12 W DC Controller (PS-3)

The PS-3 has two functions:

1. It creates a variable power supply from a fixed DC voltage source
2. It acts as a variable power resistor for load testing DC power supplies, batteries, solar panels …

+

When purchased as PS-3+, the PS-3 is supplied with this 15 V / 800 mA regulated DC plugpack

Contents

1 Assembly guide

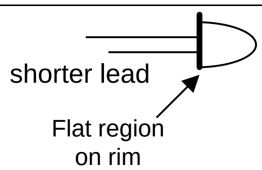
Before assembly

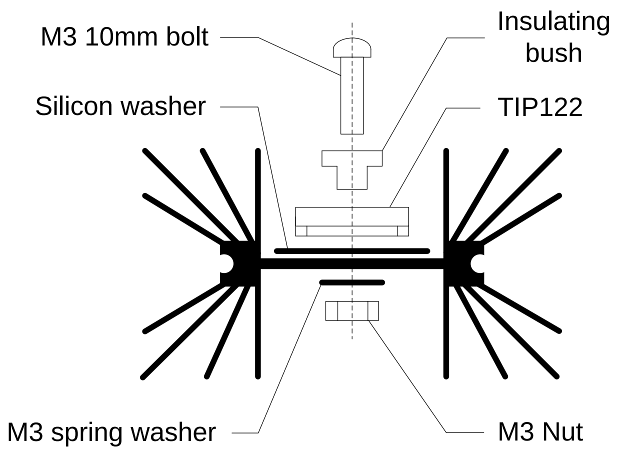
Wash hands before handling components. Contamination affects solderability and long-term reliability of the assembly.

During assembly

- Wear eye protection, particularly when cropping wires – flying offcuts injure eyes
- There are no static-sensitive CMOS components in the PS-3 kit, so wrist-straps and anti-static mats are not essential, but are always wise to use when handling electronic components
- When bending the lead-wire of a component, grip the wire with small pliers and bend the **free end** of the wire – so the pliers isolate the component package from bending forces
- After loading wire-leaded components onto the PCB, semi-clinch (45° bend) and crop the wires to about 1.5mm from the board surface
- Use a fume extractor when soldering.

Assembly sequence (refer to documentation in kit)

Component	Comment
R1 – R4	Non-polarised, but for ease of reading colour codes load resistors with gold tolerance bands toward the top edge or right hand side edge of PCB.
D2	Polarised, so align silver cathode band on diode package with cathode stripe on PCB component outline.
D1, D3	Polarised, so align the small flat section on the rim of the plastic LED package (identifying the cathode) with the flat region on the PCB component outline. 
	The LED pads are arranged such that a 5-way header pin connector can be loaded instead of LEDs. The PS-3 can then be enclosed in a box, and connected to off-board LEDs and to an off-board potentiometer (see RV1).
C1 – C3	Polarised, so insert positive polarity lead-wires (longer) into the holes marked '+', and negative polarity lead-wires (shorter, and aligned with negative marking on capacitor body) into the unmarked holes.
F1	Non-polarised, so can be loaded either way around, but insert device only as far as the pre-formed bends in the lead-wires to ensure thermal clearance from the PCB

RV1	Pads are provided for two different potentiometer pinouts, and also a 3-way header pin connector – for connecting to an off-board potentiometer if desired. Use the pads that suit your application.
J1 – J3	Check orientation of wire-entries before soldering
Q1 and heatsink	Load Q1 and the heatsink in the following sequence: Loosely bolt the TIP122 transistor to the heatsink, ensuring that the insulating bush passes through the metal tab on the TIP122, the silicon washer, and into the mounting hole in the heatsink. Refer to the assembly sketch below Insert the TIP122 pins into the holes on the PCB, ease the assembly down, and insert the heatsink pins into their mounting holes. Push the heatsink to the PCB surface Solder the two heatsink pins to their pads Firmly tighten the TIP122 mounting bolt, then crop and solder the TIP122 pins.
	
Rubber feet	Peel the self-adhesive feet away from the protective backing, and mount them on the four corners of the PCB.

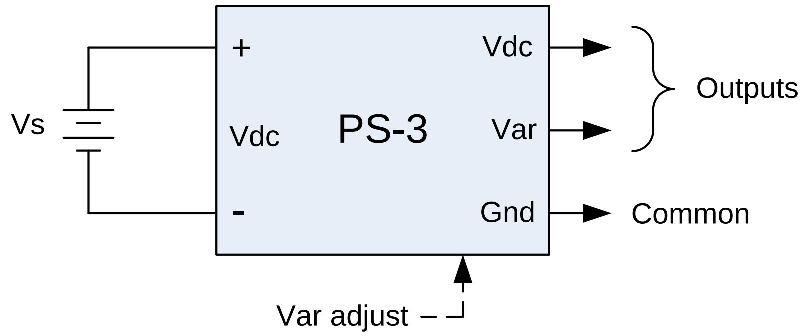
After assembly

- In a well ventilated area, clean resin from the completed assembly with isopropyl alcohol and a small flux brush
- Buff the soldered side of the cleaned assembly with a clean, stiff-bristled paint brush - a 25 mm wide paint brush with bristles cut back to about 20 mm length is ideal
- Visually inspect all solder joints, and re-work / re-clean where necessary
- Wash hands to remove resin and solder residues
- Test the assembly using the **Test procedure** in this document

