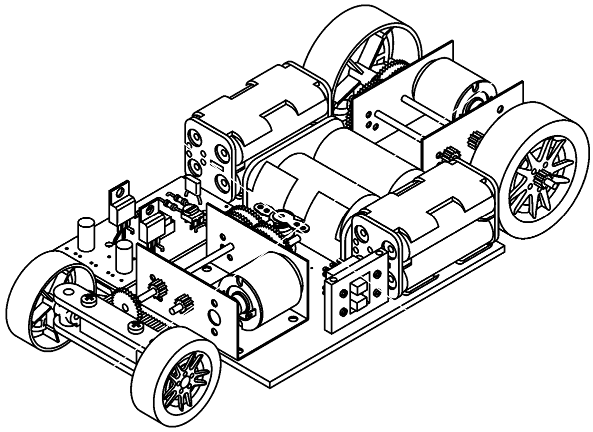
FOLLOW THE WHITE LINE VEHICLE

DESCRIPTION

The creation of a *FOLLOW THE WHITE LINE* vehicle requires the student to design and build a vehicle, which is capable of following a white line taped to a dark surface. Light Dependent Resistors determine the position of the vehicle relative to a white line, and steer it along that.

The project requires the student to:

- design and fabricate the vehicle chassis and steering mechanism
- identify, select, assemble and solder components on to the Printed Circuit Board
- carry out wiring on the remaining electrical parts (eg battery holders, motor/gearbox)
- layout, measure, mark, cut, shape, drill and assemble the vehicle and components as required.
- Carry out testing, diagnosis and evaluation of the completed vehicle



The vehicle could be approximately 130 x 300 in size. The final size of the vehicle depends on the layout of the components by the designer. Two gearbox and motor assemblies are used: one to steer the vehicle and the other to drive the vehicle. Light Dependent Resistors (LDRs) mounted on the vehicle determine the position of the vehicle relative to a white line. The information gathered by the LDR's is sent to the electronic circuit controlling the vehicle's steering.
Note: The prototype vehicles, that the drawings and design options are based on, were constructed by year 10 students, who had two years experience in electronics.

COMPONENTS REQUIRED

a) COMPONENTS SUPPLIED

The following components are supplied in a plastic bag, for the construction of one vehicle:-

1 x	Printed Circuit Board (FWLV)	1 x	2.4V 0.5A Light globe
2 x	1K Ohm Resistor	1 x	Globe Holder
1 x	220K Ohm Resistor	2 x	Front Wheel axle (knurled pin 3x20mm)
1 x	470K Ohm Resistor	2 x	Front Wheel knuckles
1 x	8 Pin I.C. socket	1 x	Gear Rack
1 x	LM 741 – I.C.	1 x	Steering link
1 x	1K Ohm Trimpot	2 x	Wheels 38 mm dia (Front)
1 x	1 μF Met. Poly Capacitor	2 x	Wheels 52 mm dia (Rear)
2 x	100 μF Electrolytic Capacitor	2 x	4 AA Battery holder
1 x	TIP 122 Transistor	1 x	2'C' Battery holder
1 x	TIP 127 Transistor	2x	Self-tapping screws 2.6mm x 4 long
2 x	Light Dependent Resistor	2x	Self-tapping screws 2.5mm x 10 long
2 x	Slide switch (small)	2x	12T Pinion Gear
4 x	Bolts (for Switches)	1x	30T Spur Gear
		3x	50Tx10T Spur Gear (yellow/2.6mm hole)

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Revised: 20th April 2009

2x *MULTI-RATIO kits for kits,* ***in each****:*

1x Multi-ratio Gearbox case
1 x S18 Electric motor (round)
2x 2.5 dia x120 mm long steel rod
1x 3mm inner dia 1.0 thick Washer
2x M2.6x 4 self-tapping Screws
2x 50Tx10T Spur gears (white/2.4mm hole)
1x 50Tx10T Spur gear (yellow/2.6mm hole)
2x 12T Pinions 2.4 hole
1x 10T Pinion 1.9 hole

b) ADDITIONAL REQUIREMENTS

b1) The following are available from us, and need to be ordered separately: AA batteries (HD), 2.3mm, 2.6mm and 3.5mm diameter drill bits.

b.2) The following material is to be supplied by the student / designer: fine, multi-strand electric hook-up wire (assorted colours); black PVC insulation tape; material for the various body components (PVC or acrylic sheet etc), and everything else!

DESIGN STAGE

The major aspects of this project are the design, construction and assembly of the vehicle. The design stage is crucial. At this stage the location of all the components is worked out. It is best to do this by laying all of the components on a sheet of graph paper. The layout affects the size and shape of the vehicle's chassis, as well as the ease of assembly. Particular attention should be paid to the design of the steering mechanism and clearances to the front wheels. For this, an accurate drawing is necessary, so that the components can be made accordingly.

- Drawings of the vehicle we built are provided at the end – for reference purposes.

For information to help with design, please read the entire unit first for ideas: especially Sections 2.1 Steering Gearbox and motor; 2.2 Clearance to the front wheels, 2.3 Locating the steering gear box; 3. Gearbox and Motor assembling, 5.1 Rear wheels, 6.1 Light Globe and LDR Placement, 10. Calculation of turning circle.

Note: before assembly is commenced, the gearbox ratios need to be selected for both the steering gearbox and the drive gearbox. The Multi ratio gearbox kits provide a choice of 4 gears, depending on the desired reduction speeds (below). Refer to Section 3 for gearbox assembly information.

- for the Steering Gearbox, we used the Fourth reduction ratio
- for the vehicle's Driving Gearbox, we chose the Third reduction ratio

1. CHASSIS

Choice of Material: For the prototype vehicle 3 mm PVC was used. This material was chosen as it is easily cut, shaped, drilled and glued. MDF and Acrylic are some other options, but were not chosen for various reasons (can you work out why?).

