SIMPLE ELECTRICALS
PARTS 1A & 1B

BASIC ELECTRICAL TERMINOLOGY
BATTERY TYPES & INFO
WIRING & FUSES
SWITCHES & RELAYS
SIMPLE ELECTRICAL CIRCUITS
LIGHTING & LED's

A beginners guide to the invisible world of electrical energy !!
This Tutorial is the first of a series of 4 sessions dealing firstly with electrics and secondly with electronics.

Part 1 will be presented in two 45 minute sessions (Part 1A and Part 1B) but, to keep things simple, these notes contain both parts.

Part 2 will be presented in two 45 minute sessions by George Hartnup and will cover basic electronics. This will lead to a series of Practical Self Built tutorials where participants can build their own miniature circuits such as servo testers, integrated mixer & speed controller and other interesting and useful gizmos.
Notes for these will be presented closer to the time.

Compiled and presented by: Iain Moffatt

I am indebted to many information sources quite a few of which are available on the Web. Direct access to these sources provides much more information than I have quoted here.

A separate source list is available to go with this Tutorial Series.

INTRODUCTION

For many folk electrical energy is a bit of a mystery and I think we have all learned to treat it with considerable respect. However in model making terms the voltages that are commonly used do not offer the same degree of hazard as those using mains power (240 volt in the UK and 110 volt in the USA and much of Europe).
Furthermore in models we invariably make use of DC (Direct Current) whereas mains power comes in the form of AC (Alternating Current). We do however convert DC into square wave AC when using an ESC (Electronic Speed Controller).

Never the less it is very possible to generate considerable power from low voltage Direct Current sources that will draw much higher currents than are normally encountered in domestic circumstances. Ideally this power should be used to do useful work like driving an electrical motor for boat propulsion but, if through incorrect connections or bad electrical joints, the power is converted to heat energy you have a very good source of ignition!!
I am sure you all know someone whose boat either burst into flames or disappeared in a cloud of smoke.

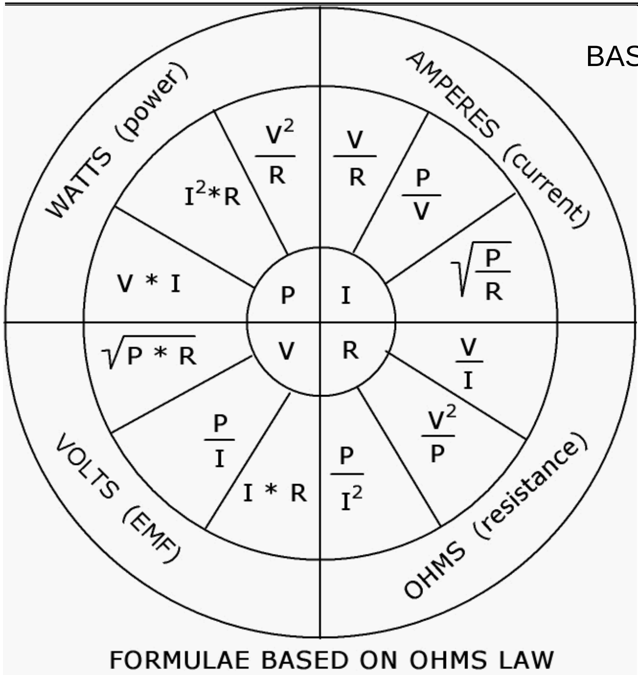
This series of Tutorials provide information and guidance that, if followed properly, should ensure that you are never a member of the pyrotechnics brigade !

TERMINOLOGY

As in every walk of life Terms abound ....
None of it is really difficult but you do need to talk the talk if you are going to get things right first time.
So here goes with the least you need to know:

Term	***Symbol***	***Meaning***
Direct Current	DC	An electrical supply where the voltage is constant over time.
Alternating Current	AC *f* ~	An electrical current whose magnitude and direction vary cyclically, as opposed to direct current, whose direction remains constant. The usual waveform of an AC power circuit is a sine wave, as this results in the most efficient transmission of energy. However in most modelling applications square waveforms are used. The majority of countries have adopted a frequency **(*f*)** of 50 cycles per second **(~)** whereas the USA and Canada use 60 cycles per second.
Amps	A	A unit of current. A pressure of 1 volt will pass a current of 1 amp through a resistance of 1 ohm. .Other common units are milli-amps (mA) Current is the rate of consumption of electrical energy
Ampere-hour	Ah	A unit of quantity of electricity. One unit represents a current of 1 amp flowing for 1 hour.
Farad	F µF pF	Unit of capacity. Practical units are micro-farads **(µF)** or pico-farad **(pF)** = one billionth of a farad. In electrical terms a condenser may be likened to a balloon in a circuit that is capable of absorbing energy spikes, releasing them slowly and thus smoothing out the voltage supply (as on DC electric motors). Condensers may also be used to accumulate an energy charge which may suddenly be released to provide a burst of energy like that needed to drive a photographic flash gun.
Horse-power	HP	In electrical terms 1 horse-power is the equivalent of 746 watts

Term	Symbol	Meaning
Kilowatt	kW	1000 watts or 1.34 horse-power
Ohm	Ω	Unit of resistance. 1 ohm is defined as that resistance that will pass a current of 1 amp when 1 volt is applied. Resistance varies directly as the length of a conductor and inversely as the cross section. Thus, for a given length, a larger diameter conductor will have a lower resistance than a thinner one.
Volt	V	A unit of potential or, if you prefer of electrical pressure.
Watt	W	Practical unit of power measurement this is the product of Volts and Amps. (watts = volts x amps)
Sub-divisions of Units & Prefixes		
Kilo	k	one thousand
Mega	M	one million
Milli	m	one thousandth part
Micro	Ω	one millionth part
Pico	p	one billionth part
Basic Formulae		
To calculate the Power of an electric motor in Watts multiply the applied voltage by the measured stall current		Watts = Volts x Amps
To calculate the current that will flow through a system		Current (Amps) = Applied Voltage / measured resistance in Ohms
Common Terms		
ESC		Electronic Speed Controller. There are many manufacturers, some of which make more reliable gear than others! Make sure to buy reversing controllers and, if you can afford it, waterproof ones.
TX		Term for a Radio Control Transmitter.
RX		Term for a Radio Control Receiver.
Cell		The basic storage unit consisting of an anode; a cathode and electrolyte. The simple torch battery comprises a single cell
Battery		Technically a battery is made up of 2 or more cells. For example a 6 volt lead acid battery will have 3 cells. A 9 volt PP3 battery will have 6 cells.
Buss Bar		A term used to describe an electrical distribution header from which power is taken through bolted cable connections. In industrial applications it is usually made of high purity copper and is of rectangular cross section. Small examples may be found in domestic ‘consumer panels’ where connection is via fuse blocks or circuit breakers.
Automatic Circuit breaker		A term used to describe a circuit breaker that contains a current sensitive switch element which opens the circuit breaker when the current rating is exceeded. Miniature versions are available that are suitable for model applications.



BASIC FORMULAE

The diagram on the left shows the various formulae that may be used in DC power calculations.

P = power in Watts
V = Volts
I = current in amperes
R = resistance in Ohms

Example:
an electric motor having a resistance of 30 ohms and connected to a 12 volt battery will draw 12/30 amps = 0.4 amp.
The same motor will generate (12*12)/30 watts = 4.8 watts

SOURCES OF POWER IN MODELS - BATTERIES

Apart from IC (internal combustion) engines, Steam power and of course the wind, there is only one source available - batteries.

Unfortunately (or perhaps fortunately!) there are many different types of battery available to the model maker to-day. Each has its own strengths and weaknesses and if we are to make best use of the weight limitations imposed by simply building a boat we need to at least be aware of these.

Before discussing the various types of battery you MUST be aware of a few pretty basic principles. Firstly, any battery stores electricity in the form of chemical energy. If the battery is short circuited by connecting the terminals together the stored energy is immediately released, the current being only limited by the resistance of the wire making the connection. Since wire is designed to have very low resistance, the current that flows will be very high. Energy flowing through a circuit generates heat and so, at high currents, the connecting wire can become hot enough for the insulation to first melt and then catch fire.
Furthermore the battery itself is likely to be destroyed and some types can even explode because the chemical reaction will release more gases that can be safely vented from the battery case.

NEVER SHORT CIRCUIT ANY BATTERY.

Battery Type	*Power to Weight Ratio*	*Energy to Size*	*Charge/ Discharge Efficiency*	*Self Discharge Rate*	*Durability*	*Nominal Cell Voltage*
Dry Cell				shelf life 1.5 yrs		1.5V
Lead Acid	180	60-75	70-92%	3% - 20%/month	500-800 cycles	2.0V
Gell Cell	180	60-75	70-92%	3% to 20%/month	500 to 800 cycles	2.0V
NiCD	150	50-150	70-90%	10% /month	2000	1.2V
NiMH	250-1000	140-300	66%	30%/month	50-1000	1.2V
LiPO	up to 2800	300	99.8%	5%/month	>1000	3.7V

In the above table, the higher the value in the Power/Weight Ratio and Energy to Size ratio columns the smaller/lighter will be the battery pack for any given supply requirement.

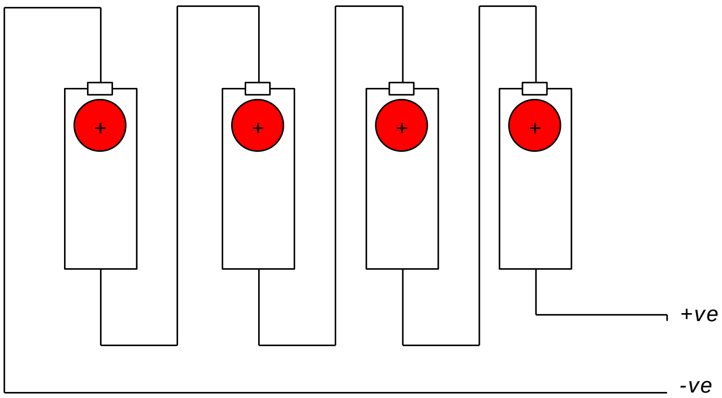
Lithium-ion Batteries are not included since it is not normally possible to purchase these in a form useable to the modeller and, even were it possible, given the hazardous nature of this battery type, it could NOT be recommended.

BATTERY INTERCONNECTIONS

Batteries & cells may be interconnected to give either different voltages or increased current capacity.

Most commonly cells will be connected in SERIES thus giving a higher final output voltage. Connecting in PARALLEL would give the same voltage but an increased current capacity

SERIES CONNECTION



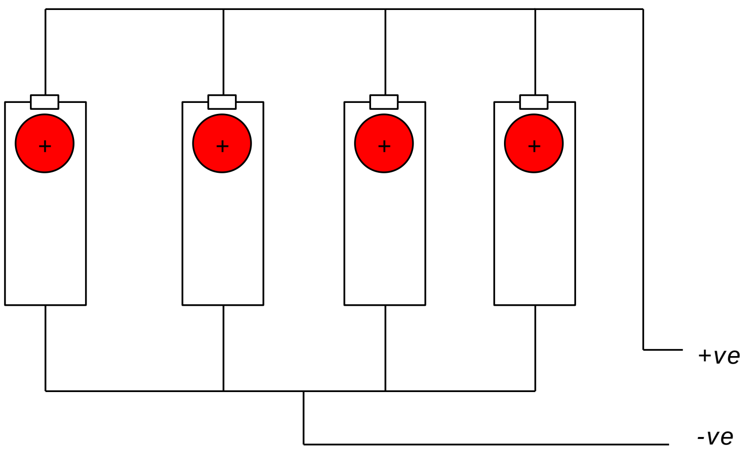
Output voltage :
Number of Cells * cell voltage

Dry cells = 4 * 1.5 = 6volts

Rechargeable cells = 4* 1.2 = 5 volts

Current capacity as for 1 cell.

PARALLEL CONNECTION



Output voltage

Dry cells = 1.5 volt

Rechargeable cells = 1.2 volt

Current capacity = 4 * cell current capacity.

The same rules apply to ANY battery type but **please note**
[1] battery types should NOT be mixed and
[2] individual cells should all have same current capacity.

The primary reason for this is to avoid one cell becoming the ‘weak link’ and discharging before the rest. If this happens, the discharged cell will be ‘driven’ by the remaining cells and can go into a state of deep discharge and become useless.

