Salvage Server Project 'Junk Ideas' 3:

The Tech2 L200 Variable Voltage Regulator

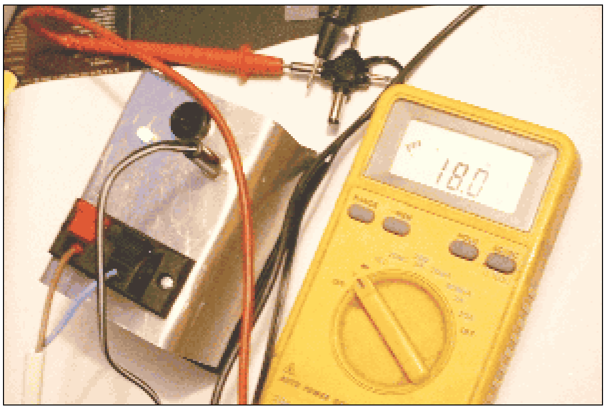
Produced by the Free Range Salvage Server Project, November 2003
http://www.fraw.org.uk/ssp/

Power is a problem. You always need it, but you don't always have a mains supply. So this regulator, originally designed as part of the Tech2 festival in 2002, was developed to solve the problem. It is able to regulate the variable voltage from a battery down to a constant voltage – for powering equipment like laptops.

The Tech2 Regulator

The Tech2 Regulator is a variable voltage regulator designed for powering equipment from a battery pack. It was designed during a renewable energy workshop as part of the *Tech2* festival [see http://tech2.southspace.net/] at the Folly Gallery, Lancaster, in August/September 2002 (hence the name *Tech2*).

Most digital equipment functions at a wide range of non-standard voltages – from 7 volts (V) to 22V. These require a mains adapter. So if you want to go mobile, beyond the mains, creating these various voltages can be difficult. One option is to use a standard 12V or 24V battery and a mains inverter. But this actually is quite wasteful. You lose 10% of the energy in the inverter, and the power supplies for most low-voltage equipment may often consume as much power as the equipment itself.



Converting from a fixed battery voltage down to a pre-set DC voltage is more efficient (around 95% – 98%). But to do this you need a regulator. The Tech2 Regulator is designed to produce DC voltages from 5V up to 32V, using different 'packs' of batteries producing a nominal voltage of 12V, 18V, 24V, 30V or 36V. This is more efficient because the regulator need only regulate the voltage between 3V to 10V of the battery voltage, wasting less energy in the process.

The information on the Tech2 regulator is split into three parts:

- *Theoretical* – a technical guide to what the Tech2 Regulator is and how it works. The purpose of this section is to provide sufficient information for a person to develop their own version of the Tech2 Regulator.
- *Components* – a table of the components required to build the Tech2 Regulator, and how to obtain them. This looks at the opportunity to obtain the components from junk as well as new.
- *Building* – an implementation of the Tech2 Regulator, in fact the design prototype, utilising a mixture of new and recovered parts (including an simple, scrap enclosure to mount the regulator in).

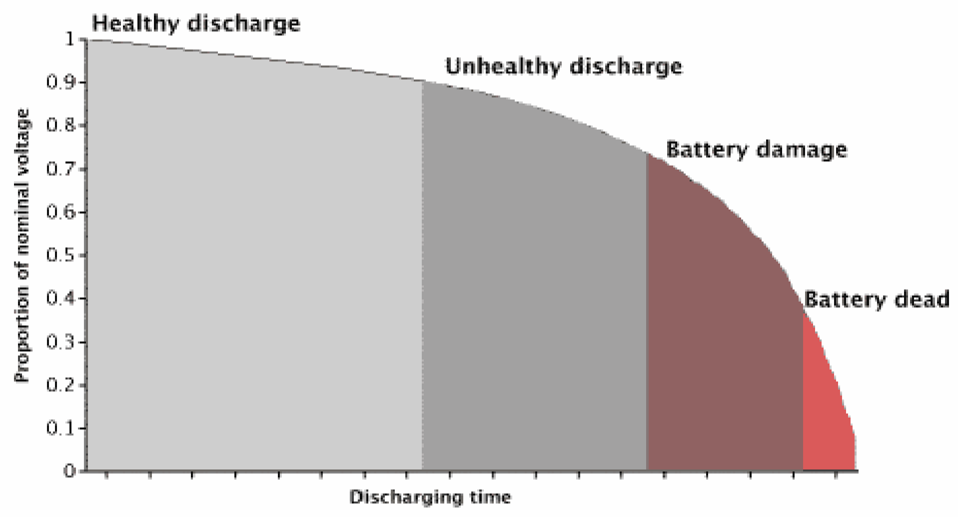
1. The Theory of the Tech2 Regulator

This section looks at the theory of the Tech2 regulator. It explains the technical background to the design of the regulator, and the detail of its operation. An more practical illustration of the regulator design in use is provided in the *building* section. Further information on the materials needed to build the regulator can be found in the *components* section.

1.1. Batteries and voltage regulation

The Tech2 Regulator is a small, variable voltage regulator designed to power laptop computers and other low-powered digital equipment from batteries. To power digital equipment requires a steady voltage, usually between quite tight voltage limits. Batteries do not provide a constant voltage over their discharge cycle, and so a voltage regulator is a way of ensuring that the battery

SLA Battery Discharge Graph



always provides a constant output to the equipment it powers.

When we talk about batteries we're really talking about *sealed lead-acid* (SLA) batteries. These are highly efficient versions of car batteries, with additional design features to stop them leaking acid and noxious gases (unless you really abuse them whilst charging). Other types of battery, such as Nickel-Cadmium (NiCad), Nickel-Metal-Hydride (NiMH) or Lithium Ion (Lion) are either not powerful enough or are so expensive as to be beyond the means of trash-tech projects.

SLA batteries have a particular discharge characteristic. The voltage drops as they discharge. This is caused by the breakdown of chemically-bound energy on the lead plates of the battery. A battery has a 'nominal' voltage – for example 12 volts (V). But the actual voltage of the battery fully charged will be around 13.2V to 13.8V. As it discharges the voltage falls, and controlling this fall is essential to preserve the life of the battery – see the graph above (drawn for a standard SLA battery). A well looked after a battery will last 500 to 1,000 discharge/recharge cycles. But if you regularly 'deep discharge' an ordinary SLA battery the damage mounts up, significantly shortening the lifetime. If you completely discharge the battery, and leave it like that for a little while, it will cease to function. So when not in use regularly check their voltage, and if required, top-up by charging.

SLA batteries come in different types. Standard SLAs can discharge to about 90% of their nominal voltage – so for a 12V battery that's around 10.8V. Beyond that and you begin to accumulate damage. Below around 9.5V you begin to do serious damage, and by 5V you're going to be killing your battery. An alternative to standard SLAs is the 'deep cycle' SLAs (DC-SLA). This has more highly engineered lead plates, and special catalysts to help reduce the build-up of compounds that shorten the life of the battery. DC-SLAs will discharge down to about 10V without causing serious damage. But below that and the battery will begin to accumulate damage, shortening the life.

Apart from the nominal voltage, batteries are also rated by their capacity – the higher the capacity the larger and heavier the battery. The capacity is measured in *Amp-hours* (Ah). For a 12V battery, a 1Ah capacity will deliver, theoretically, 12V with a current of 1 Amp for 1 hour. A 4Ah battery would deliver 1 Amp for 4 hours, 2 Amps for 2 hours, or 4 Amps for 1 hour, etc. For standard SLAs, to ensure the voltage does not drop to far, you would only use 25% to 40% of this capacity. So a 4Ah battery will only really give you 1.5A for 1 hour. A DC-SLA can be discharged to 45% to 55% of the capacity, giving you half of the rated capacity.

The purpose of voltage regulation is to iron out all these variations. The voltage regulator resists the flow of current, dropping the voltage down to a constant level. But unlike a normal, fixed resistor in a circuit, the regulator changes dynamically in response to the incoming voltage level. The output is therefore constant to within only a few percent of the set level.

