AN766

Pin-Compatible CMOS Upgrades to Bipolar LDOs

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INTRODUCTION

Bipolar low dropout regulators (LDOs) have become common place in a variety of portable applications, such as cell phones, pagers and PDAs. Their popularity stems from small packaging, high output current capability and precision output voltage specifications. However, the bipolar process technology from which these devices are fabricated brings inherent disadvantages, such as excessive supply current. This application note outlines the advantages of small geometry CMOS LDOs over bipolar LDOs and provides comparative test data of key regulator specifications for a popular pin-compatible bipolar LDO over Microchip's CMOS LDOs.

SUPPLY CURRENT: CMOS VS. BIPOLAR

Figure 1(A) and Figure 1(B) compare the block diagram for a common bipolar regulator with that of an equivalent regulator fabricated in CMOS. The supply current to the bipolar device is composed of the bias current, plus a "ground current" (I_{GND}) component shown in Figure 1(A). This is a fraction of the output current (determined by the h_{FE} of the pass transistor) sunk through the output stage of the error amplifier. The "ground current" component of the CMOS regulator shown in Figure 1(B) is virtually zero, due to the extremely large drain-to-gate impedance of the CMOS pass transistor.

Another bipolar LDO pitfall occurs when a battery supplies V_{IN} and approaches a "low" condition. If the battery voltage is just below the level required to satisfy the minimum dropout voltage, the bipolar LDO responds by driving its PNP pass transistor as hard as possible in a fruitless attempt to restore V_{OUT} within regulation. This action causes a substantial increase in ground current, driving it as high as several milliamps. In turn, this causes an even greater load on the battery and further depresses battery voltage. This continues until the battery is exhausted.

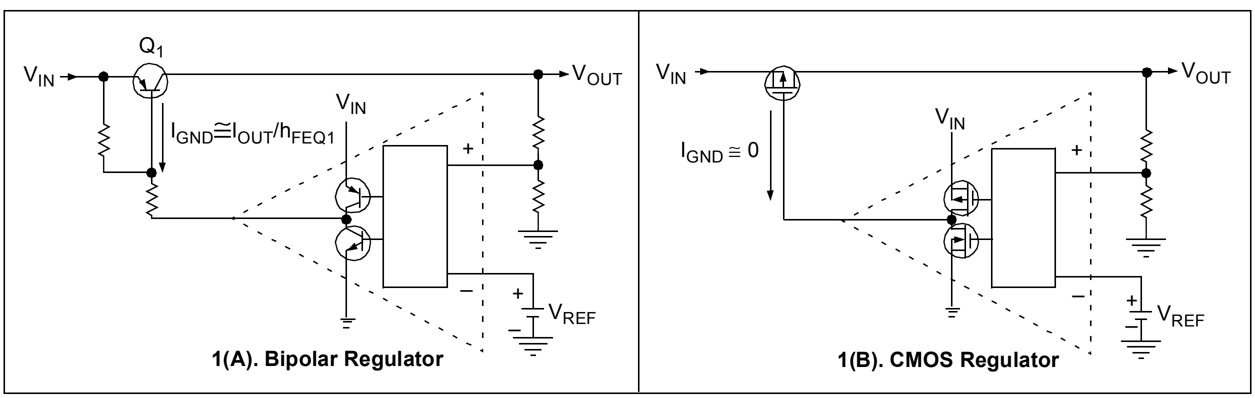

FIGURE 1: *Bipolar vs. CMOS LDO Regulator Schematics.*

MICROCHIP'S CMOS LDO FAMILY

The CMOS LDO family from Microchip offers fixed and adjustable outputs with output currents of 50 mA, 100 mA and 300 mA in packages as small as the SOT-23A-5 (see Table 1). They're equipped with an ERROR output, a reference Bypass and Shutdown inputs in various combinations. The ERROR pin is an open-drain output which is normally high, but goes low when the LDO output falls 5% out of regulation. When the SHUTDOWN input is pulled low, the regulator's circuitry is turned off and the supply current of the LDO drops to 0.5 µA (max). The BYPASS input provides a means to add a capacitor to the LDO's internal reference for lower noise operation. The BYPASS pin may be left unconnected, if desired.

