You build a mains or renewable energy power supply for a laptop or other sensitive device, plug it in, turn it on and BANG – smoke comes from the power supply, laptop, or both! Here’s a junk idea to avoid making such an expensive mistake.

What is a Dummy Load?

An appliance of some kind is in technical terms a load – it draws power. We can simulate this using a device, a dummy load, that draws power at a known rate. Dummy loads are usually nothing more than a large resistor. The supply voltage is dropped across the resistor and the energy contained in the supply current is dumped as heat – often an awful lot of heat!

Dummy loads are common in amateur radio where they are used for tuning transmitters without actually transmitting. They are less common in other areas of amateur electronics. However, this project has been developed as a way of testing not just mains power supplies, but also renewable energy systems where you need to dump the energy whilst you are setting up. However, this design is only designed for use in extra-low voltage systems, or ELV. Technically that’s less than 50 volts, but this design was built specifically for use with 12V and 24V systems.

Current and Power Rating

If you short circuit a battery you develop a large current. Large lead-acid cells can create short circuit currents in excess of 500 amps. This is because the shorting wires have very little resistance. If you connect a resistor into the circuit the current will rise to a point that is dependent upon the value of the resistor (see the table on the next page to see how much current a resistor draws). Then, providing that the resistor has a big enough power rating, the resistor will happily burn-off the heat created by
the current. Electric fires use the same principle. The bars of the electric fire have a resistance that means one kilo-Watt of heat will be produced by the fire at mains voltage (and only at mains voltage).

You can calculate the maximum current drawn by a load resistor using Ohms law:

\[
\text{Current (A)} = \frac{\text{Voltage (V)}}{\text{Resistance (R)}}
\]

However, this is the easy part. The most important issue in the design of the dummy load is that the power output should not exceed the power rating of the load resistor. You can calculate the maximum power that a resistor will dissipate using the power equation:

\[
\text{Power (W)} = \text{Current}^2 \times \text{Resistance (R)}
\]

Conversely, if you know the power rating of a load resistor you can calculate the current that it can handle by re-arranging the above equation:

\[
\text{Current (A)} = \sqrt{\frac{\text{Power (W)}}{\text{Resistance (R)}}}
\]

The calculated power rating for a resistor usually represents the level that will cause problematic overheating. Therefore the resistor used should have a capacity about 1.25 to 1.5 times more than the calculated figure. Likewise the main current path in the circuit (discussed later) must use wire that has a capacity of 1.25 to 1.5 times the maximum calculated current.

## Current Control

As noted above, if you have a fixed resistor then connecting it to a battery or power supply will create a fixed level of current or power load. Whilst useful for checking circuits at a single load, it's not very useful for checking how the power supply works at different power levels. Therefore we need to be able to vary the power drawn by the load without the hassle of continually disconnecting and reconnecting different values of resistor.

The dummy load uses a field effect transistor, or FET, to switch the circuit on and off. By varying the period that the FET switches on or off, using a system called pulse width modulation (see the box on the next page), we can vary the amount of time that the FET is on and how much load the resistor will draw.

FET transistors are able to switch very large...
currents using a very small control voltage. That means we can avoid using very expensive power components, such as high power variable resistors or rheostats. Instead the dummy load control circuit uses a single low power variable resistor and a single integrated circuit to change the switching period, or duty cycle, of the FET and hence how much current the load will draw (see the box below).

### Current Control and Pulse Width Modulation (PWM)

The power figures used to rate resistors are quoted in Watts. This is a measure of the power flowing every second. Therefore if we turn off the flow for half a second, only half the power, and hence current, will flow. This is the theory behind pulse width modulation, or PWM. By turning off the current flow for a greater proportion of the time we reduce the current flow.

The dummy load control circuit (discussed on the next page) creates a triangular waveform that is used to switch the load resistor on and off. The triangular waveform oscillates between 1.2 volts and 6.8 volts. This is fed into a comparator along with a control voltage that is set by a variable resistor. If the control voltage is greater than the level of the triangular waveform the comparator switches the transistor off. If the control voltage is less than the voltage of the triangular waveform it switches the transistor on. Consequently the interaction between the triangular waveform and the rising control voltage switches the transistor off for a progressively longer period of time. Therefore we can finely control the width of the pulses by varying the control voltage.