BATTERY DISCHARGE RATES

In all types of battery drawing power from the battery results in a build up of heat within the battery. If excessive power is drawn (I.e. excessive currents) it is quite possible to destroy a battery or at the very least significantly reduce its life.
The maximum current that may safely be drawn from a cell varies from one battery type to another but is generally proportional to the cross sectional area of the plates within the cell..
In lead acid cells it is normally possible to draw very high currents for a short time but, in most cases it is essential that the battery is NOT fully discharged. In the case of car batteries for example, starting can draw up to 600 amps for a few seconds.
It is normally accepted that all types of battery have 'best performance' and a 'peak' discharge rates.
The best performance is aimed at maximising battery life (useable cycles) and minimising the increase in internal resistance of the battery over time.

Most folk ask the question that really concerns them .... what battery should I use?
As far as discharge rates are concerned:

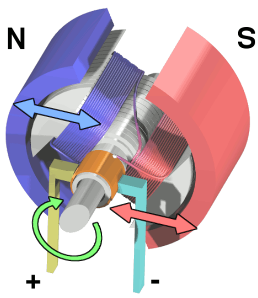
Lead Acid or Gell cells	Max. rate = 5 x battery rate
	Best rate = 0.2 x battery rate

As an example, a 6 volt 4 Ah lead acid battery can happily supply up to 20 Amps but clearly only for around 12 minutes after which the battery starts going into deep discharge.

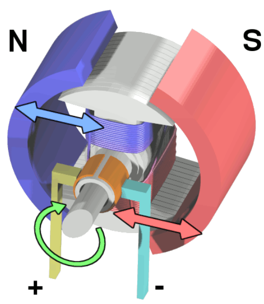
NiCd cells	Max. Rate = 20 x cell capacity
	Best rate = 1 x cell capacity
NiMH cells	Max Rate = 5 x cell capacity
	Best rate = 0.5 x cell capacity

Obviously it is possible to pull even greater currents from any battery set but the longevity of the cells will be reduced. Fast Electrics guys routinely pull up to 60 amps from their battery packs for 15 to 20 minutes but the cells can get very hot.

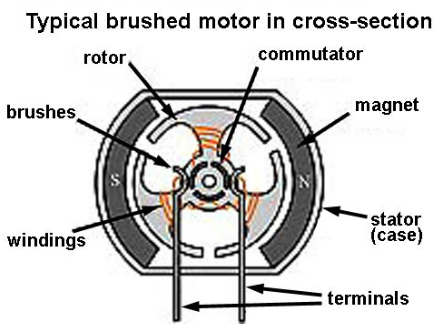
BASIC MOTOR THEORY - Permanent magnet motors

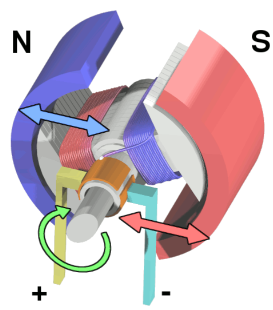


A simple 2 pole DC electric motor. When the coil is powered, a magnetic field is generated around the armature. The left side of the armature is pushed away from the left magnet and drawn toward the right, causing rotation



The armature continues to rotate.





When the armature becomes horizontally aligned, the commutator reverses the direction of current through the coil, reversing the magnetic field. The process then repeats.

In a model motor, the bit that goes round is termed the "armature" and the magnets inside the motor case are termed the "stator". The cross section shows a typical 3 pole motor.

When the armature of a 2 pole motor is displaced at 90 degrees to the stator poles the motor develops no torque and will refuse to start. For this reason commercial model motors are produced with an odd number of poles on the armature (normally 3 or 5). In general the 5 pole motor will have a smoother performance at low speeds than the 3 pole but will cost more. The number of poles increases the complexity of the commutator and so motor weight will increase.

The rotational speed of a DC motor is proportional to the voltage applied to it, and the torque is proportional to the current.

Two measurements are important in comparing the performance of DC permanent magnet motors; firstly is the ‘no-load’ current, measured when a motor is not connected to anything and is running free; secondly there is the “stall” current measured when the motor shaft is held stationary.
In general terms the rating of control devices (speed controllers; relays etc.) should be based on the stall current if you are to avoid damage should the prop become tangled in feathers, weed etc..

BASIC MOTOR THEORY - Brushless Motors

In a conventional (brushed) DC motor, the brushes make mechanical contact with a set of electrical contacts on the rotor (called the commutator), forming an electrical circuit between the DC electrical source and the armature coil-windings. As the armature rotates on axis, the stationary brushes come into contact with different sections of the rotating commutator. The commutator and brush system form a set of electrical switches, each firing in sequence, such that electrical-power always flows through the armature coil closest to the stationary stator (permanent magnet).

In a BLDC motor, the electromagnets do not move; instead, the permanent magnets rotate and the armature remains static. This gets around the problem of how to transfer current to a moving armature.
In order to do this, the brush-system/commutator assembly is replaced by an intelligent electronic controller. The controller performs the same power distribution found in a brushed DC motor, but using a solid-state circuit rather than a commutator/brush system. A brushless motor is in effect a 3 phase AC motor,, the main reason for the vastly improved performance over DC brushed motors.

The great majority of brushless motors are uni-directional, that is to say they can NOT be reversed by simply switching the wiring connections. Reversing ESC’s can be obtained and prices are rapidly dropping. A 15 amp controller can be purchased for around £20 for example.
You MUST NEVER connect two brushless motors to a single speed controller so for a twin screw boat you will need two speed controllers as well as two motors.

Brushless motors deliver considerably more power/torque than their brushed equivalents and it is for this reason that they have found great favour with the flying & fast electric boat fraternity. However this performance does come at a price.....
The performance of brushless motors is frequently compared to their i.c. equivalent i.e. ‘replacement for 40 size engines’ etc. and this gives an idea of the sort of power which is on offer!!

SIMPLE WIRING TECHNIQUES

As in many things, adopt the KISS principle (Keep It Simple Son) when dealing with electric wiring in model boats. There is seldom any need for complex power distribution systems which, for many, simply lead to confusion when attempting repairs.

Some simple tips:

- ❑ When wiring to the circuit from battery to ESC or to Resistive Speed Controllers (Bob’s Boards and the like) adopt the age old convention of Red wires are connected to the positive battery terminal and Black wires to the negative terminal.

Many ESC's now use European standard colours where Brown is Positive and Blue is Negative so have a care.

- Stuff which is not polarity sensitive (lights etc.) - use any colour other than red or black.

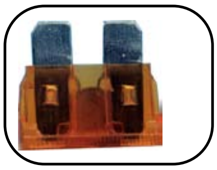
- When selecting wiring for power connections I always select a wire diameter that is capable of carrying 1.5 times the maximum current draw of the motor. This should ensure that it is the fuse that blows rather than the wire overheating and turning into a mini electric fire!! Since the current carrying capacity of a wire is proportional to its core diameter, thin wires on power circuits are a no-no. (see the sizing chart on the next page).

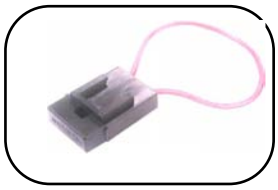
- Lighting circuits seldom carry any significant current (I.e. usually less than 0.5 amp) so wiring may be thin (and flexible) and still be OK.

- Do NOT bind power, lighting and other signal wires in a neat bundle. This simply increases the likelihood of introducing interference into the various circuits. OK to bind power wires for currents below 10 amp. OK to bind lighting wires. OK to bind signal wires. But NOT all together!!

- For Power Wiring from batteries to ESC's to motors, you can safely use automotive crimp connectors to make connections on scale models. However, on really high current draw circuits (fast electric etc.) the gold plated solder type connectors are much superior. Remember the automotive connectors are colour coded by the wire diameter that they are designed for and NOT by positive, negative etc..
  Bullet and spade connectors conventionally come in 3 colours - red, yellow and blue where red is for the smallest wire and yellow for the largest. The bullet (or spade) part of all colours is the same size so you can connect a yellow bullet to a blue socket etc. if necessary.
  In power connections I cannot recommend the terminal block approach for most folk. It is too easy to short circuit wires by mistake. Furthermore repeated tightening of the clamp screws is likely to fray the wire end and increase the probability of a short.

- If you have extensive wiring within a hull it is always worth fitting an 'earth' connection between the motor casing and the propeller tube. Why? Simply because electric motors are 'noisy' devices and they do generate interference in the radio frequency range. Capacitors are (should be) fitted between the motor terminal and the motor case to suppress much of the 'noise'. Suppression is improved by fitting an earth connection. Many folk go through life never having had a problem that needed an earth but others have all sorts of problems with jittery servos and erratic speed controllers at least some of which are due to interference.
  A typical case where this can be beneficial is a model submarine where everything is crammed into a small space. When the model submerges the RC reception reduces as the sub goes deeper but the 'noise' does not and can over power the rc transmission.





- Fuses and Fuse holders.
  A fuse only needs to be installed in one of the connecting wires. For motor protection, always install the fuse between the battery and the speed controller. In submarines please remember that, if the motor fuse blows, the RX will also lose power if you are using the BEC system. This may well invalidate any emergency surface technology that is being used. Check before fitting a fuse.
  The simplest way to provide fuse protection is to use bladed fuses as used in cars with an in-line fuse holder. These fuse holders can be clipped together to make up a fuse bank which can be siliconed to the boat hull.

- You can use glass fuses but the overall size will be greater and not as neat. In line holders for glass fuses tend to be rather larger and are difficult to fix.

- Distribution Boards
  A lot of folk who build model tugs with twin screws, bow thrusters and working winches prefer

to build a miniature distribution board that contains all the fuses in one place. This is definitely a good idea but whether or not it is practical will depend on the boat, the space available and the access.

- Switches

There is always much debate about this issue! However there are four ways to switch electrical power: A magnetic Reed switch; an RC controlled Switcher or an RC controlled switcher plus a relay or a mechanical switch.
** Reed Switches - low current rating and generally only suitable for lighting circuits unless they are used to control a relay in which the capacity of the relay will govern. Standard size up to 2 amp switching; miniature up to 0.5 amp switching. Great for subs 'cause there is no penetration of the hull but equally useful on scale models where mechanical switches would be too obvious.

** RC controlled switchers - we learned how to build one of these last session. Used alone they have limited power handling (the one we built has a current capacity of 0.5 amp) but they can be used to switch a relay thus increasing the current handling capacity to several amps.

** Mechanical switch - simplest of all 'cause you only need to work out where to put it! Do remember however that if it is used to switch battery power on and off it MUST be rated to handle the maximum current load of the motor(s) plus all the other stuff. All switches are advertised with a current rating. For motor switching - 1.5 times the stall current of the motor.
Toggle versus slide?: it's all a matter of preference - me I go for toggle every time. Why? 'Cause the toggle action (snap) makes a cleaner contact and reduces the probability of sparking and hence burning of contacts. Secondly slide switches are always rated lower than toggles (0.2 amp versus >20 amp). Lastly it's also easier to water proof toggle switches.

- Relays

Relays come in two basic forms. A simple electro-mechanical switch or a solid state switch. Both types can have a number of configurations (poles) but will always have one contact set that is closed when coil power has been removed.

- Electro-mechanical versions use a small wire wound coil (electromagnet) to move the switch contacts. When a current flows through the coil, the resulting magnetic field attracts an armature that is mechanically linked to a moving contact. The movement either makes or breaks a connection with a fixed contact. When the current to the coil is switched off, the armature is returned by a force approximately half as strong as the magnetic force to its relaxed position. Usually this is a spring. 'Latching' relays are also available where the relay will stay in its last position until re-activated.

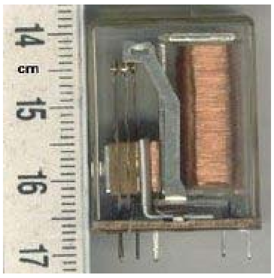
The relay therefore has two ratings; firstly the voltage required to operate the coil and secondly the voltage & current capacity of the switch contacts.

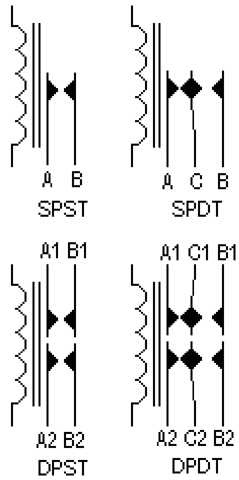
Solid state relays use electronic components to carry out the switching and so can be significantly smaller than their electro-mechanical equivalent.

Always remember that a relay needs a power source to operate and so the control circuit can be relatively complex. (There will be a practical session on building a relay operated RC switcher later in the series)
Also remember that, when connected to a power source, relays consume electrical power even though it may only be a few milliamps and, if left connected when the boat is 'on the shelf'' can run down the battery.

In model making they are used to increase the current handling capacity of a primary switching circuit such as a reed switch. Note that a 'reed relay' is simply a reed switch with a coil of wire round its outer diameter that is used to move the contact reeds. This takes the place of a permanent magnet. It does NOT increase the current carrying capacity of the reed switch.