1.2. The limits of regulator design

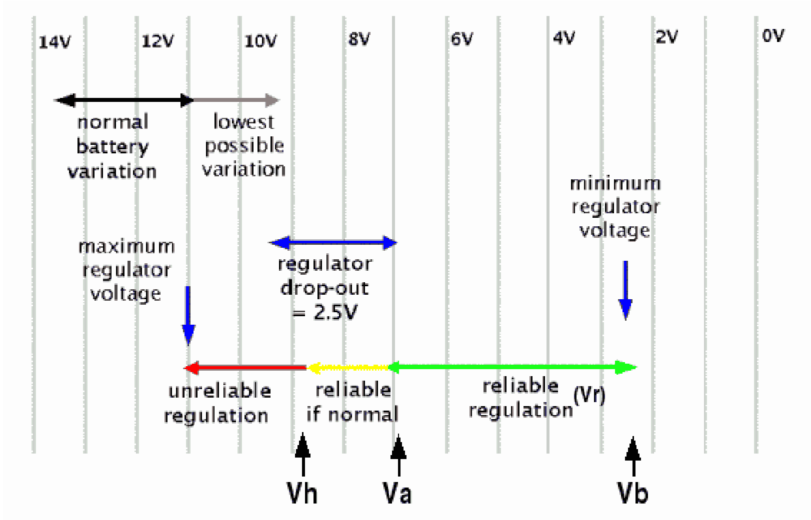
Voltage regulators work by resisting current flow – holding back energy to create a drop in the voltage. The internal characteristics of the regulator means that there has to be a certain difference between the varying input voltage and the constant output voltage, otherwise the regulator will go haywire or shut down. This voltage – the *drop-out voltage* – is specific to each type of regulator.

When planning the design of the regulator it is important to consider the range of the input voltage. There must be a minimum difference between the regulated voltage, and the input voltage, of at least the level of the drop-out voltage (Vd). For batteries there are two lower levels – the lowest level that can possibly be reached (Vl), and the lowest voltage that the battery will normally be discharged to (Vn). Finally, the regulator itself has a lower limit to regulation (Vb). The five key design limits of this system are therefore:

- The lowest voltage possible is the regulator's lowest limit, Vb.
- The highest reliable limit, *Va*, to regulation is Vn – Vd.
- The highest limit, *Vh*, under normal operation is Vn – Vd.
- The range of reliable regulation, *Vr*, is Vb up to Va.
- The range of unreliable regulation, *Vu*, is Va to Vh.

To design a reliable, and efficient regulator we also have to minimise the difference between the lowest input voltage, Vi, and the regulated voltage, Vr. Every volt increase between these two figures means the regulator must burn off more heat.

Designing the Voltage Regulator



Given that we are using batteries, losing more heat means losing energy – which could have powered the equipment. We can't change the regulated voltage, so we have to lower the input voltage by changing the voltage of the battery. At most, we don't want to regulate over a range of more than 6V. That means varying the voltage of the battery pack by 6V in either direction (with a little overlap if possible). The range of voltages produced by different combinations of batteries are shown in the table below:

Nominal voltage, V	Made up from	SLA range, V	Reliable output, V
36V	3 x 12V	33V to 39.7V	24V to 30V
30V	5 x 6V	27.5V to 33V	18V to 24V
24V	2x 12V	22V to 26.5V	12V to 18.5V
18V	3 x 6V	16.5V to 19.8V	7V to 13V
12V	1 x 12V	11V to 13.2V	3V to 8V

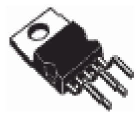
(battery packs should ideally be made of identical brand, capacity and voltage cells)

So, for example, if you wanted 16V, the most efficient way to obtain it would be to regulate down from a nominal 24V battery. But if you wanted 12V (a borderline option) the most efficient option would be to regulate down from 18V (using 24V would burn off far more energy).

1.3. A regulator using the L200C

There are many types of fixed and variable voltage regulator available. For a practical design, that can power anything from a network hub to a laptop computer, we need something that can supply 0.5 to 2 Amps of current (regulators are class on their current capability, in addition to their operating voltage). For this task the *L200C* is ideal.

According to the data sheet,



> "*The L200 is a monolithic integrated circuit for voltage and current programmable regulation. Current limiting, power-limiting, thermal shut down and input over-voltage protection (up to 60 V) make the L200 virtually blow-out proof. The L200 can be used to replace fixed voltage regulators when high output voltage precision is required and eliminates the need to stock a range of fixed voltage regulators.*"

This makes it idea for this purpose. It also, unlike a switched mode step-up or step-down regulator required few external components. A simple circuit for the L200 regulator is shown on the next page.

The critical components are the three resistors, R1, R2 and R3. Together, R1 and R2 control the level of the regulated voltage. R3 controls current limiting. In actuality, current limiting is only required where you want to limit the current to protect the equipment that you are powering. You'd only really need to do this if the equipment were extremely sensitive to current, or because it used a very low level of current – for example, less than 0.5A.

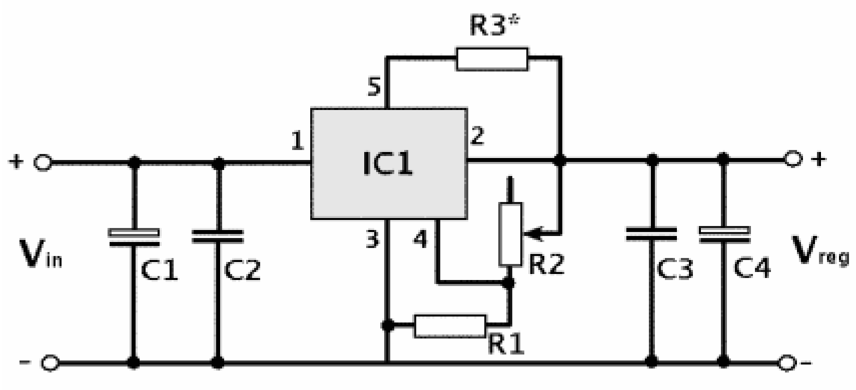
The equations (right) show how to calculate the values for R1, R2 and R3. *Vout* is the regulated output voltage. *Vref* is the L200's internal voltage reference – this floats around 2.77V, but due to temperature changes can wander between 2.64V and 2.86V. R2, or both R1 and R2, a variable

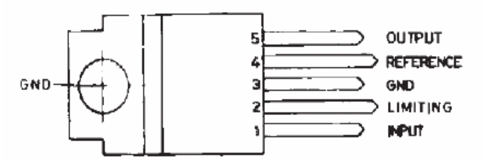
$$V_{out} = V_{ref}\left(1 + \frac{R2}{R1}\right)$$

$$R1 = R2 \Big/ \left(\frac{V_{out}}{V_{ref}} - 1\right)$$

$$R3 = \frac{0.45}{I_{o\,max}}$$

L200C Regulator Circuit





resistors. This is what allows you to calibrate the output voltage of the regulator just by turning a screw. The process of calculating the values of R1 and R2 is made slightly more complex because resistors are only available in 'preferred values' – standard values of resistance. Therefore you have to select one of these preferred values for R1 and R2.

When R1 is a fixed (not variable) resistor, it is usually a low preferred value such as 680, 750, 920, 910, 1000, 1100, 1200, 1300 or 1500 Ohms (the Ohm is the standard unit of resistance). The best presets (presets are adjustable resistors that can be manually set to a specific value) are the high-accuracy *cermet potentiometers*. These have a screw thread inside that makes them very easy to adjust to a very fine level – far easier than the cheaper options where you simply turn a screw through three-quarters of a turn. Cermets also have a higher power rating than the standard circular presets.