The figures below, taken from an oscilloscope, shows the triangular waveform and the output from the comparator. The comparator is either fully on or fully off. We measure the width of the pulses, or the duty cycle, in terms of a percentage – 100% is fully on and 0% is fully off. At 100% the comparator is fully on. At 95% the control voltage rises just above the lower voltage of the triangular waveform and transistor is turned off for 5% of the time. As the control voltage rises to one quarter and then three quarters of the waveform voltage the duty cycle decreases to 75% and 25%. At 5% the transistor is switched off for most of the time and at 0%, when the control voltage is higher than the triangular waveform, it does not switch on at all.

The effect of this is to reduce the current, and hence the load, the load resistor draws. If a load resistor theoretically draws 6 amps, at a duty cycle of 50% it will only draw 3 amps, or at 25% 1.5 amps. This is how the control circuit of the dummy load is able to finely control how much power the dummy load unit will draw.
The Control Circuit

The circuit diagram for the control unit is shown below. There are essentially three parts to the circuit:

- The components around Q2 form an 8V voltage regulator that powers the control unit.
- The components around Q3a to Q3c form the oscillator that creates the triangular waveform.
- The components Q3d and R2 form the comparator and pulse width control system that drives the FET.

There are two major limitations to the voltage at which the circuit can operate. One is the working voltage of the FET, but the other is the maximum working voltage of the 7808 voltage regulator. The 7808 was chosen because it was spare – a 7806 (6 volt) or 7805 (5 volt) would have worked equally as well. Most 78XX voltage regulators have a maximum input voltage of around 36 volts to 40 volts. The use of a regulator is important because it allows the dummy load to have a wide operating voltage.

Another restriction is the drop-out voltage of the regulator – the minimum difference between the regulated voltage and the voltage input that is allowed to ensure reliable regulation. For most 78XX type regulators this is around 2.5 to 3 volts. If you want the circuit to work with a 12 volt battery system then it has to work down to around 11 volts. Therefore a 7808 is the highest voltage regulator that's suitable.

The oscillator is a little more complex. Q3a is a unity gain amplifier that works from the potential divider formed by R7 and R8. This will produce a voltage that is half of the regulated output – 4.0V. This is used as a voltage reference by Q3b and Q3c which form the oscillator. Q3b creates a square wave signal oscillating at a few hundred Hertz. This is fed to Q3c which turns it into a triangular waveform.

R2 is a multi-turn cermet trimmer. In order to work over its entire range you have to turn the screw on the trimmer eighteen times. This means that you have a far greater level of control over its resistance, and hence the load drawn by the dummy load. You could use a standard three-quarter turn trimmer, but you wouldn't have the same level of control. Ideally R2 should be a linear trimmer. However, you can use a logarithmic trimmer (as was used in this design) and it works fine, but you lose some precision at the lower current end of the scale.

R2 acts as a potential divider to provide the control voltage to the comparator Q3d. The triangular waveform is connected to the non-

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Circuit Diagram of the ELV Dummy Load (see end of report for the component list)
inverting (‘+’) input of Q3d and the control voltage to the inverting (‘−’) input. This means that when the waveform voltage exceeds the control voltage (or + > −) the comparator outputs its positive supply voltage – around 8 volts. When the control voltage is higher than the waveform voltage the comparator outputs 0V. This means that the FET is either switched fully on or it is switched fully off.

As an indicator an LED has been added to the output of Q3d. The LED is a standard red LED with a forward current of 15 milliamps (mA). Ordinarily, given that the voltage coming out of Q3d is just under 8 volts, the series resistor for this LED (R3) would only need to be a few hundred ohms. However, in order to reduce the current drain through Q3d a 1,000 ohm resistor was used. This means that the LED lights a little dimly, but it does its job – it warns the unit is working at a high current.

