

## 04.7 emech.drive Driving motors

1 The DC motor requires DC electrical power provided by a circuit called the “driving” circuit. For industrial motors at least, these circuits must provide significant power, and for this reason a separate (from the control circuit) power supply is often used. There is a quick-and-dirty way to drive a DC motor at variable speed: since its angular velocity is reliably proportional to its voltage, place a potentiometer in series with the power supply and motor. However, this has disadvantages that include the power being limited and dissipated at high potentiometer resistance (low speed). For most applications, we will need either a current (or power) amplifier or—more likely—a microcontroller and an integrated circuit to produce a pulse-width modulation driving signal.

### *Pulse-width modulation*

2 *Pulse-width modulation* (PWM) is a technique used to deliver an effectively variable signal to a load (in this case a motor) without a truly variable power source. A pulse of full source amplitude is repeated at a high frequency (e.g. 20 kHz), delivering a signal that is effectively averaged by the load dynamics such that its effects on the load are nearly continuous. The fraction of the period that the signal is high (on) is called the *duty cycle*  $\delta$ . The following figure shows a PWM signal  $v(t)$  and its average  $\bar{v}(t)$  with a few parameter definitions.

3 The mean of any periodic signal can be computed with the integral

$$\bar{v}(t) = \frac{1}{T} \int_0^T v(t) dt,$$

which is easily evaluated for a PWM signal:

$$\bar{v}(t) = \frac{Aw}{T} = A\delta.$$

4 This result shows that if a PWM signal is delivered to a load, such as a DC motor, that is relatively unaffected by high-frequency signals, the effective signal will be simply the product of the source amplitude  $A$  and the

duty cycle  $\delta$ . The duty cycle can have values from 0 to 1, so the effective DC signal produced varies linearly  $\delta$  from 0 to  $A$ .

*PWM with a microcontroller and integrated circuit*

**5** A microcontroller such as the myRIO or Arduino can easily produce a PWM signal; however, this signal is typically *low-power* and cannot drive even small DC motors. Therefore it is common to include a special kind of integrated circuit (IC) that uses the microcontroller's low-power PWM signal to gate a high-power DC source signal for delivery to the motor. We use a connectorized printed circuit board (PCB, e.g. a PC motherboard)—the [Pololu motor driver carrier](#)—that includes on it a [STMicroelectronics VN1H5019](#) H-bridge motor driver *integrated circuit* (IC, i.e. a microchip).

**H-bridge circuits** **6** We want to drive DC motors at different effective voltages *and* different directions. An H-bridge circuit allows us to reverse the direction of the PWM signal delivered to the motor. The following is a diagram of the H-bridge circuit.

**7** The switches S1-S4 are typically instantiated with MOSFET transistors. As shown in the figure below, during the high duration of the PWM pulse, either S1 and S4 (a) or S2 and S3 (b) are closed and the others are open.

- (a) motor driven one direction
- (b) motor driven the opposite direction

**8** Recall that a DC motor can be modeled as a resistor and inductor in series with an electro-mechanical transformer. The inductance of the windings make it an “inductive” load, which presents the following challenge. We can't rapidly change the current flow through an inductor without a huge spike in voltage, and the switches do just that, leading to switch damage. Therefore, during the low or “off” duration of the PWM signal, S1-S4 cannot all be simply opened. There are actually a few options for switch positions that allow the current to continue to flow without inductive “kickback.”

**9** What's up with the diodes? Technically, they could be used to deal with the kickback, but they typically are not because they dissipate power.

However, they are used to do just that to ease the transition between switch flips, which are never quite simultaneous.

### Motor curves

**10** Motors are often characterized by three *steady-state* curves:

1. a torque  $T$  versus angular velocity  $\Omega$  curve;
2. an angular velocity  $\Omega$  versus voltage  $v$  curve, which has slope  $1/k_m$ ;  
and
3. a torque  $T$  versus current  $i$  curve, which has slope  $-k_m$ .

**11** We will develop our own motor curves for the DC motor in the lab by simultaneously measuring  $v$ ,  $i$ , and  $\Omega$ . Unfortunately, we will not be measuring  $T$  directly, and so we will be unable to measure all these curves directly; however, we will be able to infer them based on the (reasonable, but not perfect) assumption that the motor has no power losses. In the end, they should look something like the following (using our usual sign convention).

**12** In order to construct such curves, we will measure  $v$ ,  $i$ , and  $\Omega$ . The following sections describe the measurement process.