TABLE 1: MICROCHIP CMOS LDO FAMILY

Device	Maximum Output Current (mA)	Adjustable Output	ERROR Output	BYPASS Input	$\overline{\text{SHDN}}$ Input	Package	$V_{DROPOUT}$ @ Max I_{OUT} (Typ. mV)
TC1014	50	**Note 1**	—	X	X	SOT-23A-5	85
TC1015	100	**Note 1**	—	X	X	SOT-23A-5	180
TC1185	150	**Note 1**	—	X	X	SOT-23A-5	270
TC1054	50	**Note 1**	X	—	X	SOT-23A-5	85
TC1055	100	**Note 1**	X	—	X	SOT-23A-5	180
TC1186	150	**Note 1**	X	—	X	SOT-23A-5	270
TC1070	50	X **(Note 2)**	—	—	X	SOT-23A-5	85
TC1071	100	X **(Note 2)**	—	—	X	SOT-23A-5	180
TC1187	150	X **(Note 2)**	—	—	X	SOT-23A-5	270
TC1072	50	**Note 1**	X	X	X	SOT-23A-6	85
TC1073	100	**Note 1**	X	X	X	SOT-23A-6	180

Note 1: Fixed Voltage Outputs available at 2.5, 2.7, 2.85, 3.0, 3.3, 3.6, 4.0 and 5.0 Volts (contact factory for custom voltages).

2: Outputs may be adjusted from 2.2V to V_{IN}.

MICROCHIP VS. BIPOLAR: TEST RESULTS

The performance of Micrel's MIC5205-3.0 LDO was compared in a side-by-side bench test with Microchip's TC1015-3.0 CMOS LDO (both are 3V fixed output regulators). The devices have compatible pinouts and exhibited comparable performance with a few key exceptions.

Supply Current

The circuit shown in Figure 2 was used to measure supply current. Supply current was measured with a 100 µA load, a 50 mA load and a 100 mA load at 25°C. The results are summarized in Table 2. As outlined earlier, the supply current for the bipolar device consists of both a quiescent (bias) current and a larger "ground current" component. When the output current is at 100 mA, the bipolar LDO has a significantly higher supply current when compared to the Microchip CMOS LDO.

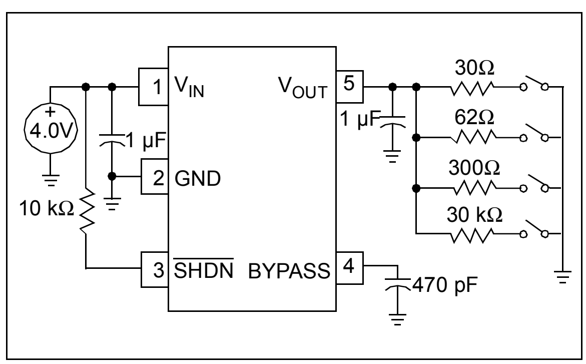

FIGURE 2: Measuring Supply Current and Dropout Voltage.

TABLE 2: SUPPLY CURRENT COMPARISON

Device	I_S (µA) at T_A = 25°C		
	I_{OUT} 100 µA	I_{OUT} = 50 mA	I_{OUT} = 100 mA
TC1015	50.3	52.6	55.4
MIC5205	77.2	341	771

Dropout Voltage

The circuit shown in Figure 2 was used to measure dropout voltage with loads of 100 µA, 10 mA, 50 mA and 100 mA at 25°C. The dropout is defined as the voltage difference from V_{IN} to V_{OUT} at the given load, with V_{OUT} at 2% below the nominal value.

The results are summarized in Table 3. The TC1015 has better dropout performance for 100 µA, 10 mA and 50 mA loads. As noted earlier, the maximum current rating for the MIC5205 is 150 mA, versus 100 mA for the TC1015.

TABLE 3: DROPOUT VOLTAGE COMPARISON

Device	$V_{DROPOUT}$ (mV) at T_A = 25°C			
	I_{OUT} 100 µA	I_{OUT} = 10 mA	I_{OUT} = 50 mA	I_{OUT} = 100 mA
TC1015	2	17	65	180
MIC5205	5	50	111	158

Load Transient Response

The test circuit of Figure 3 was used to measure the LDO's response to a 100 µA to 100 mA load transient, with measurements being made at 25°C. The results summarized in Table 4 were derived from estimating recovery times shown in the oscilloscope Figure 4 to Figure 9.

