

# High Performance Portable DC Bench Power Supply: Save Money and Free Up Bench Real Estate by Building Your Own

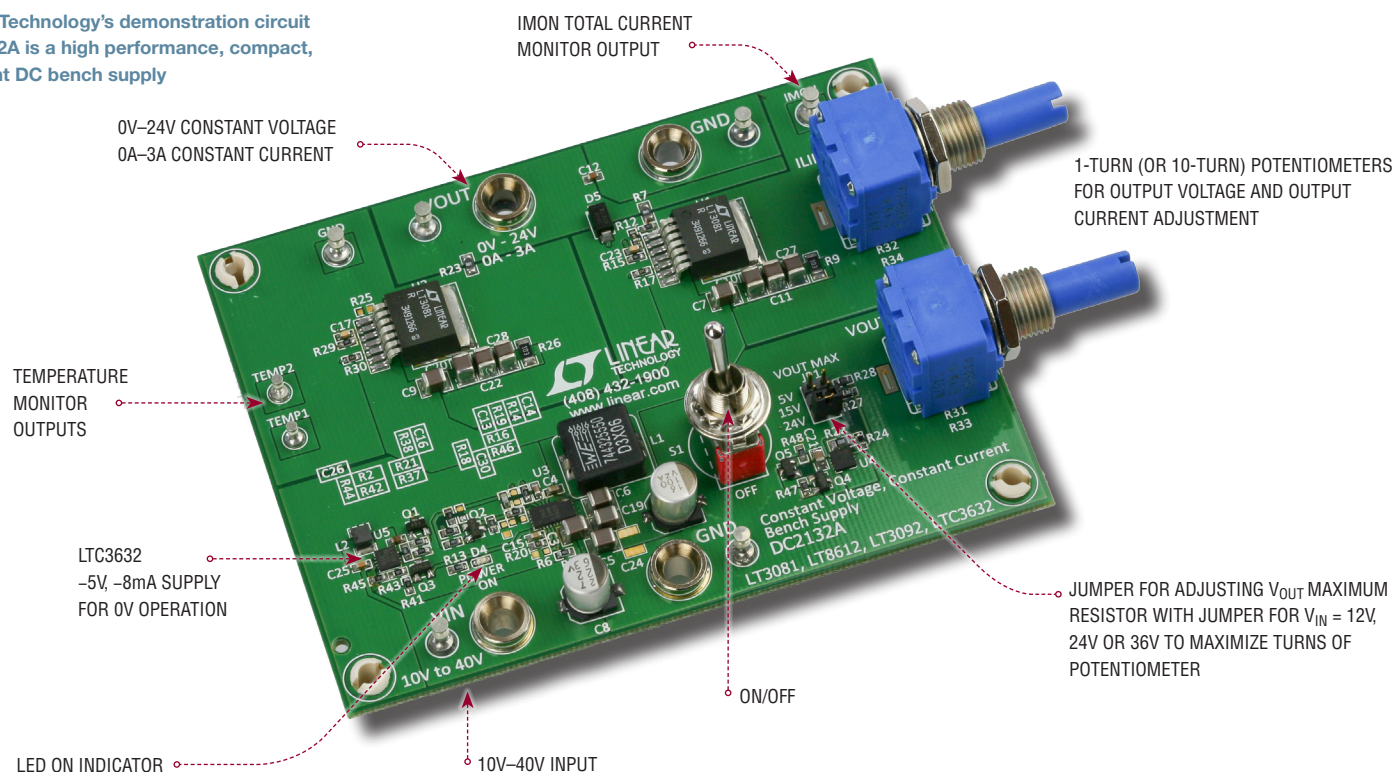
Keith Szolusha

The bench power supply, along with the soldering iron and handheld multimeter, is a required item in any electronics lab toolbox. Some projects require only a single, constant voltage supply, but more often, properly testing and debugging a project demands a variety of voltages and currents. Significant debugging time can be saved by using a high performance adjustable bench supply to dial in voltage and current at will. Unfortunately, typical universal adjustable bench power supplies are bulky and expensive—at least the better-performing versions—and have a number of limitations. None are truly portable (handheld) due to necessary heat dissipation structures. Furthermore, even high cost supplies do not support zero current or voltage, and cannot match the transient and short performance exhibited by the supply shown here.

Save money and free up benchtop space by building your own high quality bench power supply. The key component to this supply is the LT3081 linear regulator surrounded by a short list of easy-to-get components (see Figure 1). The LT3081's unique current-source reference and voltage-follower output amplifier make it possible to connect two linear regulators in parallel for up to 3A and over 24V of adjustable current and voltage output control. Linear regulators at the output suppress output ripple without requiring large output capacitors, resulting in a truly flat DC output and small size.

In the supply shown here, parallel LT3081s are preceded by a high performance,

Linear Technology's demonstration circuit DC2132A is a high performance, compact, efficient DC bench supply



The key component to the supply is the LT3081 linear regulator surrounded by a short list of easy-to-get components. The LT3081's unique current-source reference and voltage-follower output amplifier make it possible to connect two linear regulators in parallel for up to 3A and over 24V of adjustable current and voltage output control. Linear regulators at the output suppress output ripple without requiring large output capacitors, resulting in a truly flat DC output and small size.

synchronous step-down converter, in this case, the 40V, 6A LT8612. No heat sink or fan is required, in direct contrast to linear bench supplies featuring power transistors that require heat sinks and forced airflow (fans) to sufficiently dissipate the heat.

