Swansea University

College of Engineering

Electronic & Electrical Engineering Course Programmes

EG-252 Group Design Exercise:

Micromouse

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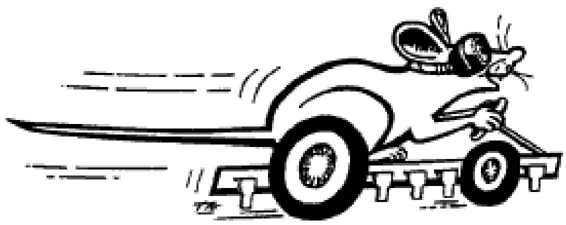
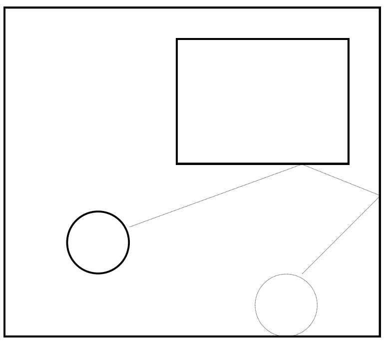
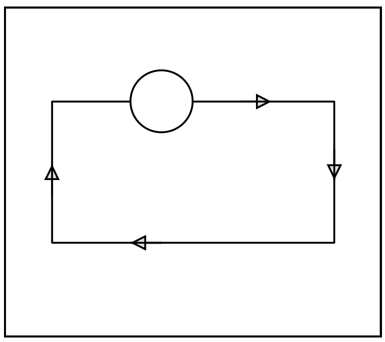
EG-252 Group Design exercise is made up of two parts. The first part is a series of experiments and teaching centred on the Freescale AW60 microcontroller. This is combined with the team-based activities which lead to the design and construction of a small wheeled robot called a micromouse. The micromouse is required to perform a number of specified tasks, including line following and obstacle avoidance.

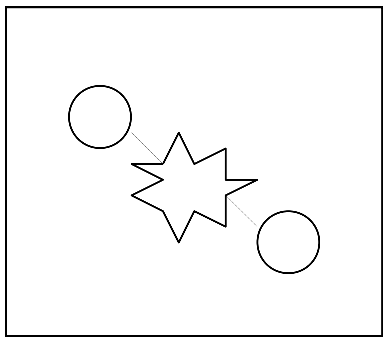




Obstacle avoiding



Line following



Combat

1. Introduction

1.1 Why have group projects?

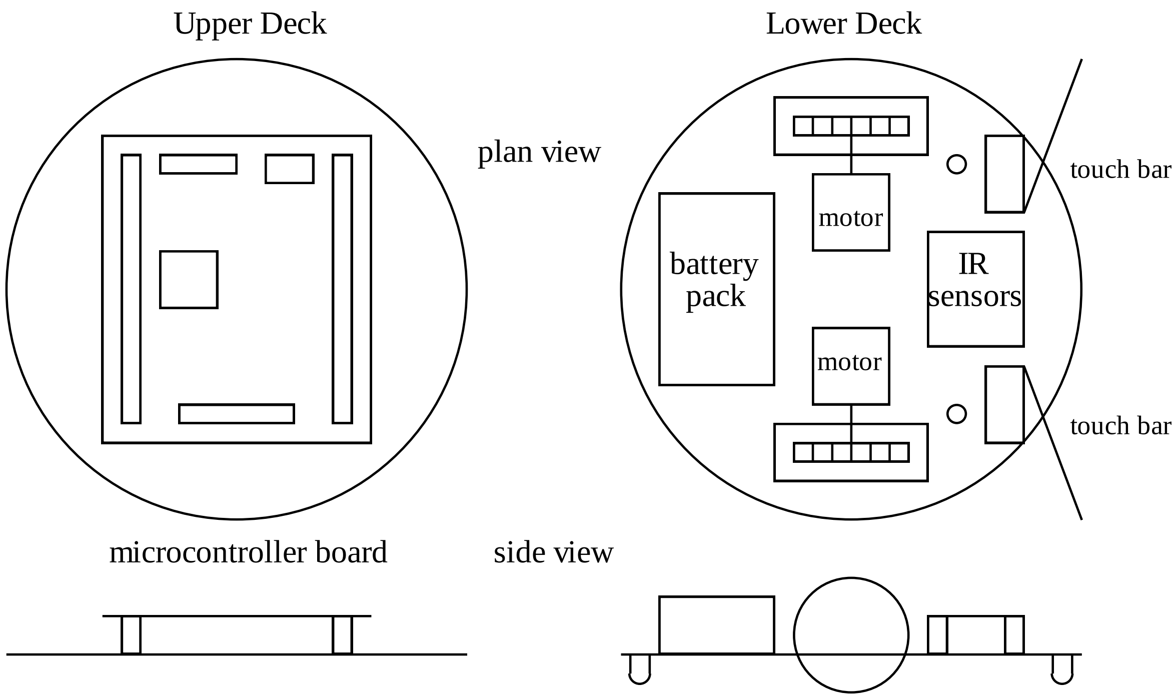
Group project work is a valuable part of an Engineering degree. It is part of the accreditation requirements of the IET that Electrical Engineering undergraduates should have training in group work, as it provides a model for future employment when employees will have to work as part of a team. In our degree scheme, the group project also provides specific training in the use of microcontrollers. Another benefit of group project work is through the "espirit de corps" resulting from the close association with fellow students over a long period of time (October - May).

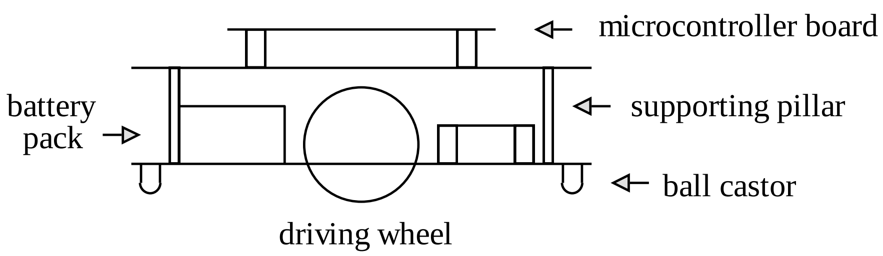
The former Department of Electrical & Electronic Engineering first introduced group projects about 20 years ago. These early group projects ran for one term only, and students selected subject areas from a short list including Circuits, Radio Communication, Semiconductors, and Microprocessors. Each student took part in two group projects, one in the Christmas Term and the other in the Easter Term.

This format was eventually replaced with the single group project. The Micromouse group design exercise has been through several major changes, but certain features have been kept all the way through. The exercise is worth 20 credits, so it carries a significant fraction of the marks available in one session. The same exercise is taken by all students, ensuring uniformity in the work required and in its assessment.

1.2 What is a Micromouse?

A Micromouse is a small, wheeled robot equipped with sensors appropriate to the tasks.





The drawing above indicates the major components of a micromouse. The actual design of individual micromice does not have to adhere rigidly to this drawing; originality of design will be a factor in the assessment of the micromouse.

Some standard parts will be available to the teams, including the microcontroller board, chassis plates, motor/gearbox units, and wheels. All micromice will feature these parts in some arrangement. Other parts, including IR sensors, white line sensors, touch bars, will be at the discretion of the teams.

1.3 Rules of the Micromouse Group Design Exercise

Task 1: White Line Following

The micromouse must be capable of following a rectangular track consisting of a 50 mm white line on a matte black background. The dimensions of the track are laid down in the rules for the IEE "Formula 3" Schools Micromouse web site. Sample boards are available for practice runs. Micromice are allowed to use line or edge following algorithms, and are allowed to run in either direction around the track.

Recommended sensors for this task are visible LEDs and photo-resistors.

Assessment of the line following task will be based primarily on time taken to complete a circuit of the track, with marks taken off for deviations from the line.

Task 2: Obstacle Avoidance

The micromouse must avoid contact with walls and routine obstacles such as table and chair legs, small boxes, and other micromice. Recommended sensors for this task are modulated infra red detectors and mechanical switches.

Maximum marks will be awarded to micromice which avoid obstacles without physical contact, and show some selectivity in their response to obstacles. Marks will be taken off micromice which become "trapped" or which routinely collide with obstacles.

Task 3: Micromouse Combat

The arena for micromouse combat will be a white rectangle on a matte black background. The micromouse must remain within the rectangle; if it leaves the rectangle it must stop immediately and will be deemed the loser of the bout, regardless of the reason it left the rectangle.

The micromouse must seek other sources of infra-red modulated light and steer towards the source. If the front impact sensors detect a collision, then the micromouse must back off and may be awarded a "touch". The infra-red sensors have the lowest priority; the mouse must seek the source only if there is no conflict with the white floor sensors or if there is no impact detected. The floor sensors have the highest priority; if the edge of the rectangle is found then the mouse must abandon its attack and move so as to regain its position in the arena.

The combat final will be between pairs of micromice, "seeded" according to their performance. Assessment of the task will be based on the number of "touches" scored by each mouse on its opponent. The bout will end immediately if one mouse leaves the arena. If both mice are still in the arena at the end of the bout, the judges will consider the number of "touches" scored by each mouse. The mouse scoring the best of three bouts will go forward to the next stage of the contest.

Special Feature

A special feature should be incorporated in the electronics, mechanics, or software of the micromouse. This should be a technical rather than a decorative feature; for example "go faster" stripes do not count. The team have a budget to purchase additional components as required for their special feature.

1.4 Assessment

The module EG-252 is worth 20 credits (200 marks). Forty marks are carried by the microcontroller exercise which runs in the first term. A further ten marks are available for a demonstration of the second task (obstacle avoidance) just before the Christmas vacation. Progress on the web site carries ten marks, reviewed at the same time just before the vacation. The remaining 140 marks will be awarded at the end of the exercise in May. This final assessment will include a demonstration of line following and the Combat final, together with interviews of the teams. The assessors will be looking for power saving strategies in the micromice, for example turning off sensors which are not in use for a particular task.

The team website, which will include all the technical details, must be available for assessment one week after the assessment day. An approximate costing should be included, which takes into account "failed attempts" at building printed circuit boards.

2. Motors and Motor Control

2.1 Choice of motor

There are a number of types of motor which could be used for driving the micromouse.

Permanent Magnet DC: motors of this type are available in a vast range of sizes and power. They are simple to drive, and their speed can be controlled by varying the applied DC voltage or by means of pulse width modulation (PWM).

Brushless DC: these motors are more expensive than PMDC motors, and tend to be used in applications where low noise and high reliability are essential, e.g. in computer disc drives. They require a special drive circuit which also provides speed control.

Stepper: stepper motors are expensive and require special drive circuits. They have an enormous advantage over DC motors in some applications, as they move by an exact angle with every step and do not need positional feedback. Stepper motors can rotate very slowly, so gearboxes are not always necessary. A major disadvantage is that they take electrical power even when stationary, which is not very good for battery economy.