Relays use the same terminology as other switches to describe their configuration i.e. SPST = single pole single throw etc. The wee diagram below illustrates this.





Left shows a miniature relay as used in electronics applications.
Right shows a solid state relay that has no moving parts.
Both are designed to be installed on a printed circuit board.

- Securing electrical wiring (sorting out the tangle of wires once and for all)
  I do most heartily recommend tidying up your wiring installation. Apart from anything else it makes the whole much easier to work with especially when it comes to fault finding.
  However please remember - do NOT run power wires in the same bundle as servo wires. In fact I try to keep them on opposite sides of the boat if possible.
  Above all keep your RC aerial wire well away from any other wires, power, lighting or otherwise.

  Do NOT cut wires too short ! So many times I have seen boats fail to work because connectors pop off when a wire is disturbed or when a superstructure is put on. After all it doesn't actually save you money either. Equally of course don't make them overly long - you just increase the tangle.

  I use thick sewing thread to tie stuff up. To attach wires to either the inside of the hull or superstructure consider using a dab of silicon sealer/adhesive. It's cheaper than the self adhesive pads that you can get - however these are useful where you have several wires to secure. Consider using plastic drinking straws as a form of conduit. These can be obtained in lengths up to a couple of feet I believe. Makes running wires very easy - simply push through.

  If you use 'in-line' fuses, make sure you position them where you can get at them and leave enough slack in the wiring harness! There is nothing worse than a fuse that's buried below a motor or a servo.

- If you have to extend a wire -
  do NOT join two bits by twisting the cores together and hoping for the best (after all this is the land of sod!) OK for a temporary repair or a test but ....
  If you must do this then [1] pop on a bit of shrink wrap tube, [2] twist the wires [3] apply a spot of solder on the twist and [4] heat the shrink wrap with the soldering iron to seal the join.

ELECTRICAL WIRE

There are more types and sizes of electrical wire than you can shake a stick at!!!
So, to keep things simple, the following is a list of the most useful types and sizes available from Maplin stores. NOTE: AWG denotes American Wire Gauge. The **larger** the number, the **thinner** the wire. Against each one I have suggested likely uses.

Please bear in mind that wiring only has to be 'flexible' when it joins components either one of which must be moved frequently (for example connections to a battery pack). In other parts of the installation, stiff wires which are largely self supporting can be useful in minimising the tangle that always seems to develop inside models. For me, tangles can be confusing, particularly since there are a limited number of colours available so that is not always possible to differentiate that way!
Regardless of this .... power connections from batteries to motors or speed controllers should ALWAYS follow the Red = Positive; Black = Negative principle; cross connecting ESCs can be fatal (to the ESC that is!)

AWG	*Core Diameter mm*	*Current Rating Amps*	*Automotive Crimp Colour*
10	2.59	55	yellow
12	2.05	41	yellow
14	1.63	32	blue
16	1.29	22	blue
22	0.65	7	red
28	0.32	1.4	Not Suitable
32	0,20	0.53	Not Suitable

In flexible wiring, each core is made up of a number of wire strands. The greater the number of strands in a given wire gauge the more flexible the wire will be.

Wiring for automotive applications can have between 7 and 22 strands.
Insulation on wiring makes it more stiff - not a problem if the wire is to remain in one place. However for connections that must be made and remade on a regular basis, a more flexible wire is better - really flexible wire will have silicon insulation and many strands in the core. However it will cost more.

Really small wiring (28 to 32 AWG) can be joined by using the miniature blade or bullet connectors that are sold for audio speaker connections.

In the following table a 'core' is made up from a number of 'strands'. The more strands, the more flexible the wire. for example "1/0.6mm" means a single core with a single strand 0.6mm in diameter and ... "55/0.1mm copper" means a single core with 55 strands of 0.1mm copper wire.

Car wiring

Code	Rating		(mm2)	(mm)
XS69A	3A	2 x14/0.19	0.395	5.4x2.7
XS70M	6A	2 x20/0.19	0.57	5.6x2.8
XS71N	10A	2 x28/0.19	0.79	6.0x3.0
XS72P	15A	2 x42/0.19	1.19	6.6x3.3
XS73Q	20A	2 x75/0.19	2.12	7.6x3.8
XS74R	25A	2 x50/0.3	3.53	8.4x4.2
XS75S	35A	2 x80/0.3	5.65	10.0x5.0
XS76H	50A	2 x140/0.3	9.89	12.4x6.2

Available in black & red

Semi-stiff wire designed for automtive use and is therefore generally available in small quantities.
Excellent for power handling where components do not have to be moved frequently but is quite bulky.
In higher current ratings the wire becomes very bulky (7 to 12mm in diameter) and is therefore not all that good for use in small spaces.

Bell Wire

Single core: 1/0.6mm copper 22AWG (23SWG)
Sheath: 03mm PVC
Overall diameter: 12mm
Nom. conductor area: 028mm2
Max. working voltage: 1000V rms
Colours: black, blue, green, red, white, yellow.

Low power permanently installed circuits like lighting.
Wire is rigid, so once bent to shape it stays there and the shape can be stuck to say the inside of a superstructure with a couple of small blobs of silicon.
Can be difficult to solder onto !!

Wiring continued ....

Light-Duty Equipment (10/0.1)
Specifications:
Stranded core, single: 10/01mm copper
Sheath: 0.3mm PVC
Overall diameter: 0.9mm
Nom. conductor area: 00785mm2
Max. working voltage: 1000V rms
Max. current: 0.5A
Colours available: Black, Blue, Green, Red, White, Yellow

As above, but wire is flexible and thinner (see max current) so fixing needs more silicon blobs!
***Must NEVER** be used to connect motors or speed controllers.*
***Can be used** to make servo extension leads where only signal power is carried.*

High Current Wire (50/0·25)
Specifications:
Stranded core, single: 50/025mm copper
Sheath: 0.8mm PVC
Overall diameter: 3.81mm
Nom. conductor area: 2.5mm2
Max. working voltage: 600V
Max. current: 30A
Colours: Black, green, red

Thick semi-stiff wire good for connections between speed controllers and motors where the current does not exceed 30A.
Up to 850 size motors on scale boats ONLY.

***Must NEVER** be used for fast electric boats where currents can easily exceed 50 A.*

Miniature Extra Flexible Wire
Specifications:
Stranded core: 30/01mm copper
Sheath: 1mm very flexible PVC
Overall diameter: 2.0mm
Nom. conductor area: 0.24mm2
Max. working voltage: 650Vdc, 500Vac
Max. current: 15A
Colours available: Black, red

Excellent wire for small power installations up to say 400 size motors where flexibility is needed.
Costs around £0.69 per metre.

I tend to use it for most applications other than larger motor connections or lighting.

Extra Flexible Wire
Specifications:
Stranded core, single: 55/01mm copper
Sheath: 1mm very flexible PVC
Overall diameter: 2.8mm
Nom. conductor area: 0.43mm2
Max. working voltage: 650Vdc, 500Vac
Max current: 25A
Colours: Black and Red

Great for battery connections to ESC's and ESC's to motor connections.
Costs around £0.79 per metre

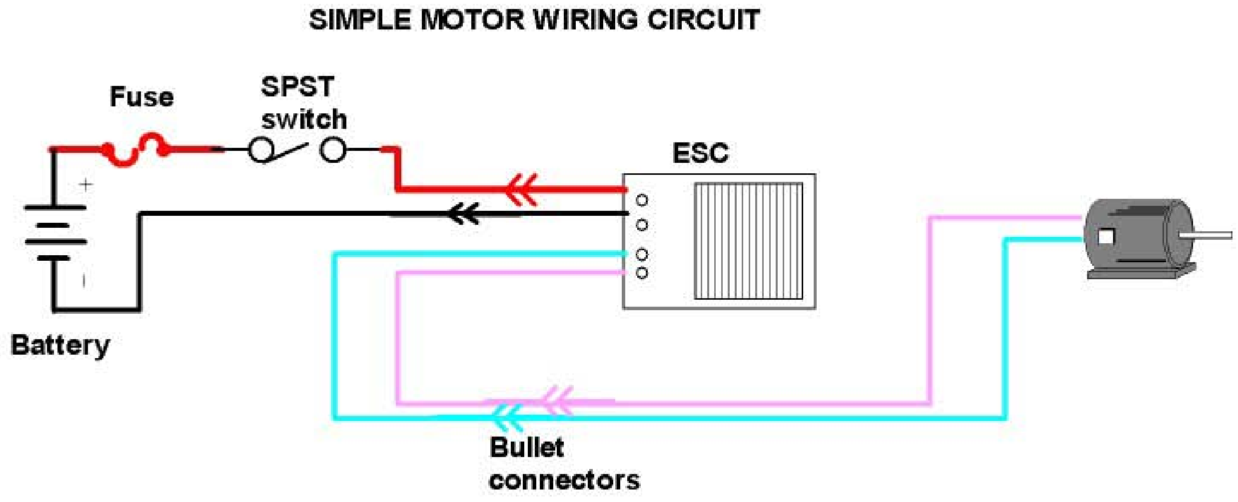
I use this for most motor/esc and battery connections on greater than 400 size motors in scale applications.

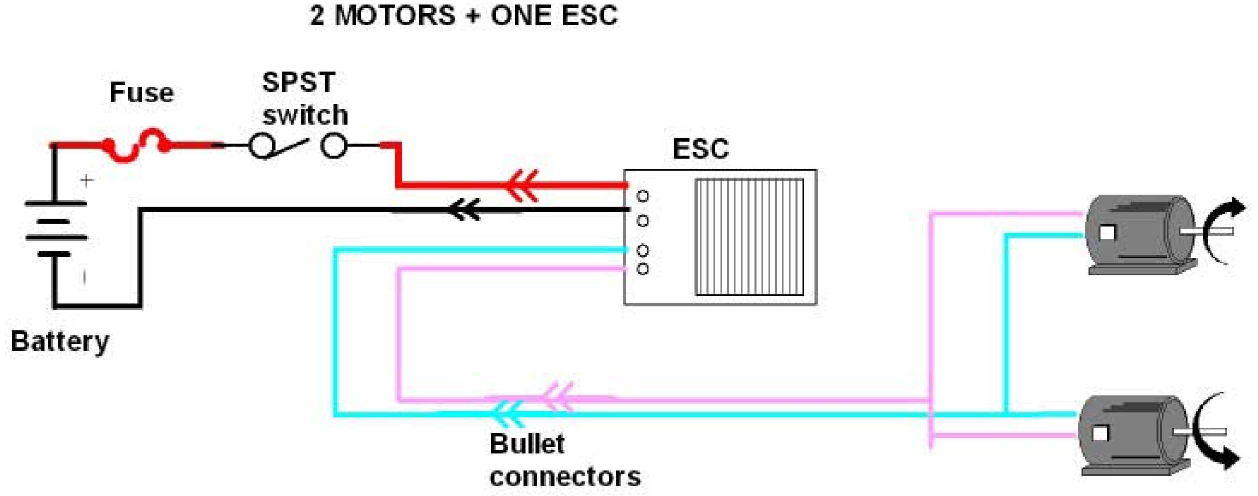
Silicone Extra Flexible Wire
Specifications:
Stranded core, single: 462/0.08mm copper
Sheath: 0.75mm silicone
Overall diameter: 3.5mm
Nom. conductor area: 2.3mm2 (13AWG)
Max. working voltage: 500V
Max. current: 32A
Colours: Black, red

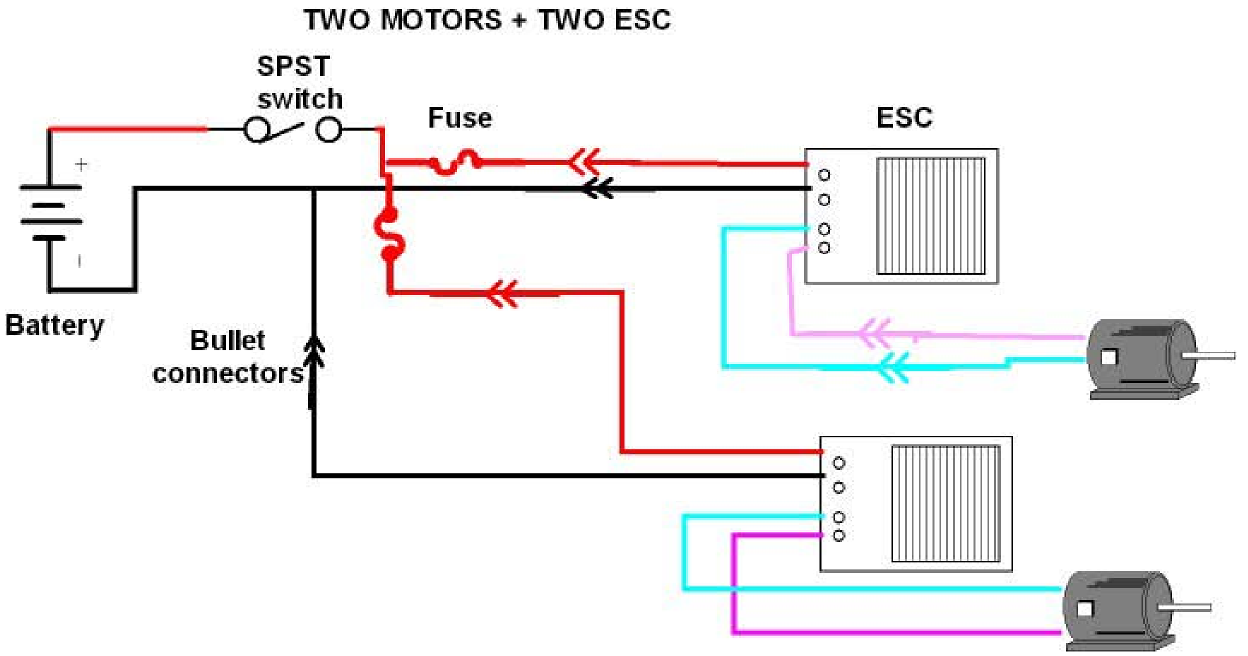
Lovely stuff this, but at £5.99 per metre you really should ask ... do I really need it?
Its primary attribute is temperature resistance (i.e. insulation will not soften and thus avoids short circuits).
Soldering needs a LOT of heat !!

