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New Linear Regulators Solve Old Problems

Bob Dobkin

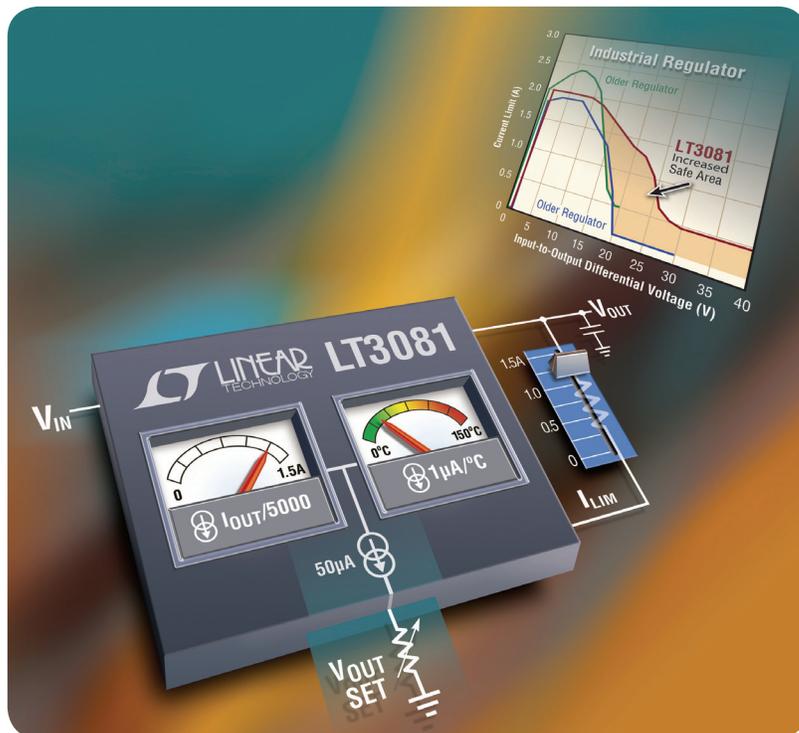
The architecture of linear regulators has remained virtually unchanged since the introduction of the 3-terminal floating voltage regulator in 1976. Architectures have settled on either the floating architecture (LT317) or an amplifier loop with feedback from the output to the amplifier. These architectures inherently limit regulator versatility, regulation and accuracy. In 2007, Linear Technology released the LT[®]3080, introducing a new linear regulator

architecture that expanded versatility, significantly improved performance, and allowed easy parallel operation. The LT3081 is one of this new class of linear regulator, specifically featuring a wide safe operating area for industrial applications.

THE OLD WAY

In the old linear regulator architecture (Figure 1), feedback resistors set the output voltage and attenuate the feedback signal into the amplifier. In this scheme, regulation accuracy at the output is a function of the percentage of the output voltage, so absolute regulation accuracy (in volts) degrades as output voltage increases, even though percentage accuracy is maintained. The bandwidth of the regulator also changes with voltage—as the loop gain is decreased, the bandwidth decreases at higher output voltages, resulting in relatively slow transient response and high ripple.

(continued on page 4)



The LT3081 is one of a new breed of linear regulator, specifically featuring a wide safe operating area for industrial applications.

The LT3081 is an industrial regulator with a wide safe operating area (SOA). It provides 1.5A of output current, is adjustable to zero output voltage, is reverse protected and has monitor outputs for temperature and output current. Furthermore, the current limit can be adjusted by connecting an external resistor to the device.

(LT3081 continued from page 1)

Furthermore, in the architecture shown in Figure 1, current limiting is fixed in the IC, requiring alternative devices or different output currents. An additional external circuit is required to match the current limit to an application or if accurate current limit is needed.

THE NEW WAY

In 2007, Linear Technology released the LT3080, introducing a new linear regulator architecture featuring a current source as reference and a voltage follower for the output amplifier (Figure 2). This new architecture has a number of advantages, including easy regulator paralleling for increased output current and operation down to zero output voltage. Since the output amplifier always operates at unity gain, bandwidth and absolute regulation are constant across the output voltage range. Transient response is independent of output voltage and regulation can be specified in millivolts rather than as a percent of output.