AC motors: small AC motors are becoming popular for many applications, including electrically driven model aircraft and for electric cars (e.g. the Toyota Prius). They are more efficient than DC motors but require sophisticated control electronics, as the speed of rotation is directly linked to the applied AC frequency.

The motors chosen for the Micromouse exercise are of the permanent magnet DC type, fitted with 50:1 gearboxes. The actual motors are manufactured by Pololu, and are listed as "micro motors with metal gearbox". Technical details are available from the Pololu website, search for item number 2203. A feature of these motors is an extended motor shaft so that a tachometer can be fitted. This is essential if the micromouse is to move in straight lines and precise distances.

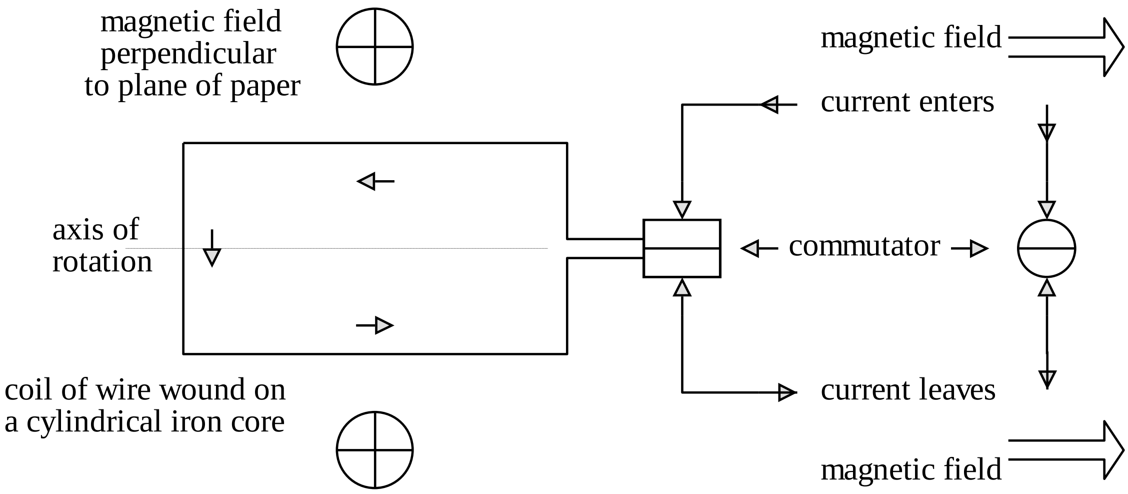
2.2 Motor Design

All DC motors have certain features in common. A fixed magnetic field repels and attracts another magnet which is free to rotate.

There are many variations on this basic design. The fixed field can be generated by an electromagnet, or, more commonly, it is produced by a permanent magnet. The rotating magnet is usually an electromagnet consisting of a coil of wire wound on an iron core. Brushless DC motors turn the whole idea "inside out" by making the rotating magnet a permanent magnet and the fixed field an electromagnet. The brushless motor avoids the problem of bringing an electric current to a rotating coil.

All DC motors must have some form of commutation. A simple permanent magnet motor uses a split metal cylinder known as a commutator to bring current to the rotating coil. It has another function: the design of the commutator and its brushes causes the current in the coil to reverse every half-turn, otherwise the motor would move a maximum of 180 degrees and then lock in place magnetically.

The diagram belows shows the current flow in a simple DC motor based on this idea. The current flow from fixed wiring through a brush onto the commutator, and out through another brush on the opposite side of the commutator. The interaction of the fixed field and the field produced in the coil of wire causes the coil to rotate so as to align itself with the fixed field. However, at a critical point the commutator faces change over so that the current in the coil is reversed. The coil is now repelled by the fixed field and moves a further 180 degrees to align itself again.



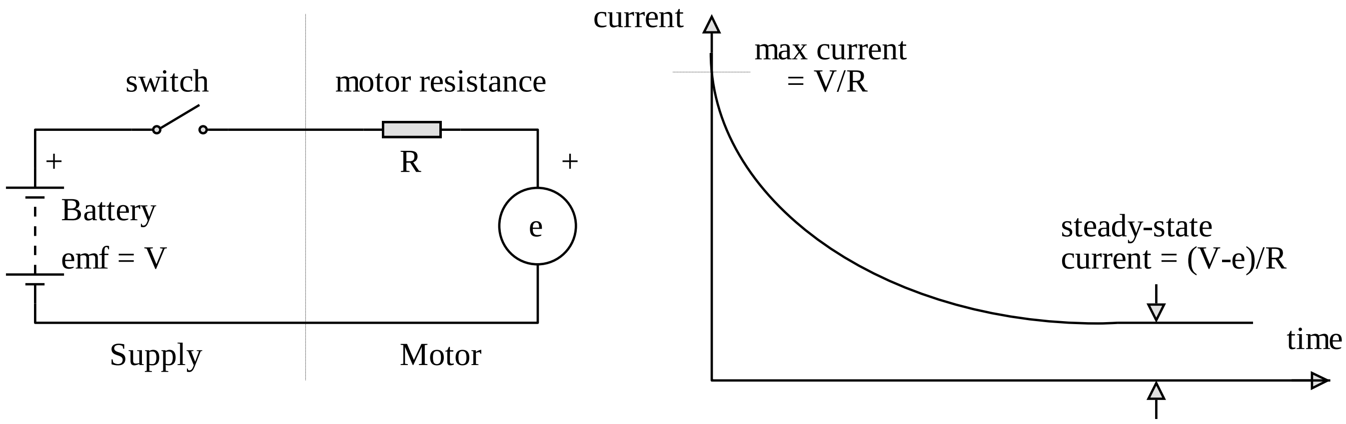
Unfortunately a very simple motor of the type shown above is not practical. It may not start when current is applied, and the direction of rotation is not predictable! Practical motors always have multiple coils and a corresponding number of faces on the commutator. The simplest practical motors have three poles and three faces on the commutator spaced 120 degrees.

More sophisticated motors have 5, 7, 9 or more poles. An odd number is essential to ensure that the motor is self-starting. The more poles, the smoother the motor runs as there is an "overlap" in the attraction and repulsion of the coils.

The Polulu motors are of the three-pole type. This is largely an economic decision, as multi-pole motors are much more expensive. The Swiss-made "Escap" motors have 7 poles and are beautifully constructed, however they cost over £50 each.

2.3 Motor Operation

What happens when a DC motor is connected to a battery? Clearly, it will start to rotate as the fixed and rotating fields begin their endless pushing and pulling. What about the current taken by a DC motor? To understand the behaviour of the motor as it accelerates it is useful to consider a model of the real motor.

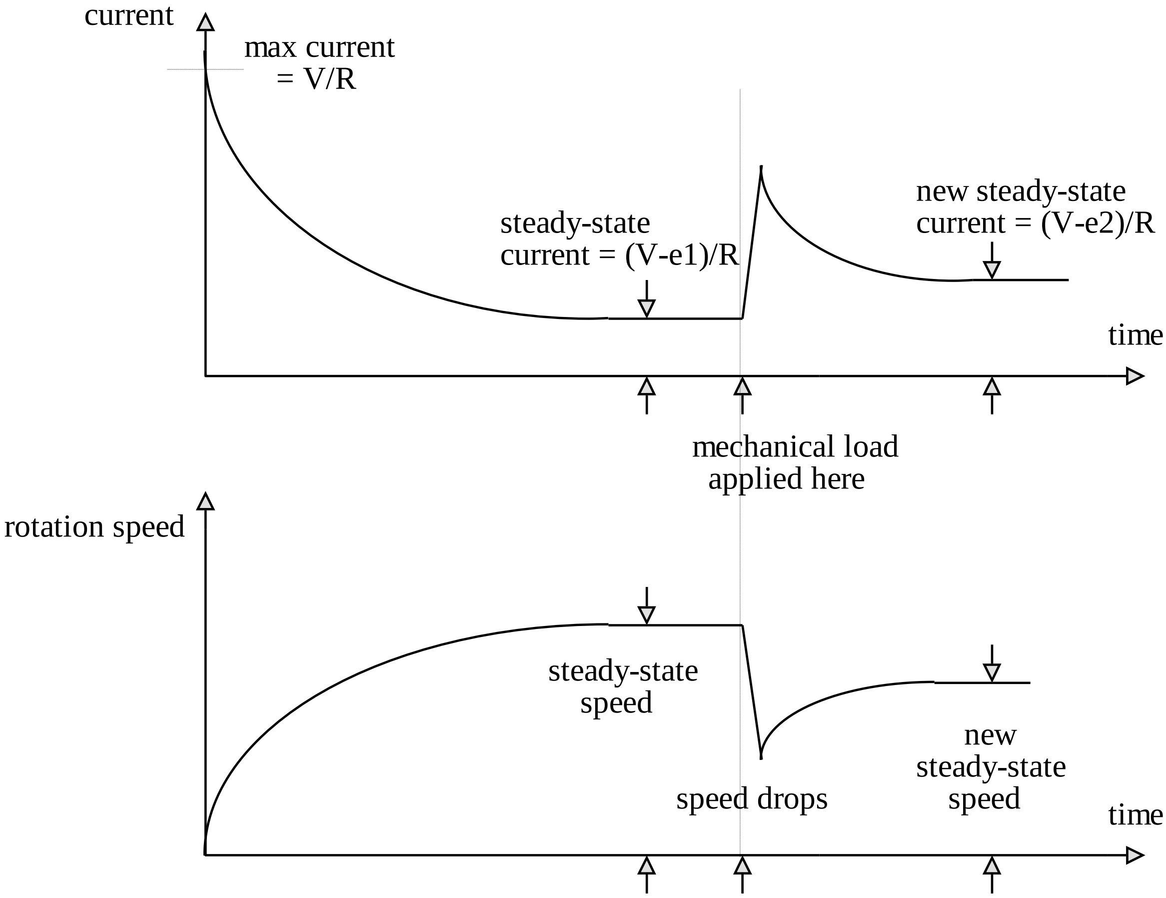


The model consists of a resistor R which represents the static resistance of the motor coils, in series with a voltage generator of emf = e. Why is there a voltage generator? Because motors are simultaneously motors and generators. Spinning a motor will produce an open-circuit voltage which is proportional to the speed of rotation. The polarity of the generated voltage opposes the applied voltage V.

Suppose the switch is closed at t=0. The instantaneous current at t=0 will be the applied voltage V divided by the coil resistance R. This can be a very high current in the case of large motors e.g. for electric traction. As the motor begins to turn, the voltage generated e increases. The current decreases because this generated voltage e opposes the applied voltage V, and the current is given by the net voltage (V-e) divided by R.

Eventually a balance point is reached at which the load and friction forces imposed on the motor are equal to the torque produced. The current has now reached a stable value. The Pololu motors take around 300 or 400 mA if stalled, falling to around 30 mA if the motor is allowed to run without any mechanical load.