I use it ONLY for battery to ESC connections where the flexibility makes removing a battery in a small space much easier.

EXAMPLE WIRING LAYOUTS







It is often recommended that when installing twin motors & twin ESC's you should also have one battery for each rather than the simple layout shown above. This is to minimise any interaction (interference) between the ESC's through the common power connection. Personally I have never had a problem, but it is worth bearing it in mind. If you do fit two batteries you must also use a Double Pole single throw isolating switch. Also remember that only one of the BEC supplies from the ESCs should be used - NOT both, in order to avoid interaction.

SIMPLE LIGHTING CIRCUITS

There are many types of lighting available for models these days. Mainly they come in three forms: **"Grain of Wheat"** bulbs, **"Pea Bulbs"** and **LED's**.
Remember to think laterally when considering lighting: Dolls House lights & model railway lights can sometimes be very useful.

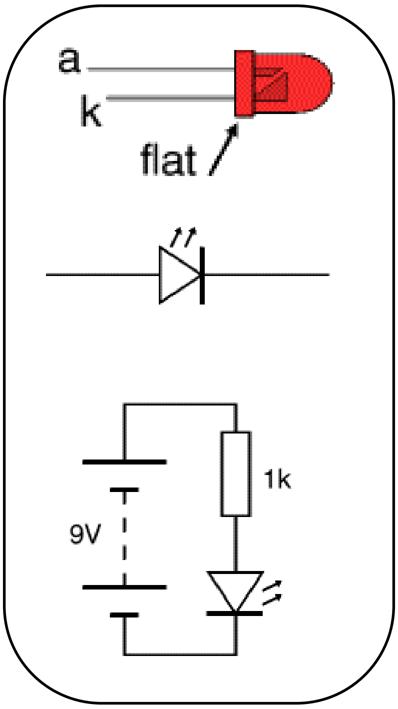
INCANDESCENT BULBS

Grain of Wheat and **Pea bulbs** are sub miniature and miniature incandescent bulbs in glass cases, usually with terminal leads around 150mm in length. They can be either 3 volt (most Graupner stuff) or 6 volt or 12 volt. You MUST make sure you know the operating voltage .... a 3 volt bulb on a 6 volt supply will burn out almost instantaneously!
Typically they draw around 65mA.
Sub-miniature usually around 3mm dia and 8mm overall.
Miniature 5 to 6mm dia and 10-12mm overall.
Colouration is applied using a lacquer coating.
Bulbs are NOT polarity sensitive so wires may be connected either way round.

LED's (Light Emitting Diodes)

LED's also come in many types, usually based on their intensity.
LEDs emit light when an electric current passes through them.

They will have short terminal bars, one longer than the other. The longest bar must be connected to the positive terminal if the LED is to work. Most are suitable for direct use where voltage is between 1.5 and 3 but will need a resistor in series on higher voltages..
Typically they draw around 30mA.
Colouration is sometimes indicated by tinting the plastic material of the case.



Connecting and soldering
LED connections
LEDs must be connected the correct way round, the diagram may be labelled **a** or **+** for anode and **k** or **-** for cathode (yes, it really is k, not c, for cathode!).
The cathode is the short lead and there may be a slight flat on the body of round LEDs. If you can see inside the LED the cathode is the larger electrode (but this is not an official identification method).

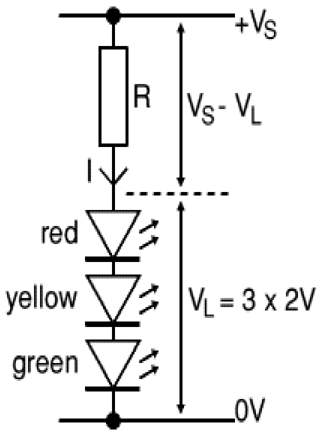
LEDs can be damaged by heat when soldering, but the risk is small unless you are very slow. No special precautions are needed for soldering most LEDs.

Testing an LED
Never connect an LED directly to a battery or power supply greater than 3 volt!
It will be destroyed almost instantly because too much current will pass through and burn it out.

LEDs on greater than 3 volt must have a resistor in series to limit the current to a safe value; for quick testing purposes a 1kohm resistor is suitable for most LEDs if your supply voltage is 12V or 6 volt. Remember to connect the LED the correct way round

Colours of LEDs
LEDs are available in red, orange, amber, yellow, green, blue and white.
Blue and white LEDs are more expensive than the other colours.

The colour of an LED is determined by the semiconductor material, not by the colouring of the 'package' (the plastic body). LEDs of all colours are available in un-coloured packages which may be diffused (milky) or clear (often described as 'water clear'). The coloured packages are also available as diffused (the standard type) or transparent.



Connecting LEDs in series
If you wish to have several LEDs on at the same time it may be possible to connect them in series. This prolongs battery life by lighting several LEDs with the same current as just one LED.

All the LEDs connected in series pass the same current so it is best if they are all the same type.
The power supply must have sufficient voltage to provide about 1.6 to 2V for each LED (4V for blue and white) plus at least another 2V for the resistor. To work out a value for the resistor you must add up all the LED voltages and use this for VL.

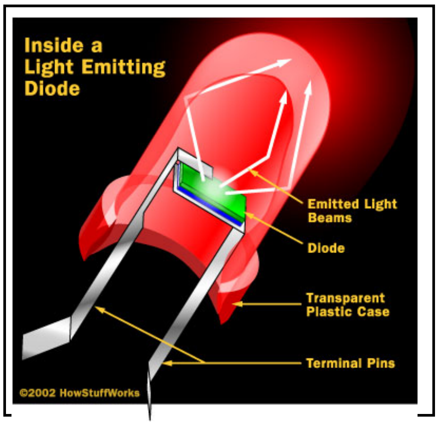
Example calculations:
A red, a yellow and a green LED in series need a supply voltage of at least (3 × 2) + 2 = 8V, so a 9V battery would be ideal.

VL = 2 + 2 + 2 = 6V (the three LED voltages added up).

If the supply voltage VS is 9V and the current I = 15mA (= 0.015A)

Resistor R = (VS - VL) / I = (9 - 6) / 0.015 = 3 / 0.015 = 200ohm,

so choose R = 220ohm (the nearest standard value which is greater).



So, in balance, although LEDs may offer a smaller package size, the circuit can be a bit more complicated. This is balanced by the fact that LEDs usually have a much longer service life than incandescent bulbs.

However, in many cases the governing criteria on models is one of bulb size! It is no use having a navigation light that is several times bigger than a mans head in scale terms. It will just look bad ....

subminiature LED
Dome is 1.8mm diameter

LED with built in resistor
5mm dia by 15mm long for use on 12 volt car electrics

So .... How to choose ?
Masthead navigation lights - 3 LEDs in series offers the more compact choice since there are only two wires; together they draw only 35mA max and can be run from a 4.8 volt (3 cell) battery pack with no resistor needed.
Cost - between 19 and 25p per LED
3 grain of wheat or pea bulbs would need to be connected in parallel, run off a 3 volt (2 cell) battery pack and would consume 3*65mA = 175mA.
Cost - about 50p per bulb.
Pea bulbs probably cost much the same as grain of wheat bulbs.
Please note: prices are based on say Maplin ...... NOT what model shops charge!!!!!!

BATTERY INFORMATION

Lead Acid (commonly designated as Pb from the Latin plumbus for lead)

Lead acid batteries consist of a number of ‘plates’ of lead (the electrodes) hung in a chamber and surrounded by an electrolyte. The plates are interleaved with ‘separators’ whose purpose is to prevent the lead plates short circuiting.
A Wet Cell battery uses a liquid electrolyte of dilute sulphuric acid.
In a Sealed Lead Acid (SLA) battery the electrolyte is gelled and absorbed onto a glass fibre mat. Although the cost of manufacture is higher, sealed lead acid batteries or "gel cells" have a longer life, higher capacity and are safer than wet cells.

These batteries <u>must be stored in a charged condition</u> and they self-discharge at a moderate rate. Therefore they should be re-charged at least once a year to remain in good condition, even if only stored.
If the temperature is raised - garden shed in summer - recharge more frequently.

SLA batteries can be used anyway up, but always charge upright.

You can replace a wet Lead Acid battery with a Sealed Lead Acid battery, of similar capacity without altering the circuit or charging circuit.

Freeze/ thaw stable these batteries withstand lower temperatures better when they are fully charged.

Car type batteries and to a lesser extent SLA batteries can evolve Hydrogen and Oxygen whilst being charged. These gases form an explosive mixture. Allow ventilation to batteries whilst charging.

Charge batteries with a DC current, positive terminal to positive terminal.
The voltage must be greater than the battery or battery pack voltage. The current must be limited and the current cut off when the battery is fully charged.
Full charge is sensed either by a rise in voltage, a rise in resistance or a rise in temperature.
Battery chargers are designed to supply a suitable current for the batteries with which they where designed to work.
Unless chargers are labeled otherwise, remove the battery after 16 hours.
More sophisticated chargers will switch to a trickle when they sense the battery is fully charged. This is fine for Lead-Acid batteries but NiCd and NiMh should not be left on 'maintenance' charge for more than a few days.

As a rule of thumb, the charging current is one eighth of the Ah (in Amps) or mAh (milleamps) rating of the battery. A full charge takes about 1.4 times the label capacity.
E.g. NiMh Battery 1800mAh capacity
Charging current 1800 divided by 8 = 225 mA
Charging time 1800 divided by 225 x 1.4 = 11.2 hours

Fully charged and not connected to anything a 12 volt battery should have a voltage of between 12.6V and 12.8V.
Unconnected and fully discharged it should have a voltage of between 11.8V and 12V.

Fully charged and open circuit a 6 volt battery should have a voltage of between 6.3V and 6.6V

At no time should the temperature rise much beyond blood heat.

<u>NEVER RECHARGE A LEAD ACID OR SLA BATTERY BY CONNECTING IT TO ANOTHER BATTERY DIRECTLY.</u>

If you do so there is no limit to the currents which may flow and this will probably result in the battery under charge being destroyed. At the least it is likely that the casing will bulge under the internal gas pressure and may split and leak (assuming it doesn’t actually explode.

NICKEL-CADMIUM CELLS (NiCd)

These are still the most frequently available rechargeable battery available although with the use of Cadmium being largely banned in the EU, they will gradually disappear from the market place.

Unlike lead acid cells and 'dry cells', these only generate a voltage of 1.25 volts per cell. So, whereas a 4 cell pack of dry cells will supply 6 volts, replacing them with NiCds will only produce 5 volts.

The nickel-cadmium battery (commonly abbreviated NiCd and pronounced "nye-cad") is a popular type of rechargeable battery using nickel(IV) oxide and metallic cadmium as electrodes.

The principal advantages of NiCd over other rechargeable types is lower weight for a given quantity of stored energy, good charging efficiency, small variation in terminal voltage during discharge, low internal resistance, and non-critical charging conditions.There are two types of NiCd batteries: sealed and vented. This article mainly deals with sealed cells.