Finally, L1 is a few turns of wire on a ferrite toroid. The waveform produced by the oscillator has a very low frequency, but the harmonics produced by Q3d could theoretically be in the radio frequency band. The purpose of L1 is to dampen the harmonic frequencies to prevent them being emitted from R1 when it is switched by the FET.

The FET and Load Resistor

The critical part of this project is the FET and the load resistor.

As noted earlier, any resistor connected across a power supply will conduct current up to a theoretical maximum level. In selecting R1 you should consider what will be the greatest current that the dummy load will be required to handle. This is because once you reach this level the load will not conduct any more current – for a higher current you will have to change the value of R1.

For this project a 2 Ohm, 300 Watt vitreous enamel resistor was used (see pictures above). This has the benefit that it doesn't need a heatsink. These resistors are popular as dump loads in renewable energy applications, and their tubular construction means that they dissipate heat well. In use it was hung from a hook using a small wire loop fixed to one end. It would be possible to use high power wire wound or metal film resistor, but these nearly always need a heatsink to dissipate the level of heat for which they are rated.

Note also that the maximum current will vary according to the supply voltage. That's not a problem with a narrow voltage range, but if you switch between different voltages you have to take the current load into account. For the design shown here the maximum current at 12 volts is around 5.6 amps. But at 24 volts that rises to nearly 12 amps (see the table on page 2). Provided that the resistor has a sufficient power dissipation working over a wide voltage range is not a problem. However, it might create a problem with the FET.

For this project the FET chosen was a HUF75333P3. This is an N-channel ultra-FET that has a very low internal resistance. Any N-channel FET will do for this job, but the critical factor is the maximum working voltage and current rating. The HUF75333P3 can handle up to 56 amps at 55 volts – more than enough for the maximum 30 volts/15 amps that this dummy load was developed for. If using other FETs you will need to check that the selection of load resistor and operating voltage does not drive the device to more than 75% or 80% of its rated capacity.
Building the Dummy Load

This is a “junk” project, and so as far as possible the components and hardware are salvaged. For this reason the project has been designed for assembly onto a stripboard to eliminate the need to manufacture a printed circuit board.

A suggested stripboard layout is shown in the diagram below. A picture of the prototype board (which differs slightly from the example stripboard below) is shown on the right. The design requires just twelve cuts to be made in the metal tracks of the board, and twelve wire links are used. Other than that, assembly is quite straightforward. Q3 is placed in an IC socket not just to protect it during soldering, but also so it can be re-used if you desperately need one. The fiddly bit is making L1, by putting two turns of insulated hook-up wire around a small ferrite toroid or bead.

In the prototype project all the parts, with the exception of the load resistor, were mounted on a large heatsink. The specification of the heatsink was far in excess of what is required to dissipate the heat produced by the FET, but it was the only large piece of metal to hand at the time. A 20cm-square piece of thick mild steel sheet would have worked equally as well.

The main current draw on the control board is...
the LM324 op-amp. However, this draws so little current that the one amp voltage regulator doesn’t require a heatsink. In terms of the overall energy efficiency of the dummy load, given that the load resistor might be dumping up to fifteen amps of current, the sixty milliamps used by the control board is irrelevant.

The FET was fixed to the heatsink with an M3 nut and bolt. However, because most FETs have their drain connected to the fixing tab this would mean that the heatsink, or any other metal object the FET was connected to, would be connected to the positive terminal of the power supply. For the design of this project that’s not a problem, but if the negative lead were to accidentally touch the heatsink it would short out the FET and create a surge of current up to the maximum theoretical capacity of the resistor – possibly damaging any low current devices connected to the load.

To prevent any accidental power surges the FET was mounted on an insulating pad, with a plastic bush around the fixing bolt, to electrically isolate the drain of the FET from the heatsink. Note also that to prevent the legs of the FET contacting the heatsink a piece of PVC tape was stuck to the heatsink. Then, to prevent the legs of the FET being bent and broken, the wires were fixed to the heatsink using more PVC tape (see picture, above left). Also, to prevent mechanical stress, a long length of heavy duty wire was soldered to the FET and then coiled beneath the control board before being fixed into the terminal block.

