Application Note

LDO Current Limit Behavior During Dropout Operation

TEXAS INSTRUMENTS

ABSTRACT

This application report describes the current limit protection behavior when operating during dropout operation for low dropout voltage (LDO) regulators. The TLV758P is used as an example device in this application report but this applies broadly to most TI LDO regulators.

Table of Contents

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1 Theory of Operation

1.1 Current Limit and Foldback Behavior

The TLV758P LDO device has an internal current limit circuit that protects the regulator during high-load current faults or a short circuit event. The current limit is a hybrid brickwall-foldback scheme. When the current limit circuit detects a high-load current fault and the output voltage is above the $V_{FOLDBACK}$, the brickwall scheme limits the output current to the current limit I_{CL}. If the output voltage is pulled below $V_{FOLDBACK}$ then the output current starts to fold back until it reaches the short circuit current limit, I_{SC}.

$$V_{FOLDBACK} = 0.4 \times V_{OUT(nom)} \quad (1)$$

where:

- I_{CL} = 720 mA
- I_{SC} = 350 mA

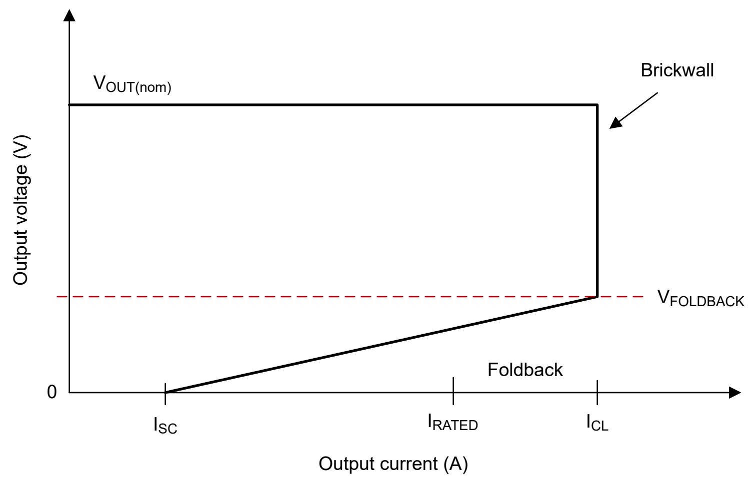


Figure 1-1. Foldback Current Limit

1.2 Current Limit Circuit

The standard internal current limit circuit of LDO regulators uses a sense FET with a series resistor at its source. This series resistor (R_S) senses the current flowing through the internal passFET. The CL sense point goes to a differential state by comparing against another reference value, where current limit sense is $V_{IN} – V_{CL\_SENSE}$. Therefore, the voltage drop across resistor R_S determines if the current limit is engaged or not in order to regulate the output current within a given range of I_{CL}.

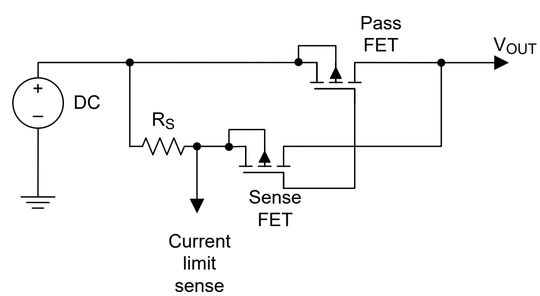


Figure 1-2. Simplified Current Limit Circuit

During dropout operation ($V_{IN}<V_{OUT(NOM)}+V_{DO}$), the sensed current decreases, due to a decrease of V_{DS} across the sense FET. This reduction in sense current requires the output current to increase before the current limit circuit takes over and starts regulating the current.

2 Current Limit Dring Dropout Operation

2.1 Bench Results

Performing a load transient is one method to test for current limit using a bench setup. The TLV758P has a current limit range of 530 mA up to 865 mA, which is given for the condition of $V_{IN} = V_{OUT(nom)} + 1.0$ V. When testing current limit, it is recommended to use a load that is approximately 50% higher than the maximum current limit to enter current limit. (See Figure 2-1)

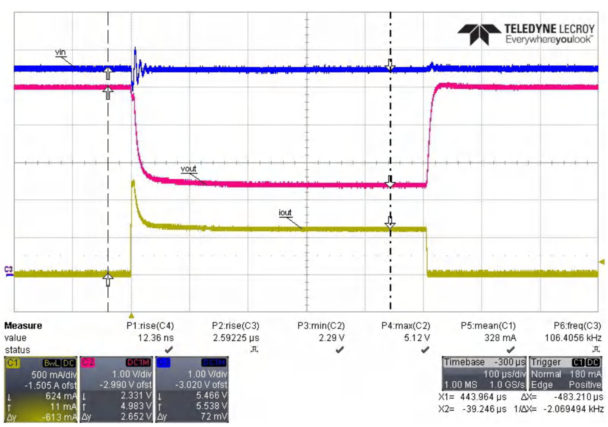
During the load transient event, there is a peak current value of 1.2 A, which is expected with the test conditions. The current limit circuit is a feedback loop which means there is a minimum response time which corresponds to the bandwidth of the feedback loop. Consequently, the device requires approximately 20 µs for the current limit circuit to activate, then it starts to regulate the output current to approximately 620 mA.