TABLE 4: DROPOUT VOLTAGE COMPARISON

Device	100 µA to 100 mA Recovery Time (µsec)	100 µA to 100 mA Recovery Time (µsec)
TC1015	2	3
MIC5205	20	>1000

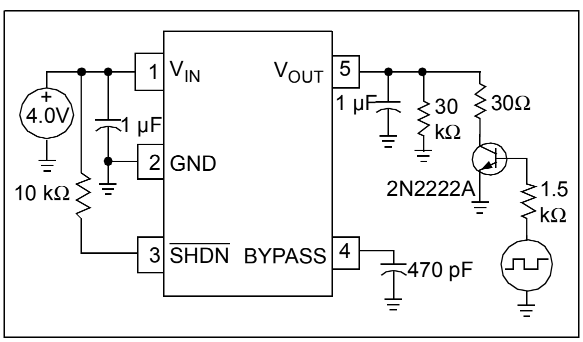

FIGURE 3: Load Transient Response Test Circuit.

Figure 4 shows the response of the MIC5205 (trace 1) and TC1015 (trace 2) to a 100 µA to 100 mA load step change. Trace 3 is the signal used to switch the 100 mA load, as shown in the circuit in Figure 3. The 100 mA load is switched on for 200 µsec and off for 800 µsec (in order to view the TC1015, the scope's gain and time base will change in Figure 5 to Figure 9). The MIC5205 has not resumed normal regulation (800 µsec) after the 100 mA load is removed and produces a 1.4V output spike that is roughly 100 µsec wide when the load is switched on again.

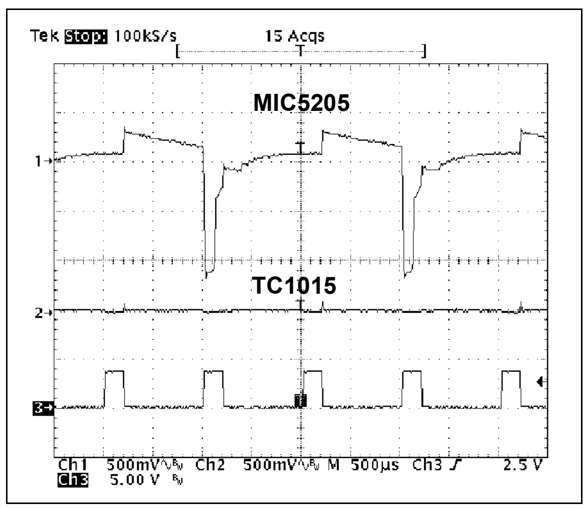

FIGURE 4: 100 mA Load Transient, both LDOs.

As shown in Figure 5, the recovery time of the MIC5205 improves if the 470 pF bypass capacitor (used to improve output noise characteristics) is removed. Even with the bypass capacitor removed, when the 100 mA load is switched on, there is a 0.9V spike roughly 20 µsec wide (see Figure 6). It is likely that a larger output capacitor will be required.

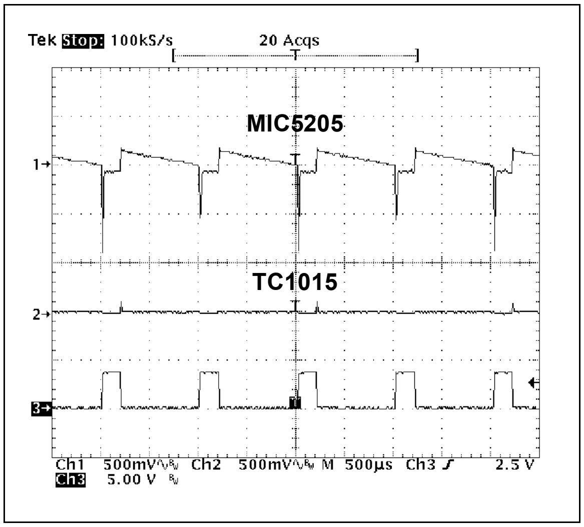

FIGURE 5: 100 mA Load Transient, no bypass Capacitor on MIC5205.

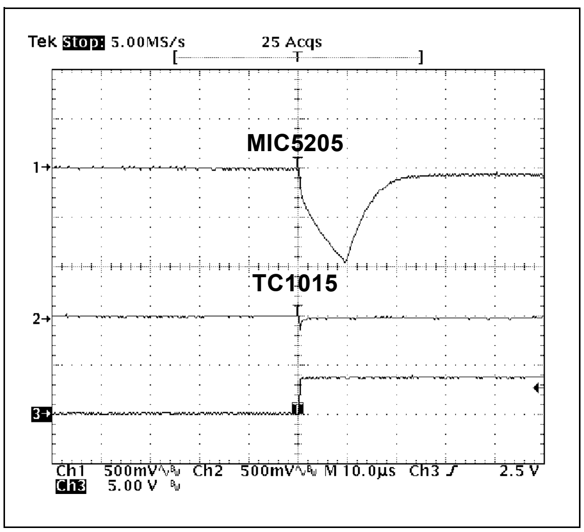

FIGURE 6: 100 µA to 100 mA Load Transient, no bypass Capacitor on MIC5205.