Nickel-cadmium cells have a nominal cell potential of 1.2 V. This is lower than the 1.5 V of many popular primary cells, and consequently they are not appropriate as a replacement in all applications. Unlike common primary cells, a NiCd cell's terminal voltage only changes a little as it discharges. Because many electronic devices are designed to work with primary cells that may discharge to as low as 0.90 to 1.0 V per cell, the relatively steady 1.2 V of a NiCd is enough to allow operation. Some would consider the near constant voltage a drawback, as it makes it difficult to detect when the battery charge is low; this is usually a minor concern.

NiCd batteries used to replace nominally 9-V "transistor radio" batteries usually only have six cells, for a terminal voltage of 7.2 volts. While most pocket radios will operate satsifactorily at this voltage, some manufacturers such as Varta made 8.4 volt batteries with seven cells, for more critical applications.

12 V NiCd batteries are made up of 10 cells connected in series.

When compared to other forms of rechargeable battery, the nickel cadmium battery has a number of distinct advantages.

* The batteries are more difficult to damage than other batteries, tolerating deep discharge for long periods. In fact, <u>NiCd batteries in long-term storage are typically stored fully discharged</u>. This is in contrast, for example, to lithium ion batteries, which are highly volatile and will be permanently damaged if discharged below a minimum voltage. In addition, NiCd batteries typically last longer, in terms of number of charge/discharge cycles, than other rechargeable batteries, and have faster charge and discharge rates than lead-acid batteries, with minimal loss of capacity even at high discharge rates.

* Compared to lead-acid batteries, NiCd batteries have a much higher energy density. This means that, for a given battery capacity, a NiCd battery is smaller and lighter than a comparable lead-acid battery.

* Nickel metal hydride (NiMH) batteries are the newest, and most similar, competitor to NiCd batteries. Compared to NiCd, NiMH batteries have a higher capacity and are less toxic, but are still slightly more expensive. In addition, a NiCd battery has a lower self-discharge rate (for example, 20% per month for a NiCd, versus 30% per month for a NiMH under identical conditions). In both types of cell, the self-discharge rate is highest for a full charge state and drops off somewhat for lower charge states. In addition NiMH batteries experience a voltage drop as it nears full discharge, which a NiCd does not. Finally, a similarly-sized NiCd battery has a slightly lower internal resistance, and thus can achieve a higher maximum discharge rate (which can be important for applications such as power tools).

Disadvantages
The primary trade-off with NiCd batteries is their higher cost. They require extra labor to manufacture, and thus, are typically more costly than lead-acid batteries. Typically nickel and cadmium are more costly materials than those used for lead-acid cells.
Another disadvantage of NiCds is that certain usage patterns may cause a "false bottom" effect. Specifically, if the battery is consistently discharged to the same level, then fully recharged, the battery will eventually stop discharging on its own upon reaching this threshold. (See memory effect below for more details on this effect).

One of the Nickel-Cadmium's biggest disadvantages was that the battery exhibited a very marked negative temperature coefficient. This meant that as the cell temperature rose, the internal resistance fell. Thus could pose considerable charging problems particularly with the relatively simple charging systems employed for lead-acid type batteries. Whilst lead-acid batteries could be charged by simply connecting a dynamo to it, with a simple electromagnetic cut out system for when the dynamo is stationary, or an over current occurs, the nickel-cadmium under a similar charging scheme would exhibit thermal runnaway, where the charging current would continue to rise until the over current cut out operated or the battery destroyed itself.

NICKEL-METAL HYDRIDE CELLS (NiMH)

A nickel-metal hydride battery, abbreviated NiMH, is a type of rechargeable battery similar to a nickel-cadmium (NiCd) battery but has a hydrogen-absorbing alloy for the anode instead of cadmium. Like in NiCd batteries, nickel is the cathode.
A NiMH battery can have two to three times the capacity of an equivalent size NiCd and the memory effect is not as significant. However, compared to the lithium-ion battery, the volumetric energy density is lower and self-discharge is higher.

Common penlight-size (AA) batteries have nominal capacities C ranging from 1100 mA·h to 2700 mA·h at 1.2 V, usually rated at 0.2×C rate. Useful discharge capacity is an inverse function of the discharge rate, but up to around 1×C rate, there is no significant difference.

Charging:
The charging voltage is 1.4-1.6 V/cell. Duracell recommends "a maintenance charge of indefinite duration at C/300 rate". A fully charged cell measures 1.35-1.4 V (unloaded), and supplies a nominal average 1.2 V during discharge, down to about 1.0 V (further discharge may cause permanent damage).

Voltage Depression ("Memory Effect") from repeated partial discharge can occur, but is reversible through charge cycling.[2]

When fast-charging, it is advisable to charge the NiMH batteries with a smart battery charger to avoid overcharging, which can damage batteries and cause dangerous conditions. Modern NiMH batteries contain catalysts to immediately deal with gases developed as a result of over-charging without being harmed. However, this only works with overcharging currents of up to C/10 h (nominal capacity divided by 10 hours). As a result of this reaction, the batteries will heat up considerably, marking the end of the charging process. Some quick chargers have a fan to keep the batteries cool.

Some equipment manufacturers consider that NiMH can be safely charged in simple fixed (low) current chargers with or without timers, and that permanent overcharging is permissible with currents up to C/10 h. In fact, this is what happens in cheap cordless phone base stations and the cheapest battery chargers. Although this may be safe, it may not be good for the health of the battery.
According to the Panasonic NiMH charging manual, permanent trickle charging (small current overcharging) can cause battery deterioration and the trickle charge rate should be limited to between 0.033×C per hour and 0.05×C per hour for a maximum of 20 hours to avoid damaging the batteries.

Long-term maintenance charge of NiMH batteries needs to be by low duty cycle pulses of high current rather than continuous low current in order to preserve battery health.

Brand new batteries, or batteries which have been unused for some time, need "reforming" to reach their full capacity. For this reason new batteries may need several charge/discharge cycles before they operate to their advertised capacity.

Discharging
Care must also be taken during discharge to ensure that one or more cells in a series-connected battery pack, like the common arrangement of four AA cells in series in a digital camera, do not become completely discharged and go into polarity reversal. Cells are never absolutely identical, and inevitably one will be completely discharged before the others. When this happens, the "good" cells will start to "drive" the discharged cell in reverse, which can cause permanent damage to that cell.
Once noticeable dimming or slowing of the device is noticed, it should be turned off immediately to avoid polarity reversal. A single cell driving a load won't suffer from polarity reversal, because there are no other cells to reverse-charge it when it becomes discharged.

Self-discharge
NiMH has had a somewhat higher self-discharge rate than NiCd in the past. However, this is no longer the case. The self-discharge is 5-10% on the first day[3], and stabilizes around 0.5-1% per day at room temperature. This

is not a problem in the short term, but makes them unsuitable for many light-duty uses, such as clocks, remote controls or safety devices, where the battery would normally be expected to last many months or years.
The rate is strongly affected by the temperature at which the batteries are stored with cooler storage temperatures leading to slower discharge rate and longer battery life. (So perhaps there is a case for keeping your NiMH's in the fridge!!)
The highest capacity cells on the market (> 2700mAh) are reported to have the highest discharge rates.

Comparison with other battery types

- They are not expensive, and the voltage and performance is similar to standard alkaline batteries in those sizes; they can be substituted for most purposes. The ability to recharge hundreds of times can save a lot of money and resources.

- NiMH batteries are particularly advantageous for high current drain applications, due in large part to their low internal resistance. Alkaline batteries, which might have approximately 3000 mA·h capacity under low current demand (200 mA), will have less than 1000 mA·h capacity under 1000 mA (reference). Digital cameras with LCDs and flashlights can draw over 1 A, quickly depleting alkaline batteries after few shots. NiMH can handle these current levels and maintain their full capacity.

- Sometimes, voltage-sensitive devices won't perform well because the voltage of NiMH batteries is lower than disposable batteries at equivalent sizes. Even though the voltage is lower, it can be beneficial for the length of the discharge cycle, since the low internal resistance allows NiMH cells to deliver a near-constant voltage until they are almost completely discharged.

LITHIUM-ION BATTERY

Lithium-ion batteries (sometimes abbreviated Li-ion batteries) are a type of rechargeable battery commonly used in consumer electronics.
However they are quite unsuitable for model use given all their disadvantages and can NOT be recommended particularly since they require the use of special charging equipment.
.
They are currently one of the most popular types of battery for portable electronics, with one of the best energy-to-weight ratios, no memory effect, and a slow loss of charge when not in use.
<u>They can be dangerous if mistreated</u> and unless care is taken their lifespan may be reduced. Although originally intended for consumer electronics, Lithium-ion batteries are growing in popularity with the defence and aerospace industries because of their high energy density.

LITHIUM-ION POLYMER BATTERY

<u>In balance, if a battery of this type is already fitted to a device, then well and good but if retro-fit is being considered, please take great care to ensure that installation instructions are closely followed and that ONLY the specified battery charger is used..</u>
Lithium-ion polymer batteries, or more commonly lithium polymer batteries (abbreviated Li-poly or LiPo) are rechargeable batteries which have technologically evolved from lithium-ion batteries. Ultimately, the lithium-salt electrolyte is not held in an organic solvent as in the lithium-ion design, but in a solid polymer composite such as polyethylene oxide or polyacrylonitrile. The advantages of Li-poly over the lithium-ion design include lower cost manufacturing and being more robust to physical damage.

Since no metal battery cell casing is needed, the battery can be lighter and it can be specifically shaped to fit the device it will power. Because of the denser packaging without intercell spacing between cylindrical cells and the lack of metal casing, the energy density of Li-poly batteries is over 20% higher than that of a classical Li-ion battery and approximately three times better than nickel-cadmium (NiCd) and nickel metal hydride (NiMH) batteries.

A compelling advantage of Li-poly cells is that manufacturers can shape the battery almost however they please, which can be important to mobile phone manufacturers constantly working on smaller, thinner, and lighter phones. Another advantage of lithium polymer cells over nickel-cadmium and nickel metal hydride cells is that the rate of self-discharge is much lower.

Li-poly batteries are also gaining favour in the world of radio-controlled aircraft, where the advantages of both lower weight and greatly increased run times can be sufficient justification for the price. However, lithium polymer-specific chargers are required to avoid fire and explosion. Explosions can also occur if the battery is short-circuited, as tremendous current passes through the cell in an instant.
Radio-control enthusiasts take special precautions to ensure their battery leads are properly connected and insulated.
Specially designed electronic motor speed controls are used to prevent excessive discharge and subsequent battery damage. This is achieved using a low voltage cutoff (LVC) setting that is adjusted to maintain cell voltage at (typically) 3 V per cell

Another word of warning from the USA:
Lithium cells must be charged very differently than NiCad or NiMH. They require a special charger specifically designed to charge lithium cells. In general any charger that can charge lithium ion can charge lithium polymer, assuming that the cell count is correct. You must NEVER charge lithium cells with a NiCad or NiMH only battery charger. This is dangerous. Charging cells is the most hazardous part of using lithium batteries. EXTREME care must be taken when charging them. It is important to set your charger to the correct voltage or cell count. Failure to do this can cause the battery to spew violent flames. There have been many fires directly caused by lithium batteries.