Suppose that a mechanical load is applied suddenly to the motor shaft. Then the speed of rotation drops suddenly, so that the generated voltage e decreases. The net voltage (V-e) increases, and hence the current. The higher current causes the motor to accelerate but it does not quite reach its original speed. The motor settles down with a higher current and a lower speed of rotation. The increase in current multiplied by the voltage represents the power required to drive the mechanical load.



The graphs above show how the rotation speed builds up to reach a steady-state value and at the same point the current levels out at (V-e1)/R. Then the mechanical load is applied, causing the rotation speed to drop. Next the speed builds up again until a new steady-state is reached. The new current is (V-e2)/R, where e1 > e2.

What happens if a rotating motor is disconnected from its supply, and left open-circuit? The rotation speed gradually decreases as the rotational energy is dissipated in friction within the motor and external rotating parts.

What happens if a rotating motor is disconnected from its supply, and a low resistance is connected between the motor terminals? The rotation of the motor continues to generate an emf, but with no supply to oppose it current will flow in the opposite direction. In consequence, the motor rapidly comes to a halt and its rotational energy is dissipated as heat in the coil resistance R.

There are thus four distinct states when driving a DC motor, and all four are required to control the micromouse. The four states are:

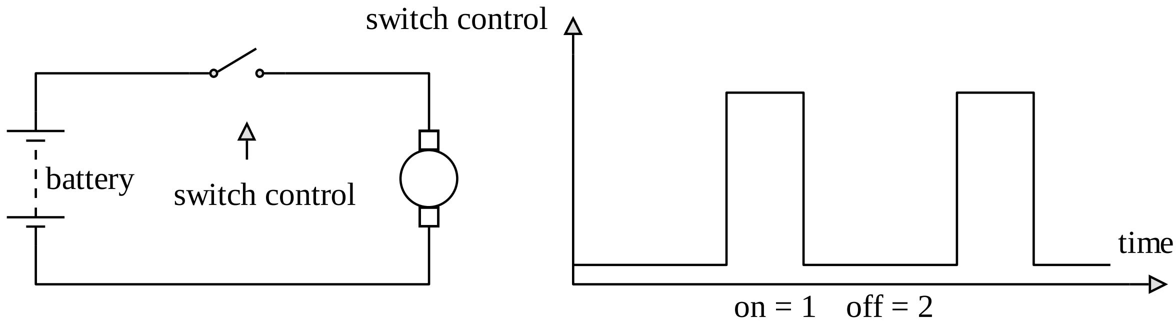
1. Voltage applied +/-; the motor rotates clockwise (forward)
2. Voltage applied -/+; the motor rotates counter-clockwise (reverse)
3. Motor open-circuit; the rotation speed decreases slowly (free run)
4. Motor short-circuit; the motor stops abruptly (braking)

Care must be taken when braking large motors as the sudden change in rotation speed can cause damage to the couplings and motor shaft.

2.4 Motor Speed Control

An accurate means of controlling the speed of the motor is essential for micromouse. A simple way would be to control the applied voltage, however this is not convenient in a machine powered by a battery. An alternative would be to place a resistor in series with the battery and the motor. This will reduce the speed of rotation of the motor, but the starting torque will be reduced as the initial current will be limited by the series resistor. There is also the problem of Ohmic heating of the series resistor.

The technique most commonly used to control the rotation of DC motors is Pulse Width Modulation. This technique allows high currents (and hence high torque) at low rotational speeds, and there is no power dissipation in the controlling circuit.

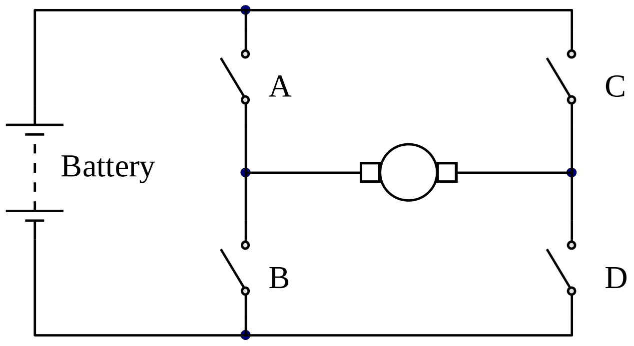


In the example above, the switch is closed for one unit and open for two units. In consequence, the average value of the applied voltage is reduced to 1/3 of maximum. Varying the ratio of on time to off time will result in a smooth variation in rotation speed.

The switch is not a mechanical device, it is a semiconductor such as a bipolar transistor, a MOSFET, or a thyristor. The speed of switching is important; if it is too slow, the motor will judder as it attempts to keep up with the on/off pulses. If it is too high, then the inductance of the motor coils will exhibit a high reactance, limiting the maximum current flow. A good compromise for the switching speed is in the range 100 to 500 Hz.

2.5 Directional Control: the H-Bridge

A simple on/off switching arrangement is satisfactory for unidirectional operation. If the motor must be reversed, then a more sophisticated circuit is required.

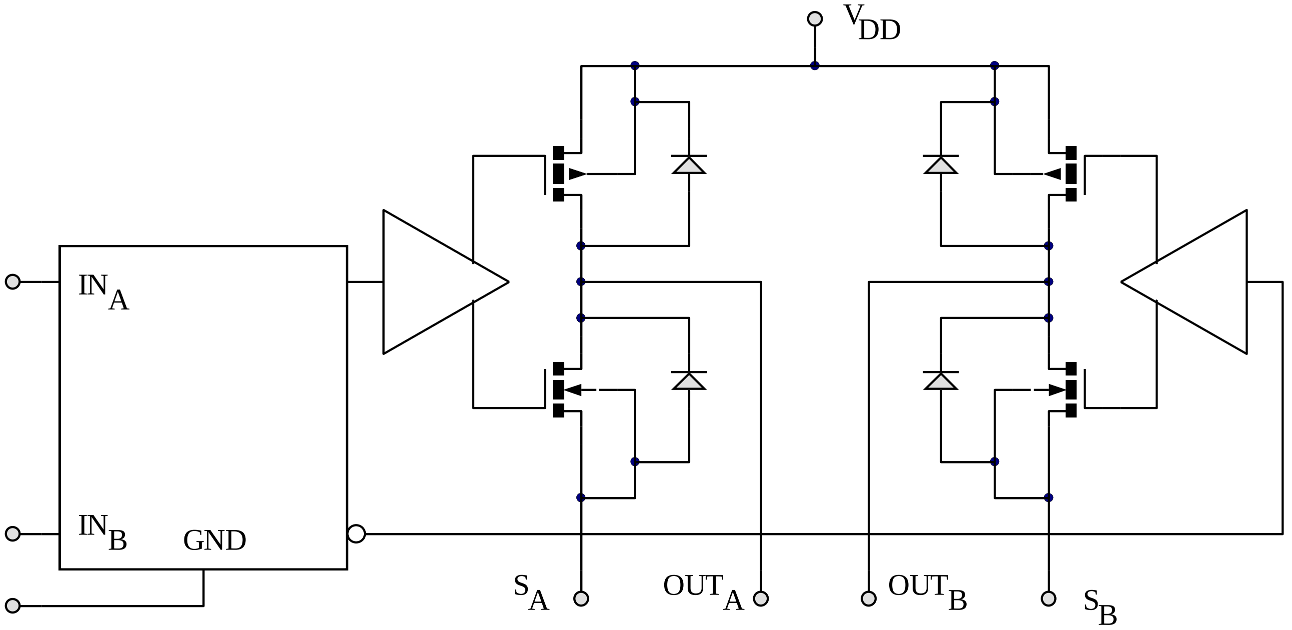


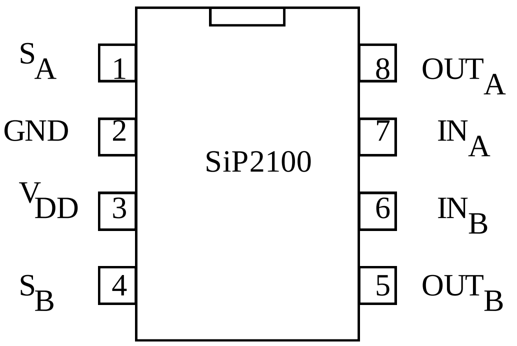
Consider the circuit above, in which a DC motor is connected to a battery using four switches. There are 16 possible states for the switches, of which some are forbidden, some are useful, and some do nothing.

A and D closed: current flows left to right through the motor (forward)
C and B closed: current flows right to left through the motor (reverse)
A and B closed: forbidden!
C and D closed: forbidden!
B and D closed: braking
A and C closed: braking
all switches open: free run

There are four useful states among the 16 possibilities, so a simple logic array is needed to code the switch controls. Many semiconductor manufacturers produce complete integrated packages for this purpose. The integrated circuit used in micromouse is manufactured by Vishay Siliconix and has four MOSFETs as the switching elements. Built-in diodes are provided to protect the MOSFETs from damage, resulting from rapid breaking of motor current. The inductance of the coil can produce a large back emf which may damage the switches. The diodes conduct and route any back emf pulses into the supply. The source connections of the "low side" MOSFETs are brought out so that the current taken by the motor can be monitored.

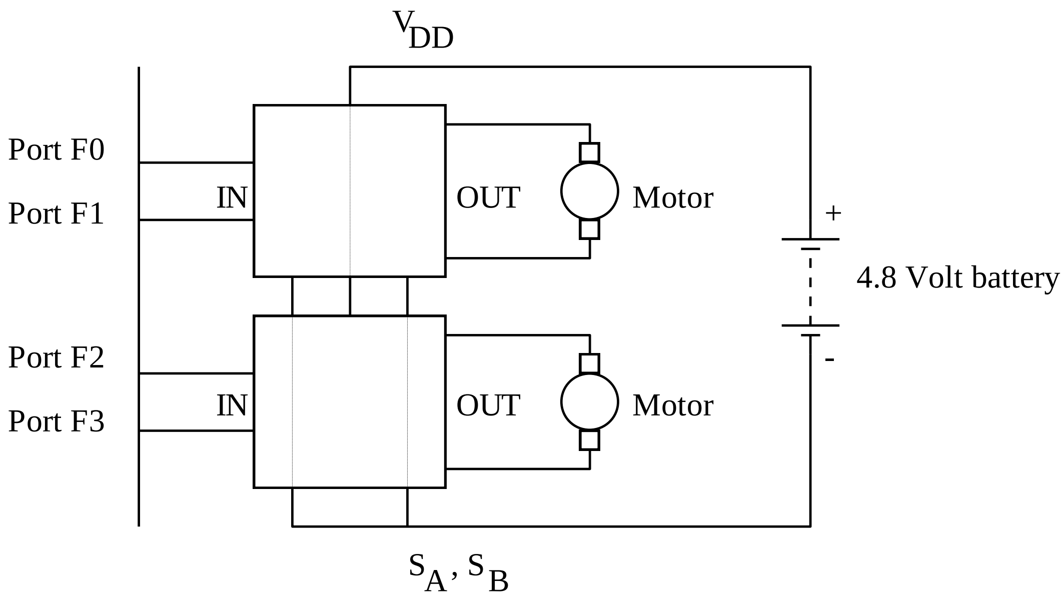
The SiP2100 integrated circuit is normally supplied in a SOIC package, which is about 4 mm square. The small size is remarkable considering that the device can handle 1 A motor current and a maximum supply of 5.5 V. Two of these devices are mounted on the AW60 board to control the drive motors.