Similarly, Figure 2-2 shows a load transient with a smaller load. The peak current reaches 902 mA and then regulates the current to approximately 620 mA, while maintaining enough headroom between V_{IN} and V_{OUT} where $V_{IN} = V_{OUT} + 0.5$ V.

However, the TLV758P has a dropout specification of 130 mV when 3.3 V ≤ V_{out} ≤ 5.5 V. Because the LDO regulator provided enough headroom to avoid the dropuout condition ($V_{IN} = V_{OUT} + 0.5$ V), the current limit behavior of the above transients is almost identical with a regulated current of approximately 620 mA. This value is within the expected range of 530 mA to 865 mA in the TLV758P *Electrical Characteristics* table.

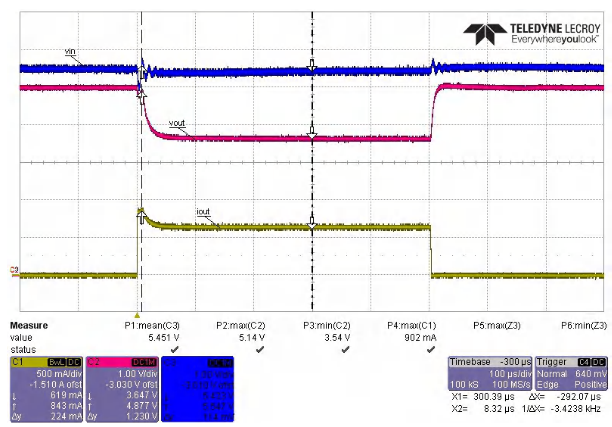
The same set of tests are performed during dropout operation by changing the input voltage to V_{IN} = 5.13 V. When the test circuit uses a 3.9-Ω load, which is well above the normal current limit trip point, the current limit circuit behaves as expected as shown in Figure 2-3.

When the load equals 5.6-Ω, the regulator does not enter current limit protection mode as shown in Figure 2-4, and instead, the regulator performs expected for a normal load transient event. By comparing the results, the data clearly shows that during dropout operation as shown in Figure 2-3 and Figure 2-4, the current limit trip point increases above 1 A due to a decrease of the sense current flowing through the internal R_S resistor. During dropout operation when current limit engages, the regulated output current becomes approximately 620 mA.



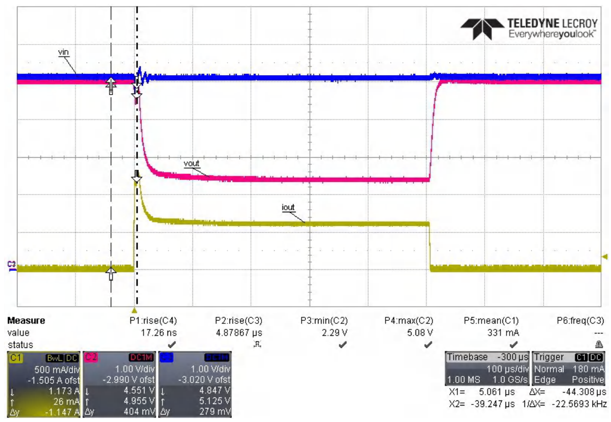
V_{IN} = 5.5 V $V_{OUT(nom)}$ = 5.0 V R_{LOAD} = 3.9 Ω

Figure 2-1. Bench Test 1



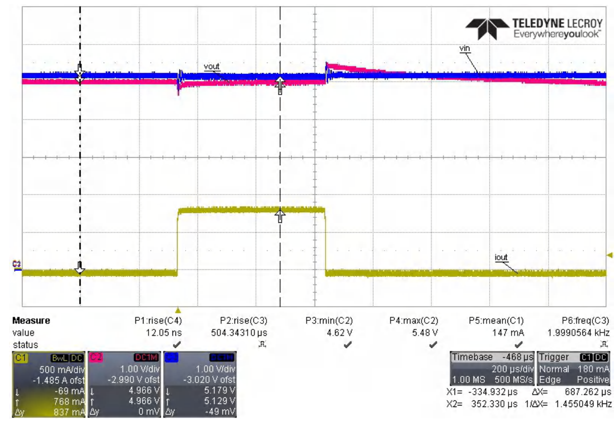
V_{IN} = 5.5 V $V_{OUT(nom)}$ = 5.0 V R_{LOAD} = 5.6 Ω