2 Specification

2.1 PS-3 as a Variable DC supply

Figure 2-1
Input and output connections

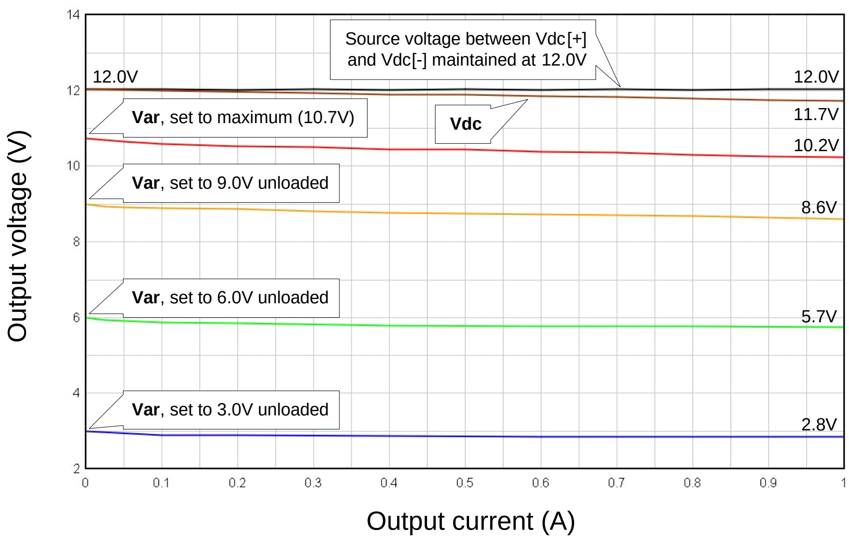


Parameter		Typical range or value (Voltages relative to **GND** unless otherwise stated)
DC source	**Vs**	Via **Vdc[+], Vdc[-]** screw terminals, or 2.1 mm DC power connector
	Voltage	3 V to 22 V
	Current	1 A maximum
Fixed DC output	**Vdc, Gnd**	**Vdc** is connected to **Vdc[+]** through a polyfuse (≤ 0.5 Ω 'cold')
	Voltage	Within 0.5 V of **Vs** at 1 A load current
	Current	1 A maximum (polyfuse limited)
Variable DC output	**Var, Gnd**	
	Voltage range	0 V to [**Vdc** – 1.4 V] (The 1.4 V loss is across the TIP122 junctions)
	Output current, **Iout**	1 A maximum, polyfuse limited
	Voltage regulation	See graphs below for typical test results to 1.0 A with Vs = 12.0 V
Power dissipation	**P_D**	12 W maximum. P_D ≈ (**Vs** - **Var**).(Iout)

Figure 2-2
Load regulation graphs

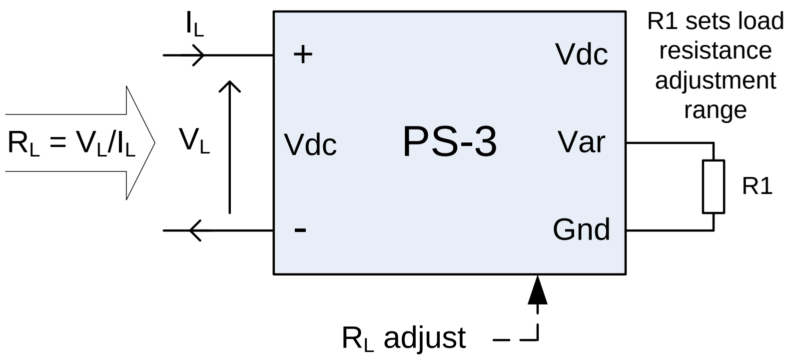
To keep the PS-3 power dissipation less than 12 W, limit the maximum current to:

$$I_{out}(\max) = \frac{12W}{(Vs - Var)}$$



2.2 PS-3 as a Variable DC load

Figure 2-3
Input and range-resistor connections



Parameter	Typical range or value (Voltages relative to **GND** unless otherwise stated)
Connection	Usually via screw terminals **Vdc[+]** and **Vdc[-]**
Voltage range, $\mathbf{V_L}$	3 V to 22 V
Current, $\mathbf{I_L}$	1 A maximum (polyfuse limited)
Maximum power, ($\mathbf{V_L \cdot I_L}$)	12 W + P_{R1} (power is shared between the PS-3 and R1)
Input resistance range, $\mathbf{R_L}$	See Figs 2-4 to 2-7, and *Circuit operation* in Topic 4

Choosing range-resistor R1

Load power ($P_L = V_L.I_L$) is shared between transistor Q1 in the PS-3 and external resistor R1.
Q1 has a maximum power rating of 12 W, and typical wire-wound resistors (R1) are available with 5 W and 10 W ratings. To ensure that both Q1 and R1 operate within their power ratings, use the devices within the **V_L/I_L adjustment regions** shown in Figures 2-4 to 2-6:

Figure 2-4
R1 = 1 Ω, 5 W or 10 W

R_L range: 3 Ω to 13 Ω at 1 A, and >13 Ω at reduced current (to keep P_{Q1} below 12 W)

Best used for low-voltage, high-current loading, with P_L up to 13 W (P_{Q1} = 12 W, P_{R1} = 1 W).