IN_A	IN_B	OUT_A	OUT_B	
1	0	1	0	Forward
0	1	0	1	Reverse
0	0	0	0	Braking
1	1	HiZ	HiZ	Free-Run

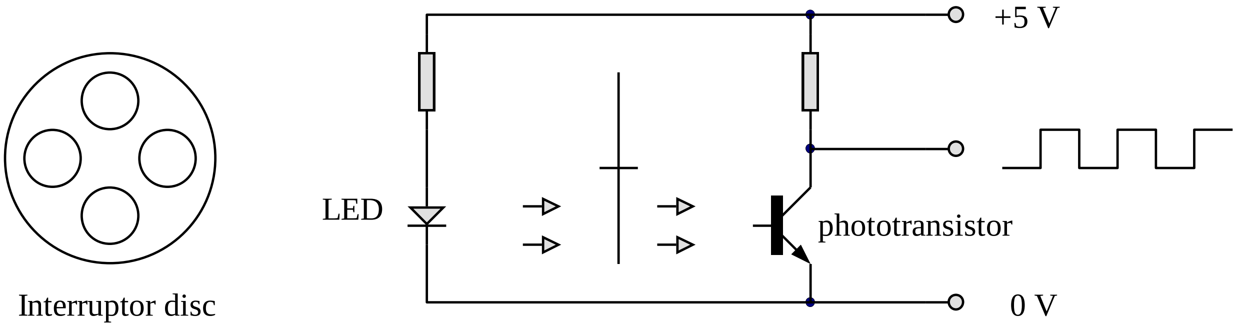
The two SiP2100 devices are connected to the AW60 microcontroller as follows:



The choice of ports is not random! Ports F0-3 are connected to outputs from the counter/timer unit inside the microcontroller so that the PWM waveforms can be driven directly by the hardware of the AW60. This can result in a very compact programme to control the motor speeds. Alternatively, the PWM waveforms can be generated by means of a foreground pogramme (not recommended) or by means of interrupts.

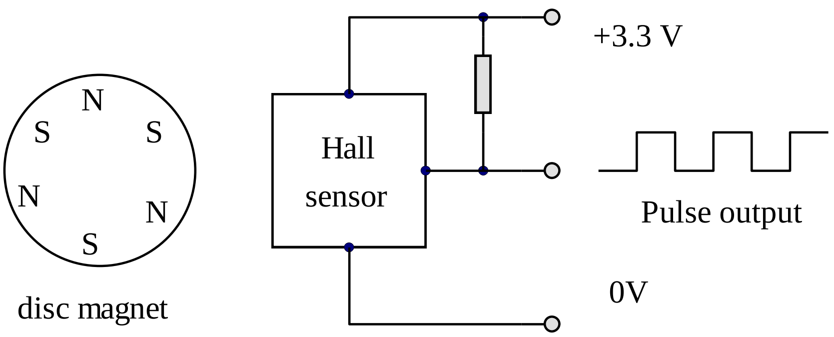
2.6 Motor Feedback

The motors will rotate at similar speeds if given the same battery voltage and PWM on/off ratio (duty cycle). However, for really reliable motor control some form of feedback is required. One technique that has been used successfully in the past is to attach interruptor discs to the motor shafts, and to count the rotations as pulses from a combination of light-emitting diode and phototransistor. For example, suppose the motor is fitted with a disc having four holes. The gearbox has a ratio of 50:1, so each rotation of the driving wheel will produce 200 pulses! Given driving wheels of 42 mm diameter, this means that linear movement is measured in units of $42\pi/200 = 0.65$ mm approximately.

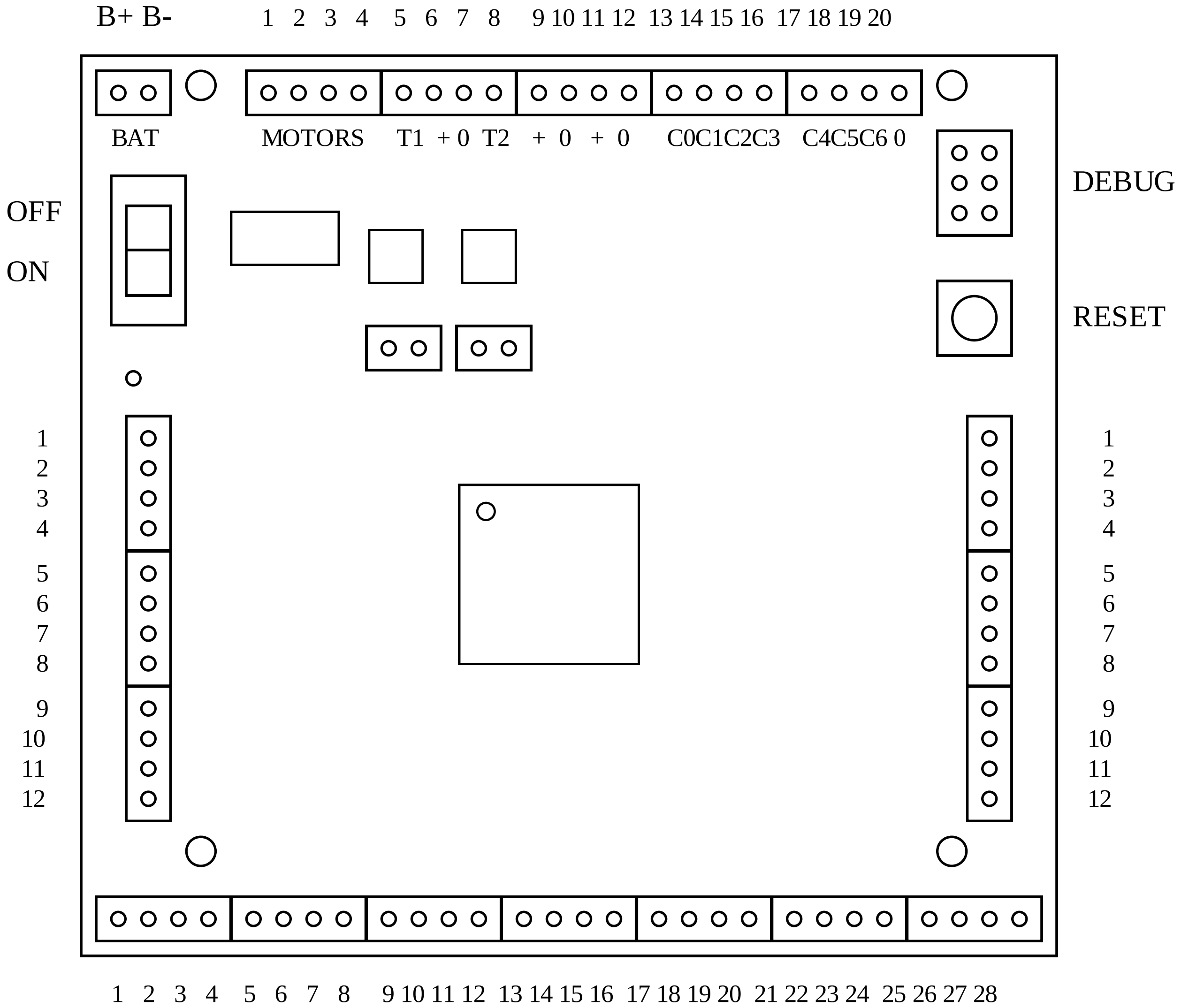


The pulses can be measured using another of the counter/timer pins on the microcontroller. The technique employed in the past has been to measure the time from the leading edge of one pulse to the leading edge of the next. Strictly speaking, this is the period rather than the frequency, however much greater accuracy can be achieved compared with measuring the number of pulses per second.

The latest tachometers from Pololu use a disc magnet and Hall effect sensors to detect rotation. The net effect is the same as with the interruptor disc, in that the microcontroller receives a square wave which is proportional in speed to the wheel rotation. According to the specification, the disc magnet has 6 poles (NSNSNS) and so there are 6 transitions for every rotation. This results in a linear resolution of $42\pi/(50$ times 6) which is approximately 0.45 mm. Higher resolution is possible by using both the tacho outputs and both edges of the pulses. For more information refer to the Pololu website, part number 3081.



3. AW60 Microcontroller Board



3.1 Introduction

The microcontroller board is based on the Freescale MC9S08AW60 microprocessor, which is one member of a large family of devices built around a common processor core. This particular version has 60 k bytes of programme memory, 2 k bytes of RAM, and numerous input-output devices including two serial ports, a serial peripheral interface, 10-bit ADC, and two comprehensive counter/timers. Information on the AW60 processor can be found on the Freescale website, by searching for the document MC9S08AW60. A family reference manual is available from the same website, HCS08RM.

Most of the ports are brought out to screw terminal connectors around the edge of the board. A 6-pin plug allows connection to the debug hardware.

A low drop-out regulator is included on the board, so that batteries of different voltage can be connected. The minimum battery voltage is 4.8 V to ensure correct operation. The maximum battery voltage depends on the motor controller integrated circuits, however a practical limit is 5.5 V when the motors are considered as well. A 3.3 V supply is available from several terminal block pins, with a maximum total current of around 200 mA. The actual value depends on the battery voltage.