Table 1 shows the family of regulators based on this architecture and their main features. Along with different output current variations, these regulators are specifically designed to add functional features not previously available in linear regulators. There are monitor outputs for temperature, current and external control of current limit. One device (LT3086) also has external control of thermal shutdown. A new negative regulator provides monitoring and can operate as a floating regulator or an LDO. All of these new regulators can be paralleled to

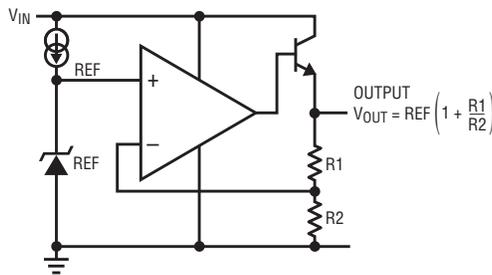


Figure 1. The traditional linear regulator architecture suffers from limitations on versatility, regulation and accuracy.

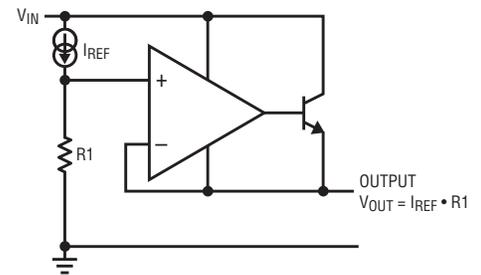


Figure 2. The new linear regulator architecture features a precision current source reference. This improves regulation and transient response over the old architecture. Output voltages down to zero are now possible. Paralleling for greater output current and user-defined current limiting are now easy.

increase current capability, provide balanced current sharing, and spread heat.

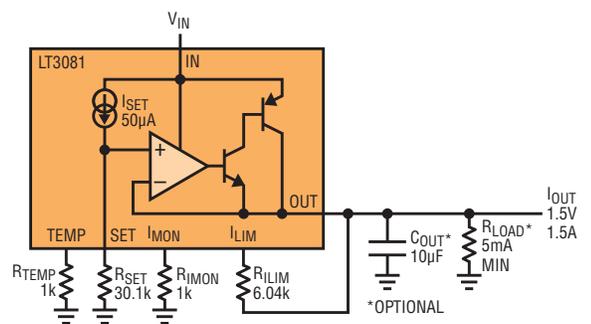
THE LT3081 INDUSTRIAL REGULATOR WITH WIDE SAFE OPERATING AREA

The LT3081 is an industrial regulator with a wide safe operating area (SOA). It provides 1.5A of output current, is adjustable to zero output voltage, is reverse protected and has monitor outputs for temperature and output current. Furthermore, the current limit can be adjusted by connecting an external resistor to the device. Figure 3 shows the basic hookup for the LT3081.

Temperature and Current Monitor Outputs

Temperature and current monitor outputs are current sources configured to operate from 0.4V above V_{OUT} to 40V below V_{OUT} . Temperature output is $1\mu\text{A}/^\circ\text{C}$ per degree and the current monitor is $I_{OUT}/5,000$. These current sources are measured by tying a resistor to ground in series with the current source and reading across the resistor. The current sources must continue to work even if the output is shorted. The dynamic range for the monitor outputs is 400mV above the output so, with the output shorted

Figure 3. Basic regulator using the LT3081



The benefit of using an internal true current source as the reference, rather than a bootstrapped reference, as in prior regulators, is not obvious. A true reference current source allows the regulator to have gain and frequency response independent of the impedance on the positive input.

or set to zero, temperature and current can still be measured. Using a 1k resistor provides sufficient margin and ensures operation when the output is shorted.

One Resistor Sets the Output Voltage

The output is set with a resistor from the SET pin to ground and a 50 μ A precision current source set to the output. The internal follower amplifier forces the output voltage to be the same voltage as the SET pin. Unique to the LT3081, an output capacitor is optional. The regulator is stable with or without input and output capacitors. All the internal operating current flows through the output pin and minimum load is required to maintain regulation. Here, a 5mA load is required at all output voltages to maintain the device in full regulation.