The LT8612 efficiently steps down 10V to 40V at high or low current to a dynamically adaptive output voltage, which remains just above the output voltage of the bench power supply (output of the LT3081 linear regulator). The output of the LT8612 is low ripple and conversion is efficient over the full range of

the bench supply. Power loss across the LT3081 devices is minimized by keeping their input just above dropout. This bench supply includes the uncommon ability to adjust both the voltage and current limit down to zero. A complete schematic of this mixed-mode DC bench supply is shown in Figure 2.

### PARALLEL LINEAR REGULATORS STEADY OUTPUT, CONTROL VOLTAGE AND CURRENT

Linear regulators are commonly used at the output of step-down converters to suppress switching power supply ripple

with a minimal efficiency hit. The parallel LT3081 linear regulators shown in Figures 1 and 2 knock down the output ripple of the LT8612 and accurately control constant voltage and constant current output of the power supply. The LT3081 has the unique ability (for linear regulators) to be easily paralleled for higher output currents.

Figures 1 and 2 show how two parallel LT3081s double the supported current of a single LT3081 (1.5A) to 3A. A few parallel connections and two small 10mΩ ballast resistors are all that is needed to accurately share current

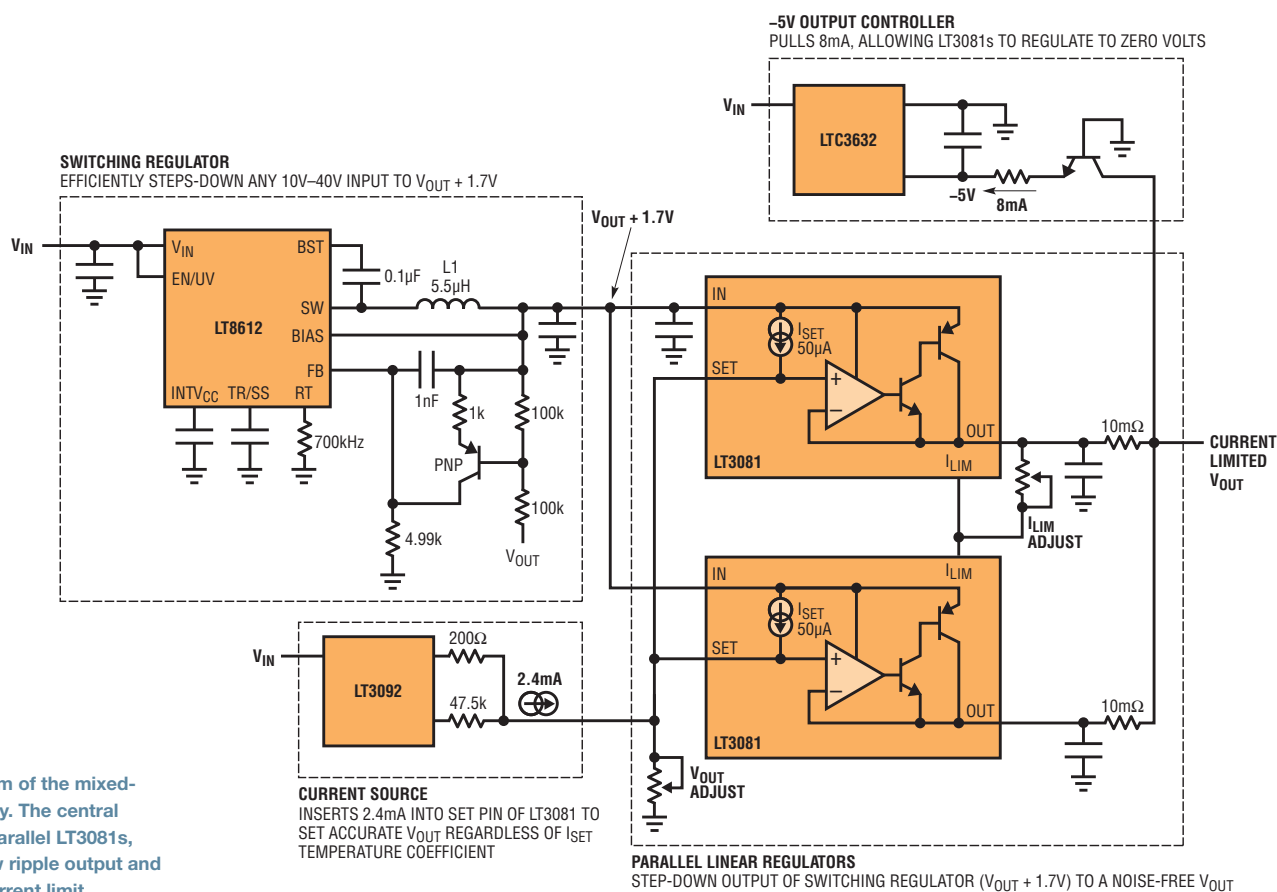


Figure 1. Block diagram of the mixed-mode DC bench supply. The central components are the parallel LT3081s, which produce the low ripple output and set the voltage and current limit.

