Tiny, Resistor-Programmable, µPower 0.4V to 18V Voltage Reference

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Introduction

The LT6650 is a 0.4V to 18V adjustable voltage reference that runs from low voltage and consumes only a few microamps. It features a low-dropout (LDO) characteristic, can source or sink current, can be configured in either series or shunt mode and saves space in the tiny 5-lead ThinSOT-23 package.

Figure 1 shows a block diagram of the reference. Its 400mV internal voltage reference is connected to the non-inverting input of an operational amplifier. The inverting input is brought to a pin, thus making a series-mode reference adjustable to any output voltage from 400mV up to (V_{SUPPLY} – 0.35V) by using two external resistors. It can also be configured as

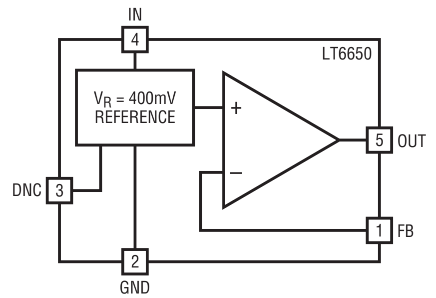

Figure 1. Block diagram of 1% accurate micropower 0.4V to 18V adjustable reference.

a fixed 400mV reference by simply connecting the output to the op amp inverting input. While the LT6650 is designed as a series reference, it can be used as a shunt-mode reference simply by shorting the positive rail to the output pin—it can be programmed to produce any precision "zener" voltage within the wide supply range (1.4V to 18V) by selection of the two external resistors.

Specifications

Table 1 summarizes the performance of the LT6650. The supply current is only 5.6µA and the supply voltage may range from 1.4V to 18V, which permits battery-powered equipment to be plugged into an unregulated wall adapter without the need for peripheral circuitry to limit the voltage input to the reference. The 400mV internal reference is ±1% accurate over the –40°C to 85°C temperature range and is also fully specified from –40°C to 125°C for extended temperature range

Table 1. LT6650 Performance (T_a = 25°C, V_{IN} = 5V, V_{OUT} = 400mV, C_L = 1µF, unless otherwise noted)

Parameter	Conditions	Min	Typ	Max	Units
Input Voltage Range	–40°C ≤ T_A ≤ 125°C	1.4		18	V
Output Voltage	–40°C ≤ T_A ≤ 85°C	396 –1	400	404 1	mV %
Line Regulation	1.4V ≤ V_{IN} ≤ 18V		1	6	mV
Load Regulation	0 to –200µA (Sourcing) 0 to 200µA (Sinking)		–0.04 0.24	–0.2 1	mV mV
Output Voltage Temperature Coefficient			12		µV/°C
Dropout Voltage	V_{OUT} = 1.4V I_{OUT} = 0µA I_{OUT} = 200µA sourcing		75	100 250	mV mV
Supply Current	1.4V ≤ V_{IN} ≤ 18V		5.6	12	µA
FB Pin Input Current	V_{FB} shorted to V_{OUT}		1.2	10	nA
Turn-On Time			0.5		ms
Output Voltage Noise	0.1Hz to 10Hz		20		$µV_{P–P}$
Thermal Hysteresis	–40°C to 85°C		100		µV

applications. The rail-to-rail output delivers 200µA in both sourcing and sinking modes of operation.

How it Works Inside

Figure 2 shows the simplified schematic of the reference. Transistors Q1–Q7 form the band-gap-derived 400mV reference that is fed to the non-inverting input of the error amplifier formed by Q8–Q12. The resistors R1–R3 set the correct current flow into the internal reference, while R4 provides for post-package trimming capability. Transistors Q20 and Q21 form the rail-to-rail output stage and are driven by Q13–Q19. Resistors R5–R8 and the I_2 current generator establish the gain and quiescent operating current of the output stage. In conjunction with the minimum recommended output capacitance of 1µF, stabilization is assured through Miller compensation inside error amplifier Q8–Q12. Pins are ESD protected by diodes D1–D3.