The heatsink was drilled using a 3mm drill – two holes for the control board, one for the FET, and three for the 30A terminal block. For simplicity most of the holes were tapped to accept 4BA screws (which were in the junk box). M3 nuts and bolts would have worked equally as well. The stripboard requires some form of stand-off spacer, and for this two 2cm length of the outer PVC insulation stripped from heavy duty mains cable was used (reuse and recycle!). Threaded onto the screws, it compresses when the screws are tightened to form a rigid support for the board (see the lower picture on the previous page).

Finally, when all the components have been fixed to the heatsink, the various parts can be wired together. This is shown in the schematic diagram at the top of the next page.

It would have been easier just to solder wires to the control board. The reason for using a PCB mounted terminal block is that the control board is a self contained unit, and could be borrowed from this project for building/testing other devices that required a pulse-width modulation driver (motor speed controllers, light dimmers, etc.). The use of the terminal block also makes it easier to connect and disconnect the wires for other purposes – such as connecting an oscilloscope (shown in the schematic diagram over the page).

The light duty (thin) wire could be any lightweight solid or multi-strand wire. This is because it’s never going to carry more than one hundred milliamps. For this purpose some six amp multi-stranded wire was used – way over the specification required, but it was available from a scrapped wiring loom. However, care must be taken when selecting the heavy duty
(thick) wire for the main current path (see circuit diagram). The wire must be able to carry, without overheating, the maximum current drawn by the load resistor. Whilst solid cored twin and earth cable (usually rated around thirty or forty amps) is OK, 24 amp multi-stranded hook wire was used. The main benefit is that multi-stranded wire is more flexible, and the wire can be regularly bent and moved without thinning or breaking the metal conductor.

Everything is held together using a block of six, 30 amp terminal blocks. It’s important that the components of the dummy load are connected in the order shown. If the FET is connected before the load resistor it will overheat and blow (N-channel FET’s should only be used on the low side, or negative supply side, of a load). It’s also important that the positive lead for the control board is connected before the load resistor otherwise the board will not get enough voltage to operate correctly.

As shown in the schematic, two of the terminals are used to connect a multimeter to measure the load current. The multimeter must have the capacity to measure the maximum current drawn by the load resistor or it will be fried!

Rather than permanently connecting a multimeter the probes of the meter can be screwed into the terminal block only when the dummy load is used. However, if you want to calibrate the load to a specific current for routine testing the multimeter is not required – you can just connect the two terminals together with some heavy duty wire (as shown in the schematic). To calibrate the dummy load all you need to do is connect it to an appropriate battery or power supply, adjust R2 until the multimeter reads the required current, disconnect, and then replace the multimeter with a wire link.

If you are using a very low value resistor in the dummy load there is always the risk that you might produce a current that could damage the FET, the wiring, the multimeter, or most importantly the power supply that you are testing. For greater protection you could install a fuse between the positive terminal of the power supply and the terminal block – which, to protect the whole wiring circuit, would need to be located at the power supply end. An automotive type blade use would do, although they can be a little unpredictable at lower currents. Therefore when using low currents, of less than five amps, 20mm quick blow fuses would be a safer alternative.

**Using the Dummy Load**

An ELV dummy load is a very useful device.
You can use it to check power supplies, to test battery packs, to test renewable energy power systems without the need for batteries, or to calibrate in-line components like ammeters. Whereas before you might have had to improvise using different low-voltage devices to check the power supply at different loads, with an ELV dummy load all you need to do is connect it up and twiddle R2 until you create the required load.

Assuming you were to buy the components (except the heatsink, wire and bolts – which can be easily recovered from other sources) this project will cost around £6. That's really cheap considering how versatile it is!

The main problem with using the dummy load is that you might switch on with R2 adjusted to turn the load resistor fully on. Therefore when using the load you should follow the procedure outlined below:

- Connect up everything except the load resistor, and switch on the power supply.
- If the power supply works only the control board will be using power – less than 100mA.
- Adjust R2 until the LED indicator goes out fully, then disconnect the power supply.
- Connect the load resistor, reconnect the power supply, and adjust R2 until the multimeter indicates the required current.