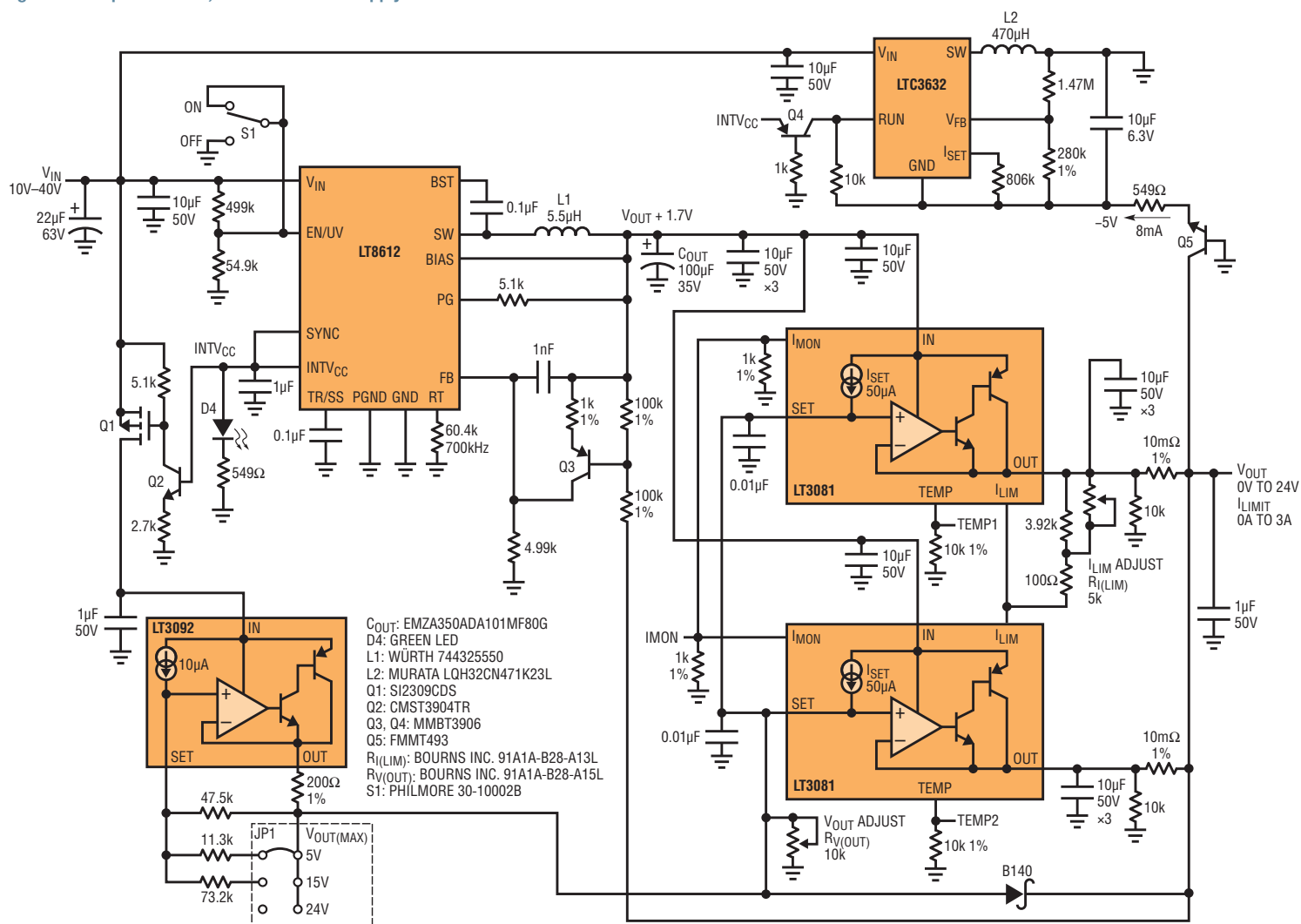
The minimum current limit of the bench power supply is 0A. The LT3081 guarantees 0A output current as long as the ILIM resistor is reduced below 200Ω. The minimum output voltage of the bench power supply is 0V. The LT3081 guarantees 0V output as long as there is 4mA pulled from the output.

between the two without a loss of output voltage accuracy. Readily available, high quality 10k and 5k potentiometers provide the control from 0V–24V and 0V–3A when connected to the SET pin and ILIM pins. Potentiometers with more turns and more accuracy can certainly be used to fancy-up one's bench supply.

The minimum current limit of the bench power supply is 0A. The LT3081 guarantees 0A output current as long as the ILIM resistor is reduced below 200Ω. A small 100Ω resistor is placed in series with the ILIMIT potentiometer to maximize the turning range and still guarantee zero current when two regulators are used in parallel.

The minimum output voltage of the bench power supply is 0V. The LT3081 guarantees 0V output as long as there is 4mA pulled from the output. The best way to do this is to use a negative supply to pull 8mA for the two LT3081s. The LTC3632 –5V regulator easily produces this negative load, dissipates little power and occupies only a tiny bit of board space.

Figure 2. Complete 0V–24V, 0A–3A DC bench supply



Once target voltage is precisely dialed-in, you don't want to see the bench supply voltage drift as load is added, increased or decreased. Ideally, it should maintain a flat regulation profile across the entire range of load currents up to the current limit. The supply shown here fulfills this requirement.

#### FLAT LOAD REGULATION AND SHARP VI CURVE

Once target voltage is precisely dialed-in, you don't want to see the bench supply voltage drift as load is added, increased or decreased. Ideally, it should maintain a flat regulation profile across the entire range of load currents up to the current limit (Figures 3 and 4).