To simplify the process for you, the voltage range produced by preferred values of a fixed R1 and a variable R2 are shown in the table below. The left column gives values for R1, ranging from 560 Ohm to 2000 Ohm. Then major part of the table is divided into two. This gives the minimum, middle and maximum voltages produced by two different variable resistors, 5,000 Ohm (5K Ohm) and 10,000 Ohm (10K Ohm).

Values of R1 and R2

	R2 = 5K Ohm			R2 = 10K Ohm		
	Min	Mid	Max	Min	Mid	Max
R1, Ohms	100	2500	4900	200	5000	9800
560	3.3	15.1	27.0	3.8	27.5	51.2
680	3.2	13.0	22.7	3.6	23.1	42.7
750	3.1	12.0	20.9	3.5	21.2	39.0
820	3.1	11.2	19.3	3.4	19.7	35.9
910	3.1	10.4	17.7	3.4	18.0	32.6
1000	3.0	9.7	16.3	3.3	16.6	29.9
1100	3.0	9.1	15.1	3.3	15.4	27.4
1200	3.0	8.5	14.1	3.2	14.3	25.4
1300	3.0	8.1	13.2	3.2	13.4	23.7
1500	3.0	7.4	11.8	3.1	12.0	20.9
1600	2.9	7.1	11.3	3.1	11.4	19.7
1800	2.9	6.6	10.3	3.1	10.5	17.9
2000	2.9	6.2	9.6	3.0	9.7	16.3
Variance:	0.1	0.4	0.6	0.1	0.7	1.2

(the figures under the 'min', 'mid' and 'max' headings are the R2 resistance used to calculate the voltage shown in the table alongside the the R1 resistance)

The main impact of increasing the size of R2 is to increase the range of the voltage swing. This is in fact not as useful as it sounds: firstly, because remember we only really want a small voltage swing; secondly, because the bigger the swing, the harder it gets to set a precise voltage with R2. But then it's up to you to chose the range of values you want. For example, with R1 at 910 Ohm and R2 using a 5K preset, you get roughly the same range as R1 at 1800 Ohm and R2 using a 10K preset. But very roughly, for a given value of R1, changing R2 from 5K to 10K almost doubles the voltage range.

Remember this one key point – what a greater range of adjustment gives us is not an adjustable regulator for a single battery voltage. It enables us to connect more than one voltage to the regulator, and then control that voltage precisely. This will be according the the rules outlined above – ideally always make the difference between the regulated voltage, and the lowest possible input voltage, somewhere between 3 and 9 volts (that is, a variation of 6V). Most important, don't forget that the absolute limits for the L200s operation are a minimum output of about 3V, and an absolute maximum output of about 36V.

Also, remember the note above about the wandering voltage reference. The last line of the table shows the variance produced by different levels of R2. This figures represent the possible variance of the voltage output plus or minus the figure shown in the table. In any case, it's rare that all the components will be spot-on according to their stated value. For this reason, double the variance shown in the table to be safe. Note that variance also increases with the total resistance of R1 and R2 combined. Therefore, if you don't want the regulated voltage to wander very far from its set value use the lowest values of R1 and R2 possible to get the output voltage you require.

Finally, current limiting. Pin 5 can be discharged through a resistor. This causes the regulator to limit the current it gives out to a set maximum. Whilst this can be useful to protect equipment, it can also be a problem:

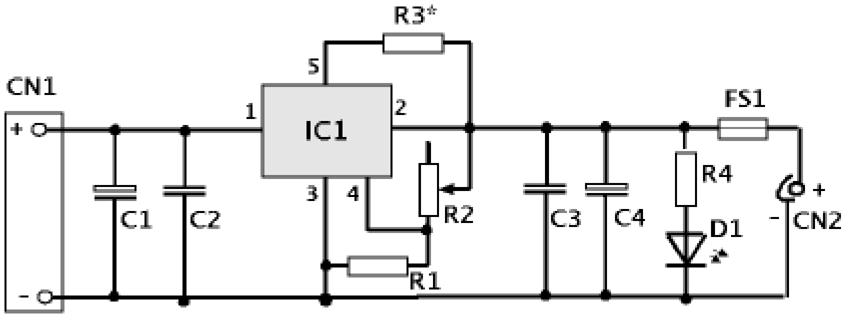
- If you limit current too low, the equipment could 'brown out' – parts of it will lose power and malfunction because they can't get the power they need; and
- R3 has to carry the whole output of the regulator – meaning that they have to be quite high power resistors, resulting in another source of energy loss.

In general, unless you've got a good reason to limit the output current, you can forget R3. The L200 can deliver up to 2 Amps (A). This is just enough to run a laptop computer adequately. Any less, and you'll have problems. Most low voltage devices will draw around 1A. The only time currently limiting becomes a necessity is when the device draws very little current, less than 0.5A. in these cases the short-circuit and overload protection built into the L200 may not register a fault in the equipment – leading to a full-on burnout. For this reason consider installing current limiting for low powered devices.

The main problem with setting R3 is that high power resistors have less preferred values to choose from. For this reason you'll probably end up connect two or more resistors in series or parallel to get the correct value.

Combination of resistors (P = in parallel. S = in series)	Current limit, A
0.68 S 0.68 S 0.47	0.25A
0.68 S 0.22	0.5A
0.27 S 0.33	0.75A
0.22 S 0.22	1.0A
0.68 P 0.68	1.3A
0.47 P 0.68	1.6A

The Full Regulator Circuit



Further information on the materials needed to build the regulator can be found in the components section.

The power rating of R3 will depend on how much current you want to put through it. You calculate this value, in Watts (W), by multiplying the maximum voltage by the average level of current supplied. For example, if you were supplying 16V at 1A that would be 16W. If you were supplying 20V at 1.5A that would be 30W. Finding resistors to meet these specifications is not easy. For this reason you'll probably find it easier to omit R3 altogether, and limit the output current by putting a fuse in the output line (this is discussed in the next section).

1.4. Full circuit operation

So far we've concentrated on the components that directly influence the regulation of the voltage or current output. The other components in the circuit also perform important functions.

Beyond the basic L200 circuit shown above, it's also important to build protection into your circuit to prevent damage. The problem is that a large lead acid battery can deliver a few hundred Amps if shorted out. This would cause serious damage to the regulator and cabling, potentially leading to a fire.

Capacitors C3 and C4 smooth the output of the regulator. C3 is a low value that smooths the ripples and noise coming out the regulator. But C4 is a very large value that stabilises the power supply to the equipment. A particular problem is equipment that contains motors and other inductive loads. These 'crowbar' the power supply, causing a sudden demand for power for a fraction of a second. By making C4 a large value it acts as an energy reservoir – supplying any transient demand for power, and then recharging when the demand returns to normal. This prevents excessive demand being put on the regulator.

Resistor R4 acts as a series resistor to control the voltage to the light emitting diode (LED) D1. It lights up when the regulator is working. It's not essential to include an indicator light, but it's useful because we're also putting a fuse, FS1, in the power line. If the fuse blows, you'll get no power. But the fact the LED is on will indicate it's the fuse that's the problem.

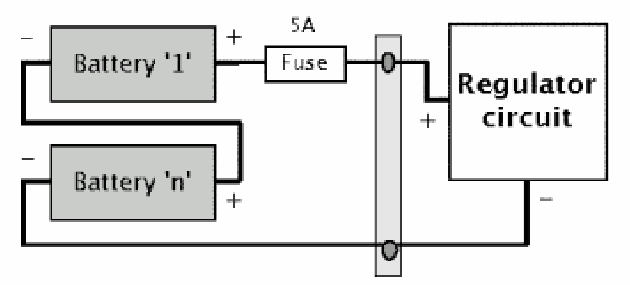
The value of FS1 should be set to a level sufficient to protect the equipment you are using. A laptop will have very short-term current demands of up to 2 or 3 Amps (for a fraction of a second). The L200 will supply these, provided a current limiting resistor (R3) is not installed. For this reason FS1 should be rated at 3 to 3.15A. However, if you are using more sensitive equipment, like a small radio, you would want to put a 0.5A fuse in. Most appliances that have a DC power input state the voltage and maximum current demand somewhere on the case. Add 50% to this figure and you'll have a good guide to the fuse rating.