The set resistor can add to the system temperature drift. Commercially available surface mount resistors have a wide range of temperature coefficients.

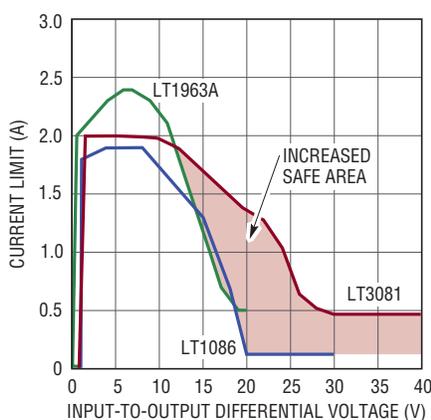


Figure 4. Comparative safe operating area performance

Depending on the manufacturer, these can go from 100ppm up to over 500ppm. While the resistor is not heated by power dissipation in the regulator, over a wide ambient temperature range its temperature coefficient can change the output by one to four percent. Lower temperature coefficient thin film resistors are available for precision applications.

Benefits of Internal Current Source as Reference

The benefit of using an internal true current source as the reference, rather than a bootstrapped reference, as in prior regulators, is not obvious. A true reference current source enables the regulator to have gain and frequency response independent of the impedance on the positive input. With all previous adjustable regulators, such as the LT1086, loop gain and bandwidth change with variations in output voltage. If the adjustment pin is bypassed to ground, bandwidth also changes. For the LT3081, the loop gain is unchanged with output voltage or bypassing. Output regulation is not a fixed percentage of output voltage, but is a fixed number of millivolts. Use of a true current source allows all of the gain in the buffer amplifier to provide regulation, and none of that gain is needed to amplify the reference to a higher output voltage.

Table 1. Linear regulators featuring updated architecture

DEVICE	OUTPUT CURRENT	I _{SET}	ADJUSTABLE CURRENT LIMIT/CURRENT MONITOR	TEMPERATURE MONITOR	LDO	COMMENTS
LT3080	1.1A	10 μ A	No/No	No	Yes	
LT3081	1.5A	50 μ A	Yes/Yes	Yes	No	Output CAP Optional
LT3082	200mA	10 μ A	No/No	No	No	
LT3083	3A	50 μ A	No/No	No	Yes	
LT3085	600mA	10 μ A	No/No	No	Yes	
LT3086	2.1A		Yes/Yes	Yes + Temp Limit	Yes	
LT3090	600mA	-50 μ A	Yes/Yes	Yes	Yes	Negative Regulator
LT3092	200mA	10 μ A	No/No	No	No	Current Source Operation Needs No Output CAP

The LT3081 extends the safe operating area, offering nearly 1A of output current at 25V of differential. Even above 25V, 500mA is still available. This allows the regulator to be used in applications where widely varying input voltages can be applied during operation.

Wide Safe Operating Area

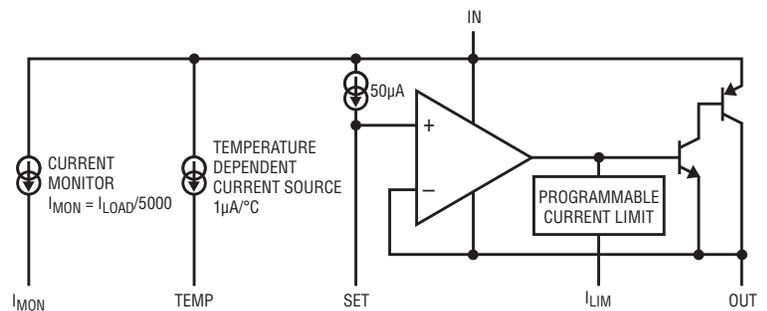
Industrial applications require a wide safe operating area. Safe operating area (SOA) is the ability to carry large currents at high input-output differentials. The safe operating area for several regulators is compared in Figure 4.