The supply shown here fulfills this requirement. The LT3081 output remains virtually flat from 0A to 1.5A. Minimum IC heating helps keep load regulation of the bench supply under 50mV for any output voltage, as shown in Figure 3—even with 15mV due to the 10mΩ ballast resistors. A 1.7V drop across the linear regulators while driving 1.5A produces a mere 30°C temperature rise with the DD package, as shown in Figure 5.

Setting the current limit knob should be just as deterministic as the voltage knob. If the current limit is set to 3.0A, the bench supply should enter current limit at exactly 3.0A and never supply higher current. A high performance bench supply must demonstrate a voltage vs current regulation curve that remains flat until it drops off a cliff to 0V when the current limit is reached. Figure 4 shows that

Figure 3. DC bench supply V-I curve shows < 50mV load regulation from 0A to 3A, falling off a cliff above 3.1A.

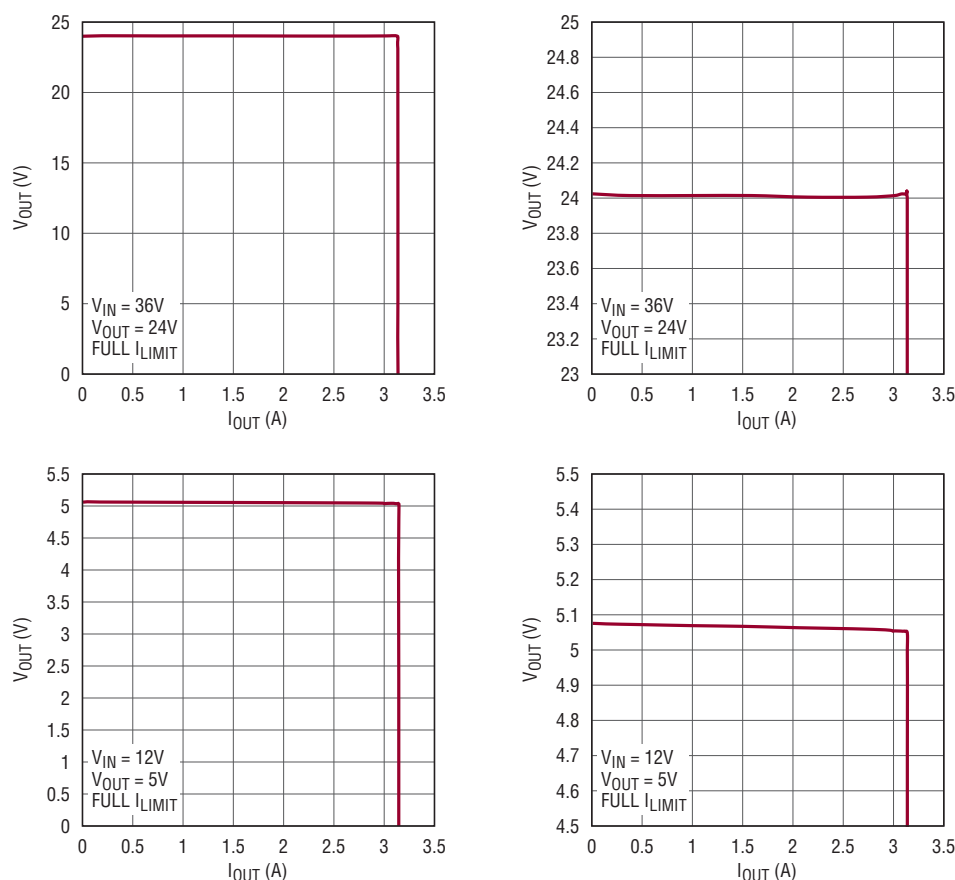
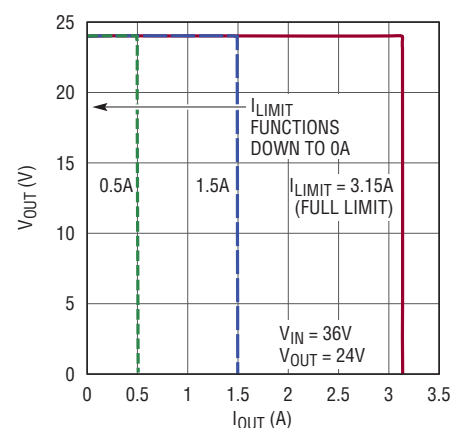


Figure 4. Adjustable current limit moves the cliff of Figure 3 to any value from 3.1A down to 0.0A.





The portable DC bench power supply can produce 0A–3A at any voltage between 0V and 24V from an input voltage of 10V and 40V, with the input at least 5V above the desired output voltage. The input can come from a front-end AC/DC converter, readily available at 19V, 28V and 36V. It can also be a simple 24VAC transformer, a rectifier bridge, and a 10mF capacitor that gives approximately 34V with 1V–2V of ripple.

the bench supply performs as desired, regardless where the current limit is set.

### SYNCHRONOUS STEP-DOWN CONVERTER KEEPS OVERALL EFFICIENCY HIGH

The portable DC bench power supply can produce 0A–3A at any voltage between 0V and 24V from an input voltage of 10V and 40V, with the input at least 5V above the desired output voltage. The input can come from a front-end AC/DC converter, readily available at 19V, 28V and 36V. It can also be a simple 24VAC transformer, a rectifier bridge, and a 10mF capacitor that gives approximately 34V with 1V–2V of ripple.

The LT8612 step-down switching converter portion of the power supply drops the AC/DC front-end voltage (10V to 40V) down to any voltage between 0V and just below its input voltage. The low ripple output of the LT8612-based converter is further dropped by 1.7V across the parallel LT3081 linear regulator to the final regulated voltage, with nearly no ripple on the output.