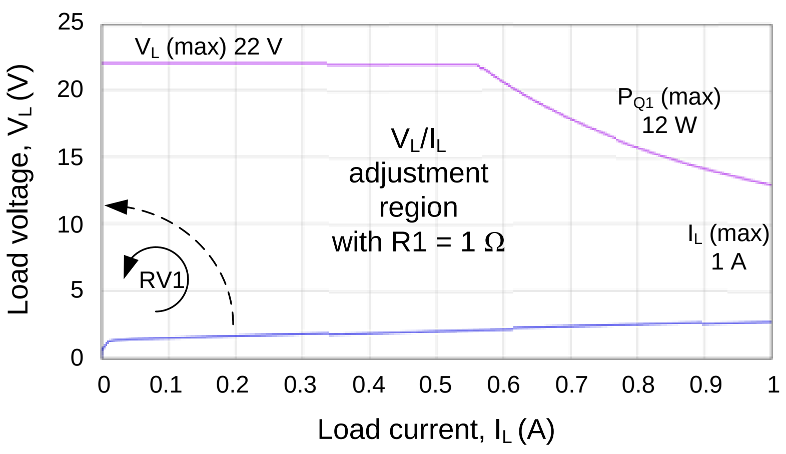


Figure 2-5
R1 = 10 Ω, 5 W or 10 W

R_L range: 12 Ω to 22 Ω at 1 A, and >22 Ω at reduced current (to keep V_L below 22 V)

Best used for mid-range voltage, mid-range current loading, with P_L up to 22 W (P_{Q1} = 12 W, P_{R1} = 10 W).

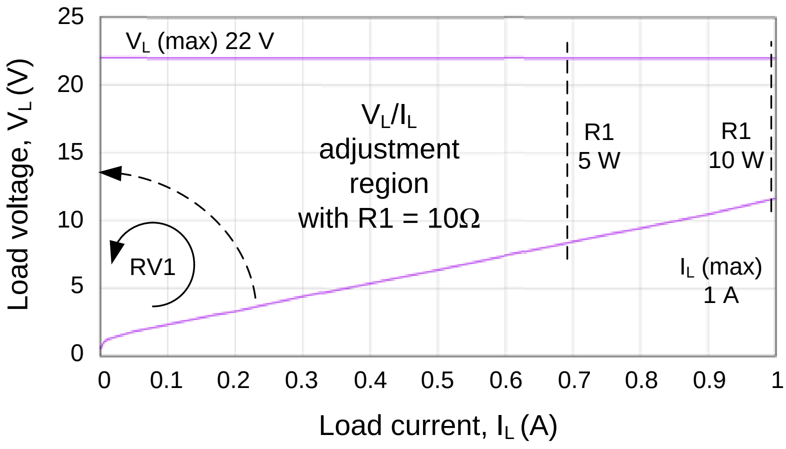
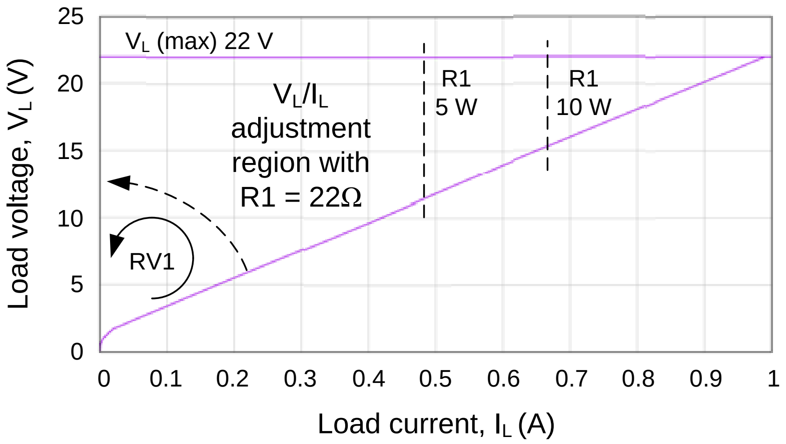


Figure 2-6
R1 = 22 Ω, 5W or 10 W

R_L range: 22 Ω to 32 Ω at 670 mA (to keep P_{R1} below 10 W), and >32 Ω at reduced current (to keep V_L below 22 V)

Best used for high-voltage, low-current loading, with P_L up to 15 W (P_{Q1} = 5 W, P_{R1} = 10 W).



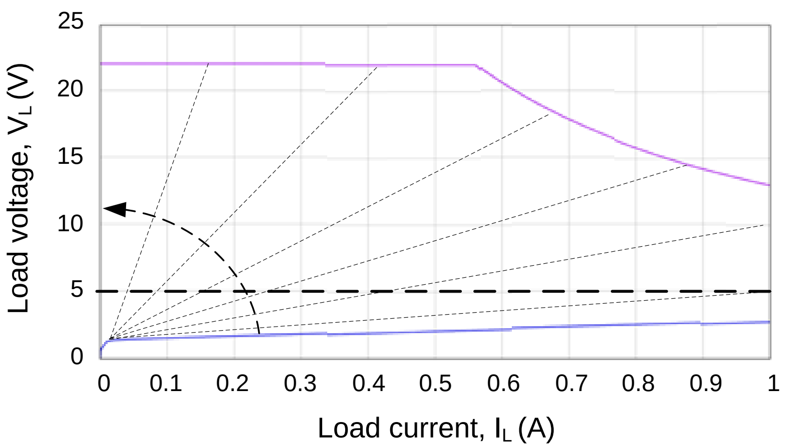
Example application: Load testing a 5 V power supply to 1 A

From Figures 2-4 and 2-7 (R1 = 1 Ω), the required 1 A current range is available in one rotation of RV1. Larger values of R1 permit finer control of the current – but over a reduced current range (about 400 mA in Figure 2-5, and 200 mA in Figure 2-6). A good compromise is to leave R1 at 1 Ω for measurements above 400 mA, and to increase R1 for measurements below that current value.

Figure 2-7
5 V power supply load test

As RV1 is adjusted anti-clockwise, the PS-3 resistance increases, as shown by the increasing slope of the resistance lines.