The LT1086, introduced in the mid-1980s, is a 1.5A regulator in which output current drops very low above 20V input/output differential. Above 20V only about 100mA of output current is available. This causes output voltage to go unregulated if the load current is above 100mA and transients on the input cause the high voltage current limit to be exceeded. The LT1963A is a low dropout regulator that also has a limited safe operating area.

The LT3081 extends the safe operating area, offering nearly 1A of output current at 25V of differential. Even above 25V, 500mA is still available. This allows the regulator to be used in applications where widely varying input voltages can be applied during operation. Wide operating safe area is obtained by using a large structure for the PNP pass device. Also, the LT3081 is protected (along with the load) for reverse input voltage.

Figure 5 shows a block diagram of the LT3081. There are three current sources: two that report output current and temperature and a third that supplies the 50µA reference current. The LT3081, while not a low dropout regulator, operates down to 1.2V across the device — slightly better than older devices such as the LT1086.

Figure 5. Block diagram of the LT3081



No Input or Output Capacitors Needed

The internal amplifier configuration, in conjunction with well regulated internal bias supplies, allows the LT3081 to be stable with no external capacitors. One caveat: it cannot be designed to tolerate all possible impedances in the input and load, so it is important to test the stability in the actual system used. If instability is found, external capacitors will ensure that the device is stable at all output currents. External capacitors also improve the transient response since it is no longer limited by the bandwidth of the internal amplifier.

Paralleling Devices for More Current

Paralleling devices—typically forbidden with prior regulators since they do not share current—is easy with these new current source reference regulators. Paralleling is useful for increasing output current or spreading the heat. Since it is set up as a voltage follower, tying all the SET pins together makes the outputs the same voltage. If the outputs are at the same voltage, only a few milliohms of ballast are needed to allow them to share current.

Figure 6 shows a distribution of the offset voltage for the LT3081. The distribution is within 1mV so ensuring 10% sharing requires no more than 10mΩ of ballast resistance. The ballast resistor can be less than an inch of a trace on a PC board or a small piece of wire, and provides good current balance from parallel devices. Even at 1V output, this degrades the regulation by only about 1.5%. Table 2 shows PC board resistance.

Figure 7 shows a schematic of two LT3081s paralleled to obtain 3A output. The set resistor now has twice the set current flowing through it, so the

Figure 6. Offset voltage distribution

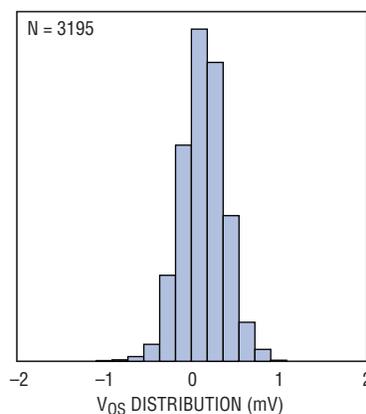


Table 2. PC board trace resistance

WEIGHT (oz)	10MIL WIDTH	20MIL WIDTH
1	54.3	27.1
2	27.1	13.6

Trace resistance is measured in mΩ/in.

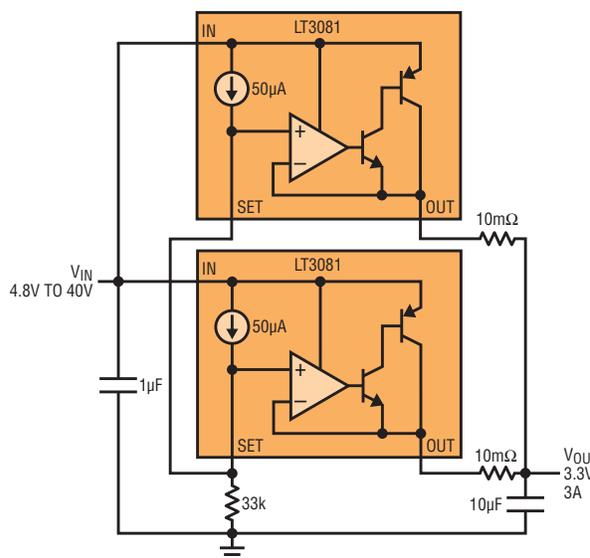
output is $100\mu\text{A}$ times R_{SET} and the $10\text{m}\Omega$ output resistors ensure ballasting at full current. Any number of devices can be paralleled for higher current. The I pins can be paralleled (if used) so one resistor sets the current limit.