2. THE STEERING MECHANISM AND THE FRONT WHEELS

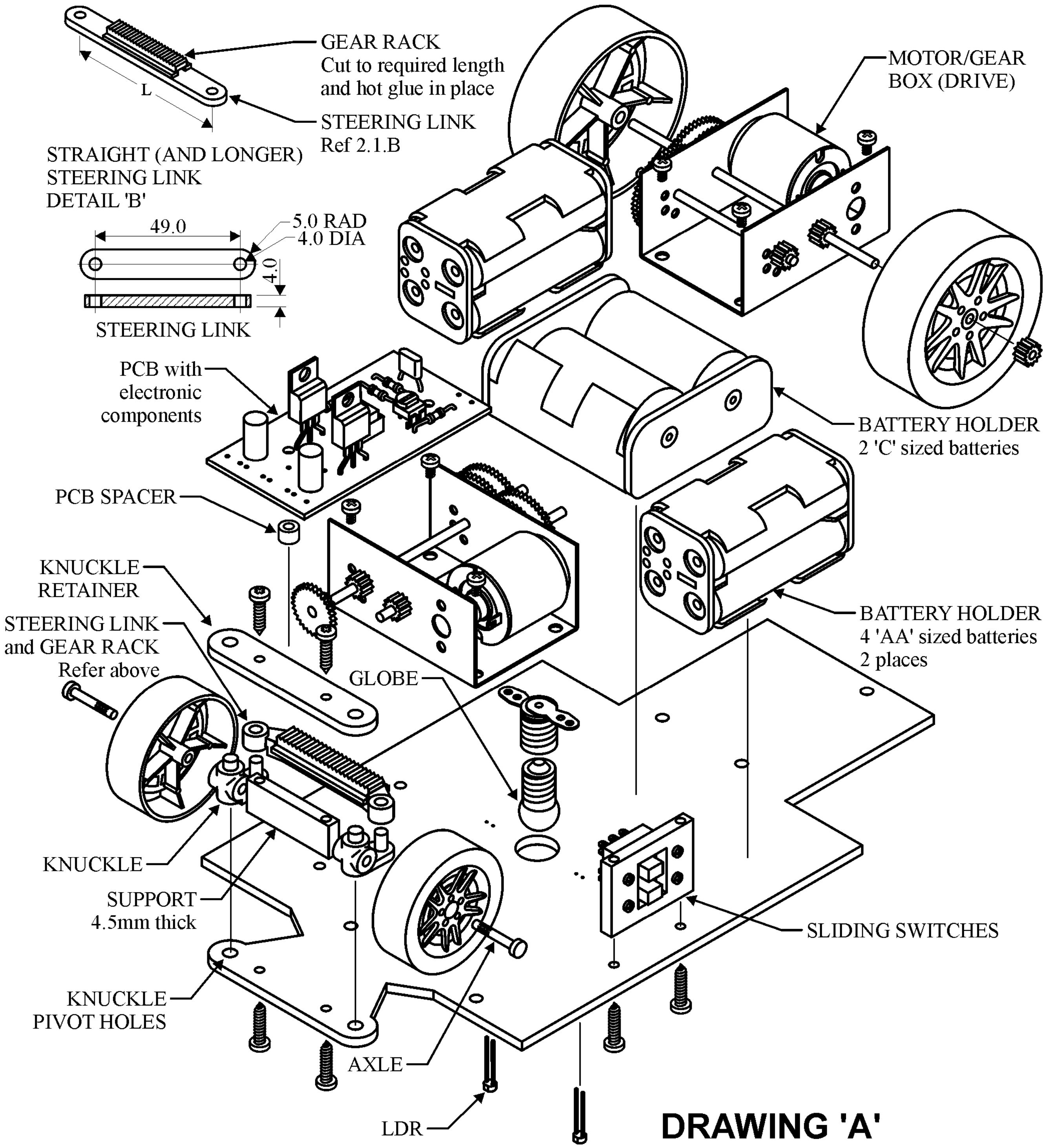
2.1 STEERING DESIGN

There are many different ways that a vehicle may be steered. Detailed below are three possible options (a, b and c), although other options may be used.

- Using the knuckles and steering link supplied, a neat construction is achieved. However, when using these parts, the front wheel track (i.e. the distance between the wheels) is rather narrow: refer Drawing 'A'.
- Using the knuckles, as supplied, but fabricating a longer steering link, will achieve a wider front wheel track. To simplify manufacture, a straight link may be used: refer detail on Drawing 'A'.

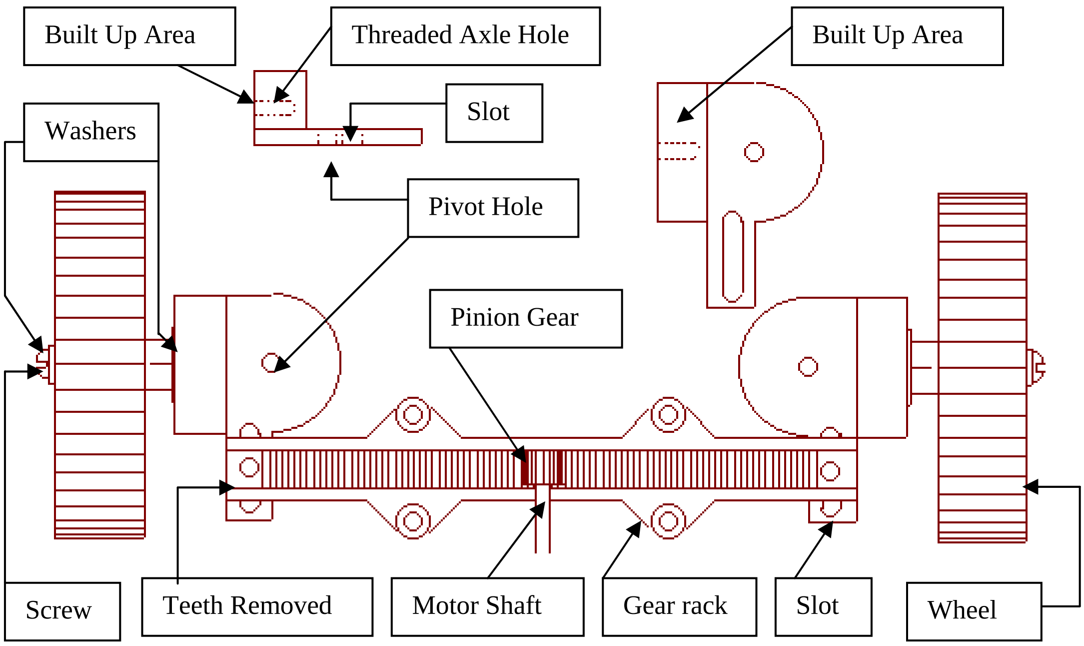
- Construction of a different design steering linkage as shown in the schematic Drawing 'B'. This requires more thought and planning, as well as a lot of construction work. This option uses the gear rack as a moving part, and will require restraining. The rack may be restrained using one of the following methods listed below: refer Drawing 'C': Methods 1, 2, and 3.