### High Efficiency Keeps it Cool

The LT8612 synchronous step-down easily supports 3A and efficiently steps down to outputs as low as 1.7V from inputs up to 40V, even at a relatively high switching frequency, 700kHz, due to low minimum on-time of 40ns. Efficiency is shown in

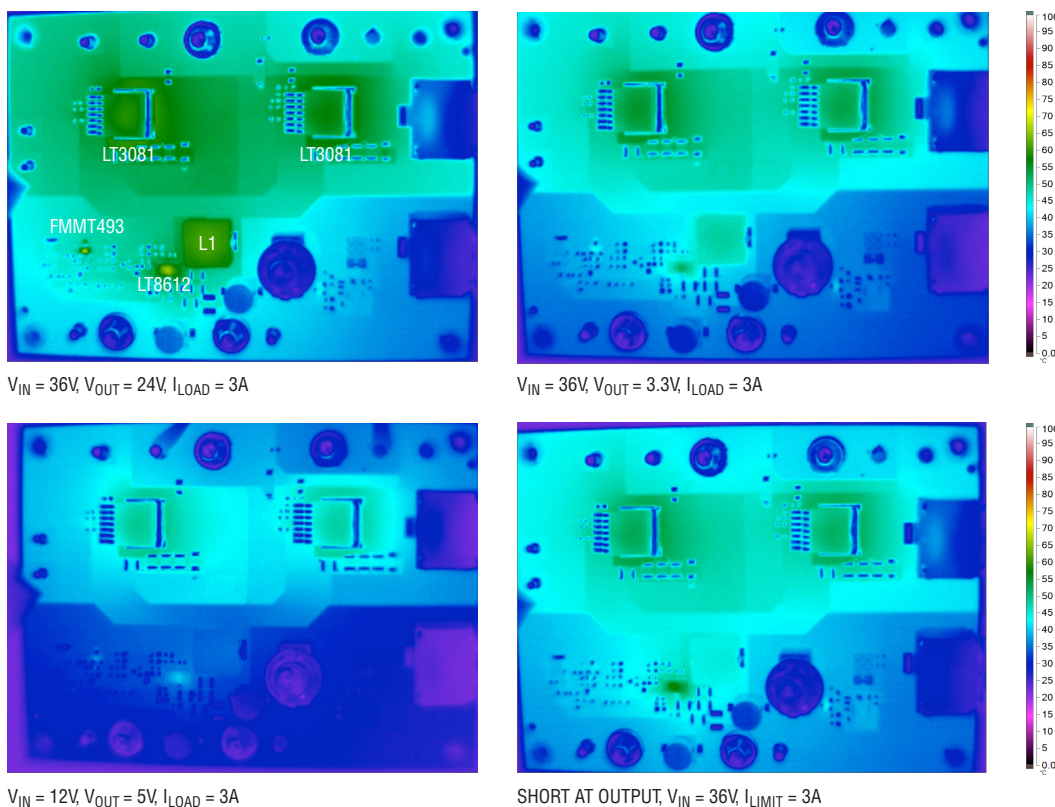
Figure 6. High efficiency at high switching frequency makes it possible to realize a converter with a few small components that remain cool at high power.

### Differential Feedback

The LT8612 uses a differential feedback scheme, shown in Figures 1 and 2, to regulate its output (the input to the LT3081 pair) to 1.7V above the bench supply output (the output of the LT3081 pair). The LT3081 works best when its input is at least 1.5V above its output, with 1.7V used here as margin for transients.

Differential feedback continues to operate during output transients and

Figure 5. Thermoscans of bench supply in high power conditions and short-circuit show that the DC bench supply components remain cool without the use of a heat sink or fan.



One way to combat current drift is to use a higher current source to drive the SET pin potentiometer. The LT3092 is an accurate current source that works up to 40V and is used to drive an accurate 2.4mA for a 24V output with a 10k resistor. Its output current is easy to adjust with the change of the set resistor value when a different maximum output voltage is needed.

short-circuits, as shown in Figures 7 and 8. When the output is shorted to GND, the LT8612 output follows it to GND. When the output is suddenly increased with a release of the short or a change in the potentiometer, the LT8612 follows the rising output of the LT3081, striving to stay 1.7V above the quickly changing output. A reasonable-sized 100 $\mu$ F output capacitor is enough to provide stability to the LT8612 over a wide range of conditions, while maintaining relatively fast transient response, though it will never move as fast as the linear regulators can.

This setup could be expanded to support 4.5A output current using three parallel LT3081 linear regulators. The switching regulator would need no change, as the LT8612 features 6A peak switch current capability.

### ACCURATE CURRENT SOURCE COMBATS $I_{SET}$ TEMPERATURE COEFFICIENT

The output voltage of the bench supply is easily adjusted by hand with a potentiometer that is connected to the SET pins of the LT3081 pair. It seems simple enough that the SET pins each source 50 $\mu$ A, and that their sum current, multiplied by an adjustable resistor, can generate the proper output voltage with no additional components. Nevertheless, that current may not be enough for a robust bench power supply solution, since it can drift a bit with LT3081 temperature.