At any resistance value, the load current is found where the resistance line intersects the dashed horizontal 5 V line.



3 Test procedure

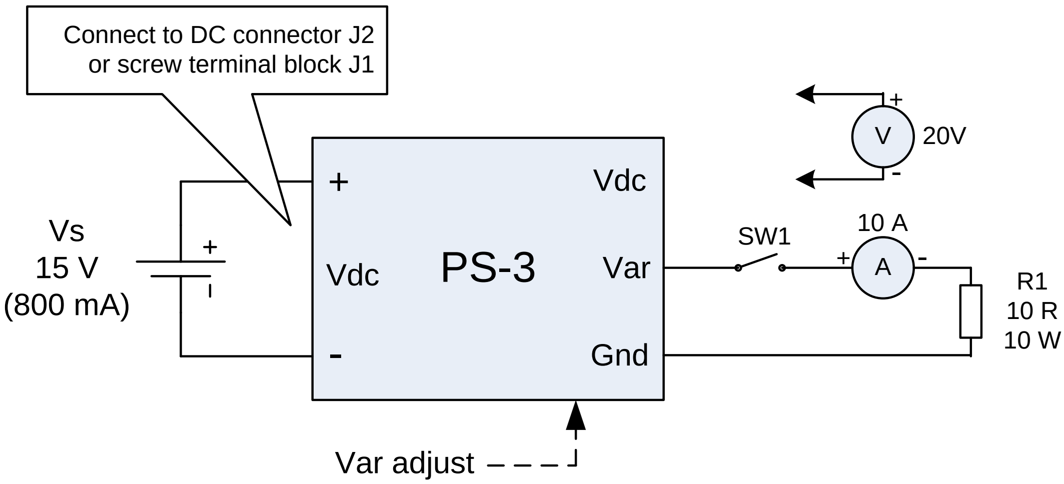
3.1 PS-3 as a variable DC supply

- Reference is made to the circuit diagram provided in the kit.
- For convenience, the DC power source for the PS-3 is assumed to be the 15 V/800 mA regulated DC plugpack supplied with the PS-3+ option

3.1.1 Required equipment (or equivalent)

- 15 V/800 mA regulated DC plugpack
- 20 V DC voltmeter and 10 A DC ammeter
- 10 Ω, 10 W wire-wound resistor
- Single-pole, single throw switch with 1 A contacts, or clip-leads
- Connecting wires and hand tools.

Figure 3-1 PS-3 test circuit (variable DC supply)



Take the actions, and make the observations and/or measurements, listed in the following test procedure. Where a PS-3 exhibits significantly different characteristics from those suggested in the procedure (with allowance for manufacturing tolerances), check all components associated with the function under test for:

- correct values and ratings
- correct orientation on the PCB
- solder joint integrity

3.1.2 Check Vs, Vdc, and short-circuit protection

<table>
<tr><th>Actions</th><th>Observations / measurements
(voltages relative to Gnd unless otherwise stated)</th></tr>
<tr><td>1. Open SW1 (disconnect load)
2. Rotate RV1 fully anti-clockwise
3. Switch ON the 15 V DC source, Vs</td><td>4. Green LED D3 illuminates
5. Measure and record Vs (at Vdc[+] on connector J1)
6. Measure and record Vdc (at Vdc on connector J3)
<table><tr><th colspan="2">Vs (unloaded)</th><th colspan="2">Vdc (unloaded)</th></tr><tr><td>Measured</td><td>Expected</td><td>Measured</td><td>Expected</td></tr><tr><td></td><td>Typ. 15 V</td><td></td><td>Typ. 15 V</td></tr></table></td></tr>
<tr><td>7. Short-circuit Vdc to GND (connector J3) with a wire link to activate protection circuits</td><td>8. Green LED D3 dims or flashes as the DC plugpack protection circuit activates and limits output current
9. If a higher-current DC power source (e.g. car battery) is used, the PS-3 polyfuse activates, limiting the output current and illuminating red LED D1.</td></tr>
</table>

3.1.3 Check Var adjustment range, Vs and Var load check

<table>
<tr><th>Actions</th><th>Observations / measurements
(voltages relative to Gnd, unless otherwise stated)</th></tr>
<tr><td>1. Leave SW1 open (load disconnected)
2. Measure Var as RV1 is slowly rotated clockwise</td><td>3. Var remains near 0V as RV1 is rotated through approximately 10% of its travel, then begins to rise
4. Var reaches about 13.6 V when RV1 is fully clockwise. (1.4 V is lost across the two base-emitter junctions in Q1)</td></tr>
<tr><td>DANGER:</td><td>During the next test, transistor Q1, the heat-sink, and the 10 Ω load resistor will become very hot. After the test, allow plenty of time to cool before touching.</td></tr>
<tr><td>5. Leave SW1 open (load disconnected)
6. Adjust RV1 to set Var(unloaded) to 8.0 V
7. Close SW1 (connect load)</td><td>8. Measure and record the load current I_L(load). Ideally this is 800 mA, but ammeter and wiring resistance will influence the value
9. Measure and record Var(loaded)
10. Measure and record Vs (loaded)
<table><tr><th colspan="2">Vs(loaded)</th><th colspan="2">Var(loaded)</th><th colspan="2">I_L(load)</th></tr><tr><td>Measured</td><td>Expected</td><td>Measured</td><td>Expected</td><td>Measured</td><td>Expected</td></tr><tr><td></td><td>Typ. 14.8 V</td><td></td><td>Typ. 7.6 V</td><td></td><td>Typ. 750 mA</td></tr></table>As well as confirming correct operation of the 15 V/800 mA DC plugpack and the PS-3, the data recorded on this page can be used to calculate load regulation as shown in the following section.</td></tr>
</table>

3.1.4 Check load regulation

Calculated from two measurements

Load regulation is defined as the percentage change in output voltage for a given change in load current – usually from no-load (NL) current to full-load (FL) current. Full-load current is the maximum operating current specified for the device.

$$\text{Load regulation} = \left(\frac{V_{NL} - V_{FL}}{V_{FL}} \right) \bullet 100\%$$

The 15 V/800 mA DC plugpack has a full-load current of 800 mA, and the PS-3 has full-load current of 1 A. The measurements recorded in paragraph 3.2 are close enough to these full-load values to yield reasonably accurate load regulation figures.