Note: The gear rack must be restrained, otherwise it will tend to rock from side to side, causing the pinion gear to jam.

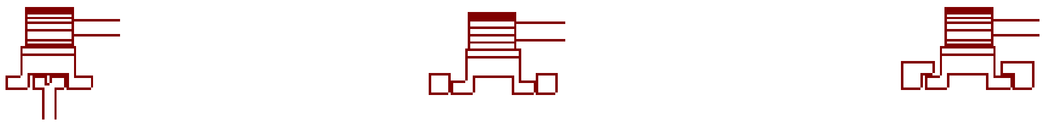


2.2 CLEARANCE TO THE FRONT WHEELS

The chassis needs to be designed, so as to provide clearance to the front wheels. This is to allow the wheels to turn approximately 20 - 25 degrees in either direction. During the design stage allow adequate clearance for the wheels, and at the construction stage add turn limiters to restrict the amount the wheels can turn.



DRAWING 'B'



DRAWING 'C'

Method 1
Uses 2mm cheesehead screws. The head just fits into the slot on the underside of the gear rack. Two screws, screwed into the chassis keep the rack in the required plane. The pressure of the pinion gear prevents the gear rack from lifting. The 2mm screw is the same type as used for the slide switches.

Method 2
Glue a strip of material to the chassis on either side of the gear rack. You will need to position the strips carefully or they may hit the protrusions around the mounting holes. If this is a problem you could remove the protrusions and lip.

Method 3
(This is a variation of method 2.)

This uses a rebate on the strip material to fit over the gear rack lip.

2.3 MOUNTING THE STEERING GEARBOX AND MOTOR

For the Gearbox and motor assembling instructions, refer Section 3.

The positioning of the steering gearbox and motor should be carried out after the design of the steering mechanism, and the wheel clearance, has been finalised. The gearbox should be placed as close as possible to the gear rack, as this allows the shaft length to be reduced, which reduces flexing of the shaft. When the gearbox location, relative to the steering rack, has been worked out, the 30T Spur gear is assembled to the output shaft. This needs to mesh with the steering rack.

The gearbox and motor may require packing between it and the chassis, to achieve satisfactory meshing of the 30T Spur gear with the gear rack. For the basic steering design, we did not require any packing, but this will depend on the steering design chosen. If required, the packing should be glued to the chassis and be large enough to accept the gearbox assembly.

2.4 MOUNTING THE FRONT WHEELS

The 38mm Front wheels each have a blind 2.4mm hole. The wheels' centres need to be drilled through, for the 3.0mm diameter front axles to be pushed through, while still allowing the wheels to turn freely.

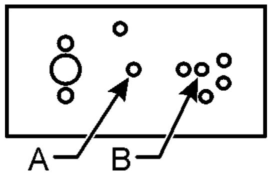
The axles (knurled pins) are then installed through the wheel centres, and firmly pushed into the steering knuckles, leaving the wheels able to rotate freely.

3. ASSEMBLING THE GEARBOX AND MOTOR

The *MULTI-RATIO GEARBOX* kit provides a choice of 4 gear ratios to choose from. Before starting assembly, the desired gear ratio must be determined for each usage (Steering / Driving), as this defines the parts to be used and the assembling procedure. Refer the Design Stage section.

3.1 GEARBOX OPTIONS

GEARBOX STAGE / Reduction ratio	OUTPUT SHAFT	RATIO
Single reduction	Hole A	1:5
Double reduction	Hole B	1:25
Triple reduction	Hole A	1:125
Fourth Reduction	Hole B	1:625

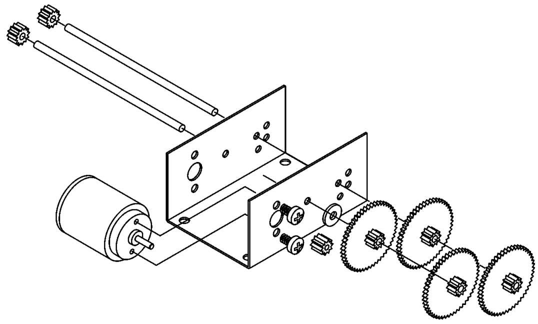


Standard Motor (S18) - Rated at 4.5V	Performance
3 Volts: ie. Powered by 2xAA batteries	6,500 rpm ##
6 Volts: ie. Powered by 4xAA batteries	12,600 rpm ##
Torque	17.9 g.cm

Motor speeds quoted are approximate rpms under load

WARNING: Using a higher voltage increases the speed of the motor, but can reduce the life of the motor.

3.2 ASSEMBLING THE GEARBOX



GENERAL:

- for this Gearbox, the holes marked 'A' & 'B' in the drawings are to be used - the available gears will not function if fitted to any other holes
- the 10T pinion gear (which has a 1.9mm hole) is press fit on to the electric motor's 2.0mm shaft
- the 12T pinions are used as locators.
- the white spur and 12T pinion gears (which have a 2.4mm hole) are press fit on to the 2.5mm shafts while the yellow spur gears are free wheeling on the shaft and have a 2.6 diameter hole.
- the outside two 50T spur gears (ie one on each shaft) must be white gears, which are press fit, while the inner (closer to the case) are yellow 50T, which are free spinning .
- the gears can be assembled onto the shaft/s with a help of small hammer.

3.2.1 GEARBOX SELECTION

Before starting assembly, and depending on the intended use of the gearbox (ie Steering or Driving):

- determine the desired gearbox ratio – as this will define which output shaft will be used as the axle
- define the length of the axle shaft, and cut (and de-burr) the steel rod to that length.

3.2.2 ASSEMBLY PROCEDURE:

Assemble the steel rods, and all the gears, to the gearcase - as shown in the appropriate drawing– Single, Double, Triple or Fourth reduction. Also refer to the exploded diagram.

3.2.1 SINGLE REDUCTION

- Fit the shaft to the hole nearest the motor (Hole A), add the 12T pinion gear (locator), with the 1.0mm washer between the case and the (white) 50T spur gear.

3.2.2 DOUBLE REDUCTION

- Start by fitting the first shaft to the hole nearest the motor (Hole A), add the 12T pinion gear (locator), with the 1.0mm washer between the case and the (white) 50T spur gear
- Add the second shaft to Hole B, and add the 12T pinion gear (locator) and the (white) 50T spur gear.