Figure 8 shows the LT3081 paralleled with a fixed regulator. This is useful when a system that has been designed has insufficient output current available. It provides a quick fix for higher output current. The output voltage of the fixed device is divided down by just a few millivolts by the divider. The SET pin of the LT3081 is tied about 4mV below the fixed output. This ensures no current flows from the LT3081 under a no-load condition. Then the $20\text{m}\Omega$ resistors provide sufficient ballast to overcome this offset and ensure current matching at higher output currents.

LAYOUT CONSIDERATIONS

With the $50\mu\text{A}$ current source used to generate the reference voltage, leakage paths to or from the SET pin can create errors in the reference and

Figure 7. Paralleling devices

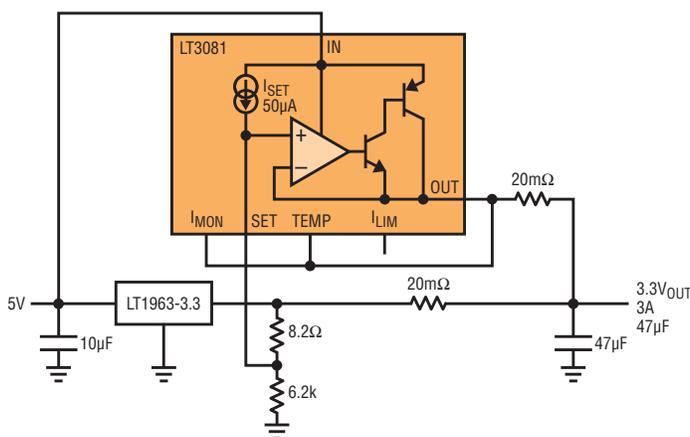


output voltages. Cleaning of all insulating surfaces to remove fluxes and other residues is required. Surface coating may be necessary to provide a moisture barrier in high humidity environments. Minimize board leakage by encircling the SET pin and circuitry with a guard ring tied to the OUT pin. Increasing the set current as shown also decreases the effects of spurious leakages.

The low $50\mu\text{A}$ SET current can cause problems in some applications. High value film potentiometers are not as stable as lower value wire wounds. Board leakage can also introduce instabilities in the output. Problems can be minimized by increasing the set current above the nominal $50\mu\text{A}$.

Figure 9 shows a solution using lower value set resistors. Here an increased current is generated through R_2 and summed with the SET pin current, giving a much larger current for adjusting the output. SET current flows through a 4k resistor, generating 200mV across R_1 . Then the current through R_2 adds to the SET current, giving a total of 1.05mA flowing through I_{SET} to ground. This makes the voltage less sensitive to leakage currents around R_{SET} . Care should be taken to Kelvin connect R_2 directly to the output. Voltage drops from the output to R_2 affect regulation.

Figure 8. Increasing the output current of a fixed regulator



The LT3081 is one of a new family of linear regulators that yields an order-of-magnitude better regulation against load and line changes compared to traditional devices. Regulation and transient response, measured in millivolts, are now maintained regardless of output voltage.