15 V/800 mA DC plugpack only

Substitute the previously measured **Vs** values into the load regulation formula:

$$\text{Load regulation} = \left(\frac{Vs(unloaded) - Vs(loaded)}{Vs(loaded)} \right) \bullet 100\%$$

$$= \left(\frac{[\qquad\qquad] - [\qquad\qquad]}{[\qquad\qquad]} \right) \bullet 100\%$$

$$= \text{..............................}\% \quad (\text{typically } 2\%)$$

Plugpack + PS-3 (complete variable power supply)

Substitute the previously measured **Var** values into the load regulation formula:

$$\text{Load regulation} = \left(\frac{Var(unloaded) - Var(loaded)}{Var(loaded)} \right) \bullet 100\%$$

$$= \left(\frac{[\qquad\qquad] - [\qquad\qquad]}{[\qquad\qquad]} \right) \bullet 100\%$$

$$= \text{..............................}\% \quad (\text{typically } 5\%)$$

PS-3 only

The load regulation of the PS-3 alone is better than that of the **Plugpack + PS-3** combination, and can be measured by maintaining **Vs** at a constant value with a variable power supply for the no-load and full-load tests. The PS-3 load regulation graphs on the specification page were produced this way.

3.2 PS-3 as a variable DC load

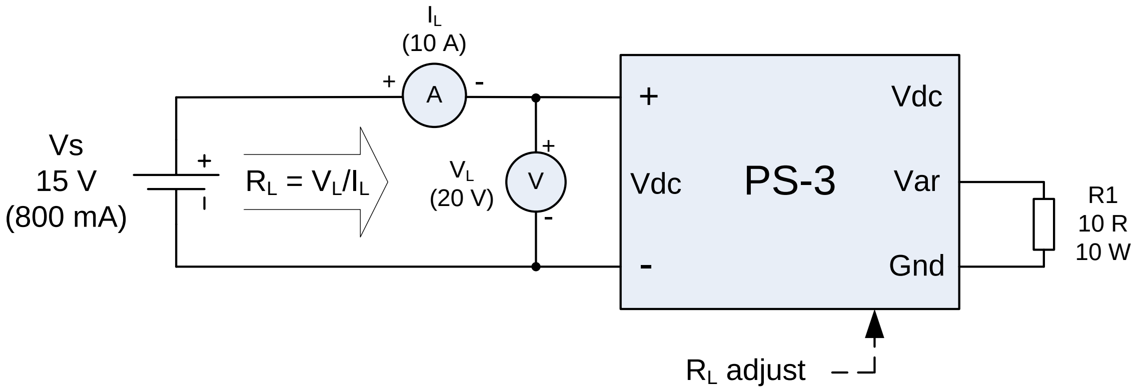
First test the PS-3 as a variable DC supply (section 3.1)

3.2.1 Required equipment (or equivalent)

- 15 V/800 mA regulated DC plugpack as supplied with the PS-3+ option
- 20 V DC voltmeter and 10 A DC ammeter
- 10 Ω, 10 W wire-wound resistor
- Connecting wires and hand tools.

Figure 3-2 PS-3 test circuit (variable DC load)

Note: If the 15 V DC source uses the DC power connector J2 and not the screw terminal block J1:
1. Connect the ammeter in series with R1, and add 22 mA to the measured I_{R1} to obtain I_L.
2. Connect the voltmeter between Vdc[+] and GND to measure V_L.



Actions	Observations / measurements (voltages relative to **Gnd** unless otherwise stated)	
1. Rotate RV1 fully anti-clockwise 2. Switch ON the 15 V DC source, **Vs**	3. Green LED D3 illuminates 4. I_L measures about 22 mA (LED D3 and potentiometer RV1 bias currents) 5. This lowest current corresponds to the highest resistance of about 680 Ω	$R_L = \frac{V_L}{I_L} = \frac{15V}{22mA} = 680\Omega$
6. Slowly rotate RV1 clockwise to about mid position, observing I_L	7. I_L steadily increases to about 600 mA (at mid position) **8. DANGER: R1 and the PS-3 heatsink become HOT** 9. Measure V_L, and calculate R_L (typically 25 Ω)	
10. Slowly rotate RV1 until I_L reaches 800 mA (the plugpack maximum)	11. Measure V_L and calculate R_L (typically 18 Ω)	
12. The current can probably be increased to 1 A (the PS-3 maximum), but the over-current protection circuit in the 15 V / 800 mA plugpack may activate. Try it anyway (R_L typically 15 Ω).		