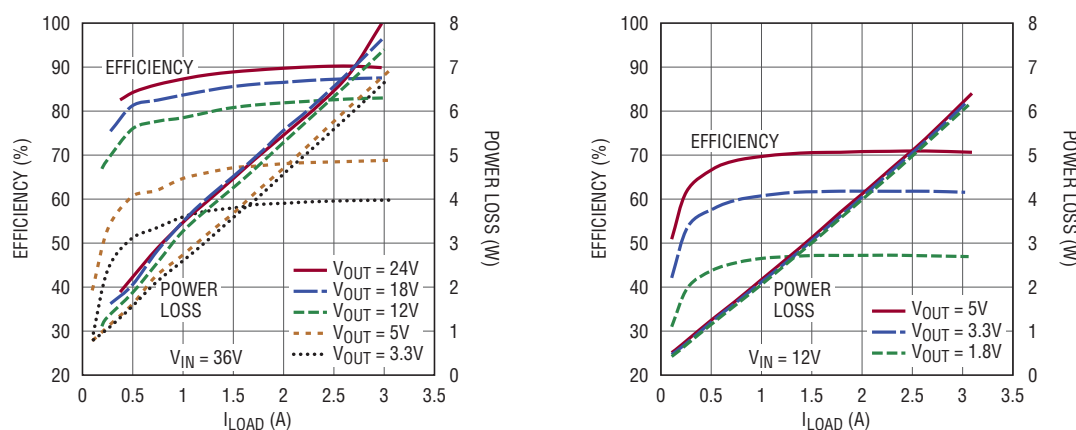
One way to combat the current drift is to use a higher current source to drive the SET pin potentiometer. The LT3092 is an accurate current source that works up to 40V and is used to drive an accurate 2.4mA for a 24V output with a 10k resistor. Its output current is easy to adjust with the change of the set resistor value when a different maximum output voltage is needed. The maximum output

voltage should be 5.5V when a 12V source is used, 15V when a 24V source is used and 24V when a 36V source is used. An input switch is used in the circuit to cut off the supply to the LT3092 when the power switch is turned off. Disconnecting this IC from  $V_{IN}$  when the switch is turned off prevents its constant current from charging up an unloaded bench supply output, saving engineers from potentially damaging circumstances.

### EASY TURN POTENTIOMETER KNOBS FOR VOLTAGE AND CURRENT

The LT3081 SET and ILIM pin functions make it easy to program the output voltage and current to any level with the simple turn of a potentiometer. Parallel LT3081s share the same SET pin connection and voltage as well as the same ILIM<sup>+</sup> and ILIM<sup>-</sup> pin connections. The 10k and 5k potentiometers are chosen to give 0V to 24V and 0A to 3A output ranges (or slightly above for a little headroom.) The potentiometers are easy to source

Figure 6. Efficiency and power loss of DC bench supply for a various input and output conditions



The bench supply shown features single-turn potentiometers with easy-to-turn shafts and right angle PCB connections. The cermet element prevents time and temperature drift with 150ppm/°C rating versus the 1000ppm/°C rating of similar plastic element versions. Less expensive plastic potentiometers are still excellent for use on a standard bench supply, or ten-turn precision potentiometers can be used for very fine trimming of both voltage and current limits.

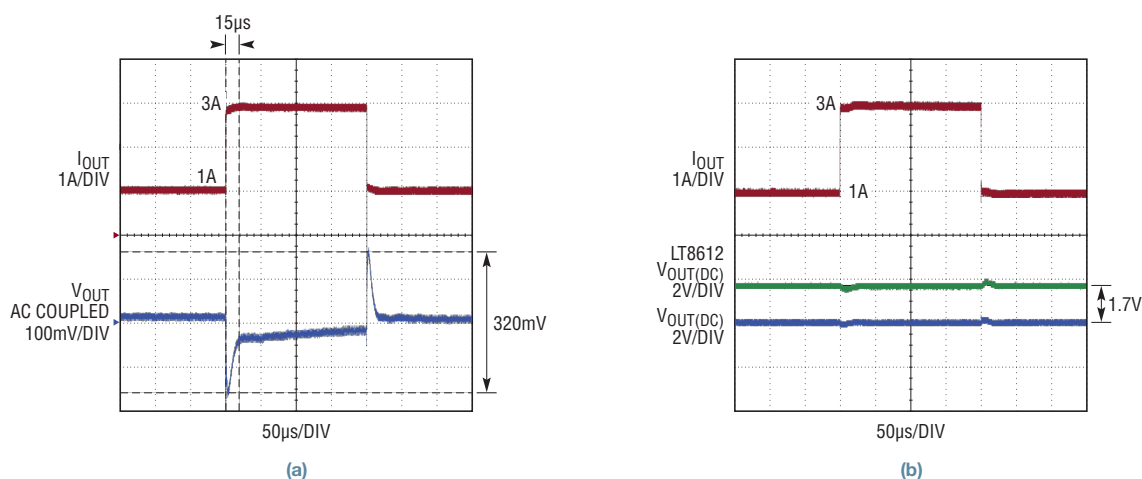


Figure 7. 5V, 1A to 3A output transient response shows (a) low output ripple and (b) LT8612 output tracks LT3081  $V_{OUT}$  through a transient.

and they can be selected from a range of performance and cost parameters.