3.2 Terminal Block Connections

Top Row Connections:

BAT B+, BAT B-: This isolated pair of terminals connects to the 4.8 V battery.

pin1: motor +	pin2: motor -	;connect to motor left
pin3: motor +	pin4: motor -	;connect to motor right
pin5: tacho input	pin6: +3.3 V	;connects to tachometer left (PTF bit 5)
pin7: 0V	pin8: tacho input	;connects to tachometer right (PTF bit 4)
pin9: +3.3 V	pin10: 0V	;Power supply for tachometer
pin11:+3.3 V	pin12: 0V	;Power supply for tachometer
pin13: Port C0	pin14:Port C1	;Port C connections (also IIC)
pin15: Port C2	pin16:Port C3	;Port C connections
pin17: Port C4	pin18:Port C5	;Port C connections (also SCI2)
pin19: Port C6	pin 20: 0V	;Port C connections

Bottom Row Connections:

pin1: +3.3 V	pin2: 0V	;Power supply connections
pin3: Port G0	pin4: Port G1	;Port G connections
pin5: Port G2	pin6: Port G3	;Port G connections
pin7: Port G4	pin8: 0V	;Port G connections
pin9: +3.3 V	pin10:0V	;Power supply connections
pin11:Port A0	pin12:Port A1	;Port A connections (digital)
pin13:Port A2	pin14:Port A3	;Port A connections (digital)
pin15:Port A4	pin16:Port A5	;Port A connections (digital)
pin17:Port A6	pin18:Port A7	;Port A connections (digital)
pin19:+3.3 V	pin20:0V	;Power supply connections
pin21:Port B0	pin22:Port B1	;Port B connections (digital + analogue)
pin23:Port B2	pin24:Port B3	;Port B connections (digital + analogue)
pin25:Port B4	pin26:Port B5	;Port B connections (digital + analogue)
pin27:Port B6	pin28:Port B7	;Port B connections (digital + analogue)

Left Column Connections:

pin1: 0V	pin2: +3.3 V	;Power supply connections
pin3: 0V	pin4: +3.3 V	;Power supply connections
pin5: Port E0	pin6: Port E1	;Port E connections (also SCI1)
pin7: Port E2	pin8: Port E3	;Port E connections (also TPM1CH0,1)
pin9: Port E4	pin10:Port E5	;Port E connections (also SPI)
pin11:Port E6	pin12:Port E7	;Port E connections (also SPI)

Right Column Connections:

pin1 :Port D7	pin2: Port D6	;Port D connections (digital + analogue)
pin3 :Port D5	pin4: Port D4	;Port D connections (digital + analogue)
pin5 :Port D3	pin6: Port D2	;Port D connections (digital + analogue)
pin7 :Port D1	pin8: Port D0	;Port D connections (digital + analogue)
pin9: +3.3 V	pin10:0V	;Power supply connections
pin11:+3.3 V	pin12:0V	;Power supply connections

3.3 Some Useful Ports

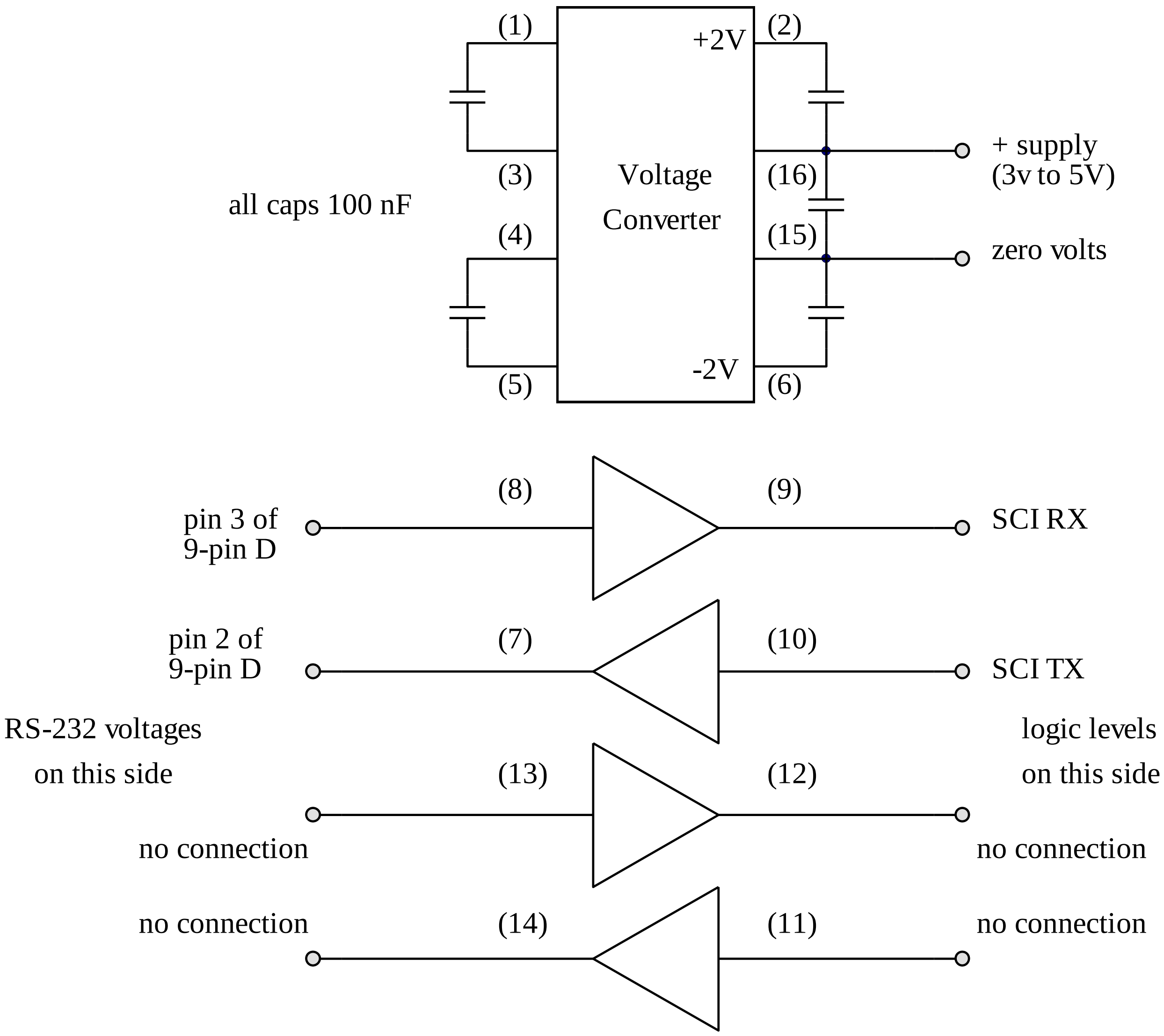
SCI1, SCI2: These pins allow the board to be connected to an RS232 interface (COM port) via a suitable interface. A standard design for the interface is available to the teams, based on the MAX3232 integrated circuit.

SPI: This is a group of four processor pins which implement a standard Serial Peripheral Interface. There are a wide range of devices which can be connected via SPI, including ADC, DAC, serial memories, port extenders, and so on.

ADC: The processor features a built-in analogue to digital converter (ADC) which takes analogue voltages as input and returns a binary number of 8 or 10 bits as required. The maximum input voltage is the same as the supply voltage, so in our case the maximum input is 3.3 V. Each quantisation step is therefore (3.3 V/256) = 13 mV approximately in 8-bit mode, or (3.3 V/1024) = 3.3 mV approximately in 10-bit mode. The time for one conversion depends on internal dividers and the processor clock, however conversion speeds of several kHz can be achieved.

IIC: This is another serial interface for peripheral devices. It is more complex to use than the SPI because the interface standard has a well-document protocol to allow multiple peripheral devices to connect via the same IIC port.

3.4 Serial Interface Adaptor



The AW60 microcontroller has two asynchronous serial interfaces, SCI1 and SCI2, which can be connected to the COM port on a PC using a suitable adaptor. A convenient device for making the adaptor is the Maxim MAX3232, which combines two RS-232 receivers, two RS-232 drivers, and a voltage converter in one 16-pin package.

The RS-232 specification requires a logic "1" level of -12 V, and a logic "0" level of +12 V. Clearly, this is not suitable for direct connection to the AW60, which operates at a maximum of +3.3 V. The MAX device translates the high voltages on the RS-232 interface (the COM port) into suitable logic levels for the AW60. It requires only a single supply voltage, as the higher + and - voltages are generated within the device using a clever circuit which charges capacitors in parallel and then discharges them in series to create first a doubled supply voltage and next a supply of opposite polarity.

This interface can operate on a supply of +3.3 V or +5 V and can be connected to either SCI port of the AW60 processor.

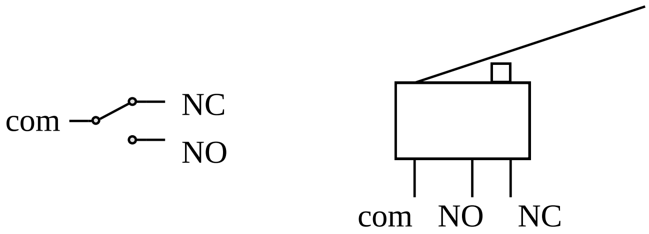
4. Sensors for Micromouse

4.1 Introduction

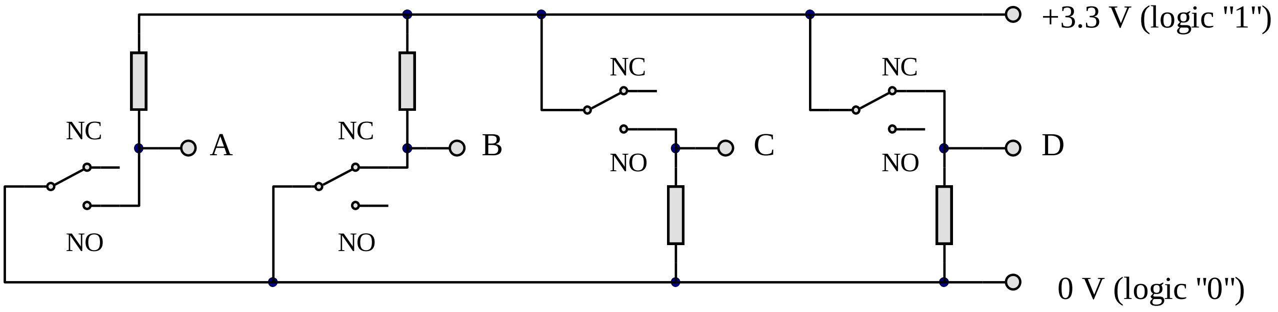
The micromouse needs various sensors in order to perform the tasks defined in Chapter 1. The touch bars are needed for obstacle avoidance and for combat. White line sensors are used for line following and staying within the arena in combat. Infra red sensors are used for obstacle location and to spot other micromice. Other sensors are available, for example an ultrasonic rangefinder. This device can provide additional information to the micromouse for obstacle avoidance and combat.