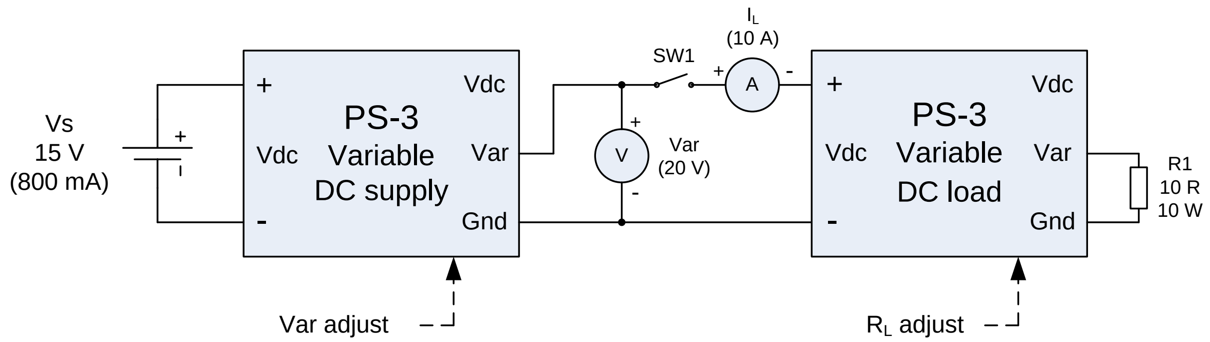
3.3 Variable DC supply & Variable DC load

Full-specification testing

A few 'spot' measurements of load regulation and input resistance for variable DC sources and loads can be misleading because they do not represent the full specification range of the equipment.

A series of measurements across the operating voltage and current ranges, presented graphically, gives a better indication of overall performance. In the following procedure, a PS-3 variable DC supply is tested using a PS-3 variable DC load – fully exercising the PS-3 in both roles.

Figure 3-3 Load regulation test circuit



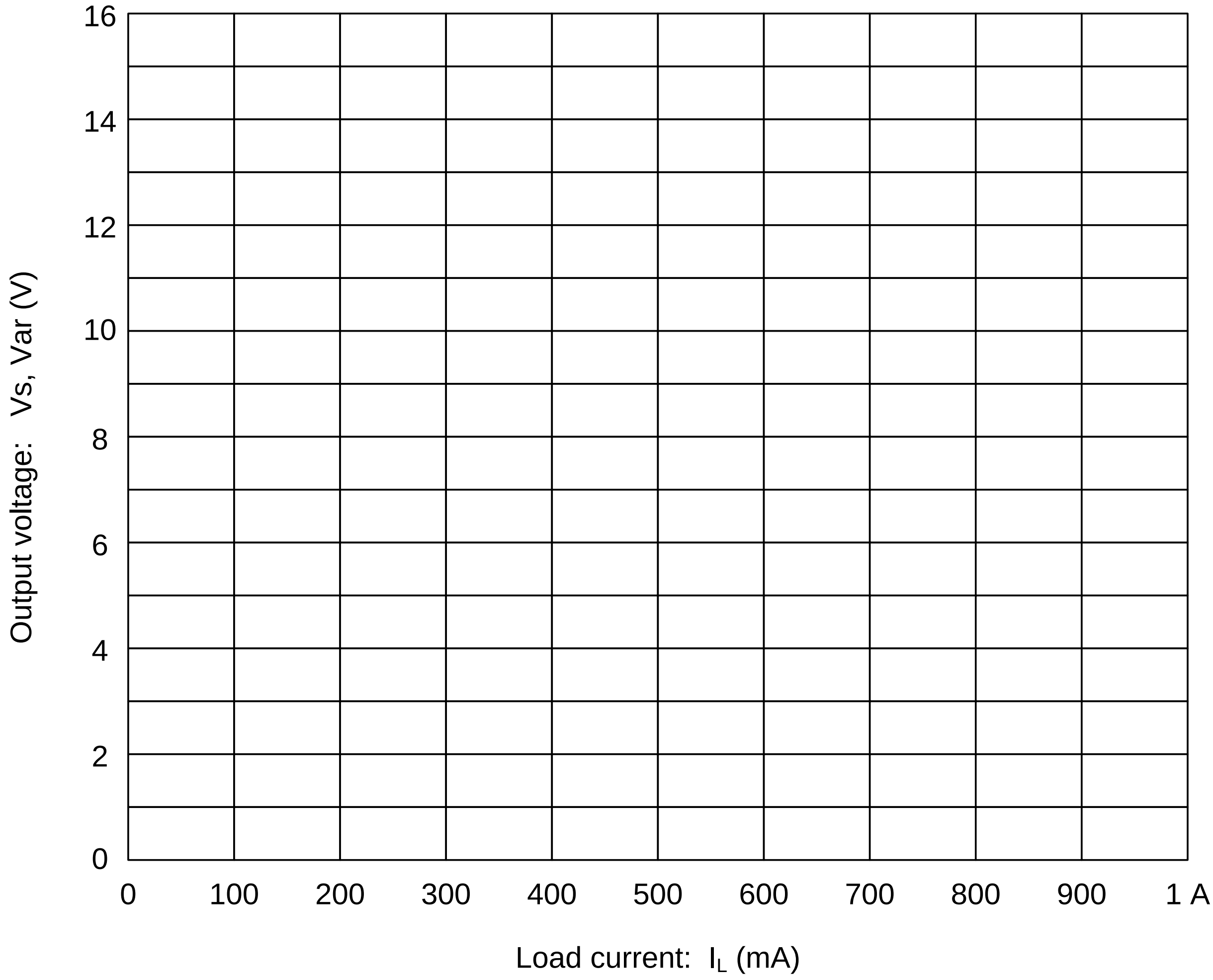
The method (all voltages relative to GND)