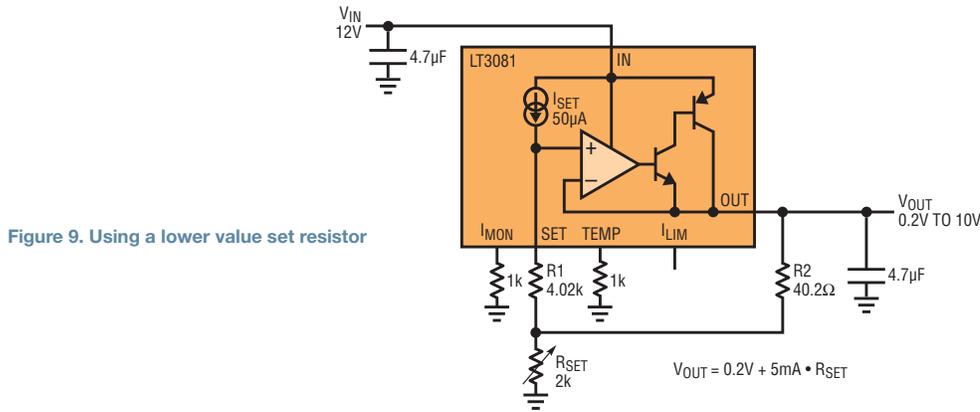


Figure 9. Using a lower value set resistor

Another configuration uses an LT3092 as an external current source of 1mA. This provides increased set current and allows the output to be adjusted down to zero. Figure 10 shows an LT3092 current source used to provide the current reference to an LT3081. The 1mA generated reference current allows the adjustment set resistor to be much lower in value while enabling the device to be adjusted down to zero.

The current monitor output can be used to compensate for line drops, as shown in Figure 11. Feeding the current monitor through a portion of the set resistor generates a voltage at the SET pin that raises the output as a function of current. The value of the comp resistor is $R_2 = 5000 \cdot R_{CABLE(TOTAL)}$ and $V_{OUT} = 50\mu A \cdot (R_{SET} + R_{COMP})$. Several volts of line drop can be compensated this way.

Figure 10. Using an external reference current

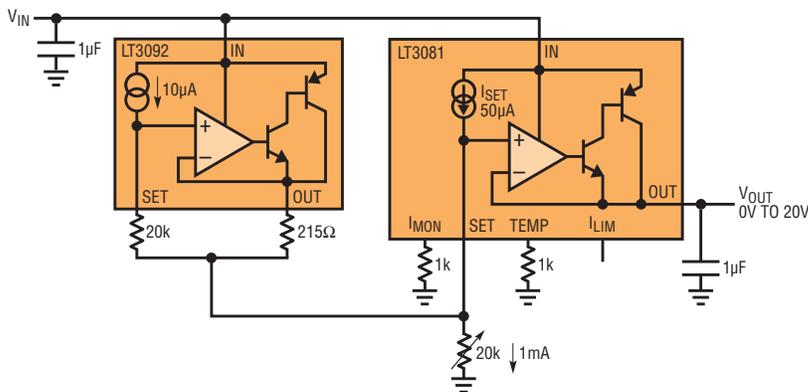
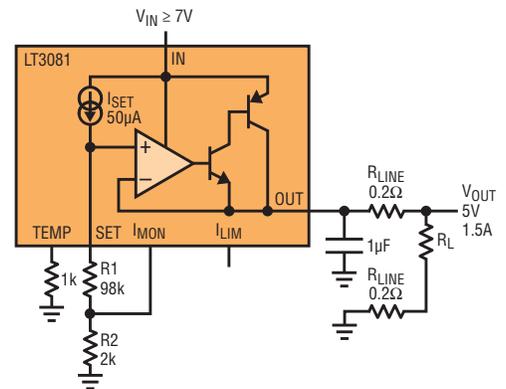


Figure 11. Using current monitor output to compensate for line drops



CONCLUSION

The LT3081 is one of a new family of linear regulators that yields an order-of-magnitude better regulation against load and line changes compared to traditional devices. Regulation and transient response, measured in millivolts, are now maintained regardless of output voltage.

These new regulators are far more robust and versatile than previous generations, offering features that were previously unavailable. Temperature and current monitoring and adjustable current limiting are now added. Paralleling these new regulators no longer requires external current balance circuitry to prevent current hogging. Line drops can be easily compensated. Current limit thresholds are now user-defined, as opposed to fixed in the regulator, and outputs are adjustable to zero. The LT3801, in particular, features a wide safe operating area to support load currents in the face of wide input swings. ■