Figure 7 and Figure 8 show the response of the TC1015 to the same 100 µA to 100 mA step change. Figure 7 shows the turn on recovery, while Figure 8 shows the turn off recovery. Both the turn on and turn off recovery times are roughly 3 µsec – much less than for the MIC5205. Figure 9 shows the TC1015 recovery when the load is switched on for only 4 µsec in order to see the turn on and turn off times in the same oscilloscope. Note that the transient spikes are less than 150 mV. The transient response for the TC1015 is more than adequate with 1 µF output and 470 pF bypass capacitors.

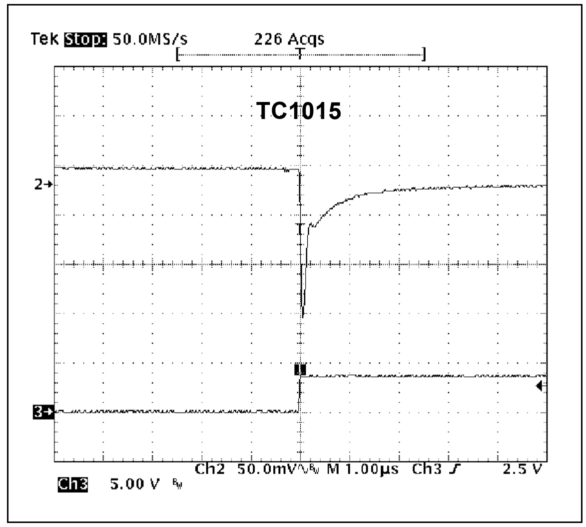

FIGURE 7: TC1015, 100 µA to 100 mA Load Transient; (Turn on Recovery).

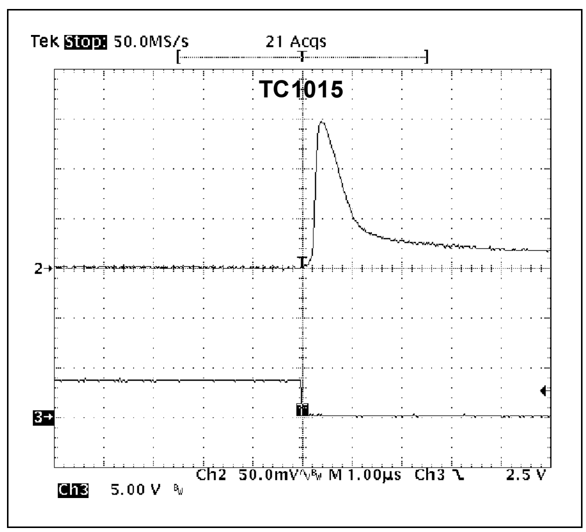

FIGURE 8: TC1015, 100 µA to 100 mA Load Transient; (Turn Off Recovery).

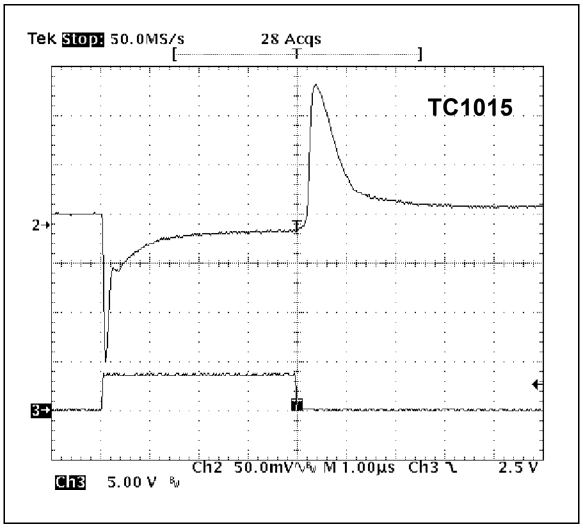

FIGURE 9: *TC1015, 100 µA to 100 mA Load Transient; (Recovery when Load is Switched on for only 4 µsec).*

SUMMARY

Although pin compatible and sharing many similar performance specifications, the TC1015 has key advantages over the bipolar MIC5205. The TC1015 exhibits a load transient response that is much better than the MIC5205, while also demonstrating superior dropout performance at loads up to 50 mA. Microchip LDOs provide equivalent to superior performance, yet have a much lower supply current. Superior performance with lower supply current makes Microchip's CMOS LDOs the regulators of choice for modern battery and low power applications.

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