1. Open SW1
2. Measure and record the unloaded DC source voltage **Vs** (at **Vdc[+]** on connector J1)
3. Adjust **Var** (variable DC supply) to the first test voltage (e.g. 12.0 V)
4. Close SW1
5. Adjust $\mathbf{R_L}$ (variable DC load) to set the first load current $\mathbf{I_L}$ (e.g. 100 mA)
6. Measure and record **Vs** (DC source voltage)
7. Measure and record **Var** (variable DC supply output voltage)
8. Adjust the load current $\mathbf{I_L}$ in convenient steps (e.g. 100 mA), recording each current and the resulting **Vs** and **Var** values in the table of Figure 3-4
9. When measurements have been made to 800 mA (or possibly to 1 A), open SW1, adjust **Var** to the next test voltage (e.g. 9.0 V), and progressively load and record it as before. R1 may need to be reduced at higher current (refer Figures 2-4 to 2-6)
10. Repeat this process for other **Var** values of interest, changing the fixed power resistor R1 as required (refer Figures 2-4 to 2-6)
11. Present the data graphically. Graphing software gives the neatest presentation, but hand plotting is often adequate – see Figure 3-5.

Figure 3-4 Load regulation measurements table

I_L (mA)	Vs (V)	Var (V)	Var (V)	Var (V)	Var (V)	Var #5 (V)
Unloaded		12.0 V	9.0 V			
100						
200						
300						
400						
500						
600						
700						
800						
900						
1.0 A						

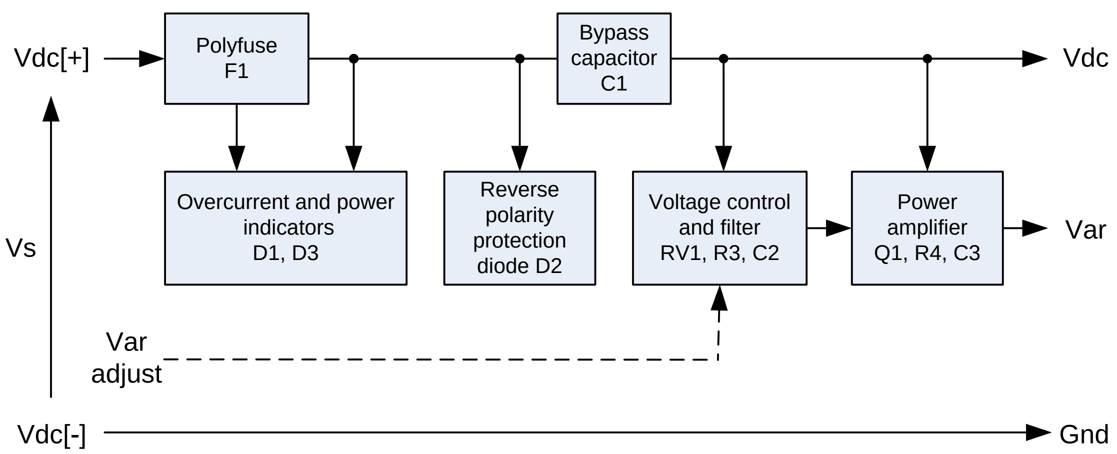
Figure 3-5 Load regulation graphs



4 Circuit operation

- Reference is made to the PS-3 circuit diagram provided with the kit
- All circuit components are assumed to be ideal. Manufacturing tolerances and temperature effects are ignored unless they contribute significantly to performance
- Unless otherwise stated, quoted voltages are relative to **Gnd.**

Figure 4-1 PS-3 functional block diagram



4.1 Polyfuse

- Polyfuse F1 is the first component in the current path from the DC source terminal **Vdc[+]**, so all PS-3 operating and load current passes through it
- While current is below 1.1A, F1 has little effect—introducing less than 0.5Ω into the current path
- When current exceeds 1.1A (allowing for manufacturing tolerance), self heating causes F1 to trip – increasing its resistance and reducing circuit current significantly
- When the load is disconnected, F1 cools and its resistance resets to a low resistance again.

4.2 Power and overcurrent indicators

Normal operating conditions (continuous current ≤1 A)

- While the polyfuse F1 resistance is less than 0.5Ω there is little voltage drop across it, and the PS-3 output voltage **Vdc** is almost the same as the DC source voltage **Vs**
- Green indicator LED D3 is connected across **Vdc** and **Gnd**, so it conducts and illuminates with current limited by resistor R2 (provided the DC source voltag**e Vs** is at least 2 V)

Overcurrent conditions (continuous current >1.1 A)

- Polyfuse F1 trips, increasing resistance significantly. Circuit current falls, and source voltage **Vs** is re-distributed with most across F1 and least across the load between **Vdc** and **GND**
- Red overcurrent indicator LED D1, connected across polyfuse F1, conducts and illuminates with current limited by resistor R1 (provided **Vs** is at least 2 V)
- D3 glows dimly, or not at all – depending on **Vs** and **Vdc**.

4.3 Bypass capacitor

- High frequency noise and transient current drawn by the TIP122 flows through the low impedance path presented by C1, bypassing the higher impedance path through the external connecting wires and DC power source. This reduces the noise voltage between **Vdc[+]** and **Vdc[-]**
- Together with the resistance and inductance of the external connecting wires and DC power source, C1 completes a low-pass filter to reduce the external electrical noise entering the PS-3.