3.2.3 TRIPLE REDUCTION

- Start by fitting the first shaft to the hole nearest the motor (Hole A), add the 12T pinion gear (locator), with the 1.0mm washer between the case and one (yellow) 50T spur gear
- Add the second shaft to Hole B, and add the 12T pinion gear (locator) and one (white) 50T spur gear.
- Install a (white) 50T Spur gear on the shaft nearest the motor.

- for the THIRD reduction ratio, this shaft is the output shaft.

3.2.4 FOURTH REDUCTION

- Start by fitting the first shaft to the hole nearest the motor (Hole A), add the 12T pinion gear (locator), with the 1.0mm washer between the case and a (yellow) 50T spur gear
- Add the 2nd shaft to Hole B, and add the 12T pinion gear (locator) and the second (yellow) gear
- Install a (white) 50T Spur gear on the shaft nearest the motor.
- Install the second (white) 50T Spur gear on the second shaft.

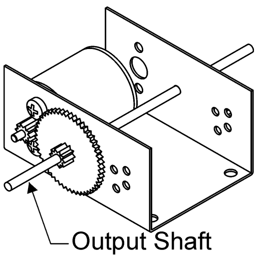
- for the FOURTH reduction ratio, this second shaft is the output shaft.

3.2.3 ASSEMBLING THE MOTOR

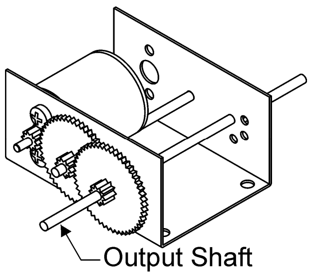
- Press the 10T pinion onto the motor shaft. Stop when the worm gear is 3mm from the motor's body.

HINT: Place the gear on the bench, insert the motor shaft into the pinion gear's hole and gently tap the end of the shaft (where it exits the motor) with a small hammer.
WARNING: Don't just push the motor down by hand, as this can push the motor armature out of its bearings and jam the motor.

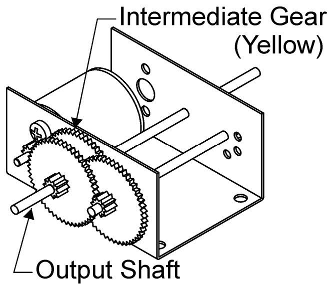
- Solder a suitable length of wire to each of the motor's terminals. The length will be dictated by the planned usage / location of the Gearbox and the other components
- Secure the motor to the gearbox case using the two self-tapping screws.



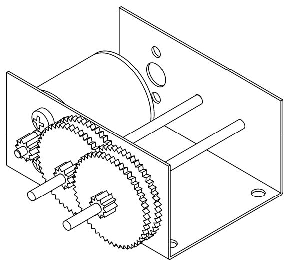
SINGLE REDUCTION
(Low ratio = high output speed)



DOUBLE REDUCTION



TRIPLE REDUCTION



FOURTH REDUCTION
(High ratio = low output speed)

4. PRINTED CIRCUIT BOARD (P.C.B.) AND WIRING

4.1 COMPONENTS AND TOOLS

- It is suggested that different colour wires are used. This will help in tracing the connections.
- The motors wires should be taped to the gearbox, to increase their durability.
- A good quality soldering iron, with a fine tip and the use of 0.71mm 60/40 solder is recommended.

4.2 POSITIONING THE COMPONENTS

Check and identify all the components for the PCB before commencing assembly. The location of the components is as printed on the PCB. The copper tracks are on the underside of the P.C.B., and the outline of the tracks is visible through the P.C.B. These will act as a guide, to help locate the components onto the P.C.B.. Drawing 'D' shows the P.C.B. and its wiring connections.

The assembly of the components to the P.C.B. should be carried out before soldering the components in place. Begin by placing the components that sit lowest on to the P.C.B.

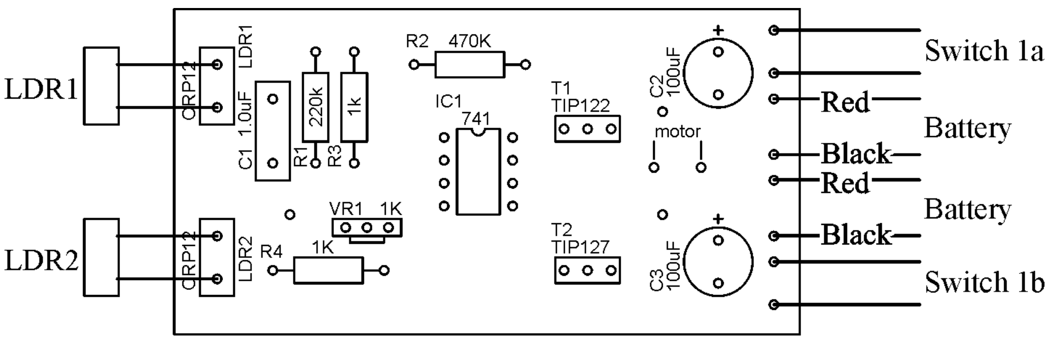
- Mount the resistors in place. Resistors are non-polarised components and do not need to be placed in any particular direction. However, the convention is that horizontal resistors are mounted with the gold band to the right and vertical resistors to the bottom.
- The I.C. socket is mounted next: make sure the notch on the socket faces in the same direction as indicated. Do NOT mount the I.C. as it may be damaged during soldering.
- Mount the 1 K Ohm Trimpot in place.
- The capacitors are mounted next: the 1 μF capacitor is non-polarised and can be mounted in any direction.
- The two 100 μF capacitors are polarised: that is, they have both positive and negative leads. These must be connected the correct way or the model will not work. The capacitor's positive and negative leads can be identified by two methods: (1) The stripe on the capacitor's body marks the negative lead or (2) the short lead is negative. Refer to the P.C.B. to determine the positions of the leads.
- The last components to be mounted before soldering are the two (Darlington) transistors - TIP122 and TIP127. The correct positioning of these is important. Note: although they appear the same, they are not interchangeable and must be placed in the correct orientation. The back of the transistor (the metal flat face, without any writing) must face to the top of the circuit board. The transistors are a snug fit and it may be necessary to wiggle them gently from side to side to fit them into the holes.

When all the components are in place, check them carefully against the printed circuit board.
Note: it's much better to spend time now, making sure all the components are in the correct position, than to waste time later on, trying to figure out why the vehicle doesn't work. If required, unsoldering and replacing damaged or wrongly positioned components will waste considerable time.