Be aware that when the current goes above five amps, even a 300 watt resistor will heat up quickly – so don't touch it! For this reason you should hang/fix the resistor in a position where you can safely leave it for a long period after use to allow it to cool down.

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**Parts List**

<table>
<thead>
<tr>
<th>Components</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>HUF75333P3 N-channel FET – but any N-channel power FET that can handle the required current and voltage will do.</td>
</tr>
<tr>
<td>Q2</td>
<td>LM7808CT or similar 1 amp voltage regulator between 5V and 8V.</td>
</tr>
<tr>
<td>Q3</td>
<td>LM324 quad operational amplifier, or similar single supply rail op-amp.</td>
</tr>
<tr>
<td>C1</td>
<td>10uF 63V radial electrolytic capacitor.</td>
</tr>
<tr>
<td>C2</td>
<td>220nF ceramic capacitor.</td>
</tr>
<tr>
<td>C3, C6</td>
<td>100nF ceramic capacitor.</td>
</tr>
<tr>
<td>C4</td>
<td>1uF 16V radial electrolytic capacitor.</td>
</tr>
<tr>
<td>C5</td>
<td>10nF ceramic capacitor.</td>
</tr>
<tr>
<td>R1</td>
<td>Vitreous enamel resistor (see text).</td>
</tr>
<tr>
<td>R2</td>
<td>100K 18 turn cermet potentiometer.</td>
</tr>
<tr>
<td>R3</td>
<td>1K0 0.6W metal film resistor.</td>
</tr>
<tr>
<td>R4, R5, R7, R8</td>
<td>100K 0.6W metal film resistor.</td>
</tr>
<tr>
<td>R6</td>
<td>47K 0.6W metal film resistor.</td>
</tr>
<tr>
<td>D1</td>
<td>Any LED with a forward current (I_f) of around 15 to 20 milliamps.</td>
</tr>
<tr>
<td>L1</td>
<td>2 turns of lightweight hookup wire on a small ferrite toroid or bead.</td>
</tr>
</tbody>
</table>

**Hardware**

- 0.1” stripboard – around 22 holes by 22 strips.
- 4-way PCB terminal block (if required).
- 6-way 30 amp terminal block
- A heatsink or a thick sheet of mild steel sufficient to mount the project on.
- 6 screws or 6 nuts and bolts to mount the dummy load onto the heatsink.
- An insulating pad and bush to mount the FET onto the heatsink (if required).
- One 14-pin IC socket for Q3.
The Honesty Box

An 'honesty box' is usually something that shops have. You can pick something and walk out quickly if you drop the correct money for the item in the honesty box. We're taking a slightly different angle on the honesty box. We'd like you to read this, and the other Free Range project materials on the web site, and honestly answer this question:

"Did you find this information useful, helpful or interesting?"

If the answer is yes, and you'd like more in the future, then it would be really helpful if you could send a donation. We leave the size of donation up to you, but please send what you can spare.

The SSP project, like the rest of the Free Range Network, does not have a membership, official funding, or staff. The human resources are donated by those taking part. The expenses for the development of new resources and information are usually begged from different sources, to support specific activities (or to put it another way, now you know why we make things from a lot of old second-hand, scrapped and discarded equipment!).

If you would like to help develop the SSP Project please send a donation, by cheque or postal order (in pounds sterling, if you live outside the UK), made payable to “Mobbs’ Environmental Investigations (Free Range/SSP)”, to –

    Projects,
    The Free Range Network,
    c/o 3 Grosvenor Road,
    Banbury OX16 5HN,
    England.

Note also: Over the coming months we will be developing new information resources and re-issuing our older publications with minor revisions. As part of this process we’re asking that people consider making a donation if they use our information as part of their own projects. Donations are not compulsory – the information will continue to be issued under the Gnu Free Documentation License so that anyone can take away the information and use it – but if people would like the SSP project to keep producing this useful documentation then we need to increase the flow of funds through the project.

Thanks!  Bok-btarrk!!

The SSP Team