Connector CN2 provides a neat and tidy way of taking power from the regulator. The main function of CN2 is to prevent the output of the regulator being shorted out accidentally – this would cause the fuse FS1 to blow.

Capacitors C1 and C2 smooth the power input to the regulator. The input is from a battery, so it doesn't need the level of smoothing normally required if you were using a rectified AC power source. C2 is quite small to smooth out line noise. C1 is larger in order to smooth the power transients created by the regulator. Together they help the regulator maintain a steady state of operation.

Connector CN1, like CN2, provides a neat and tidy way of connecting a line from the battery to the regulator. You could dispense with CN1 by wiring the cable directly to the regulator. But you'd still need some form of connector to attach the line to the battery pack.

Tech2 Regulator Battery Pack



Details of the battery configuration and fuse for the battery pack can be found in the components section.

The final element of the system is the connection to the battery pack. The battery pack is made up by one or more batteries connected in series, to increase the voltage level, or in parallel, to increase the capacity of the battery pack – or both. The battery pack ultimately has two connections – one positive terminal and one negative terminal.

By convention the positive terminal should be fused. A large battery pack contains enough potential energy, should the supply be shorted out, to meltdown the regulator and all the wiring connecting to it. The purpose of the fuse is to provide a limit to the energy allowed to flow into the system from the battery. The wiring between the regulator and the battery pack should have sufficient capacity to carry power to the regulator – at least 5 Amps. Therefore the fuse on the battery pack should be set at a level to protect the cabling connecting to the battery pack. But for the best level of protection set the fuse at the maximum level of current that the regulator is every likely to draw under any normal condition – 3 to 5 Amps.

The type of fuse and fuse holder used at this point needs to be able to handle a lot of current. Mains-type fuse holders are not much good for this. Therefore use an automotive type fuse holder with blade fuses. These are cheap and easily available.

1.5. Build platform

The circuit needs to be built on a fixed platform. There are three options available:

- *A printed circuit board* – neat and efficient, but expensive to produce as a one-off.
- *Veroboard/stripboard* – the usual media for hobbyists, cheap and simple.
- *Terminal blocks* – such as a tag board or 5 Amp/15 Amp screw terminal blocks, although this will occupy far more space and be less physically strong. You could even splice together wires and components using crimp connectors.

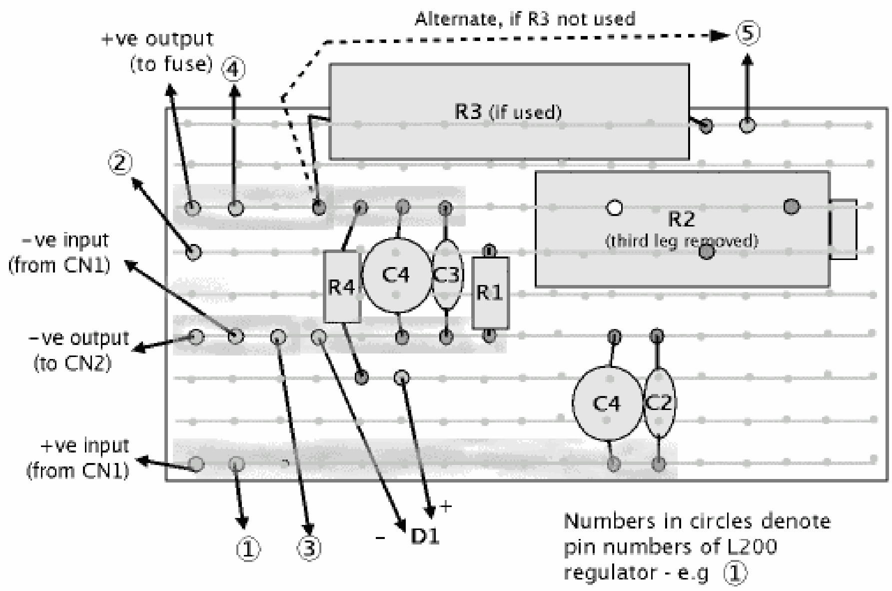
The simplest build option, for the inexperienced, is probably a terminal block. All that's required is a screwdriver to terminals and some wire to create jumpers between blocks. However, this option still requires that you solder wires onto the principle components – the regulator, cable connectors and fuse holders. In the end, you may decide that a more complex matrix board platform is only slightly more difficult to develop. Alternately, if you want to solder all the connections, you could use a tag board. But provided you are able to solder the joints correctly, a veroboard or stripboard platform is probably the best option.

Veroboard or stripboard presents a number of ways to arrange the components of the circuit. The diagram below shows a example of a matrix board layout. This is a view from the top, component side (the image from the track/solder side is mirrored). The position of the components is shown, along with the wires that need to be soldered to the board. Using standard matrix board, with tracks spaced every 0.1", has two limitations:

- The wire connections CN1, CN2, the fuse holder and the L200 regulator need to be able to easily carry 3 Amps. This makes it next to impossible to fit them into the small 1mm holes on the matrix board. For this reason the holes will need enlarging to 1.5mm or 2mm using a small drill.

- The current capacity of matrix board is not great. For this reason you need to 'reinforce' the copper strips by depositing solder onto them. The areas that need reinforcing are shown as grey areas of shading on the above diagram. You must take great care not to bridge the track that you are reinforcing to the adjacent tracks.

Example of a stripboard layout for the regulator



Finally, you'll need an enclosure/case of some sort to mount the regulator in. The main limitation here is the need to mount the regulator on a heat sink. The heat sink could be screwed to the case, and then the regulator fixed through the case to the heat sink. Alternately, you could use a heat sink of roughly the same size as the enclosure's lid. Then, drilling holes in the right location, fit the heat sink to the case in place of the lid.

2. Building the Tech2 Regulator

Most of the components used to create this regulator are 'reclaimed' – extracted from discarded equipment or bought as junk lots. Therefore the final result's not pretty, but its cheap and functional to construct.

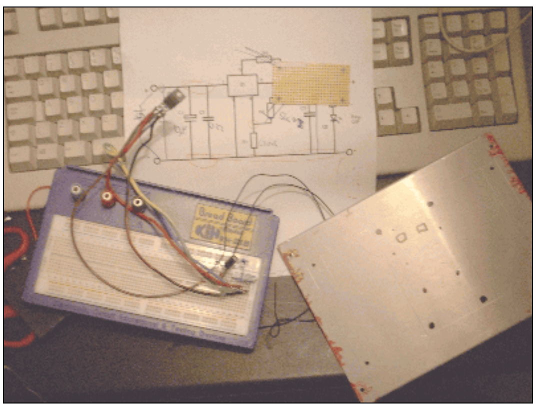
2.1. Design and testing

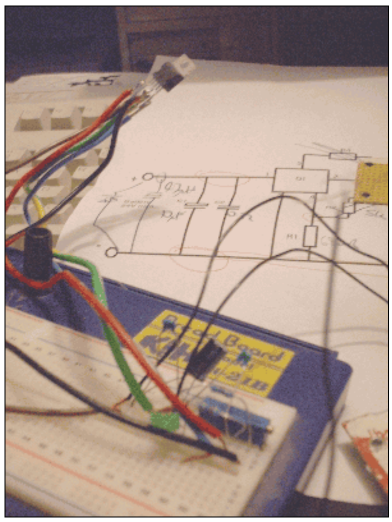
To begin, the circuit for the regulator was reinterpreted as a series of connecting blocks. All circuits can be reduced to a number of common connections between components. These are important in planning the design of the circuit board.

Before soldering the components together they were first tested as a working assembly on a *breadboard*. Breadboards are really useful because you can plug components into the board and wire them together without causing any damage to the wire leads. This means that when you have checked the design works with that set of components you can pull the components from the breadboard and solder them into place on the circuit board.

