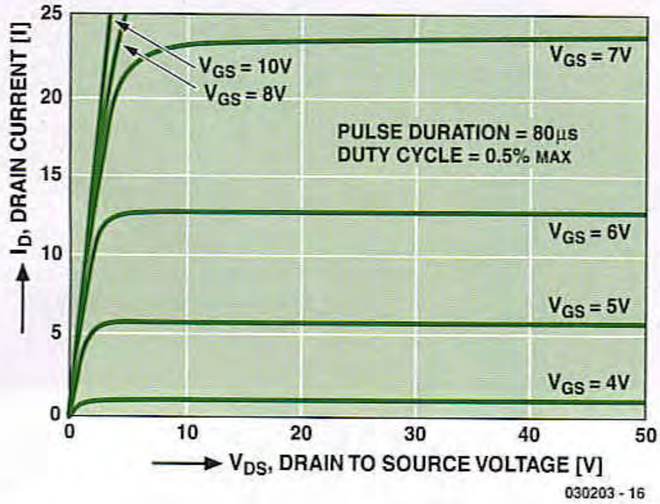


Figure 5. Most FETs can easily pass 2 Amps with a 5 V gate/source voltage (V_{GS}).

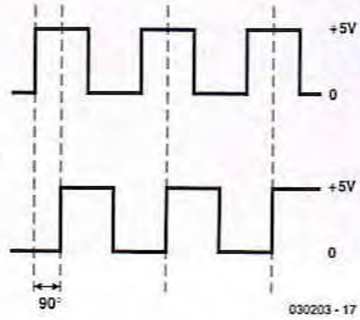


Figure 6. Two square waves are required to drive a stepper motor.

the types in the parts list or if you have some spares, you should use a type that has a minimum working voltage of 50 V and a minimum current of 4 A. Many types satisfy these criteria.

Operation

The driver circuit for the stepper motor consists of two identical halves, so we only need to look at one half. The signal at the input is converted by T9 into a square wave with an amplitude equal to that of the supply voltage to the circuit. This is necessary because the driving signal usually has a much smaller amplitude, such as 3.3 or 5 V. So T9 adapts the voltages to each other.

The signal then goes to NAND gate IC2b, once direct and once delayed by 10 µs via R7/C2. There is a purpose to this of course. The trick here is that a transition from '1' to '0' is fed through immediately, whereas a transition from '0' to '1' is delayed. The same occurs via IC1a and IC2a, but on the other diagonal because IC1a has inverted the signal. This exercise is required so that the transistors turn off immediately, but only turn on after a short delay. In this way we avoid that two transistors above each other conduct at the same time, which would short the supply. If you dare, you can leave C1/C2 from the board: you'll then find current spikes of several Amps!
During normal operation only two diagonally opposite placed transistors will conduct. For example, when T1 and T4 conduct point A is positive and point B is connected to ground. LED D1 lights up and there will also be a current through the winding of the stepper motor. If T2 and T3 conduct instead, the polarity is reversed and the current flows through the stepper motor in the opposite direction. Now D2 will light up.
At the time of switching (when the transistors stop conducting) voltage spikes occur because the stepper motor winding is a coil (self inductance). These spikes are suppressed by the LEDs and R5. These components should therefore not be left out. The darlingtons and FETs also have internal protection diodes.

Driving the circuit

The stepper motor PCB has two inputs. These are connected to our 89S8252 Flash Micro Board (see references at the end of the article).
To make a stepper motor turn requires two square waves that are 90 degrees out of phase with each other. If the waves are –90 degrees out of phase, the motor will turn in the opposite direction (see **Figure 6**). The software on the Flash Micro Board generates these square waves. **Figure 7** shows how the board connects to the driver circuit. Push-buttons connected to the board make the motor change direction, although with a little ingenuity they could also vary the speed.
The input circuit around FETs T9 and T10 has been added to make sure that the 5 V square wave from the Flash Micro Board connects seamlessly with the (usually) higher supply voltage of the stepper motor driver.
The software, which can be downloaded from the *Elektor Electronics* website, is an example so you can familiarise yourself with the techniques involved and perhaps try your hand at writing your own programs.

Connecting the motor

For a bipolar motor you should connect one winding to A and B, and the other winding to C and D. Should you find that the motor turns the wrong way round, you need only exchange the connections to A and B.
For a unipolar motor with 6 leads the centre taps are connected to the +Ve supply. The ends of one winding are connected to A and B, and the ends of the other winding to C and D. If the motor turns the wrong way round, just swap A and B.

For a unipolar motor with 5 leads the common centre tap is connected to the positive supply and the four ends of the windings are *arbitrarily* connected to A, B, C and D. If you are very lucky, the motor will turn. However, it is more likely that the motor will just vibrate a little bit. This is where plan B comes into action: keep swapping the connections until the motor turns! You won't cause any damage to the circuit or motor. Remember to turn off the

COMPONENTS LIST

For 5-9 V (values for 9-15 V in bracket)

Resistors:
R1-R4,R8-R11 = 2kΩ2 (4kΩ7)
R5,R12 = 560Ω (1kΩ5)
R6,R7,R13,R14 = 1kΩ
R15,R16 = 1kΩ (2kΩ2)
R17,R18 = 1MΩ

Capacitors:
C1-C4 = 10nF
C5,C6 = 100nF

Semiconductors:
D1,D3 = LED, red, high efficiency
D2,D4 = LED, green, high efficiency
T1,T3,T6,T8 = TIP127 or IRF9520 or diode MBR745 *
T2,T4,T5,T7 = TIP122 or IRF520
T9,T10 = BS170
IC1 = 4049
IC2 = 4093B

Miscellaneous:
14-way IC socket
16-way IC socket
Flash Micro Board software, Free Download, file no. **030203-11**

* if you do not use bipolar transistors or FETs, diodes **must** be fitted! This applies to the use of a unipolar motor.