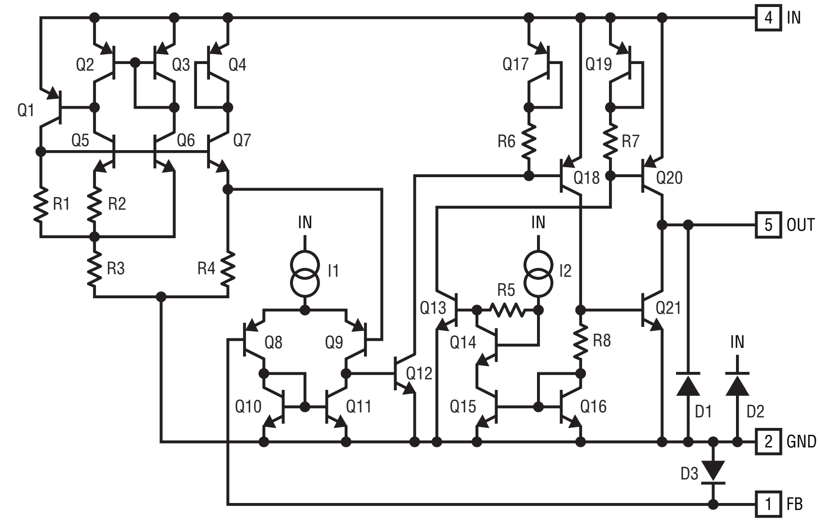

Figure 2. LT6650 simplified schematic showing detail of low-dropout topology

Applications

Battery Powered Pocket Reference

The unique pocket reference shown in Figure 3 can operate for years on a pair of AAA alkaline cells or a single Lithium coin-cell, as the circuit draws just 10µA supply current. An input capacitor of 1µF as shown should be used when the LT6650 is operated from small batteries or other sources with impedance over about 50Ω. The output is adjustable from 0.4V up to the battery supply by selecting two feedback resistors (or setting a trimmer potentiometer position) to configure the non-inverting gain of the internal operational amplifier. A feedback resistor R_F is connected between the OUT pin and the FB pin and a gain resistor R_G is connected from the FB pin to GND. The resistor values are related to the output voltage by the following relationship:

$$R_F = 2.5 \bullet (V_{OUT} - 0.4) \bullet R_G$$

The worst-case FB pin bias current (I_{BIAS}) can be neglected with an R_G of 100kΩ or less. In ultra-low-power applications where current in the voltage programming resistors might be reduced to where the 1.2nA typical I_{BIAS} becomes relatively significant loading, the relationship between the resistors then becomes:

$$R_F = R_G \bullet \frac{V_{OUT} - 0.4}{0.4 - \left(I_{BIAS} \bullet R_G\right)}$$

The minimum allowable gain resistor value is 2kΩ established by the 400mV FB pin voltage divided by the maximum guaranteed 200µA output current sourcing capability. In applications that scale the reference voltage, intrinsic noise is amplified along with the DC level. To minimize noise amplification, a 1nF feedback capacitor (C_N) as shown in Figure 3 is recommended. Any net load capacitance of 1µF or higher assures amplifier stability.

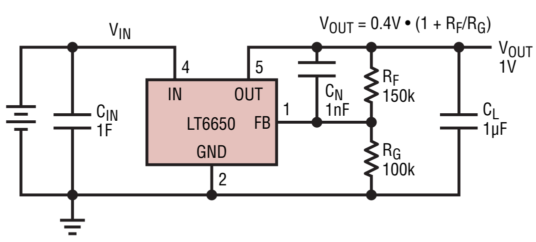

Figure 3. Battery powered pocket voltage reference runs for years on a coin cell.

Automotive Reference

In the presence of high supply noise, such as in automotive applications or DC-DC converters, an RC filter can be used on the V_{IN} input as shown in Figure 4. Due to the exceptionally low supply current of the LT6650, the input resistor (R_{IN}) of this filter can be 1kΩ or higher, depending on the difference in V_{IN} and V_{OUT}. Figure 5 shows supply rejection better than 30dB over a wide frequency spectrum, for a minimum sourcing output current of 40µA and an input filter comprising R_{IN} = 1kΩ and C_{IN} = 1µF. If even higher rejection is necessary, the input filter structure presented in Figure 6 effectively eliminates any supply transients

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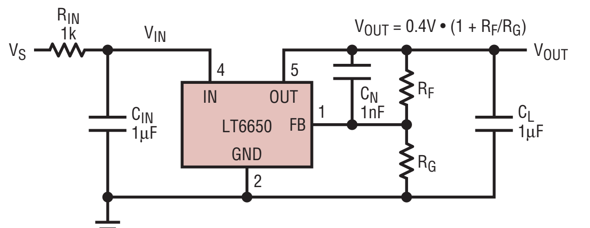

Figure 4. Simple input network for improved supply rejection

and lower their total solution cost. Smaller output capacitor values also speed up the changing of the output voltage when the CPU generates a different VID code.

Other Features

The LTC3738 has a differential amplifier for remote sensing of both the high and low sides of the output voltage. There is no reverse current during start-up, which allows the LTC3738 to power up into a pre-biased output without sinking current from the output. The LTC3738 also has a defeatable short-circuit shutdown timer. Three operation modes—PWM, pulse skip and Stage Shedding™—allow power supply designers to optimize for efficiency and noise.