The circuit will be assembled on stripboard. This is a resin board with copper strips running along it and small holes drilled at 0.1" (2.54mm) intervals. Usefully, the design of the breadboard is similar to matrix board, meaning that you can translate the design from one to the other almost directly.

Using a piece of surplus aluminium sheet, the design for the front panel was also mapped out at this stage, taking into account the size of the components and how they would need to be located within the unit. The main problems are the regulator chip – as it must be

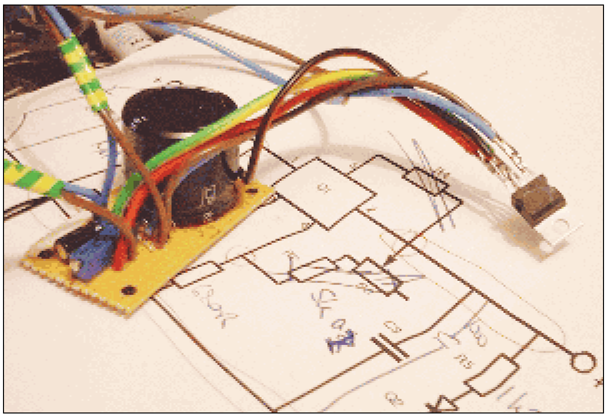


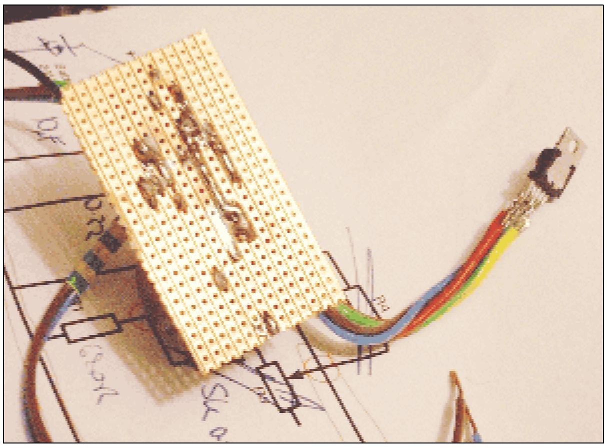


connected to a metal heat sink to dissipate heat – and the reservoir capacitor on the output of the regulator – because the only junk regulator available was very large.

2.2. Building the matrix board

Building the circuit on the stripboard was simple. The circuit had already been tested on the breadboard – all that was required was the transposition to the stripboard of the components and wires one by one.



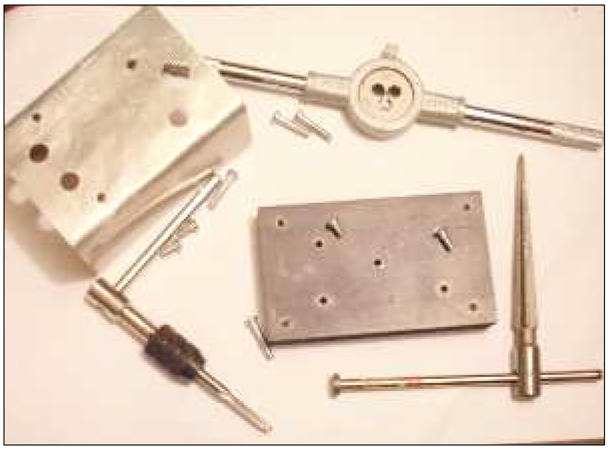


One significant consideration is the power capacity of stripboard. When operating at the regulator's limits the copper strips will be required to conduct up to 2.5 Amps at 40 volts. To ensure that the copper strips do not heat up, solder is 'mounded' along the copper strips between the components that carry the highest power load.

2.3. Machining the hardware

This design primarily uses recovered components. The heat sink for the regulator was recovered from a power supply. The front panel is made from some spare aluminium sheet.

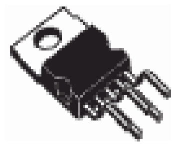
It would have been quite easy to mount everything inside a small enclosure, but there wasn't a suitable sized one to hand. So it was decided to mount the circuit board directly onto the heat sink (with the regulator underneath), and then screw the front panel to the sides of the heat sink. This required that the heat sink was drilled and then the holes 'tapped' to accept the screws.



The front panel was drilled to mount the components. The holes were roughly drilled and then enlarged to the required size using a reamer.

There were no good quality metric screws of the right size available. Unfortunately, the only tap we had available to thread the holes in the heat sink had a metric thread. To solve the problem some old imperial BA screws were cut to length and then re-threaded to the correct metric thread using a die.

2.4. Protecting the regulator

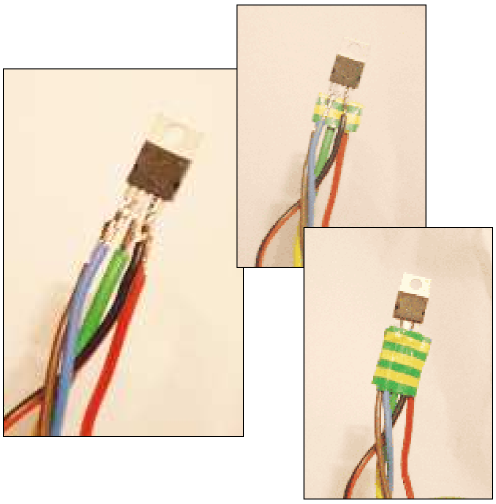


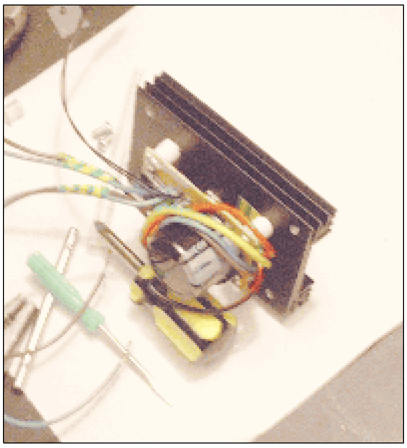
The L200 regulator has five legs. There are very close together, alongside each other. But they are also arranged in two rows to make connection easier. You have to protect the legs in some way to prevent them touching one another when you fix the regulator to the heat sink.

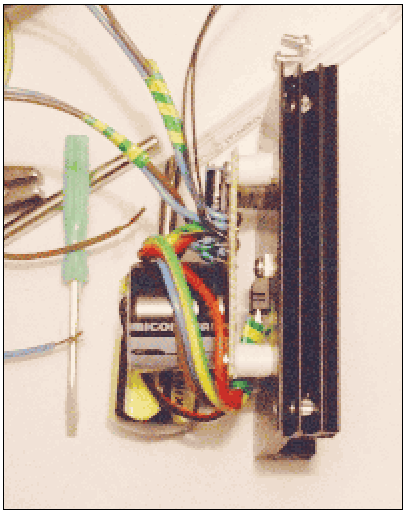
Firstly, wires, with sufficient capacity to carry the maximum load the regulator can conduct, were soldered to the legs of the regulator. Then, to isolate the two rows of legs, a piece of insulating tape was folded into a small square and inserted between the rows. Finally, insulating tape was carefully wrapped around the legs to prevent the moving from side to side.

Another consideration with the L200 regulator is that pin 3, which connects to the negative rail of the circuit, also connects to the fixing tab of the regulator. This means that the regulator will connect the heat sink – and hence the whole metal case of the unit – to the negative rail. This can be a problem if you accidentally brush the positive lead of the power supply, or the positive lead from the regulator, against the case. You'll get a big electrical arc, and blow the fuses in the line.