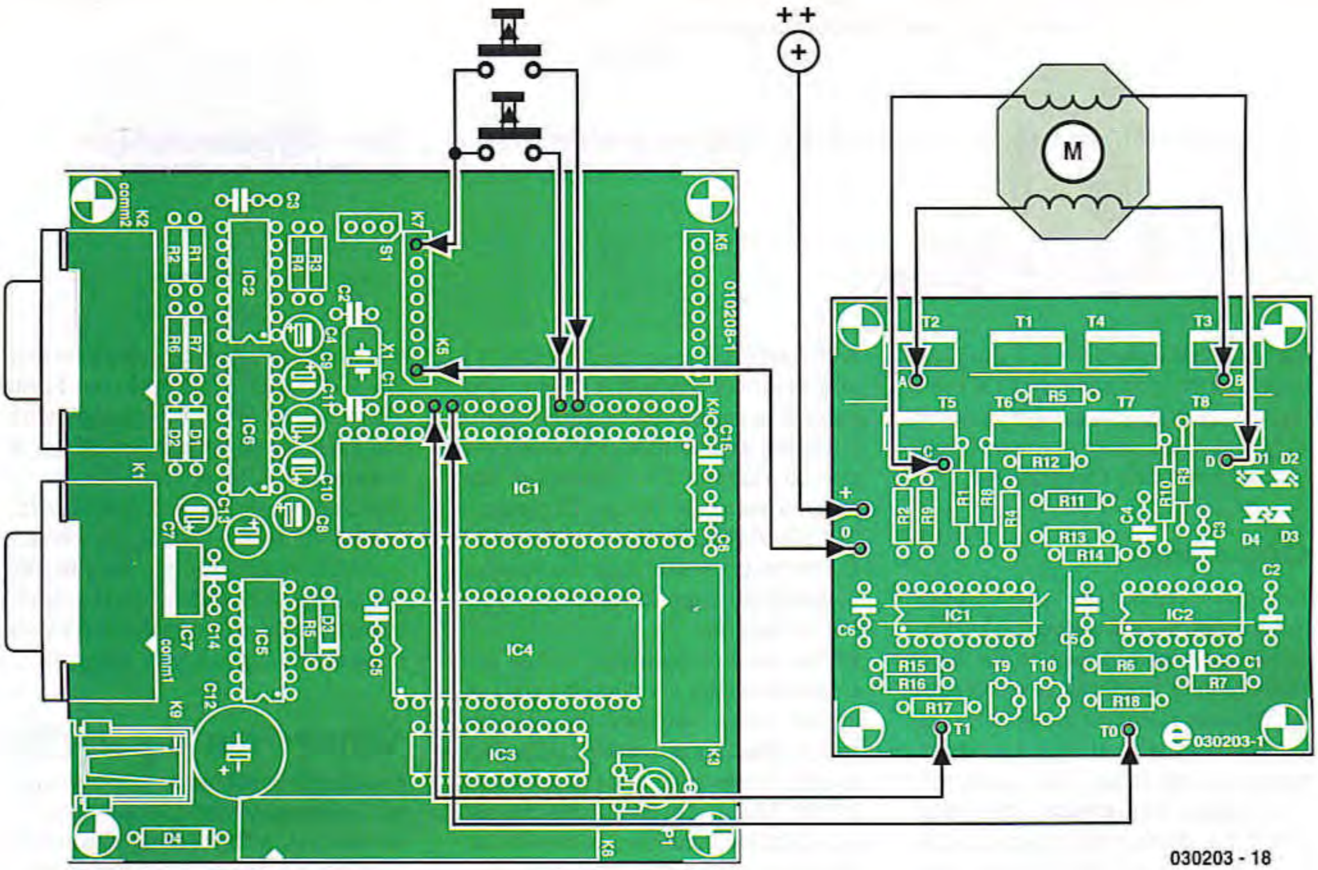


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Figure 7. This is how the Flash Board should be connected to the stepper motor driver PCB.

supply before changing any connections. Swap A and B and turn the supply on again. If the motor still doesn't turn, swap A and C. If you still don't get a result, swap A and B again.

The associated program is described elsewhere in this edition in the article 'Software? We'll do that ourselves!'.

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References:

Stepper Motors Uncovered, **part 1, Elektor Electronics November 2003.**

Stepper Motors Uncovered, **part 2, Elektor Electronics December 2003.**

89S8252 Flash Microcontroller Board, **Elektor Electronics December 2001.**

Internet

The full version of the circuit diagram, as well as the PCB layout and software for the Flash Micro Board can be downloaded from:

www.elektor-electronics.co.uk/dl/dl.htm,

select month of publication.