DRY CELLS (non-rechargeable batteries)

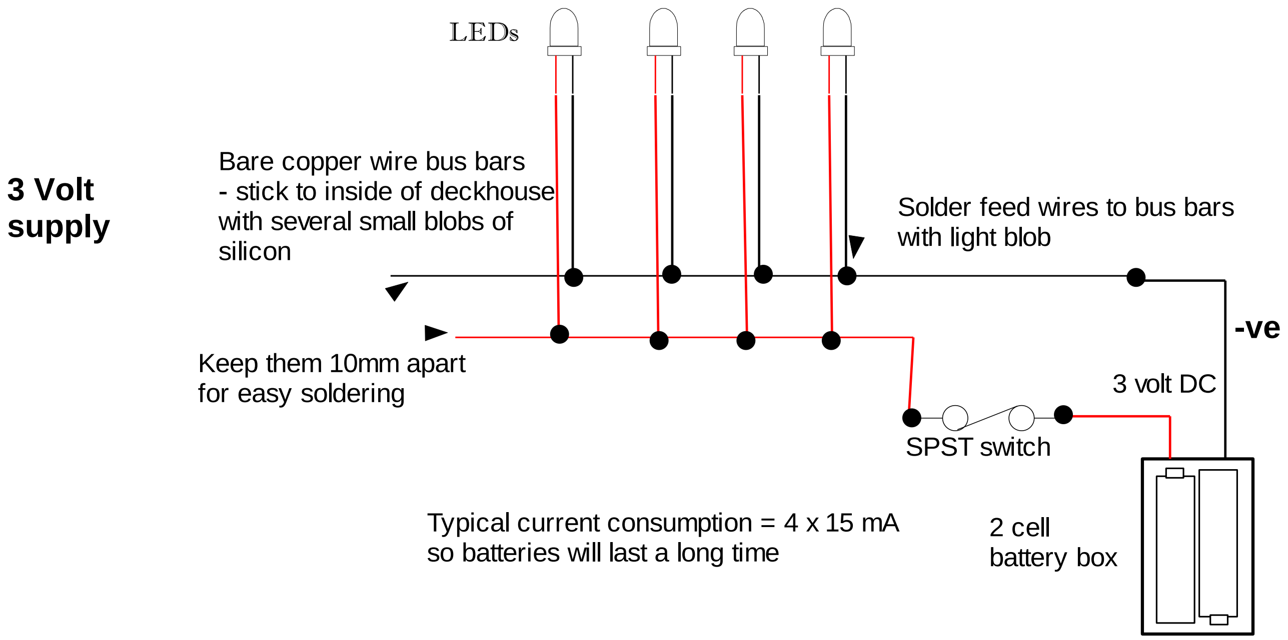
A common dry cell battery is the **zinc-carbon** battery, using a cell sometimes called the dry Leclanché cell, with a nominal voltage of 1.5 volts, the same nominal voltage as the **alkaline** battery (since both use the same zinc-manganese dioxide combination).
Multiple cells are commonly connected in series within a single case or battery compartment within a device to form a dry battery (or dry cell battery) of greater voltage than is provided by one cell. A well known dry battery is the 9-volt "transistor radio battery" (PP3 battery) which is internally constructed of a standard stack of six carbon-zinc or alkaline cells, or else three lithium cells.

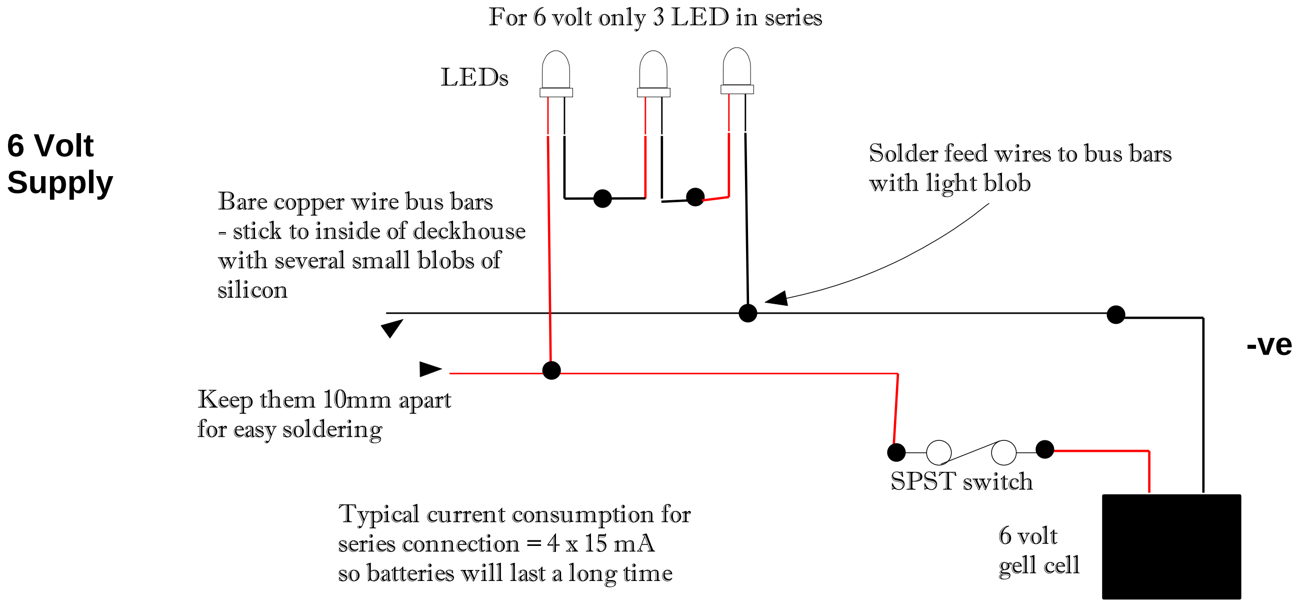
For the cheapest carbon-zinc variety, a zinc outer casing (anode) contains a layer of sodium chloride with zinc chloride aqueous paste separated by a paper layer from a mixture of powdered carbon & manganese oxide which is packed around a carbon rod (cathode).
As the cell runs, manganese is reduced from an oxidation state collecting electrons from the carbon rod, while the zinc metal anode is oxidized producing the electrons. So the electrons travel outside the cell, from the zinc casing (the negative end or anode) through contacts and wires to the carbon rod (which is in contact with the manganese dioxide powder, the actual cathode material, and so is positive).

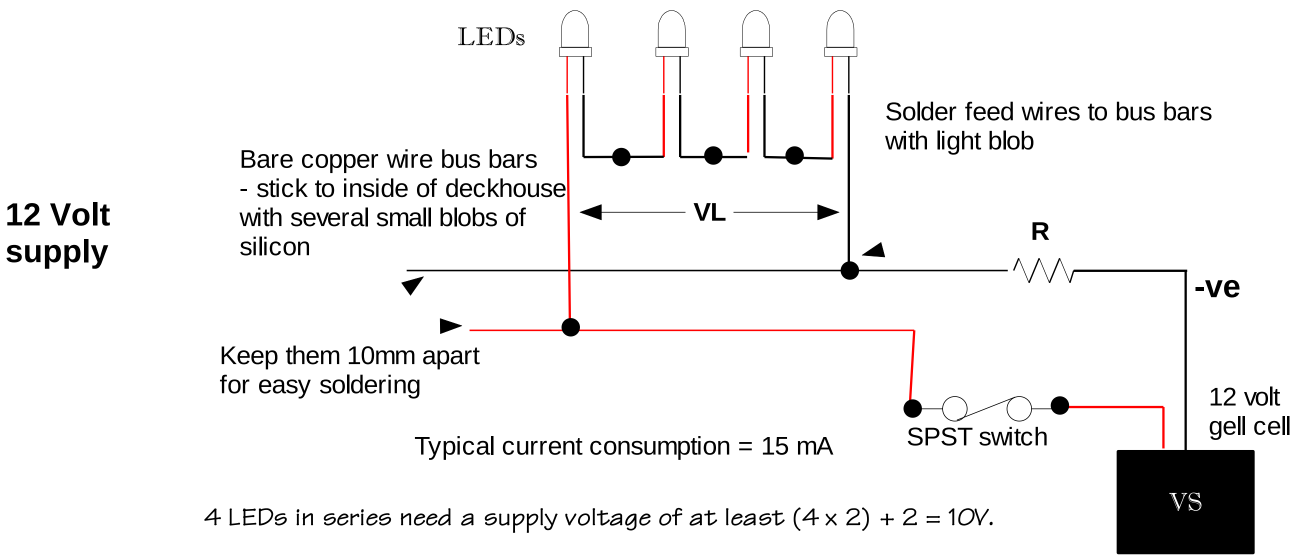
In so-called alkaline cells (see alkaline battery), some of the electrolyte in the paste is replaced with an alkaline paste of potassium hydroxide. However, the essential transfer of electrons from zinc to manganese still powers the cell.

The standard carbon-zinc dry cell is relatively cheap, and until recently, has been the most common type of cell (only recently being replaced in most uses by the alkaline type). It was the first commercial portable battery (technically, a battery is made of two or more cells).

SIMPLE LIGHTING CIRCUIT USING LIGHT EMITTING DIODES



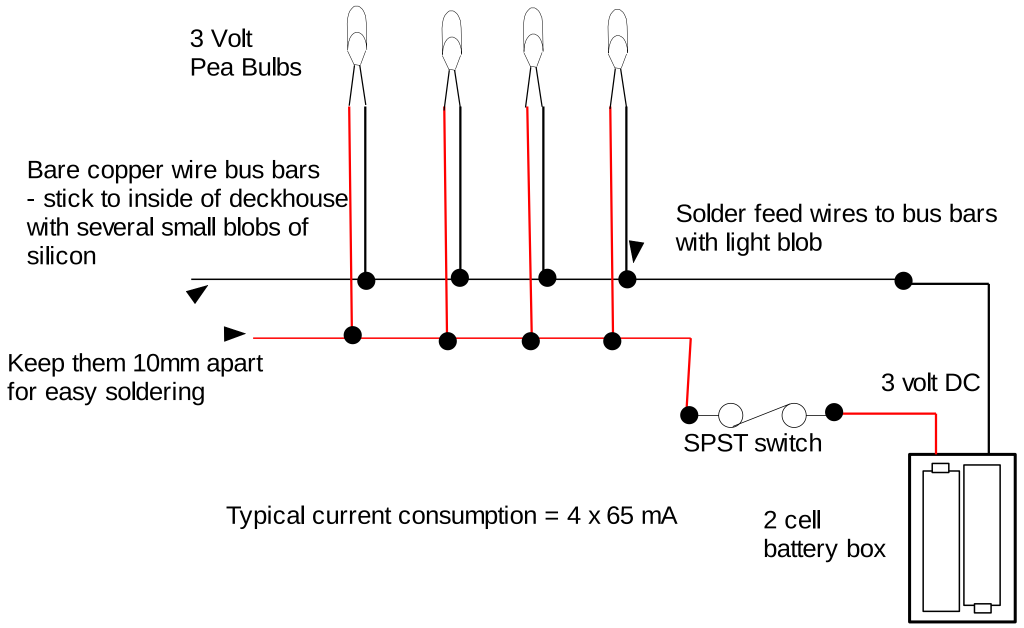


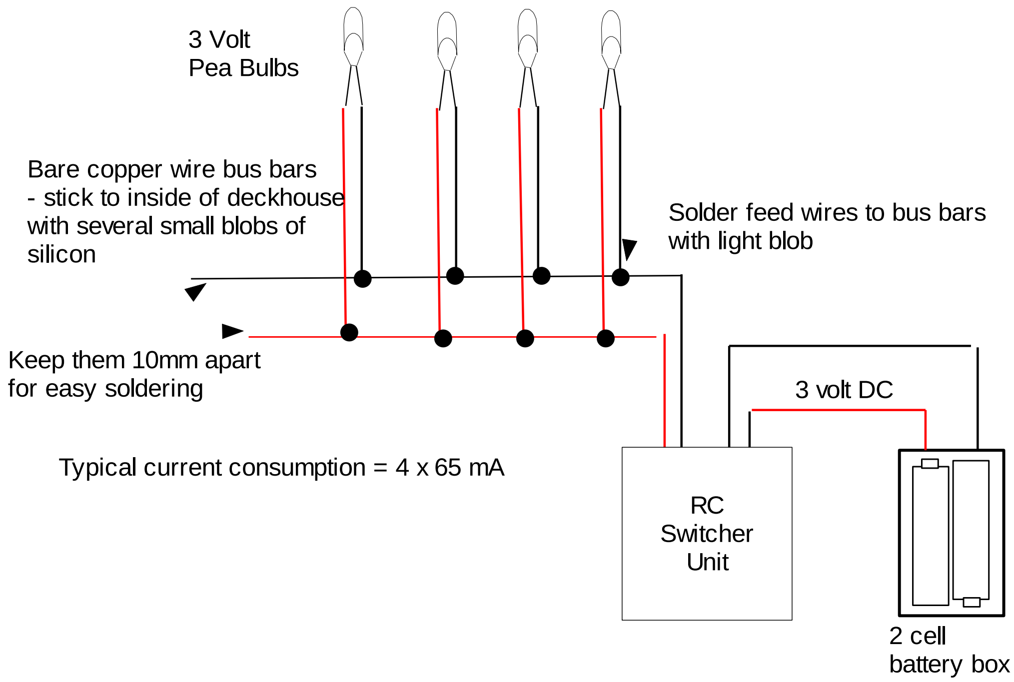


4 LEDs in series need a supply voltage of at least (4 x 2) + 2 = 10V.

VL = 2 + 2 + 2 + 2 = 8V (the three LED voltages added up).
If the supply voltage VS is 12V and the current I = 15mA (= 0.015A)
Resistor R = (VS - VL) / I = (12 - 10) / 0.015 = 2 / 0.015 = 133 ohm,
so choose R = 150 ohm (the nearest standard value which is greater).

