Motors, Batteries and Sparks

Developing a mobile robot involves joining traditional electrical technology such as motors and switches with the new: digital electronics and computers. The problem is they don't always mix. The humble 6 volt DC electric motor for example, when running generates high voltages and radio frequency (RF) electromagnetic radiation capable of destroying any electronics to which it is directly connected, and interfering with the operation of unconnected circuits. The designer must take precautions by adding components to protect the relatively delicate electronics from this onslaught. These precautions are naturally in place on the URR Cybot and would need to be incorporated in your own designs. But first, just how does the motor cause such mayhem?

The DC motor

The simple brush DC motor consists of a set of coils mounted on a shaft called an Armature. This can rotate in a static magnetic field produced by a pair of permanent magnets wrapped around (but not touching) the armature. When an electric current flows through the coils an electromagnetic field is formed which tries to align itself with the permanent field by forcing the armature to rotate. Left like this there would be no movement beyond a 'twitch' of the shaft at switch-on, so the current is now reversed through the coils, changing the field polarity and forcing the shaft to rotate further. This reversal is achieved automatically, by a sort of switch on the shaft called a Commutator. It consists of contacts mounted around the shaft making contact with the fixed Brushes that supply the current from the motor terminals. Now the shaft will rotate continuously as long as current is supplied, as the commutator keeps switching the field polarities as it goes round. Given that the supply voltage is only 6 volts, where do the high voltages come from?

Sparks

Basic electrical principles come in here. Imagine a simple wire coil connected to a battery via a switch which is closed. A steady current flows through the coil; the amount of current depending on the resistance of the coil and the battery voltage (Ohm's Law, I = V/R). Now open the switch. What happens? The current stops flowing obviously – but not immediately. If we had a perfect resistor instead of a coil, the effect would be immediate. Our coil has an additional property we call Inductance, and it gives it the ability to store energy. When we open the switch the stored energy imparts a kind of inertia on the current flow and tries to keep it going. It can't initially, so a large voltage develops across the now open switch contacts. This increases until the air in the gap 'ionizes' or breaks down, going from an open-circuit resistance to a very low resistance and allowing the current to start flowing again. Once this arc has formed the voltage collapses very quickly indeed. Now there is not that much energy stored in the coil, so the current flow soon ceases and the arc goes out. All this happens in a tiny fraction of a second as the switch opens and all you see is a brief flash or spark between the contacts. Our motor commutator is a switch operating many times a second repeatedly breaking a current flowing through the armature coils. If you had a motor where the commutator was visible, you could see these sparks as a continuous vivid blue light where the brushes touch the rotating contacts. How can this ruin our electronics?

Taming the Spark

The fireworks inside the motor cause three main problems:

1. The very high voltage appearing at the motor terminals will destroy the transistors making up your control circuits.
2. The pulse of energy in the spark contains many very high frequency components which will radiate and interfere with other circuits in the robot and your next door neighbour's television!
3. The spark is so hot it will burn away the commutator contacts eventually.

The first step to protecting your electronics is to fit a capacitor, usually of value 0.1 µF (microfarad) across the motor terminals. Have a look at your Cybot to see this capacitor. This works by providing an easy alternative path for the high-frequency current components that would have jumped across the gap as the brush lost contact. You will see two further capacitors on a Cybot motor, one between each terminal and the motor casing. Unfortunately RR have lost the plot here because this arrangement assumes the motor casing is earthed, or connected to battery negative. The Cybot motor, as you can see, is held in a plastic insulating mounting. If the case were earthed, then these capacitors would help to short-out the high-voltage high-frequency components forming that fast voltage pulse that develops as the contact opens. Without the earth connection, all we have are two capacitors connected in series between the motor terminals. The combined value of two capacitors in series is given by: $1/C = 1/C_1 + 1/C_2$. With values of 0.1 microFarad each, this gives a total value of 0.05 microFarad. This combination appears in parallel with the remaining capacitor and this time simple addition gives a final value of 0.15 – an increase not likely to make much difference. You could solder wires between the motor casings and the motor battery negative terminal, but as Cybot seems to work, I shouldn't bother.

Each motor is driven by a circuit known as an H – Bridge driver (Fig.1). It's a popular circuit for DC motor control because by turning on the transistors A, B, C & D in various permutations, you get forward and reverse, free-wheel and fast brake. Normally designers would use a single chip form, but in the case of Cybot the abundance of cheap labour in China makes it preferable to use discrete components. My replacement electronics board, Cy-Q, uses an IC H-Bridge chip, which has the added benefit of overheat protection allowing rechargeable batteries to be used without risk of damage when the motors are stalled. The capacitor across the motor is the 0.1 microFarad mentioned previously. The four red diodes are there to protect the transistors from the high reverse voltages produced by the motor when it's running. Unfortunately the Cybot design does not have these diodes! Instead, there is an additional 10 microFarad capacitor across the motor. This is very dodgy design, as a polarized device has been used. See the Cybench web site for more details about this design flaw and what you can do about it.

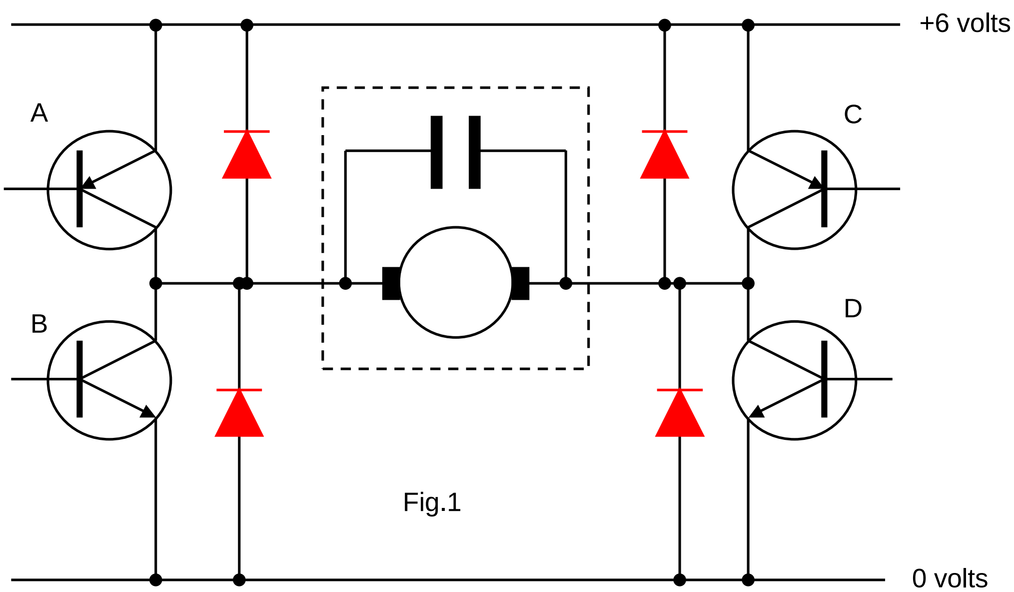

Fig.1

One Battery or Two?

Cybot uses two battery packs: one for the motors and another one for the electronics. This is the ‘safe’ approach, isolating the electrically ‘dirty’ motors from the delicate microcontroller circuits. It is not strictly necessary providing precautions are taken. The motor power and electronics power wiring should be kept separate and only meet at the battery pack terminals. 0.1 microFarad capacitors should be liberally sprinkled around the circuit boards, soldered across the power rails. Another robot I have built, for MicroMouse competition, only uses one 4 x AA battery pack and works perfectly. Take a look on my web site at http://www.wgmarshall.freeserve.co.uk/.