4.3 FINAL ASSEMBLY OF THE P.C.B.

- Once all the components are correctly located, turn the circuit board over and bend the component leads outwards, away from the component's body (about 15 degrees from vertical). This will prevent the components from slipping down while soldering them in position. (Don't bend them too far or you will have considerable trouble removing them if it becomes necessary later on).
- Carefully solder all the component leads. If you find it difficult to get to all the leads, cut off any that are in the way. When all the soldering is complete, cut the leads as close to the solder as possible. Check the soldering for any poor joints or solder bridges between tracks. Solder bridges are most likely to occur between tracks that are close together, so pay careful attention to the solder tracks where the I.C. socket and the transistors are mounted. Solder bridges must be removed before connecting power to the P.C.B.. Failure to do so may result in damage to the circuit.
- After all the soldering has been completed, install the LM741 I.C. in its place in the socket. Ensure the notch on the end faces in the same direction as on the socket. Check that the legs line up with the I.C. sockets holes and press down firmly with your thumb.

Note: it may be necessary to push the I.C.'s legs together slightly to line them up with the socket holes.



DRAWING 'D' : P.C.B. AND WIRING CONNECTIONS

5. THE DRIVING WHEELS AND THEIR GEARBOX & MOTOR

For the Gearbox and motor assembling instructions, refer Section 3.

5.1 DRIVING THE REAR WHEELS

NOTE: The original prototype vehicle built had both rear wheels driving through a solid axle: in other words it had no differential. Conventional motor vehicles have differentials, which are located between the two driving wheels. When the car turns, one wheel has to travel a greater distance – the differential allows the wheels to turn at different speeds, to compensate for this difference in distance. With the fixed axle, the original prototype vehicle tended to stall when turning.

As a differential is not practical on this scale of vehicle, other options need to be used. There are two simple solutions to this problem:

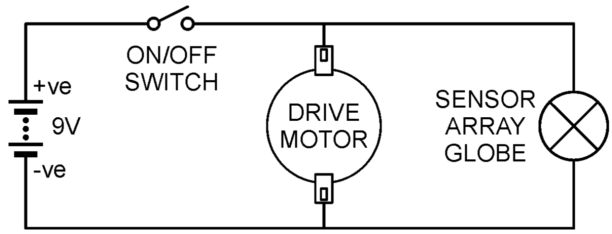
a. Use only one wheel at the back. Thus the differential problem is eliminated. Place the wheel on the centre line of the chassis.
b. Use two wheels at the back, but with only one as the driving wheel. The other wheel must be able to free-wheel on the axle. This is done by drilling a 2.6 mm diameter hole through that rear wheel's centre. The wheel is kept in place on the axle by using one pinion gear (as a locator), on the outside of the wheel. Thus the wheel is located between the gearbox's outside locator and this locator.

5.2 MOUNTING THE DRIVING GEARBOX AND MOTOR

When mounting the Driving gearbox and motor onto the chassis, ensure that the axle is at 90 degrees to the centre line of the chassis.

5.3 WIRING THE MOTOR AND LIGHT GLOBE

The wiring for both the drive motor and the light globe is relatively simple. The circuit is shown: refer Drawing 'E'. As both the motor and the light globe draw a substantial current, either alkaline or rechargeable batteries are recommended. The battery compartment supplied is for 'C' size batteries.



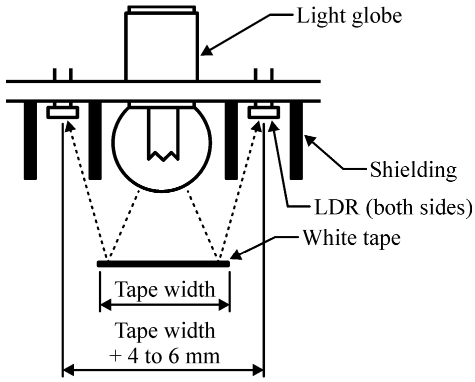
DRAWING 'E'

- Before soldering the wires for the motor, check that the wheels turn in the correct direction.

6. OTHER ELECTRICAL ASSEMBLY

6.1 THE LIGHT GLOBE AND LDR PLACEMENT

- The light globe should be on the centreline of the vehicle. To mount the light globe a 12 mm diameter hole must be drilled in the chassis.
- A suitable bracket must be made for mounting the light globe socket. Aluminium or steel strip 1 mm thick is suitable.



DRAWING 'F'

NOTE: The tape width must be selected before the LDRs are installed. The LDR's should be located on the vehicle about 2-3 mm outside either edge of the tape. For example, if using 18 mm wide tape, the LDRs should be spaced approximately 22 to 24 mm apart. However, when the vehicle has been completed, repositioning of the LDR's may be required as part of the vehicle development

- Proper location of the LDRs is critical for the satisfactory tracking of the vehicle. They should sit on either side of the globe and in line with the centre point of the globe.
- The LDRs (sensors) should be mounted as close as possible to the centre line of the front wheel axles. The LDRs can either be in front of the steering mechanism, or centrally located (ie mid-way along the chassis). Which do you think is the better choice? Why?

NOTE: if the LDRs are mounted too far ahead of the axles, the vehicle is unlikely to track satisfactorily.

6.2 SHIELDING THE LDRs

Shielding must be used between the light globe and the LDR's, to prevent direct light shining on them. The LDR's need to receive only light reflected from the white tape. Refer Drawing 'F'. Non-transparent tubing, eg: from a pen casing, may be suitable. (Hint: drilling a hole in 10mm dia. PVC rod will work.) Experimentation will determine the tubing length. Note: the prototype vehicle's tubing was 10mm long.

6.3 THE BATTERY HOLDERS

The two 'AA' battery holders each hold 4 batteries, and must be detachable, to allow the batteries to be replaced. Using Velcro tape, with a hot glue gun, is suitable. Roughen the surfaces to be glued with sandpaper. The 'C' size battery holder does not require removal and may be glued to the chassis.

6.4 THE TWO ON/OFF SLIDE SWITCHES

Two "On / Off" switches are required for the vehicle to function. One switch is for the two 'AA' battery holders, which are connected to the PCB (one side of the switch to each). The other switch is used for the rear wheel drive motor and light globe. If mounted side by side, both switches can be switched on or off at the same time. The switches should be mounted from underneath. A hole 10x12 mm is cut in the chassis for the switches, and 2.6 mm diameter holes are drilled for the screws.