4.2 Touch bars

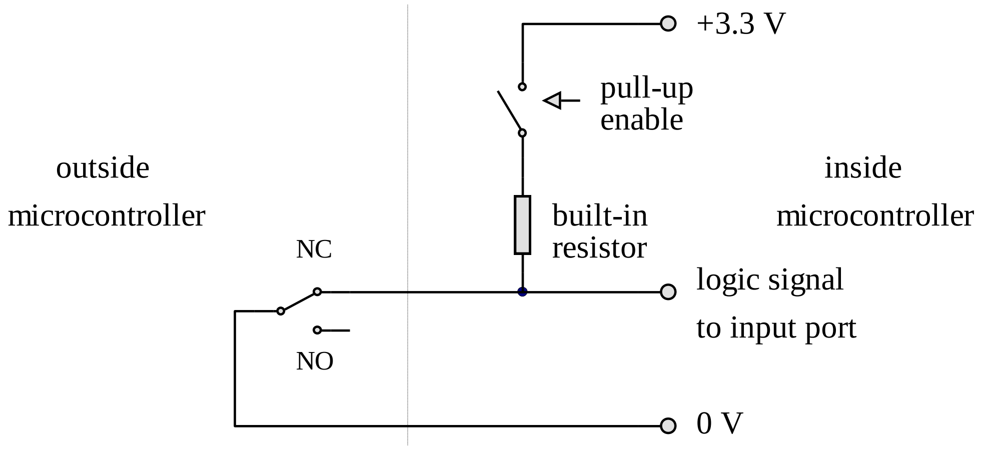
The simplest kind of sensor is an on/off switch which indicates that the machine has collided with an obstacle or another micromouse. A convenient switch is a V4 microswitch, which is a spring-loaded switch having one moving contact and two fixed contacts. When the lever is pressed, the moving contact "changes over" from the NC (normally closed) position to the NO (normally open) position.



A switch of this type can be connected to a microcontroller input port in several ways. First of all it is necessary to decide on the sense of the switching, i.e. "pressed" = logic "0" or logic "1". It is not necessary to use both contacts; a tie-up or tie-down resistor is a better solution, as there is no undefined state for the switch.



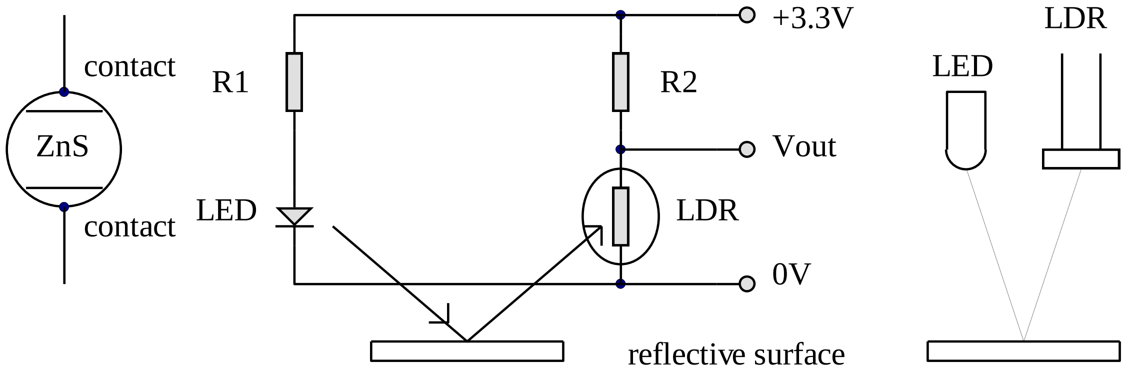
Consider the four logic outputs A-D. It can easily be seen that A and D give a logic "0" when pressed, and B and C give a logic "1" when pressed. If a logic "1" is desired, then option B is preferable to option C because the microcontroller has built-in resistors! These can be switched into operation using the PTxPE register, where "x" denotes the input port in use for the touch bars. The diagram below shows how to connect a microswitch to an input port so that the logic sense is pressed = "1". There is a small leakage of current through the resistor and closed switch, but this will not be significant compared with the current taken by other devices.



4.3 White Line sensors

The white line sensor must give a clear indication when the floor beneath the sensor is black background or white line. The sensing area is "shadowed" by the base plate of the robot, so a simple visible light detector can be used.

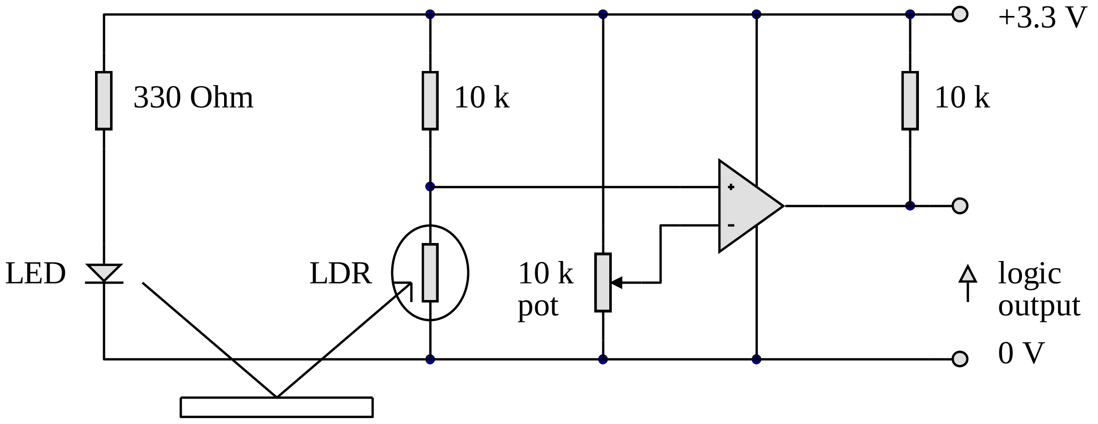
The Light Dependent Resistor is a low-cost, compact sensor which requires minimal circuitry to interface with the microcontroller. It consists of a thin film of Zinc Sulphide (ZnS) deposited on a ceramic substrate, with contact fingers deposited on each end of the film. The Ohmic resistance of such a sensor is very high in the dark (typically 100 k Ω). When the sensor is strongly illuminated, the resistance decreases to a few hundred Ohms. So a simple "half bridge" circuit can be used to convert the change of resistance into a change of voltage.



When the sensor is over a black surface, not much light falls on the LDR so its resistance is high. In consequence, Vout is high. When the sensor is over a white surface, the LDR is illuminated and its resistance is low and so is Vout.

The change in voltage may not be sufficient to give a clear 0/1 indication, so some kind of decision making is necessary. The simplest solution is to connect Vout directly to one of the analogue inputs of the microcontroller. Then a decision can be made in software if Vout is greater or less than the threshold, corresponding to a black or white surface. An example programme for "software" thresholding is available.

The following circuit is included for completeness. In practice, the "software thresholding" technique is preferable to physical comparators, as it exploits the microcontroller to good advantage and reduces the amount of extra circuitry.

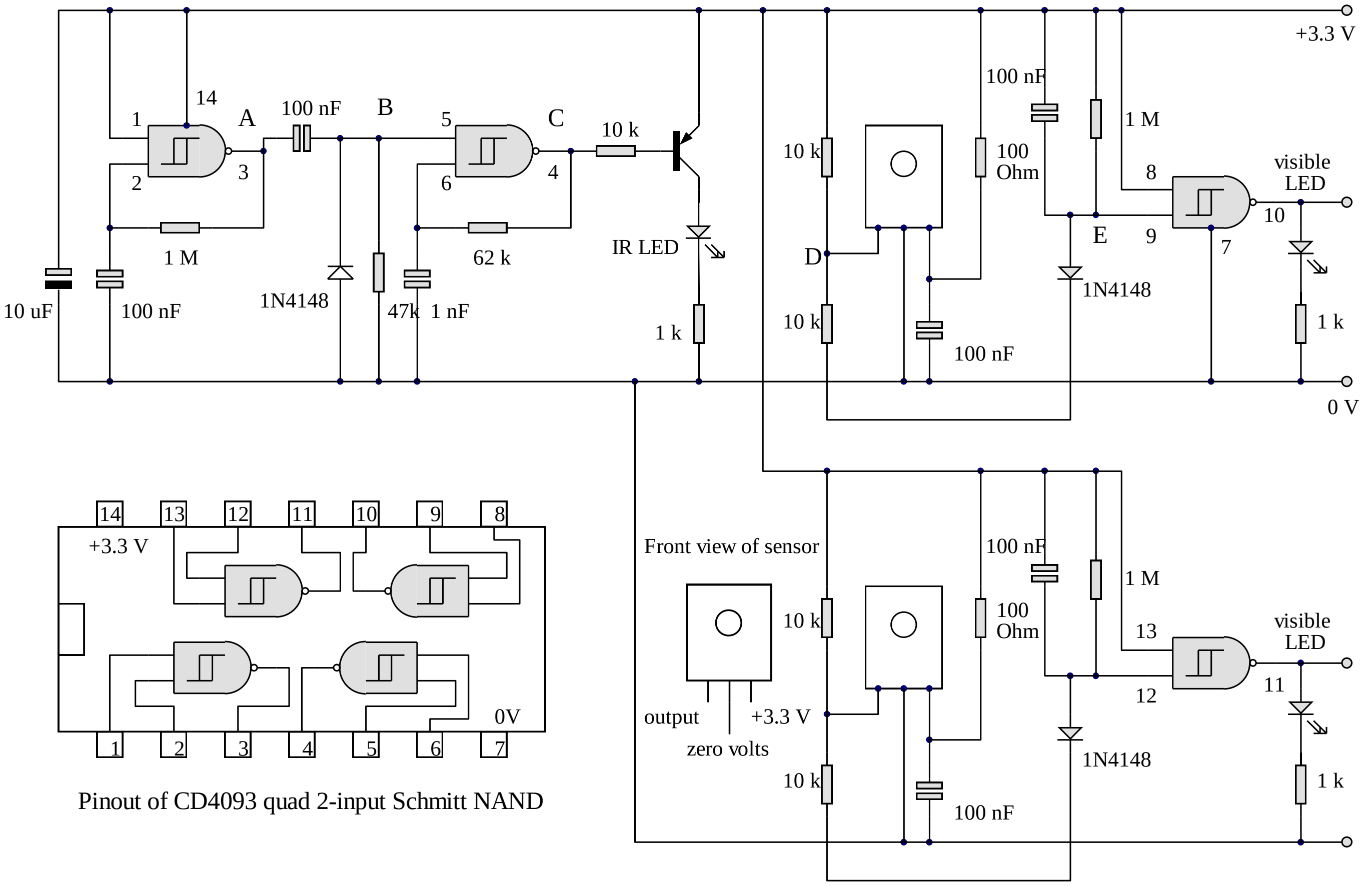


In the above circuit, Vout is connected to one input of a comparator, and the other input of the comparator is connected to a potentiometer wired between 0 and 3.3 V. Then the comparator will give a 0/1 indication depending on Vout being more or less than the reference voltage set by the potentiometer.

4.4 Infra-Red Sensors

Infra-red light lies just outside the human range of 300 nm to 700 nm wavelength. A typical infra-red LED produces light at 950 nm. In consequence, it is invisible to humans. It would not be practical to use LDR sensors to detect obstacles, as LDRs operate mainly in the visible range. There would be massive interference from other sources of light in the environment. In consequence, the sensor is based on an infra-red sensitive device with an optical filter. Even so, there is enough infra-red in the environment to mask the reflections from obstacles, so further protection is achieved by modulating the infra-red light source. The receiving sensor behaves like a radio receiver, and is "tuned" to the modulation frequency of the source. This combination of optical filtering, modulation and demodulation results in a complete sensor which is very sensitive to light reflected from obstacles, but is insensitive to environmental sources.