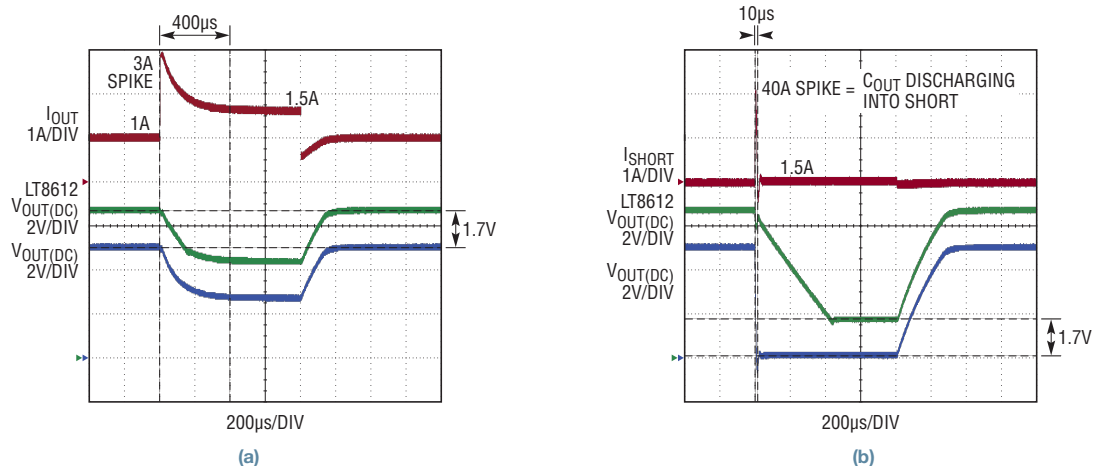
The bench supply shown in the photo on page 12 features single-turn potentiometers with easy-to-turn shafts and right angle PCB connections. They can be mounted on a side hole of a box should you decide to enclose the

PCB in a protective case. The cermet element prevents time and temperature drift with 150ppm/°C rating versus the 1000ppm/°C rating of similar plastic element versions. Less expensive plastic potentiometers are still excellent for use on a standard bench supply, or ten-turn precision potentiometers

can be used for very fine trimming of both voltage and current limits.

If  $V_{OUT}$  drift due to  $I_{SET}$  temperature coefficient is not an issue, the LT3092 current source can be removed and the 10k potentiometer can be replaced by a 250k pot with similar quality.

Figure 8. 5V output (a) overload transient and (b) short-circuit transient are well tolerated by the DC bench supply.



The most extreme overload condition is a short-circuit, which not only pushes the output over the cliff, but all the way down to ground. The bench supply gracefully maintains its current limit in short-circuit and regulates its LT8612 output to 1.7V, sourcing the limited current through the LT3081 and into the short.

### NEGATIVE CONVERTER FOR 0V REGULATION

Although it is trivial to turn the SET potentiometer down to 0V with a short to GND, the LT3081 must have 4mA pulled out of it to run down to 0V. A resistive preload from  $V_{OUT}$  to GND only pulls current when  $V_{OUT}$  is not equal to zero, so a negative supply is used instead to sink current from a 0V output. The LTC3632 negative regulator is a small -5V source that draws -8mA through a small resistor across -5V and a  $V_{BE}$  below ground (-0.6V). Although the LTC3632 turns off when the power switch is turned off, it continues to run when the power is on even when the output voltage is higher than 0V. Caution must be used when choosing the negative current transistor since  $-8mA \cdot 24.6V$  drop can be a significant source of heat if the thermal impedance of the transistor is more than  $250^{\circ}C/W$  or the negative current is increased to over -10mA.

### SHORT-CIRCUIT AND 0A CONTROL

The LT3081 also provides 0A current limit control regardless of the output voltage setting. With its current knob turned all the way up, the bench supply enforces a sharp current limit at just about 3.1A. If the load is increased above this point, its voltage appears to fall off a cliff. A simple turn of the knob moves that sharp current limit cliff down to any other value all the way to 0A, as shown in Figure 4.

The most extreme overload condition is a short-circuit, which not only pushes the output over the cliff, but all the way down to ground. The bench supply gracefully maintains its current limit in short-circuit and regulates its LT8612 output to 1.7V, sourcing the limited current through the LT3081 and into the short.

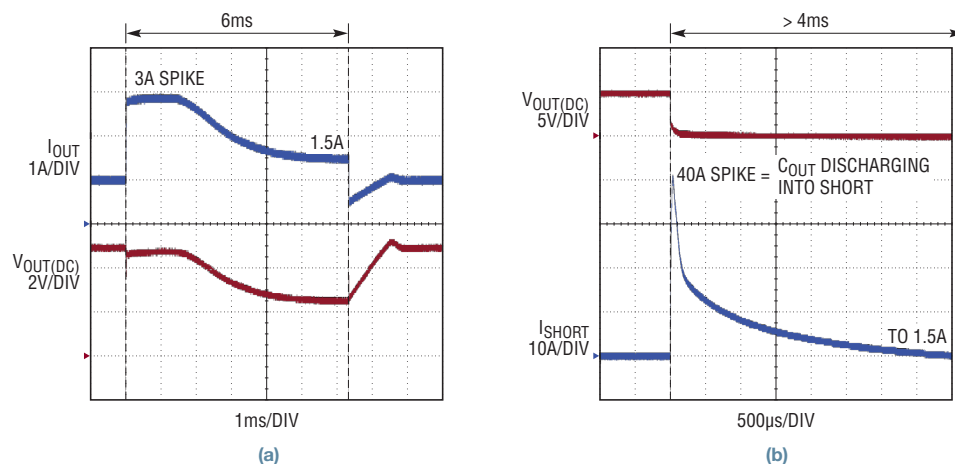
The results of a transient short-circuit are shown in Figure 8, demonstrating the short-circuit regulation of the IC and the

short-lived output capacitor discharge spike. The  $< 10\mu s$  short-circuit spike is 1/500 the duration of a commonly used high power mixed-mode laboratory bench supply (with similar settings) as shown in Figure 9. The long-lasting discharge spike shown in Figure 9 can potentially harm test equipment, a disadvantage of expensive, commonly used universal bench supplies, due to low power transistor speed and/or higher output capacitance.