7. TESTING AND ADJUSTING

After completing the design, manufacture and assembly of the *FOLLOW THE WHITE LINE VEHICLE*, a number of tests and adjustments still need to be carried out. These are detailed below.

7.1 ADJUSTMENT OF THE TRIMPOT

The Trimpot VR1 must be adjusted, so that when the LDR's have an equal amount of light falling on them, the steering motor does not turn. There are two ways that this can be carried out.
Method 1: Place some black tape or blu-tack over the ends of the LDR shields to block out all light. Then carefully adjust the trimpot with a screwdriver until the steering motor does not turn.
Method 2: Use an overhead projector, to provide light to both the LDRs. With the projector switched on, place the vehicle on top of the glass and adjust the trimpot until the steering motor does not turn.

If adjusting the trimpot does not stop the steering motor turning, the following need to be checked:

- The wiring connections to the LDRs
- The soldering on the PCB, for solder bridges or poor soldering joints
- The voltages of the battery packs. These should be about the same voltage. If the difference between them is too great, the vehicle will always turn in the same direction.

7.2 STEERING DIRECTION CHECK

After adjustment of the trimpot has been carried out, the next check is to ensure that the steering motor is turning in the correct direction. This is done by covering up one LDR at a time.

- if the right LDR is covered, the vehicle should turn left
- if the left LDR is covered, the vehicle should turn right.

If the wheels don't turn as indicated, the connections to the motor must be reversed.

7.3 CHECK OF THE DIRECTION OF TRAVEL

The next check is to ensure that the vehicle travels forward. If it doesn't, the connections to the motor must be reversed.

7.4 WILL IT "FOLLOW THE WHITE LINE"?

Switch the vehicle on and hold the back wheels off the ground. Centre the LDRs over the white line. This is done by moving the front of the vehicle to the left and right, until the steering stops turning. If this is not done properly, then the vehicle will quickly steer off the line.

8. HOW THE CIRCUIT WORKS (THEORY)

To understand how the circuit works we must first look at what are called voltage dividers.

8.1 VOLTAGE DIVIDERS

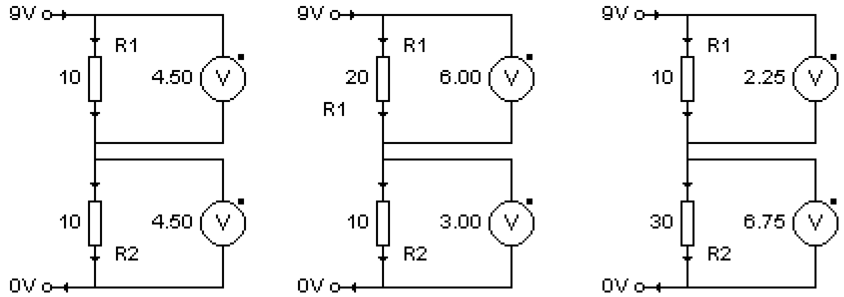


Figure 1: VOLTAGE DIVIDERS

Voltage dividers are often used to divide a large voltage into smaller voltages. The circuits that follow (refer Figure 1) will give you and idea about how the larger voltage is divided.

The meters for each circuit show how the larger voltage (9 volts) is divided up. If you look carefully you should be able to see the relationship between the circuits. The voltages are divided in the same ratio as the resistor values.

- The two 10Ω resistors are the same resistance and so have the same voltage across them.
- The 20Ω resistor is twice the value of the 10Ω resistor and so has twice the voltage across it.
- The 10Ω resistor in the third circuit is one third the value of the 30Ω resistor and so has one third of the voltage that the 30Ω resistor has.

A simple formula can be used to calculate the voltage across a resistor in a potential divider.

$$V_{out} = \frac{R1}{R1+R2} \times V_{in}$$

This will give the voltage across R1
To find the voltage across R2, simply place R2 on top.

E.g. $$V_{out} = \frac{R2}{R1+R2} \times V_{in}$$

$$V_{out} = \frac{30}{10+30} \times 9 = \frac{30}{40} \times 9 = 6.75 \text{ volts}$$

8.2 LDRs AS VOLTAGE DIVIDERS

If you look at the circuit for the White Line Follower you will notice that the inputs to the circuit - the two LDR's - form a voltage divider.

8.2.1 EQUAL AMOUNTS OF LIGHT TO BOTH LDRs - Figure 2

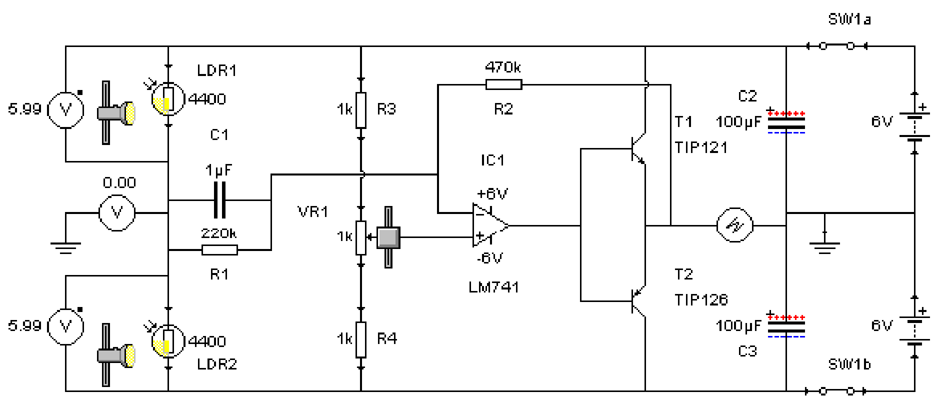


FIGURE 2: EQUAL AMOUNTS OF LIGHT TO LDR1 & LDR2

- When an equal amount of light is picked by the LDR's, their resistance should be equal. Thus each LDR has 6 volts across it. The top battery is +6 volts and the bottom battery –6 volts. This means that the mid way point, where they connect, can be seen as 0 volts or earth. This also means that if the two LDR's each have 6 volts across them, their mid point can also be considered as 0 volts.
- In practice the two LDR's will not be identical and the voltage at the mid point will not be equal to zero. The trimpot VR1 is used to adjust for this. It is set to exactly the same voltage present at the mid point of the two LDR's. This easy process is described in Section 8: Testing and Adjustment.