A complex circuit has been developed to generate the modulated light and demodulate it. The circuit modulates the light at two frequencies, at 40 kHz pulsed at 20Hz. This double modulation makes the sensor even more immune to interference, and also has the effect of reducing the current consumption as the LED is only illuminated for a small part of the time. Two sensors can be incorporated on a small PCB using just one integrated circuit.

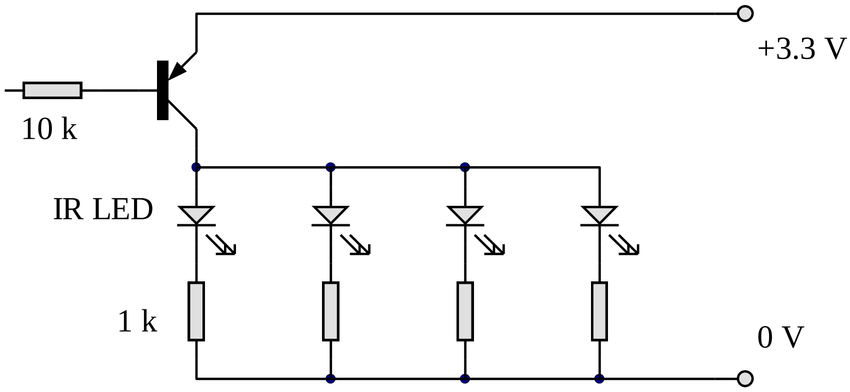


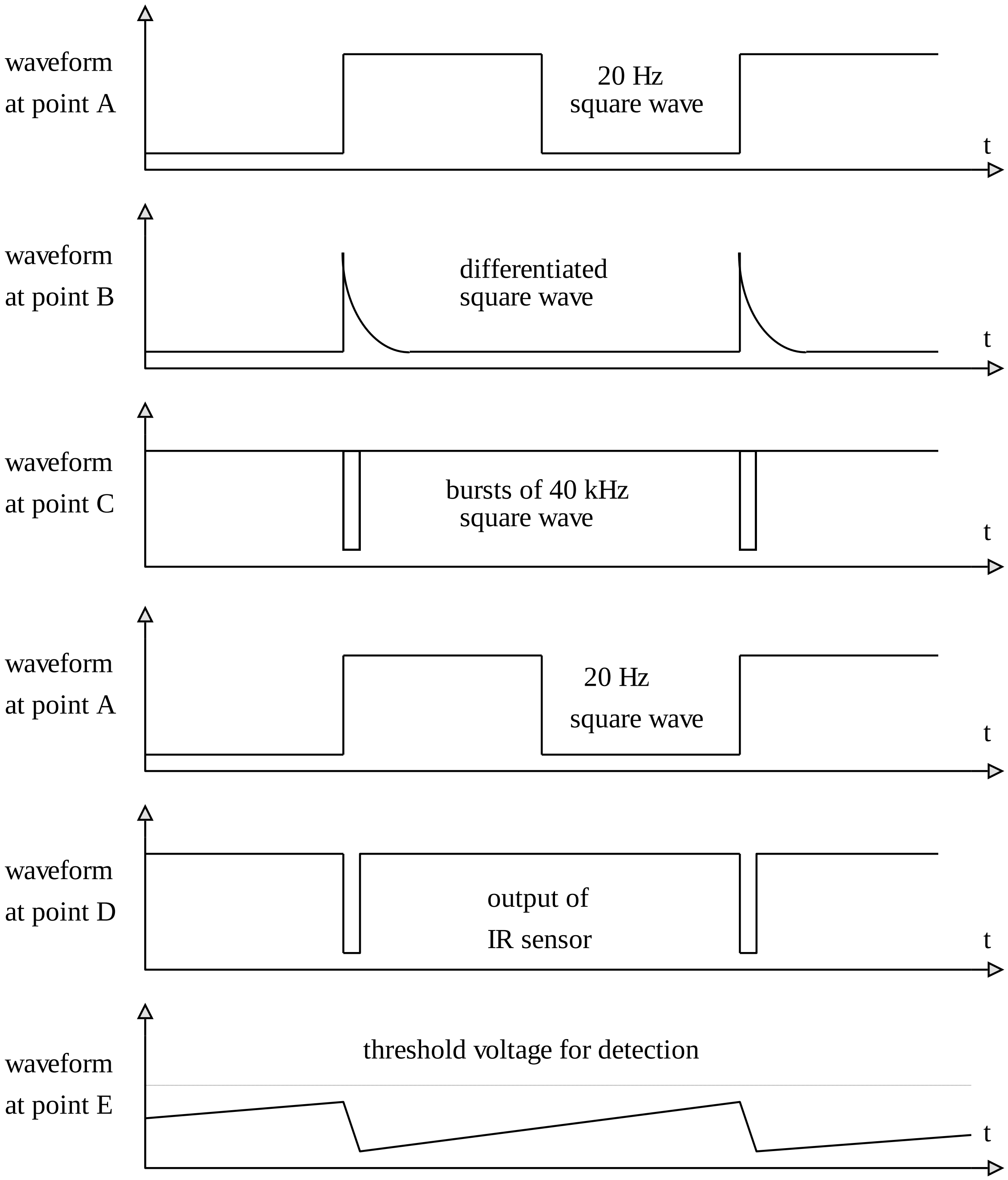
Pinout of CD4093 quad 2-input Schmitt NAND

The infra-red sensors used in this circuit are normally found in remote control receivers on televisions, CD and DVD players, in fact just about all the consumer devices that have remote control. In consequence they are mass-produced and are low cost, considering the complexity of the circuit. The part number is TSOP4838.

The integrated circuit is a CD4093 quadruple 2-input Schmitt NAND gate. This type of gate can be made to oscillate by wiring a resistor and capacitor as shown.

The first gate is a 20 Hz oscillator, producing a square wave. This drives a time constant and diode clamp which results in a narrow pulse at 20 Hz. This narrow pulse gates an oscillator at 40 kHz, producing short bursts of 40 kHz. This burst waveform controls the current in an LED via a pnp transistor. Multiple LEDs can be connected as shown in the diagram below. The pnp transistor can easily supply the current for many LEDs!





The output of the infra-red sensor is a pulse corresponding to the envelope of the burst waveform. This pulse is from 1 to 0, and is short in duration compared with one cycle of 20 Hz. A diode pump is used to accumulate several pulses, and another Schmitt input gate is used to make a 0/1 decision. The output of this gate is a clear 0/1 corresponding to no obstacle/obstacle. An LED is provided as a visual confirmation of operation.

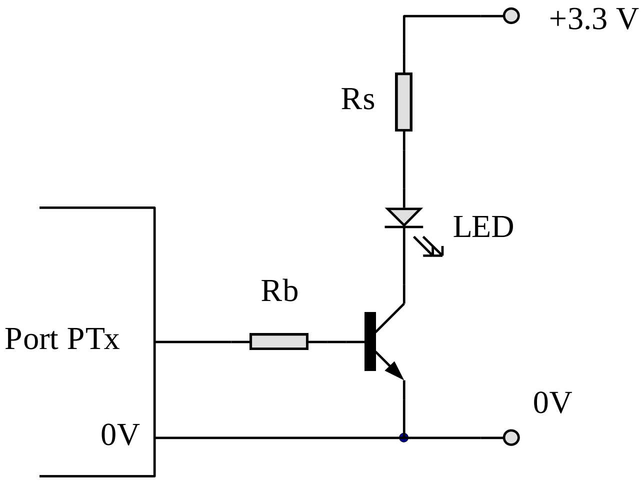
The sensitivity can be adjusted by increasing the current in the IR LED, e.g. by reducing the value of the 1k series resistor. The 10 k resistor in series with the pump diode has some effect on sensitivity, but its main function is to exclude very short noise pulses which would otherwise result in a false indication.

Useful tip: If you breadboard the circuit, try to find two IR sensors of approximately the same sensitivity for use on the final PCB.

4.5 Power Management

The technical inspection of the micromouse will include a review of the current drain in the different modes of operation. The DC motors are the largest drain on the battery, however other devices such as the visible LEDs take significant current. Some economies can be made on current drain by turning off devices not in use, for example the visible LEDs are not normally used in obstacle avoiding mode.

A simple method of switching devices on and off under programme control is to use a bipolar transistor controlled by a port of the microcontroller.



Referring to the circuit above, a white LED is wired in the collector of a NPN bipolar transistor. The resistor Rs limits the current that will flow from the 3.3 V supply.

Suppose a current of 2 mA has been specified for the LED, and that the forward voltage of the LED is 2.7 V. Then the voltage across Rs will be (3.3 V – 2.7 V) = 0.6 V. The value of Rs is given by Ohm's Law Rs = (0.6 V/2 mA) = 300 Ohms.

Now consider the output port PTx of the microcontroller. When it is in the logic "1" state it is at 3.3 V. The voltage drop across Rb will be (3.3 V - 0.7 V) = 2.6 V, assuming that the base/emitter voltage of the transistor Vbe = 0.7 V.

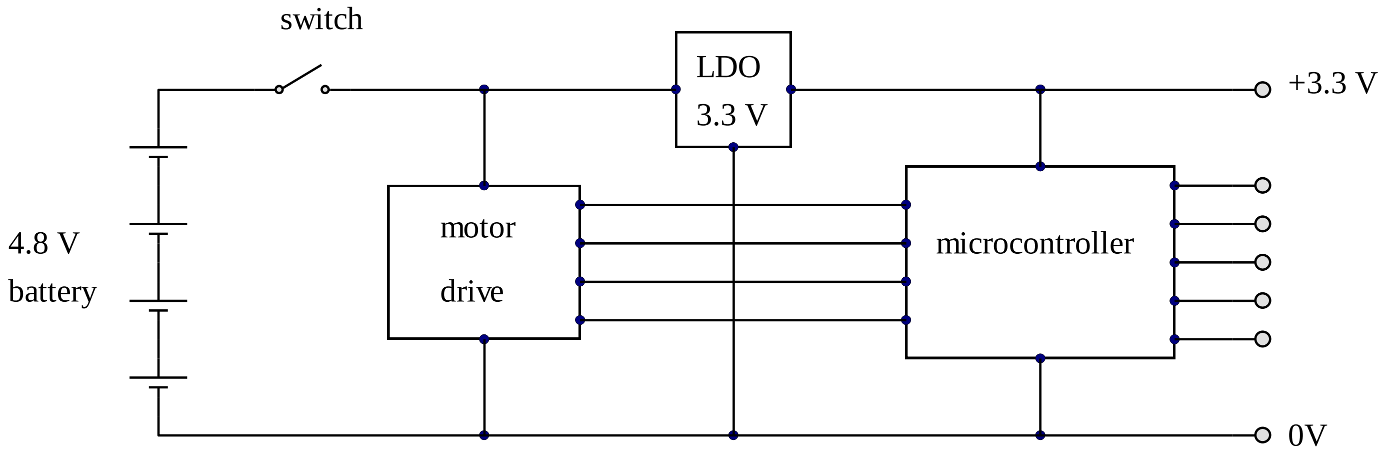
Assuming that the h_{FE} of the transistor is 200 (can be found in manufacturers data) then the base current will be (2 mA/200) = 10 μA. Hence the maximum value of Rb is given by Ohm's Law Rb = (2.6 V/10 μA) = 260 k Ohm approximately. In practice a smaller value of Rb for example 100 k Ohm would be used to ensure the transistor has a low voltage drop when it is turned on.