4.4 Reverse polarity protection diode

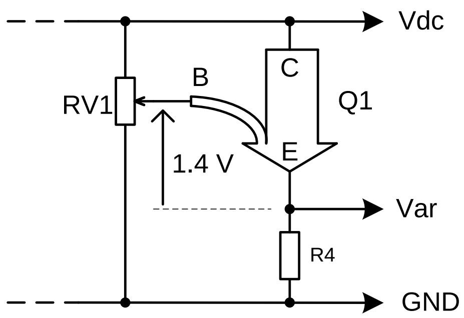
- Diode D2 is connected in reverse polarity across the PS-3 internal power supply rails **Vdc** and **Gnd**
- If the source voltage is accidentally connected with reverse polarity, D2 becomes forward biased and conducts heavily, heating and tripping F1 to reduce source current
- The circuit stabilizes with a few hundred milliamps flowing through F1 and D2, and with about 1V in reverse polarity across **Vdc** and **Gnd** – which should not damage the circuit

4.5 Voltage control and noise filters

- Potentiometer RV1 is connected across **Vdc** and **Gnd**. Rotating the wiper of RV1 adjusts the wiper voltage between **0V** and **Vdc** to drive the base of power transistor Q1
- R3 limits the maximum wiper current, and capacitors C2 and C3 reduce source and load-induced electrical noise on the output voltage **Var**

4.6 Power amplifier

- Q1 is a power darlington transistor, used as a common-collector (or emitter follower) amplifier
- As the base voltage of Q1 is varied with RV1, the emitter voltage (and therefore **Var**) 'follows' – but always about 1.4V below the base voltage due to the two base-emitter junctions within Q1
- Q1 has a current gain of about 1000, requiring little current from RV1 to deliver high load current from **Var**
- Resistor R4 keeps some current flowing through Q1 so **Var** can be adjusted without an external load connected.



Estimating Var (variable DC supply)

Var is determined by:

1. the power supply voltage (**Vdc**) across RV1
2. the position of the RV1 wiper as a fraction of full rotation (**F$_{RV1}$**). This increases from 0 to 1 as the wiper is rotated from fully anti-clockwise to fully clockwise
3. The 1.4 V offset between Q1 base and emitter terminals.1

$$V_{wiper} = (F_{RV1} \bullet Vdc)$$
$$Var = V_{wiper} - 1.4V$$
$$= (F_{RV1} \bullet Vdc) - 1.4V$$

Example: If the power supply voltage is 15 V, and the RV1 wiper is rotated to mid-position:

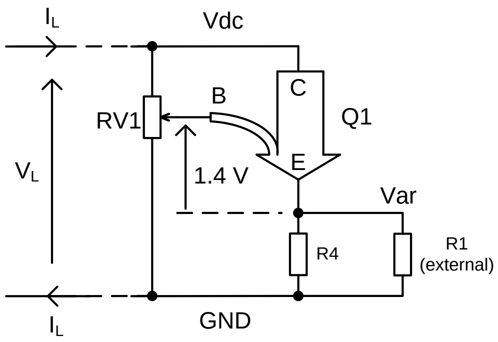
$$Var = (F_{RV1} \bullet Vdc) - 1.4V$$
$$= (0.5)(15V) - 1.4V$$
$$= 6.1V \text{ (approximately)}$$

Estimating R$_L$ (variable DC load)

In most loading applications, **I$_L$** is dominated by the current through R1:

$$I_L = \frac{Var}{R1}$$
$$= \frac{(F_{RV1} \bullet Vdc) - 1.4V}{R1}$$

$R_L = V_L/I_L$



Substituting this equation into Ohm's law for **R$_L$**, and replacing **Vdc** with **V$_L$**:

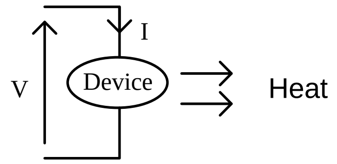
$$R_L = \frac{V_L}{I_L}$$
$$= \frac{V_L \bullet R1}{(F_{RV1} \bullet V_L) - 1.4V}$$

Example: If the load voltage is 12 V, R1 is 10 Ω, and the RV1 wiper is rotated to mid-position:

$$R_L = \frac{V_L \bullet R1}{(F_{RV1} \bullet V_L) - 1.4V}$$
$$= \frac{(12V)(10\Omega)}{(0.5)(12V) - 1.4V}$$
$$= 26\Omega \text{ (approximately)}$$

Thermal design considerations

When current flows through Q1, electrical energy is converted into heat. The temperature of the device rises until the flow-rate of heat from the device to the surrounding air (thermal power out) is equal to the conversion-rate of electrical energy into heat in the device (electrical power in):

	General formula for all devices	Additional formulas for resistors
	$P = V \bullet I$	$P = \frac{V^2}{R}$ $P = I^2 \bullet R$

Final temperatures can be estimated using a thermal model or 'equivalent circuit' and the following information:

- electrical power dissipation (P_D) in the device
- total *thermal resistance* (θ_T) along the heat flow path between the device and air
- temperature (T_A) of the surrounding air.

This theory was used to select the heatsink for the PS-3, ensuring that the highest temperature reached by the collector-emitter junctions in the TIP122 is less than the maximum 150 °C specified by the manufacturer. This calculation uses maximum values: P_D = 12 W, θ_T = 8.5 °C/W, and T_A = 40°C.

$$\begin{aligned} T_J(\text{max}) &= (P_D)(\theta_T) + T_A \\ &= (12W)(8.5°C/W) + 40°C \\ &= 142°C \text{ (acceptable)} \end{aligned}$$

Total thermal resistance (θ_T) is the sum of the individual values provided by the manufacturers of the TIP122 transistor (θ_{JC}), the silicon insulating washer (θ_{CS}), and the aluminium heatsink (θ_{SA}).

This 'series connected' thermal equivalent circuit also reveals temperatures along the heat flow path – such as transistor case, and heat sink – which can be measured to confirm the theory.