8.2.2 MORE LIGHT TO LDR1 - Figure 3

If more light falls onto LDR1 then the voltage at the mid point will become greater than 0 volts, and a positive voltage will be produced. The positive voltage is applied to the negative input of the comparator through the 220k resistor. The comparator compares the voltage on its negative input, to the reference voltage on its positive input. As the voltage on the negative input is greater than the reference voltage, the comparator produces a voltage at its output. The input voltage is inverted by the comparator, so the voltage produced at its output is a negative voltage. The negative voltage is applied to both transistors. Only transistor 2 (T2) will be turned on, and current will flow from the positive terminal of the lower battery, through the motor, transistor 2 and back to the negative terminal of the battery. This will cause the motor to turn and steer the vehicle back onto the line.
- The arrows on the circuit indicate the direction of the current flow through the motor.

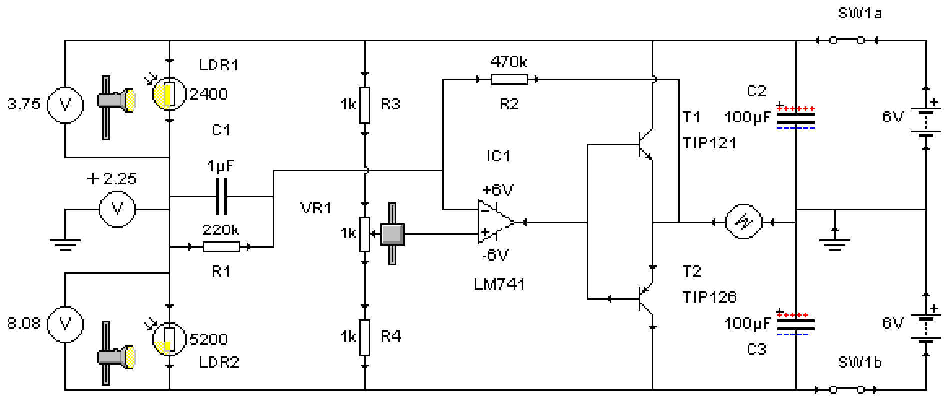


FIGURE 3: MORE LIGHT TO LDR1

8.2.3 MORE LIGHT TO LDR2 - Figure 4

If the vehicle steers off the line in the opposite direction, the lower LDR (LDR2) will pick up a greater amount of light. This time a negative voltage is applied to the input of the comparator. The comparator produces a positive voltage at its output. This causes Transistor 1 (T1) to be turned on. Current from the positive terminal of the top battery flows through Transistor 1, the motor and returns to negative terminal. This time the motor turns in the opposite direction.

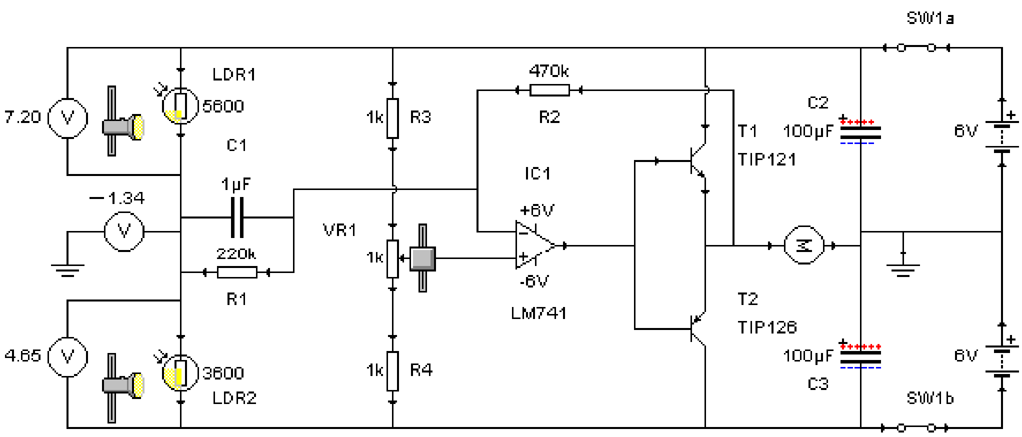


FIGURE 4: MORE LIGHT TO LDR2

8.2.4 FINE TUNING THE STEERING

The steering must be set up so that the vehicle steers back onto the white line. The capacitor C1 is used to control the damping of the electronic system. Without it, the vehicle would respond too quickly and the steering would oscillate from side to side. If the value of C1 is too large, the car will oversteer due to sluggish response of the steering. Resistors R1 and R2 control the gain of the system. This is set, to suit the size of the signals picked up by the LDRs, and amplify them to a suitable level at the output of the comparator.

Damping is affected by the spacing between the LDR's, the systems gain and the motor/gearbox characteristics. The following options may need to be considered:

- To reduce oscillation, the capacitor C1 must be replaced by a component with a larger value.
- To lessen oversteer, the capacitor C1 must be replaced by a component with a lower value.
- To reduce the gain increase the value of Resistor R1 or reduce the value of Resistor R2.

Note: The values of the components supplied, are those that were used on the prototype vehicles. Experimentation will determine if these are most suitable values for your design.

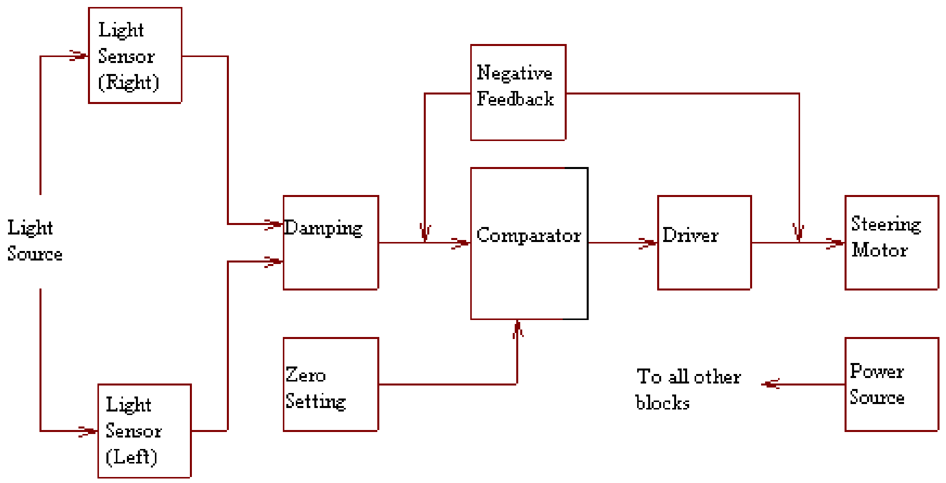


FIGURE 5 - BLOCK DIAGRAM OF THE STEERING SYSTEM

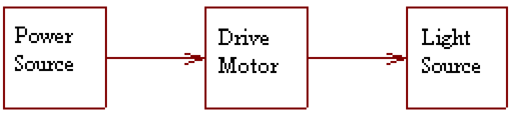
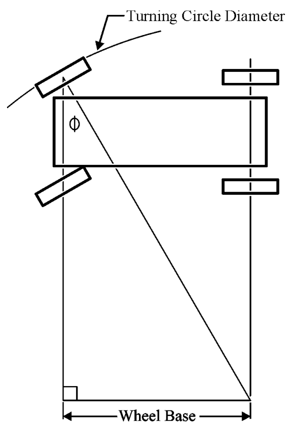