Conclusion

LTC3738 is specifically designed to simplify power supply designs for Intel VRM9/VRM10 applications. It is a complete power supply solution with essenntial thermal management features, accurate load line control, precise output voltage sensing, and comprehensive fault protection.

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from affecting the output by the inclusion of a pre-regulating Zener diode. With this extra input decoupling and the LT6650 circuitry operating from a 12V bus, 50V transients induce less than 0.5% V_{OUT} perturbation.

To obtain the micropower performance of the LT6650, quiescent currents of the internal circuitry are minute, which by nature, results in a higher output impedance than traditional references. Since output impedance is inversely related to the output stage operating current, a modest additional load current can easily reduce the output impedance by an order of magnitude from the unloaded case. Thus in applications where the output impedance and noise must be minimized, a light DC loading of the output provides enhanced performance. This loading can exist naturally in the application, or the feedback resistors can be designed to provide it. For example, setting the gain resistor value to 10kΩ establishes a moderate I_{OUT} = –40µA and decreases the output peak resistance value from hundreds of ohms to the tens of ohms shown in Figure 7.

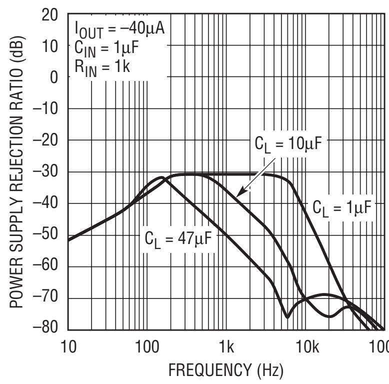

Figure 5. Improved supply noise rejection of Figure 4 reference circuit

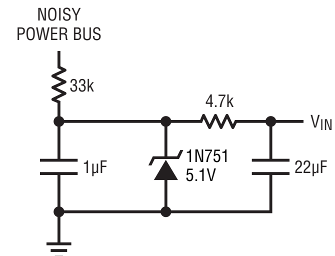

Figure 6. High noise-immunity input network allows 50V transients on automotive power bus.

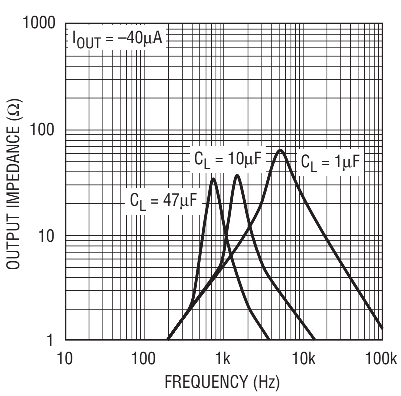

Figure 7. Output impedance is reduced while sourcing moderate current (40µA).

Shunt-Mode Reference

When the output voltage is tied to the input voltage, the high side of the rail-to-rail buffer amplifier is effectively disabled and only the low side remains active. In this mode of operation the LT6650 operates as a shunt reference as shown in Figure 8. Any shunt reference voltage from ±1.4V up to ±18V can be established by the feedback resistor selection. The noise and load capacitors have the same functions as in the series mode of operation. A 10µF minimum load capacitance is recommended for best stability and transient response. In shunt mode, an external biasing resistor R_B is connected from the power supply to the output, and delivers all the current required for supplying the LT6650 and the load current. R_B is selected to ensure the operating current of the reference (I_Z in the Figure 8 zener-diode analogy) is in the range of 30µA to 220µA under all loading conditions.

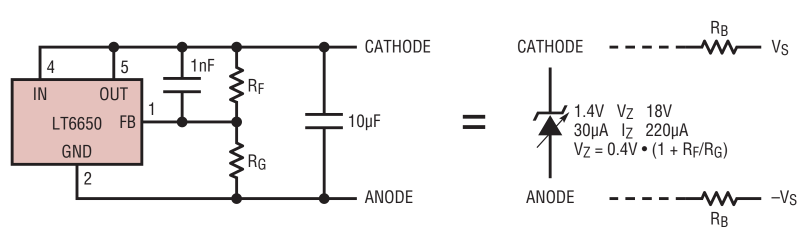

Figure 8. Create you own adjustable micropower "zener" 2-terminal reference.

Conclusion

The LT6650 voltage reference incorporates a unique blend of low voltage, micropower operation and functional versatility. With the additional features of series and shunt mode configurability, source and sink output current, wide output voltage range, adjustability, and a tiny ThinSOT-23 package, the LT6650 provides an excellent solution to the many design challenges in both portable and industrial voltage control.