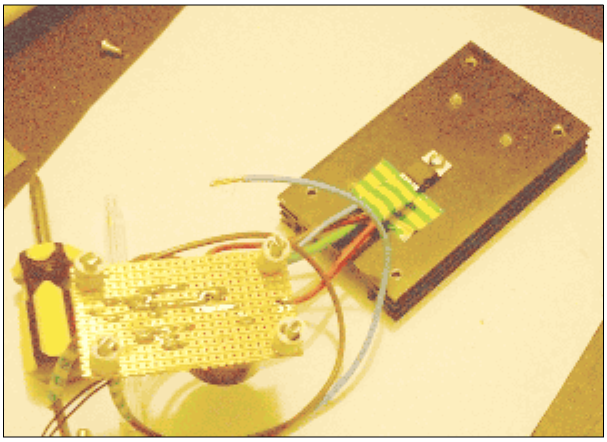
You can get insulating mounts that isolate the regulator







from the heat sink whilst still conducting heat – but there were none immediately available and so the problem was ignored, and effectively designed out by using good connectors to connect the power input and output of the unit.



2.5. Mounting the circuit board

The regulator fits underneath the circuit board. For this reason you need some sort of stand-off spacer to fit around the fixing screws – these ensure that the circuit board stands clear of the regulator chip. Spacers are usually small plastic tubes. As none were available, 1cm lengths of the external insulation from some heavy-gauge mains cable were cut using wire strippers. Length is not critical as they squash up a little when you put them under pressure.

When mounting the circuit board the important thing is to ensure that the wires to the regulator chip loop easily around the circuit board without putting them under tension. If you put them under tension it might bend the legs of the regulator, causing the legs to touch.

2.6. Assembling the front panel and screwing together

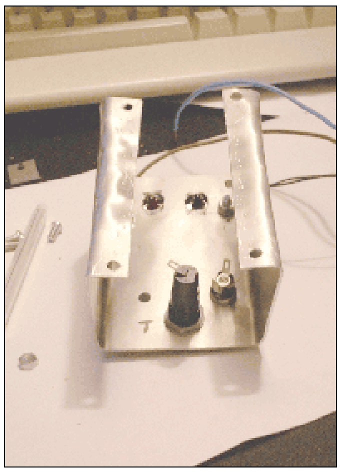
The next task is to assemble the front panel.

To connect the battery leads a spring connector, normally used for the loudspeaker connection on stereos, was used. This is a little tricky as the rear connections must pass through the metal panel without touching. The connector itself has to be bolted through the front panel (you could use self-tapping screws, but it's less secure).

The other components push through the front panel from the front or rear. The power power output connect, like the regulator, will connect the negative rail of the power supply to the front panel unless you use an insulating washers. In any case, there was little point insulating the connector because the regulator had not been insulated.

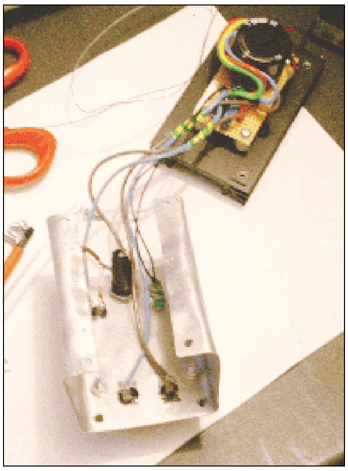
The fuse holder pushes in the front and then a plastic nut holds it from behind. Finally the LED indicator just pushed into place. To hold it firmly you have to drill a hole the exact size of the LED – in this case 5mm. For extra security you can super-glue the LED at the back to prevent it being pushed back through the panel.

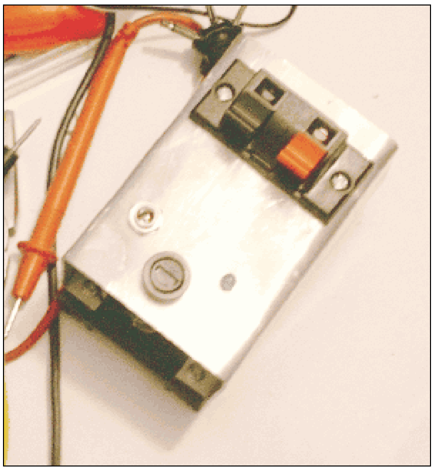
Finally, the wires were connected to the front panel from the circuit board. Enough wire had to be left to ensure that the two parts of the unit – the front panel and the heat sink/circuit board can be manipulated without putting tension on the wires. The last assembly stage involves fitting the front panel to the heat sink with four screws.

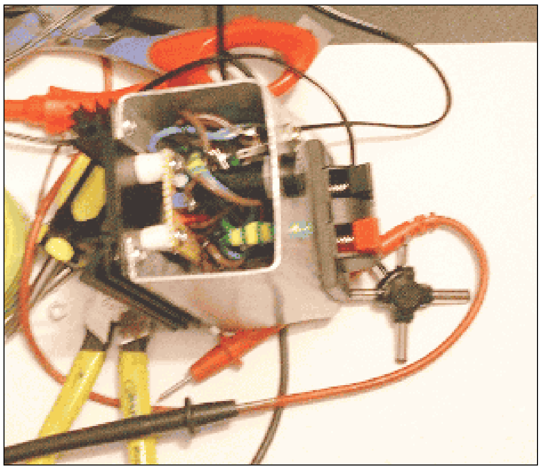


2.7. Tidying up and calibration

After assembling the unit you'll probably







need to tidy up the wires inside. There is not a serious safety problem with the unit because at most it only uses 36 volts. But problems may arise is any wires connected to the positive of the battery supply touch the case – they'll arc or spark. For this reason you should tidy the wires up to ensure they don't loop outside of the case (if you use a proper box for the unit you won't have this problem).

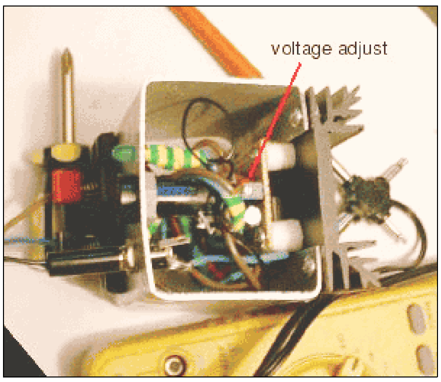
Next you test the unit. For this you'll need a multimeter that can check voltages, currents and resistances (a cheap one will do – these can be bought for less than £10 at DIY stores). You need to do the following checks:

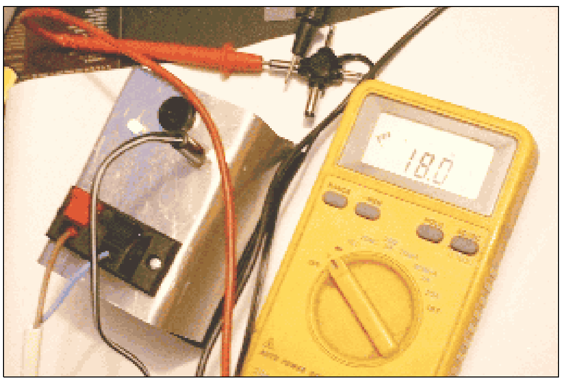
- Check the resistance between the two terminals of the battery connector. A fault – probably cause by wires touching the case, the legs of the regulator touching, or a bad connection on the circuit board – will result in a short circuit (no resistance). The resistance between the terminals should be a couple of kilo-Ohms. If there is no conductance at all then you've not connected something inside.
- Put a fuse in the fuse holder – around 3 to 3.15 Amps will do, preferably an 'anti-surge' type.
- Do the same check as above on the output connector.
- Provided these checks are OK, you can now connect a 12 to 24 volt battery – but make sure that it's fused with around a 5 Amp fuse. But first connect the red lead of the multimeter to the battery positive and the black lead to the positive input of the unit, and then set the multimeter to read a current in the range 0 to 1000 milliAmps (mA).
- After connecting up, the LED on the unit should light up. If not, there's a problem with the connections inside. At this stage the multimeter should be reading between 20 and 30 milliAmps – anything significantly more than this indicates a problem, possibly from a bad connection on the circuit board that's shorting out the power supply.
- Disconnect the multimeter and connect the battery as normal. Set the multimeter to read voltage, and then connect across the output of the unit (be careful not bridge the output terminals with your meter probe or you'll blow the output fuse). You will now see the output voltage of the unit. To adjust put a screwdriver into the 'R2' preset and turn. You will see the voltage slowly change. Keep turning until you get the voltage you require.