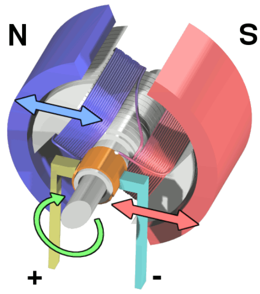
SIMPLE LIGHTING USING PEA BULBS

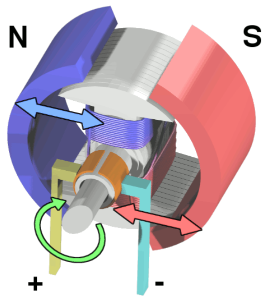




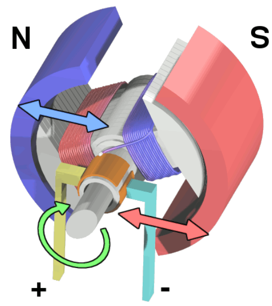
The RC Switcher unit can replace the SPST switch in any of the previous circuits BUT in the 12 volt LED circuit, you must take care to install the Resistor in either the positive or negative leads coming OUT of the switcher, going to the LEDs..

In 6 volt lighting always use 6 volt pea bulbs.
In 12 volt lighting always use 12 volt pea bulbs.
It is much simpler than having to install resistors to drop the voltage.
Pea bulbs are NOT polarity sensitive ... in other words it does not matter which way round the leads are connected.



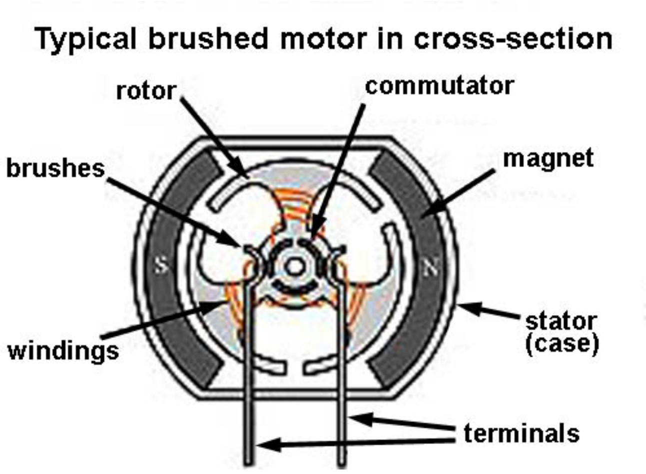


The armature continues to rotate.



A simple 2 pole DC electric motor. When the coil is powered, a magnetic field is generated around the armature. The left side of the armature is pushed away from the left magnet and drawn toward the right, causing rotation

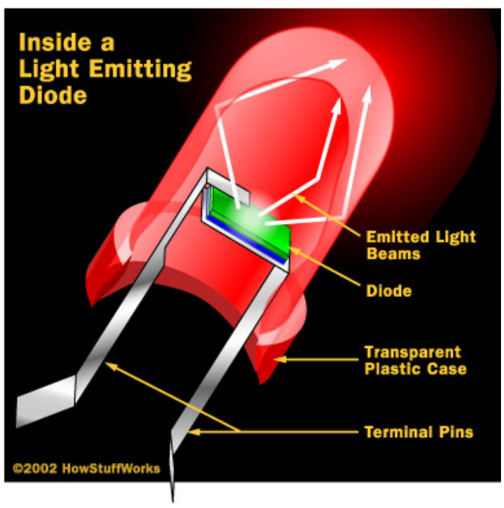
When the armature becomes horizontally aligned, the commutator reverses the direction of current through the coil, reversing the magnetic field. The process then repeats.



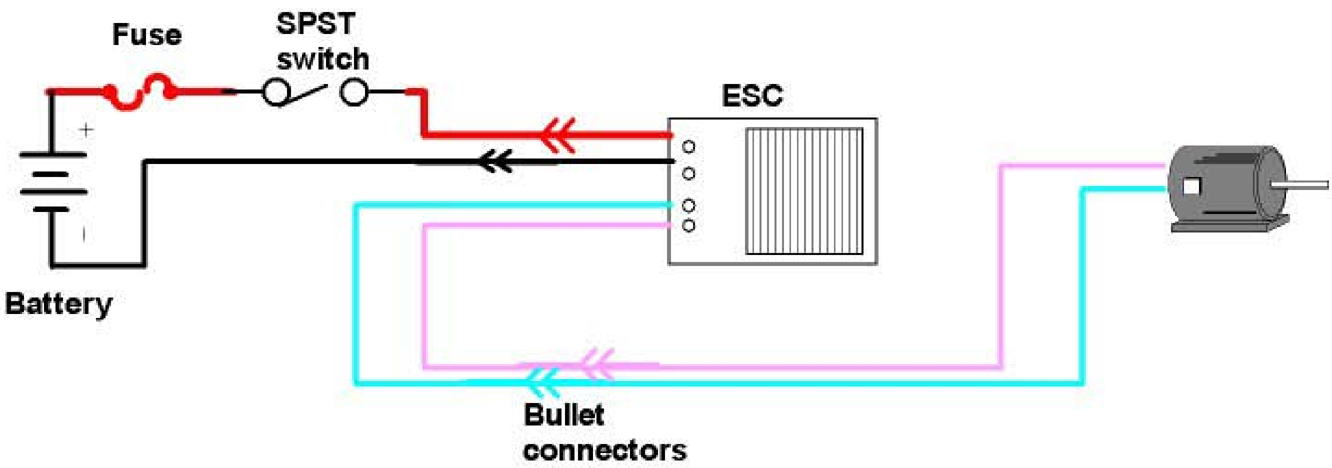
Wire and Crimp Connector sizes

AWG	*Core Diameter mm*	*Current Rating Amps*	*Automotive Crimp Colour*
10	2.59	55	yellow
12	2.05	41	yellow
14	1.63	32	blue
16	1.29	22	blue
22	0.65	7	red
28	0.32	1.4	Not Suitable
32	0,20	0.53	Not Suitable