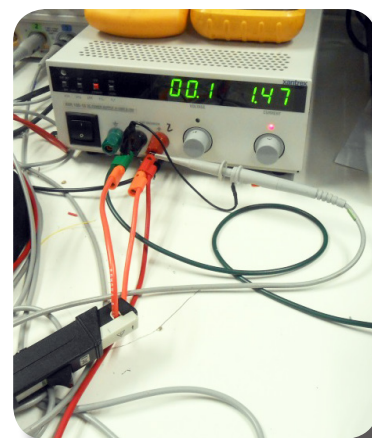
### MONITORING THE OUTPUT

Connect a multimeter or a simple analog display to the output to produce an accurate voltage readout. Add another multimeter or display in series with the output for an accurate current readout. If you want to avoid adding additional sensing equipment in series with the output, the IMON terminal can also be used as a voltage-to-current conversion.

Figure 9. Transient results for pricey XH100-10 mixed-mode bench supply, which exhibits slow transient and short-circuit response compared with the DC bench supply described in this article with similar settings (Figure 8).



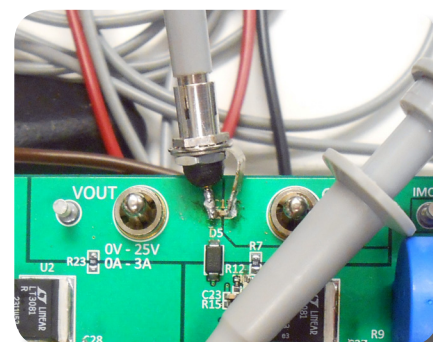
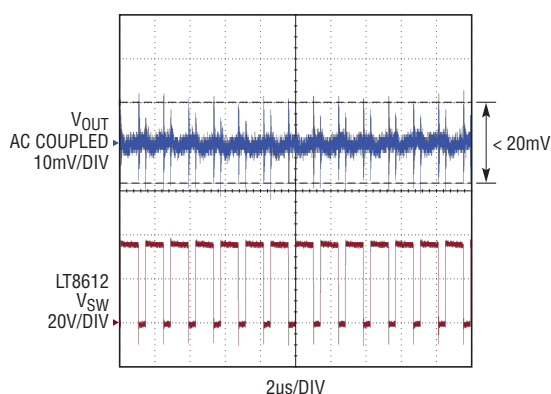
Sorenson XHR100-10 laboratory bench supply in short-circuit with 1.5A limit





This DC power supply is a handy tool for generating a constant voltage or current on-the-fly in the lab. Simply power it up with 10V–40V DC, turn on the switch, and turn the knobs. Since they are small and inexpensive, several of these portable bench supplies can be powered from the same DC input source when multiple circuit outputs and currents are needed.

Figure 10. DC bench supply has low output ripple for a mixed-mode supply with small 60 $\mu$ F C<sub>OUT</sub>.



## AC/DC INPUT

This DC power supply is a handy tool for generating a constant voltage or current on-the-fly in the lab. Simply power it up with 10V–40V DC, turn on the switch, and turn the knobs. Since they are small and inexpensive, several of these portable bench supplies can be powered from the same DC input source when multiple circuit outputs and currents are needed.

It's just easy to create a completely self-contained bench supply by adding a simple AC/DC converter on the front end. Figure 11 shows a simple 120V<sub>AC</sub> to 24V<sub>AC</sub> (5:1) transformer, a rectifier bridge and a 10mF output capacitor, which combine to produce 34V<sub>DC</sub> with little ripple. This simple AC/DC converter can be used to produce a maximum bench supply output of 22V.

The rectifier bridge should have 3A or higher rated Schottky diodes. If they run too hot, you can still avoid adding a heat sink by replacing the Schottkys with an LT4320 ideal diode bridge controller and four MOSFETs to reduce bridge heating. The size of the 10mF output cap can be changed to adjust for output ripple. At full power, 10mF cap will produce about  $\pm 1$ V ripple on the 34V DC input.

You can also piece together a universal bench supply by connecting any universal AC/DC black box converter with a 12V–36V, 3A rating. Any AC/DC converter lifted from an old laptop or purchased from an electronics retailer should work. The only restriction is that the maximum output voltage of the bench supply should remain about 5V below the minimum rating of the input voltage source.

## CONCLUSION

Build your own high performance DC bench supply for 0V–24V and 0A–3A constant voltage and current control using a couple parallel LT3081 linear regulators, a synchronous step-down LT8612, an LT3092 current source and a tiny LTC3632 negative supply. The bench supply features low output ripple with low output capacitance, excellent transient response, regulates to 0V and 0A, remains in regulation during short-circuit and stays cool with no bulky heat sinks. It can easily be coupled with an AC/DC converter or it can be powered from a DC source. The complete bench supply solution is low cost, small in size, and easy to build, despite its top shelf performance. ■

Figure 11. Simple combination of a 24V<sub>AC(RMS)</sub> transformer, rectifier bridge, and capacitor provides AC/DC 34V front-end for a complete solution.