The unit is now ready to use.

2.8. In use

As noted in the theoretical section, the regulator can produce any voltage between 3 volts, and around 2.85 volts below the battery voltage. The maximum voltage that the regulator can handle is 36 to 40 volts.





For example, the voltage of a 24 volt lead-acid battery pack will vary between a maximum of 26.5 to 27 volts, and a reasonable minimum of 21.5 to 22 volts (you can drop below this, but it will diminish the operation life of the battery if done regularly). Therefore, with a 24 volt battery, you can produce any voltage between 8 volts and 19 volts.

The issue to consider is that the more you drop the voltage, the more heat the regulator will have to dump into the heat sink – and wasted. Therefore you should minimise the voltage drop by changing the voltage of the battery (see table below). The other issue is the capacity of the batteries used. For example, a laptop computer consumes around 1.5 Amp on average, but this may rise to 2.0 Amps when the laptop's internal battery is charging. Batteries are rated in 'Amp-hours' (Ah) – but this is not a realistic value. You only want to use 50% of a deep-cycle sealed lead-acid battery's charge, otherwise you will damage it (and only 25% for an ordinary SLA). So the available capacity is half the stated capacity. Therefore:

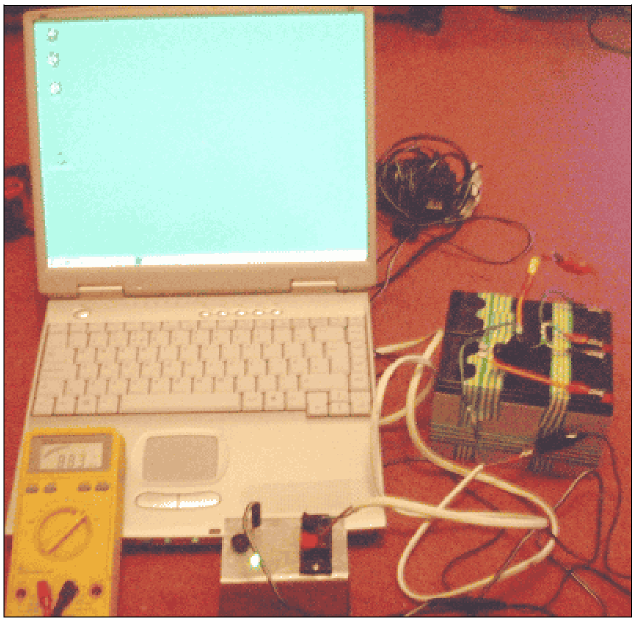
- A 4Ah battery will run a laptop for 1.3 hours, but at maximum capacity the regulator will run for 1 hour.
- A 7Ah battery will run a laptop for 2.3 hours, but at maximum capacity the regulator will run for 1.75 hours.
- A 16Ah battery will run a laptop for 5.3 hours, but at maximum capacity the regulator will run for 4 hours.
- A 40Ah battery will run a laptop for 13.3 hours, but at maximum capacity the regulator will run for 10 hours.

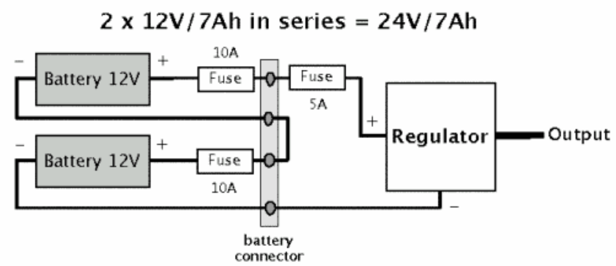
It would be very easy to wire together batteries to make the required voltage. But nearly always you'll find that you need more flexibility than that. For this reason the battery pack is wired to a four-way power connector – the type used for power connections inside a PC computer, and which you can often pick up in the junk bins of computer shops. The matching half of the power connector can then be configured in two ways:

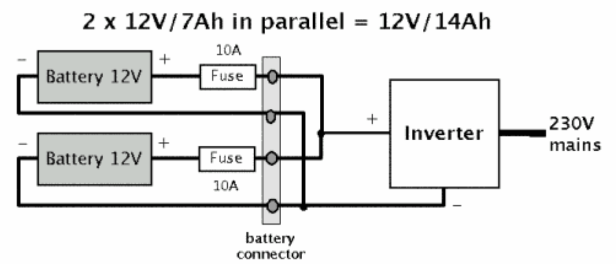
- Two of the terminals, corresponding to the positive terminal of one battery and the nagative terminal of the other, are wired together. This means that the remaining two terminals provide positive and negative connections at 24 volts.
- The two positive terminals are connected together, as are the two negative terminals, and then connections are made to these two. This give twelve volts but at twice the power rating.

The major flexibility of this option is that you can connect the regulator to the battery pack at one time, or connect, using a second power connector with the different configuration of wires, a 12 volt appliance. The most likely candidate being an inverter to convert 12 volts DC into 230 volts AC to simulate mains power. This latter option uses more power, and so the fact you have two batteries in parallel doubles the power available.

By using connectors in this way you can just plug in a different connector to the battery pack to change the configuration from series to parallel, and vice versa, rather than physically re-wiring the batteries.







3. Components for the Tech2 Regulator

This page looks at the components required to build the Tech2 regulator.

If you want to buy the components, rather than source them for junk, everything can be obtained from Maplin Electronics. For further details of their catalogue, or where their shops are located, see http://www.maplin.co.uk/.

Circuit ref.	Component	Attributes	Source/cost
IC1	L200C regulator	L200 comes in various guises, each with a diffent code suffix. The 'C' variant is a plastic ('Pentawatt') case with five legs. All variants work in a similar way.	Not likely to find as surplus, unless you rip them out of some old equipment. Maplin sell single L200CV regulators for £2.49, or £2.24 if you buy 5 or more (both inc. VAT). Other component suppliers sell the L200 for less, but with various minimum purchase levels. Maplin order code, YY74R.
R1	820R 0.25W metal film resistor	Standard 820 Ohm resistor	Available new from Maplin for a penny each, or recovered from old equipment. However, older resistors may have a lower tolerance, or be degraded, which is a problem as the accuracy needs to be within a few percent. Maplin order code M820R.
R2	5K Ohm or 10K Ohm preset/potentiometer	Standard cermet preset.	Similar values can be recovered from older electrical equipment. However it's better to have the multi-turn types rather then the simple three-quarter turn types as you can adjust the output voltage with greater accuracy. 18 turn cermet presets available from Maplin for 79p each. Order code WR48C (5K preset) or WR49D (10K preset).
R3	High power resistor	Value depends upon current limiting requirements – suggest that you seriously consider not using R3 and instead use a low value fuse in FS1.	Low value resistors are available from waste equipment, especially power supplies. The problem will be the power rating. For most applications you are going to need resistors with a power rating of at least 5W, but perhaps as high as 25W. Maplin have a restricted range of high power wire wound resistors. Other component suppliers, such as Farnell or RS, have a better selection but you will have to buy a certain minimum quantity. Expect to pay 10p to 50p depending on the power rating. If ordering from Maplin, 3W, 7W and 10W resistors available, but the 10W range has only a few preferred values.
R4	1k2 0.25W metal film resistor	The actual value of this resistor depends upon the rating of D1	Most LEDs have a forward voltage of 2.0V to 2.2V, and a current rating of 15mA to 30mA. However, reating of R4 depends upon output voltage, which might vary from 3V to 36V. 1200 Ohm (1k2) is a value that's fairly suitable across the popular voltages – 9V, 12V, 18V, and 24V. It should also suit most LED's current rating. Available new from Maplin for a penny each, or recovered from old equipment. Tolerance is not critical (10%). Maplin order code M1K2R.
D1	Standard red or green LED	Very roughly 2V forward voltage and 20mA to 30mA current consumption.	LEDs can be recovered from most electrical equipment. Unless they are made to work with higher voltages (5V/12V) or they are contain flashing chips, most 3mm and 5mm round or square LEDs should be suitable. New round 5mm LEDs can be bought from Maplin for 10p each. Order code WL27E (red) or WL28F (green).