4.6 Power Regulation

The battery provided in our standard kit of parts consists of four, 600mAh nickel metal hydride cells. They can provide 60 mA for 10 hours, or 120 mA for 5 hours, and so on. The running current for a typical micromouse is less than 300 mA, so the battery should last for several hours.

Each cell provides a nominal 1.2 V, so the battery voltage is nominally 4.8 V. This can be as high as 5.5 V when the battery is fully charged, but will fall to a steady value of 4.8V after a short period of use.

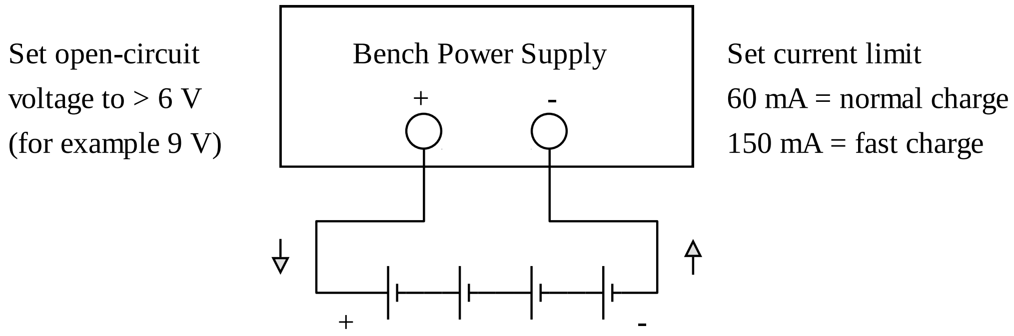
The microcontroller and surrounding circuits require 3.3 V, so some form of regulator is needed. The AW60 board is fitted with a low drop-out regulator which can accept input voltages down to 3.8 V. The maximum current for the regulator is 1 A, however for reasons of heat dissipation not more than 200 mA should be taken by the peripheral circuits, including the white line sensors and infra red interface.



It is very important that the microcontroller inputs are never more than 3.3 V or less than zero, otherwise the device will be destroyed. All interface circuits should operate from the 3.3 V outputs which are available on multiple terminals of the printed circuit board.

4.7 Battery Charging

A fully charged battery will run the micromouse for several hours. However it is a good idea to keep the battery charged. This is easily achieved using a bench power supply.



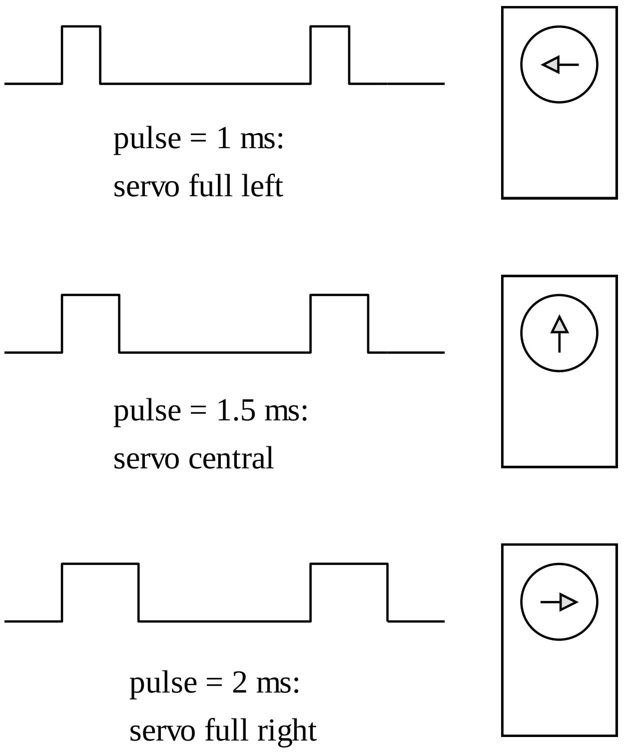
The nominal battery voltage while delivering current is 4.8 V, as each cell is rated at 1.2 V. The end point voltage of each cell while charging is 1.5 V, so a charging voltage of at least 6 V is necessary. The capacity of each cell is 600 mAh, so at a current of 60 mA the battery will take 10 hours to charge from zero initial charge. A higher charging current is permissible, but the battery may overheat if left charging for too long. For example, at 150 mA the battery will charge in 4 hours from zero. Once the battery is charged, the electrical energy is no longer converted to chemical energy, but appears as heat. In our example, with a current of 150 mA and an endpoint voltage of 6 V, the battery will dissipate 150 mA times 6 V = 900 mW so it starts to warm up. If the battery is left to charge indefinitely, the heat will cause loss of electrolyte and damage to the cells. In extreme cases, the cells can explode if left on charge at high currents, e.g. 1 A. This must be avoided at all costs! The chemicals inside the cells are corrosive alkalis, quite apart from the hazards of an explosion.

The batteries have very low internal resistance, so a short-circuit will result in a high current (maybe tens of Amps) and rapid heating with the possibility of explosion.

Only use the supplied leads to connect the batteries to your micromouse or to the charger. Random wires and crocodile clips are a sure recipe for disaster.

4.8 Controlling a Servo

Some teams have used servos to provide special features on their micromouse. The output compare function can be used to produce the waveforms needed to control a standard servo. These compact devices feature a dc motor, gearbox, and integrated electronics, so that the output shaft can be positioned in proportion to the width of the input pulse. Servos are used commonly in model aircraft and in robotics.



The servo control pulse can be produced automatically using existing interrupts on the AW60 microcontroller. For example, the main motor pwm is timed from Timer 1 overflow, which in the example programme is set to 100 Hz. Strictly speaking, the repeat frequency of the servo control pulse should be limited to 50 Hz, but experience shows that it will function at 100 Hz. The critical item is the **width** of the pulse, which needs to be controlled precisely.

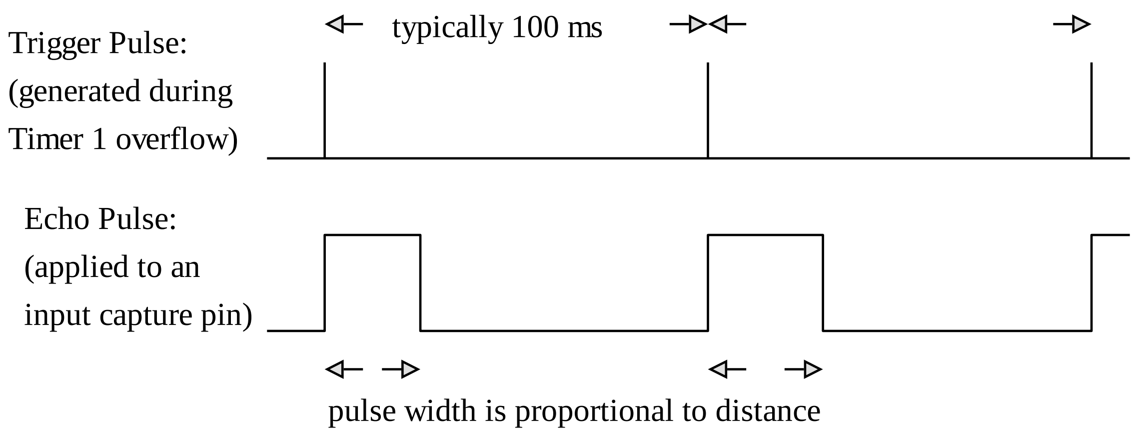
A test programme has been written which turns a designated port ON during the 100 Hz overflow interrupt. Then another interrupt, e.g. Timer 1 channel 3, in output compare mode, can be set to occur 1-2 ms after the overflow, and turn the designated port OFF. In this way, the servo position can be controlled with a single write to Timer 1 channel 3 register. The number written is proportional to the angular position, for example the central position requires a 1.5 ms pulse, which is 3000 cycles of the 2 MHz bus clock.

4.9 Ultrasonic sensor

Another application of the timer overflow function combined with input capture, is to control an ultrasonic sensor. Pulses of ultrasonic sound are sent out regularly and return if reflected from a nearby object. The input capture function can be used to time the arrival of the return pulse, which is proportional to the distance the ultrasonic pulse has travelled. The speed of sound is around 330 m/s, so that an object 1 m away will return an echo in 6 ms (out and back).

The popular SR04 ultrasonic sensors have a trigger input and an echo output. These can be connected to suitable pins on the AW60 microcontroller. There is however a minor problem with voltage levels. The SR04 requires 5 V for correct operation, so the echo output must be “clamped” to 3.3 V to prevent damage to the AW60.

Again, the Timer 1 overflow can be used to control the trigger pulse, and another channel of Timer 1 e.g. channel 4 can be used in input capture mode to measure the time elapsed since the pulse was sent. The 10 ms of Timer 1 overflow is not long enough to allow echoes to subside, so a software counter must be implemented to count (say) 10 timer overflows, corresponding to 100 ms. This operation can be a bit “hit and miss” as echoes are received from many surfaces, so the number obtained from the input capture register needs to be checked to see if it lies within certain limits.



Example programmes will be made available on the Canvas pages of EG-252 to illustrate how the servo control and ultrasonic sensor can be incorporated into the main programme. The objective is to make these functions operate completely automatically using the existing interrupt structure, so that there is no impact on the main part of the programme. These programmes will be dealt with in the associated lecture course and during laboratory sessions.

4.10 Safety Precautions

As with all laboratory and workshop activities, safety is a prime concern.

Always wear eye protection when using power tools, cutting wires or soldering. (This applies to helpers and spectators, too!)

Never use power tools unless supervised by a demonstrator.

Be careful when using glue guns, as they become very hot and should not be left on if unattended. Pools of molten adhesive on our nice clean bench tops are to be avoided.

If you need to trim plastic pieces you must work on a suitable cutting board.

4.11 Good Luck!

We have run the Micromouse exercise for many years and every year we see some new innovation, spcial feature, or technical improvement. The experience of designing an end product to a well-defined specification is a vital part of your course. In their recent accreditation visit, the representatives from the IET and the Engineering Council expressed their strong approval of the exercise, and their hope that it would continue.

The Laboratory Team wish you all the best, and look forward to seeing your creations and how they perform!