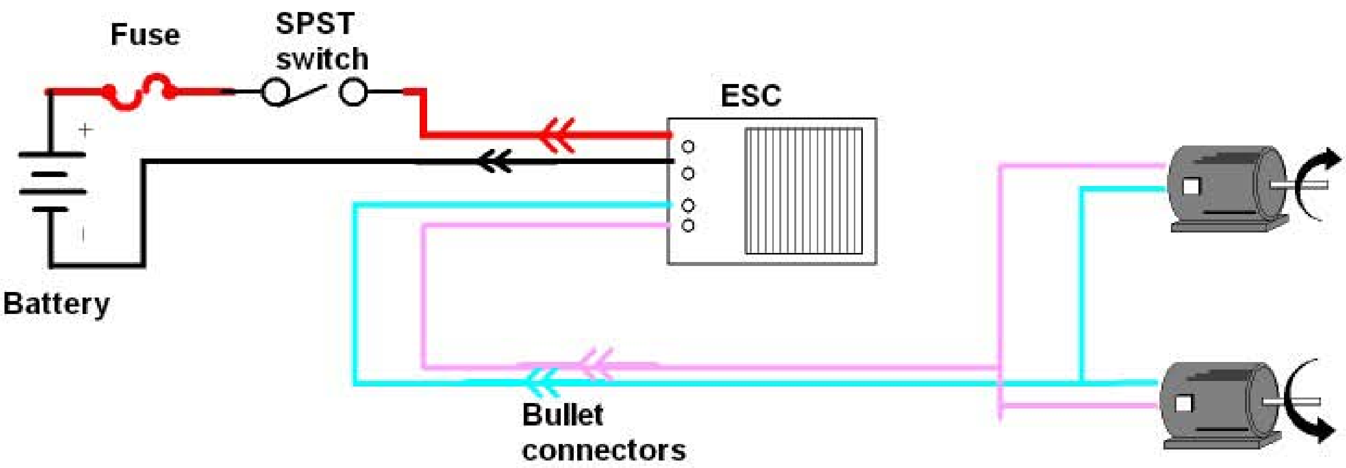
LED



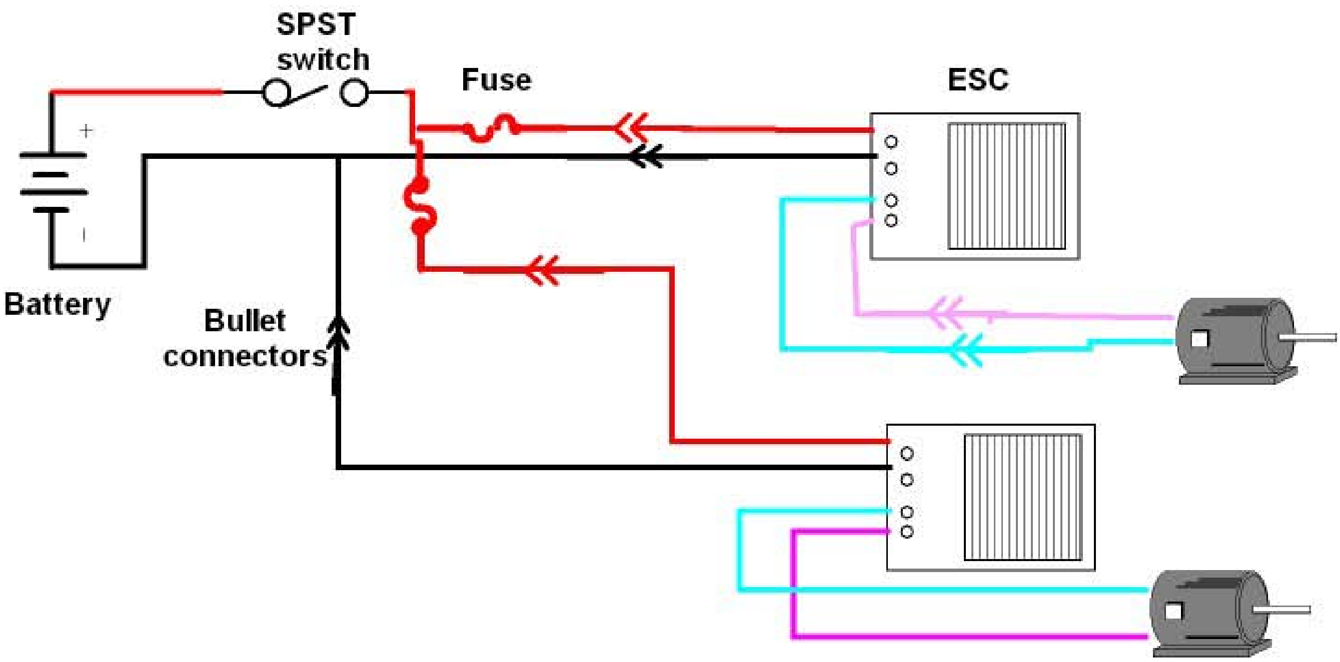
SIMPLE MOTOR WIRING CIRCUIT



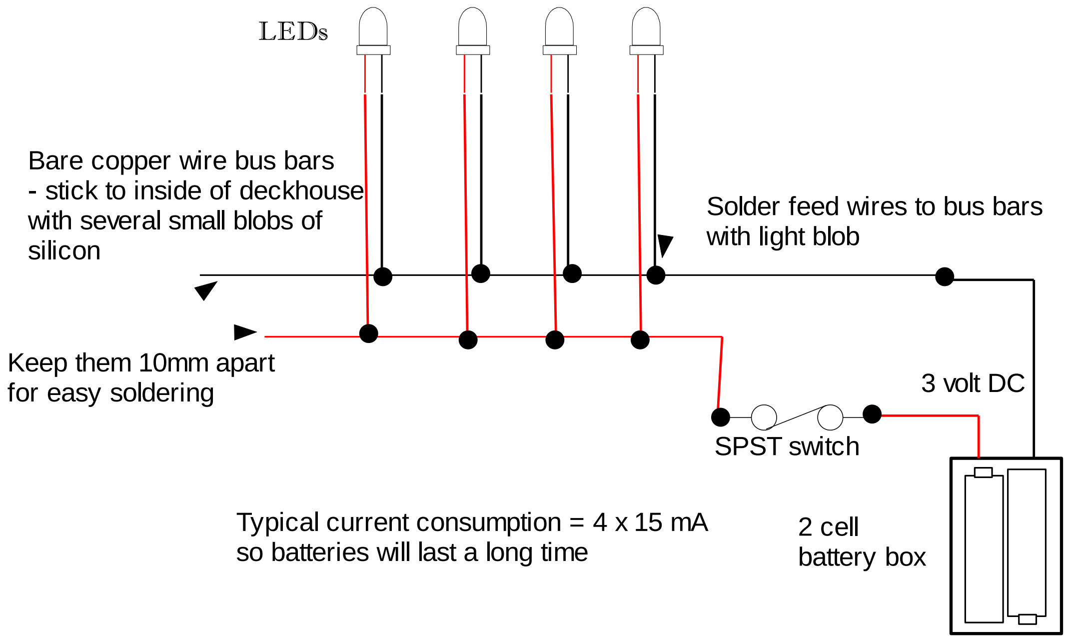
2 MOTORS + ONE ESC



TWO MOTORS + TWO ESC

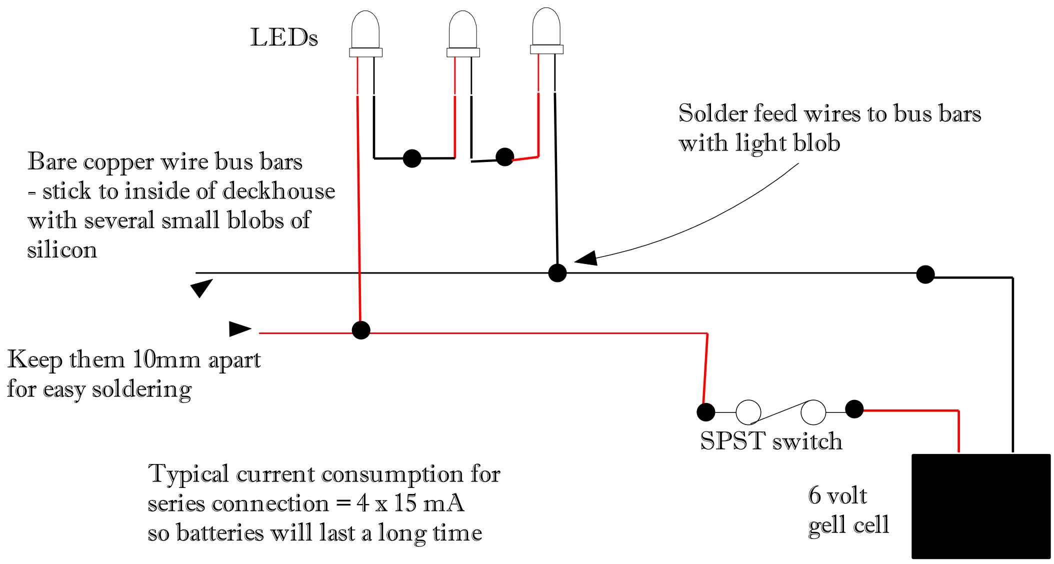


3 Volt supply

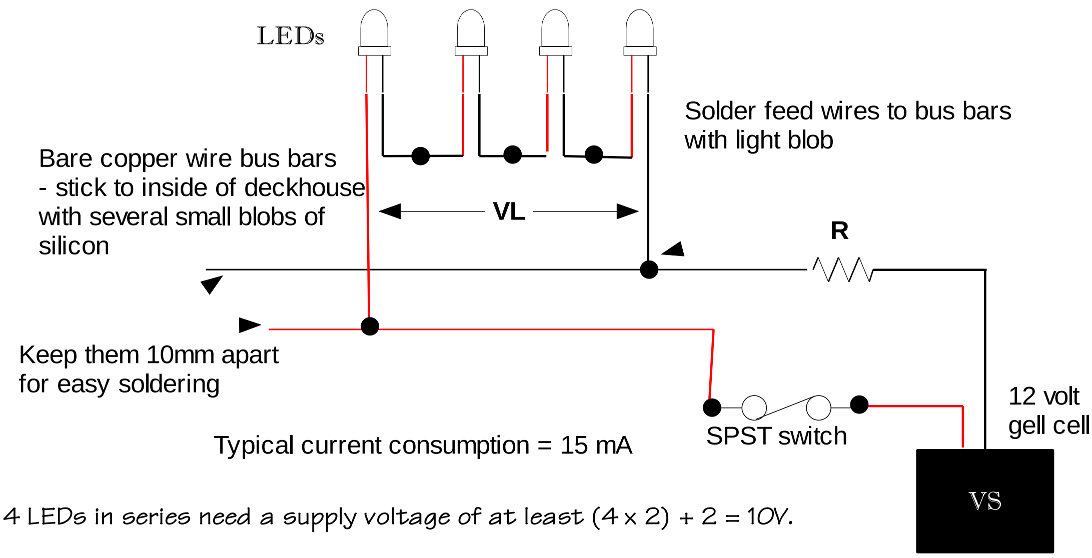


For 6 volt only 3 LED in series

6 Volt Supply

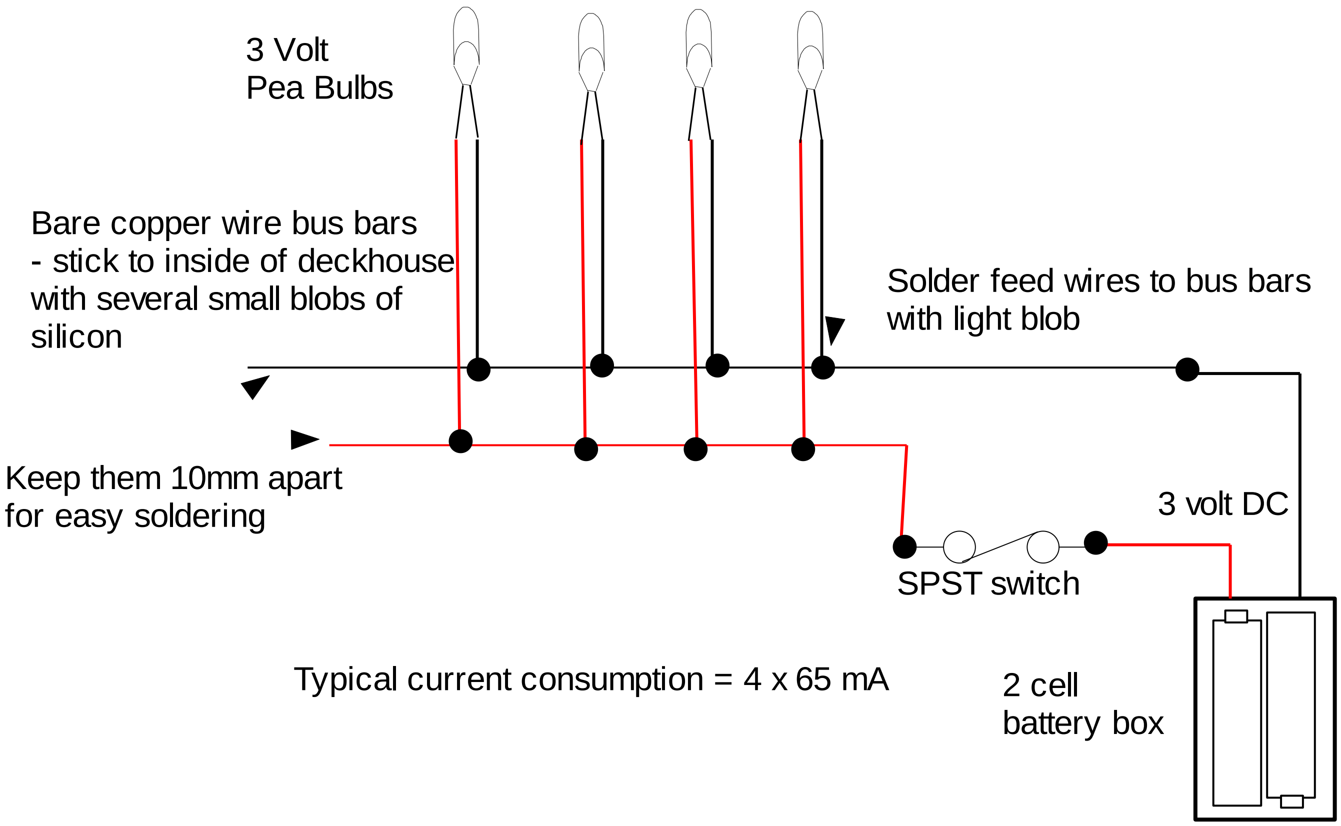


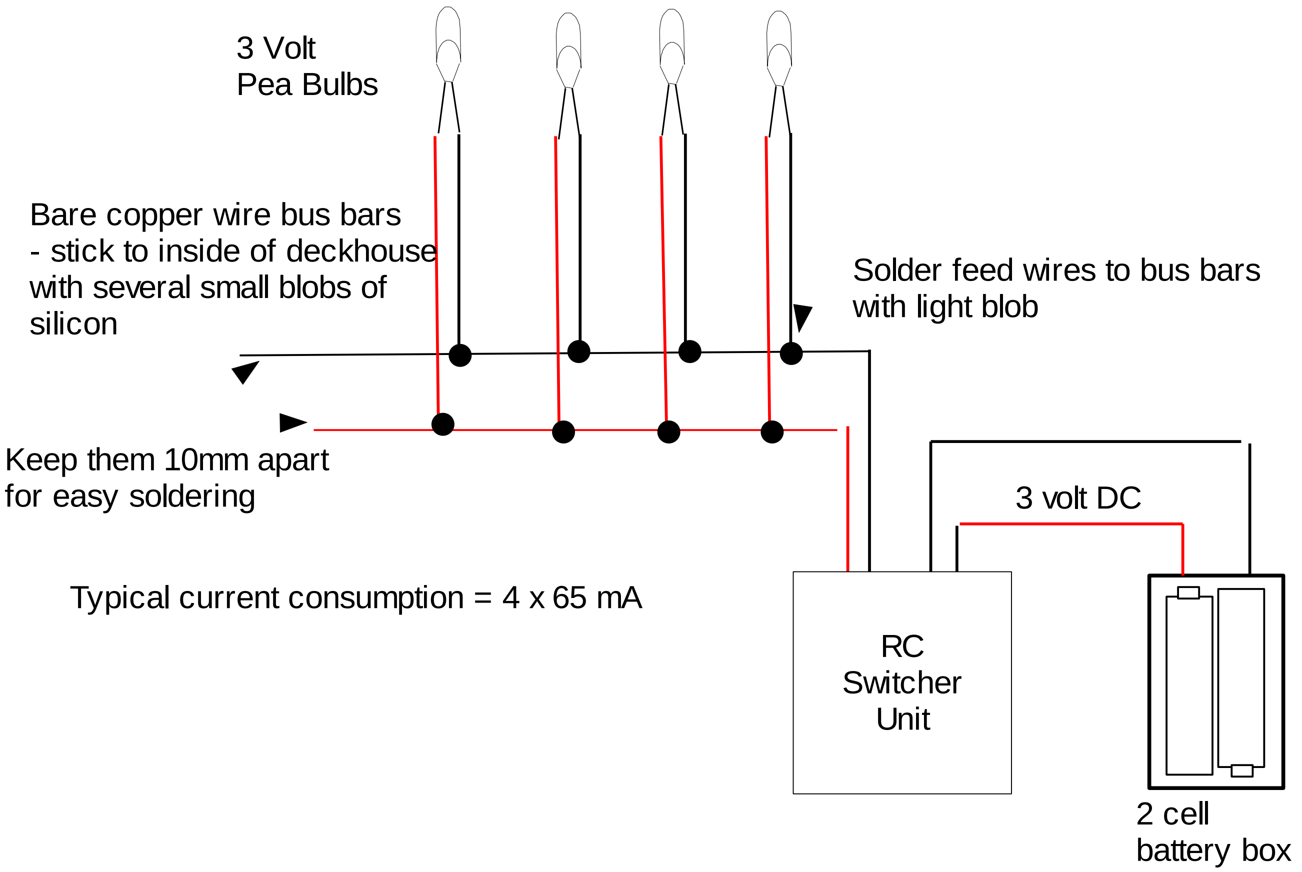
12 Volt supply



4 LEDs in series need a supply voltage of at least (4 x 2) + 2 = 10V.

VL = 2 + 2 + 2 + 2 = 8V (the three LED voltages added up).
If the supply voltage VS is 12V and the current I = 15mA (= 0.015A)
Resistor R = (VS - VL) / I = (12 - 10) / 0.015 = 2 / 0.015 = 133 ohm,
so choose R = 150 ohm (the nearest standard value which is greater).


3 Volt
Pea Bulbs
Bare copper wire bus bars
- stick to inside of deckhouse
with several small blobs of
silicon
Solder feed wires to bus bars
with light blob
Keep them 10mm apart
for easy soldering
3 volt DC
SPST switch
Typical current consumption = 4 x 65 mA
2 cell
battery box


3 Volt
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Bare copper wire bus bars
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with several small blobs of
silicon
Solder feed wires to bus bars
with light blob
Keep them 10mm apart
for easy soldering
3 volt DC
Typical current consumption = 4 x 65 mA
RC
Switcher
Unit
2 cell
battery box