Circuit ref.	Component	Attributes	Source/cost
C1	10μF 63V electrolytic capacitor	Lower voltage ratings are not suitable since they should be rated at at least twice the battery voltage. 63V (standard value for electrolytics) or higher should be OK. 50V will probably do if using a 24V battery pack or less.	10μF is a very common value, so you might be able to recover one from old equipment. But you are more likely to find the 63V rated capacitors in power supplies or old TVs where higher voltages are used. Maplin sell a 100V radial version for 5p each, order code VH24B.
C2	0.22μF (or 220nF) resin-dipped ceramic capacitor	Ceramic or polyester capacitors are OK for smoothing a pretty stable DC power source	0.22μF can be recovered from old equipment but you might have problems identifying them – some manufacturers use part codes instead of capacitance values on components. Maplin sell 0.22μF resin-dipped ceramics for 9p each, order code RA50E.
C3	0.1μF (or 100nF) resin-dipped ceramic capacitor	Ceramic or polyester capacitors are OK for smoothing a pretty stable DC power source	0.1μF can be recovered from old equipment but you might have problems identifying them – some manufacturers use part codes instead of capacitance values on components. Maplin sell 0.1μF resin-dipped ceramics for 9p each, order code RA49D.
C4	1000μF, 100V electrolytic capacitor	100V rating chosen to protect against the damage caused by reverse EMF created by inductive loads. Peak-to-peak voltages returning from inductive loads may approach 60V where the DC supply voltage is 20V or higher. 63V capacitors would be OK where low voltage or non-inductive loads are used. Alternately you could just put a blocking diode in the output to CN2, but this will burn off more energy as it would drop another 1V to 2V off the regulated output. 1000μF has been chosen as a reservoir capacitor suitable for most applications. But with equipment that creates a lot of heavy power surges (e.g., audio amplifiers) it's not enough, and you'll need to go two or four times higher.	1000μF capacitors can be recovered from old power supplies and TV – but be sure to check the voltage rating. Maplin sell 1000μF 63V capacitors for 59p each, order code VH52G. If you want to go for the higher 100V capacitor, Maplin sell these for £1.49 each, order code VH53H.
CN1	Line connector	Any variety of power connector, to suit your purpose, may be used. As CN1 connects to a battery all types of wire may be used. For this reason a level connector, like that used for loudspeaker connections, would allow the quick connection of bare wires. Otherwise use a standard battery connector, or terminal posts with screw-fittings.	Power connectors can be recovered from many types of portable equipment. Often the problem you'll have is finding a plug to fit the socket. Connectors that accept bare wires are useful in this application as you can then use any available wire to hook-up the power from the battery pack. Maplin sell a wide range of connectors. But never use a mains connector for this purpose as you risk someone plugging the mains supply into your regulator

Circuit ref.	Component	Attributes	Source/cost
CN2	Line connector	Any variety of power connector, but unlike CN1, more care should be taken to reduce the risk of short-circuiting the output.	The 2.5mm power sockets on most portable equipment would do for this application. However, a panel mounting option would be better. It all depends what you can salvage from trash equipment. Otherwise, Maplin sell a variety of panel mounting power connectors. But as noted above, never use any type of mains power connector.
FS1	20mm fuseholder, with fuse	Panel mounting fuseholder chosen – you could use a circuit-mounted or in-line fuseholder, but you'd have to open-up the enclosure to get at it. A 2A anti-surge fuse was used in the holder. 'Anti-surge' fuses will tolerate a current of slightly more than 2A for a fraction of a second before blowing. This is useful when powering a laptop as the disk drive produce transient current drains. For more sensitive equipment use lower rated fuses nearer to the current consumption of the device. If the equipment is very sensitive, use 'quickblow' fuses.	20mm fuses can be found inside older equipment – not all new equipment uses them because switched mode power supplies are fairly stable. Likewise, where there's fuses you'll be able to recover fuseholders. Maplin sell panel mounting 20mm fuseholders for 99p each, order code DA59P. Maplin also sell packs of 10 anti-surge (or 'time delay') fuses, in a variety of power ratings for £1.79 each, or packs of 10 quickblow fuses for 79p each.
Heat sink	TO220-style heat sink	Ideally you should look for a heat sink that's rated 10°C/W to 15°C/W to handle the heat load easily	A heat sink can be any lump of aluminium, but it helps if it has fins to increase the surface area. A section of aluminium window extrusion or box section, 10cm long and 3cm to 5cm wide, would qualify as a minimal heat sink. You can also recover some large heat sinks from older power supplies, stereo amplifiers and TVs. Maplin stock a variety of heat sinks suitable for this purpose.
Strip board	Standard SRBP matrix board 0.1" matrix board will do, provided that you 'reinforce' certain part of the copper strips to increase current capacity.	Good matrix board doesn't tend to get thrown away. Therefore you'll have to buy it.	Maplin stock various sizes of board. A piece twice as big as required for this project (order code JP46A) cost 79p. But it's probably more cost efficient to buy the largest board they have and cut it down for each project you develop (cost around £4).
Case	A metal case	Metal cases are preferred over plastic cases because they radiate more heat. Another option would be to fold a sheet of metal to form a squared 'U' shape and then screw or bolt this to your heat sink to form the 4th side of your enclosure.	Any type of metal box or other enclosure can be used. The important thing is that it should protect the internal components, whilst having enough space to ensure that the components need not be squashed inside the box. Also, unless you isolate the regulator from the heat sink, and some power connectors from the case, the box will be connected to the negative supply of the battery/power supply. You must ensure that no part of the positive supply has a chance to touch the inside of the enclosure. But if you want things plain and simple, Maplin sell a variety of metal enclosures suitable for this application – for example their aluminium instrument or chassis cases, costing £3 to £10.

Circuit ref.	Component	Attributes	Source/cost
Battery	A battery pack	The battery pack should be designed to suit your need for voltage and capacity – this is discussed at length in the text of the 'theoretical' section. Sealed Lead Acid (SLA) batteries usually come in 6V or 12V cells, and in a variety of capacities.	Most of the surplus SLA batteries you may obtain are likely to be near the end of their lives. This can create problems when putting two or three together because each has a different discharge characteristic. Maplin sell new SLAs in a variety of capacity, and in low (cheap) and high (expensive) quality versions. Capacities vary from 1Ah to 65Ah. They also sell 'deep cycle' SLAs (DC-SLAs). For a good quality, 12V, 12Ah SLA expect to pay £35 each. A 12V, 17Ah deep discharge DC-SLA costs £60.
Battery fuse	Automotive fuseholder with blade fuse	Automotive fuses have the advantage that they're cheap and easy to obtain.	You can obtain old automotive fuseholders from garages and vehicle breakers. Fuses can be bought cheaply at markets and DIY stores. Maplin sell an inline fuseholder, rated at 30A, for £1.29 (order code KK80B). A variety of blade fuses from 3A to 5A are available for 29p each.
Battery connector	Connectors to suit your particular battery pack	Different types of SLA have different types of connector. Some have push connectors that crimp onto wires. Higher capacity batteries have clamp connectors. You'll need to get the types of connector that suit your battery.	The nature of these connectors is such that you are unlikely to find usable connector in the trash. DIY stores, and even Argos, stock crimp connector sets that are useful for wiring up battery packs – however you nearly always don't have enough of the type of connector you require. Automotive spares dealers will also sell crimp connectors and battery clamps. Otherwise, Maplin sell a variety of crimp and clamp connectors.