FIGURE 6 - BLOCK DIAGRAM OF THE MOTOR DRIVE AND LIGHT SOURCE

9. ADDITIONAL CALCULATIONS



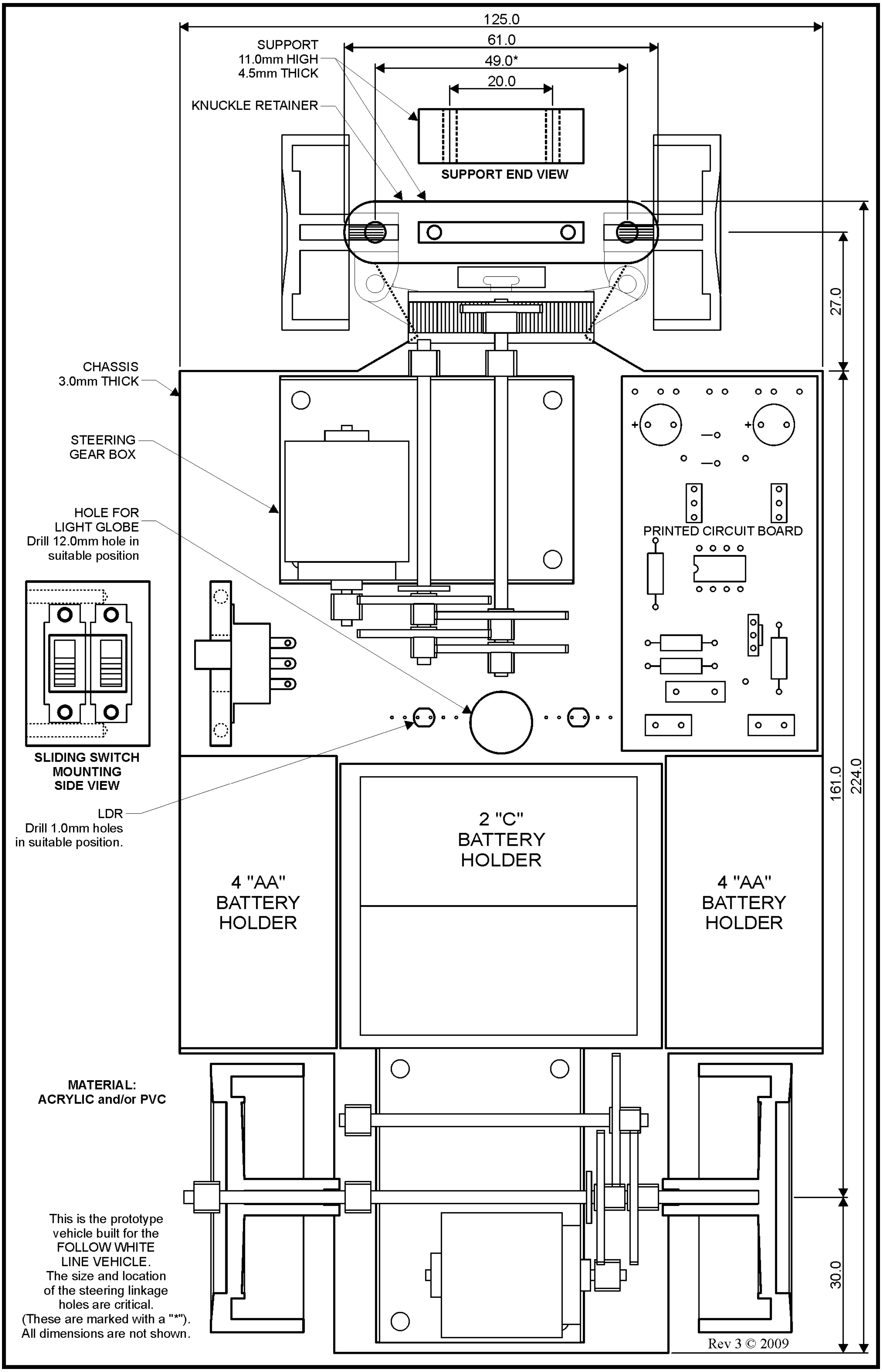
The calculation of the turning circle diameter can also be included into the design process. This is calculated as shown in the drawing and below.

The Turning circle can be calculated by the formula:

$$\text{Turning Circle Diameter} = 2 \times \frac{\text{Wheel base}}{\sin \phi} + \text{Distance from Axle Centreline to Outside of Tyre}$$

Where ϕ = Steering angle of the Outside front wheel

Now that you've completed your fully working *FOLLOW THE WHITE LINE VEHICLE*, and know the Theory behind it: – WELL DONE !!!


125.0
61.0
49.0*
20.0
SUPPORT
11.0mm HIGH
4.5mm THICK
KNUCKLE RETAINER
SUPPORT END VIEW
27.0
CHASSIS
3.0mm THICK
STEERING
GEAR BOX
HOLE FOR
LIGHT GLOBE
Drill 12.0mm hole in
suitable position
PRINTED CIRCUIT BOARD
SLIDING SWITCH
MOUNTING
SIDE VIEW
LDR
Drill 1.0mm holes
in suitable position.
2 "C"
BATTERY
HOLDER
4 "AA"
BATTERY
HOLDER
4 "AA"
BATTERY
HOLDER
161.0
224.0
MATERIAL:
ACRYLIC and/or PVC
This is the prototype
vehicle built for the
FOLLOW WHITE
LINE VEHICLE.
The size and location
of the steering linkage
holes are critical.
(These are marked with a "*").
All dimensions are not shown.
30.0
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