Figure 2-2. Bench Test 2



V_{IN} = 5.13 V $V_{OUT(nom)}$ = 5.0 V R_{LOAD} = 3.9 Ω

Figure 2-3. Bench Test 3



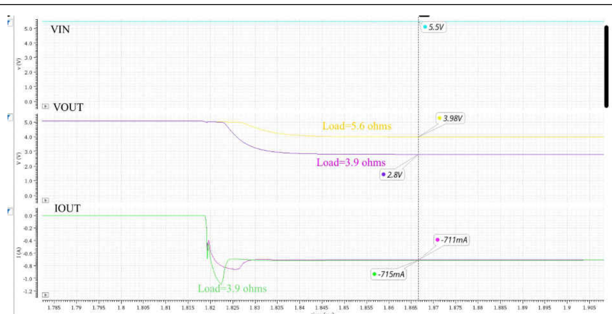
V_{IN} = 5.13 V $V_{OUT(nom)}$ = 5.0 V R_{LOAD} = 5.6 Ω

Figure 2-4. Bench Test 4

2.2 Current Limit vs Input Voltage

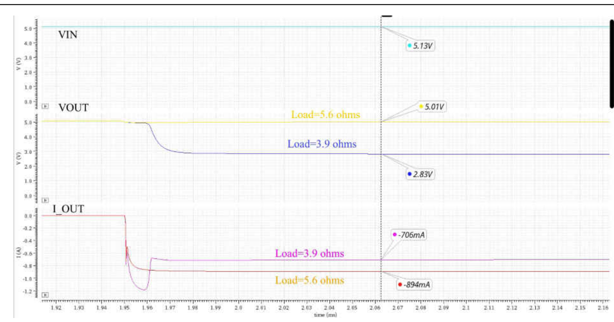
Due to the nature of the current limit circuit architecture, when the TLV758P initiates dropout operation with V_{DO}= 130 mV, the R_S resistor consumes a voltage between 60 mV and 70 mV. Hence, the sense device does not have sufficient drain-to-source voltage (V_{DS}), which causes the sense current to decrease. When the sense current decreases, the maximum current limit range increases.

During bench testing, the TLV758P regulator was capable of supplying a current level near 900 mA during dropout operation. After the current exceeds 900 mA and enters current limit protection mode, the TLV758P current limit circuit limits the current to a value within the I_{CL} range between 530 mA and 865 mA. Figure 2-5 and Figure 2-6 show this behavior verified using simulation data .



V_{IN} = 5.5 V $V_{OUT(nom)}$ = 5.0 V R_{LOAD}=3.9 and 5.6

Figure 2-5. Simulation Results A

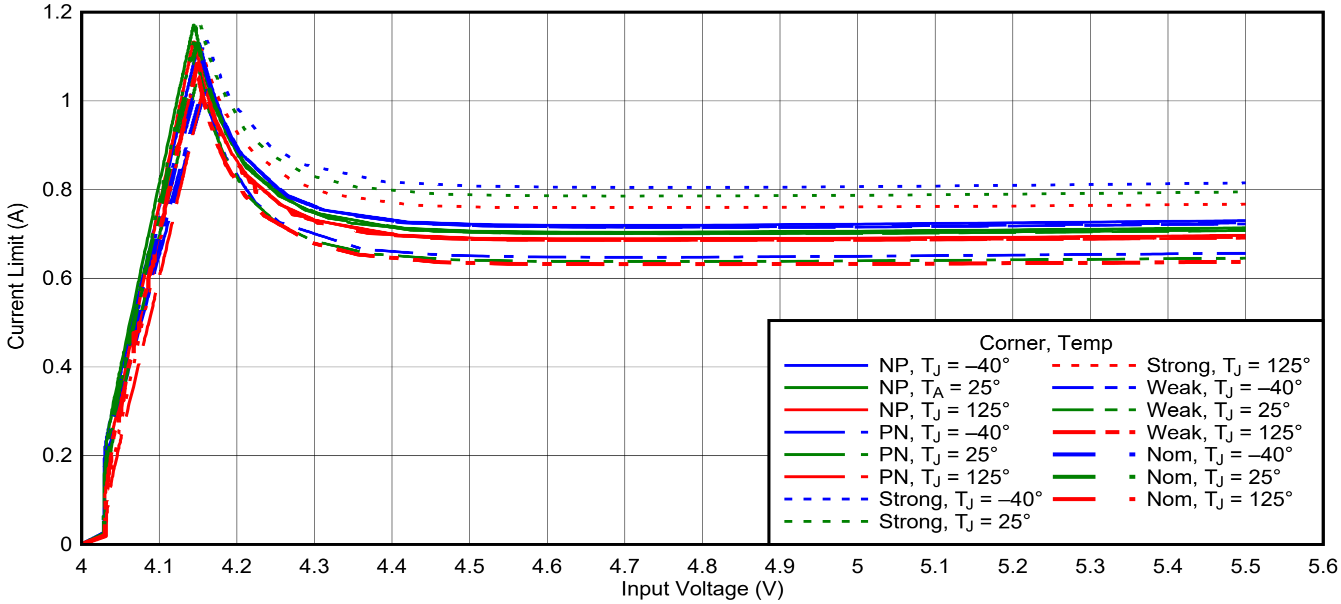


V_{IN} = 5.13 V $V_{OUT(nom)}$ = 5.0 V R_{LOAD}=3.9 and 5.6

Figure 2-6. Simulation Results B

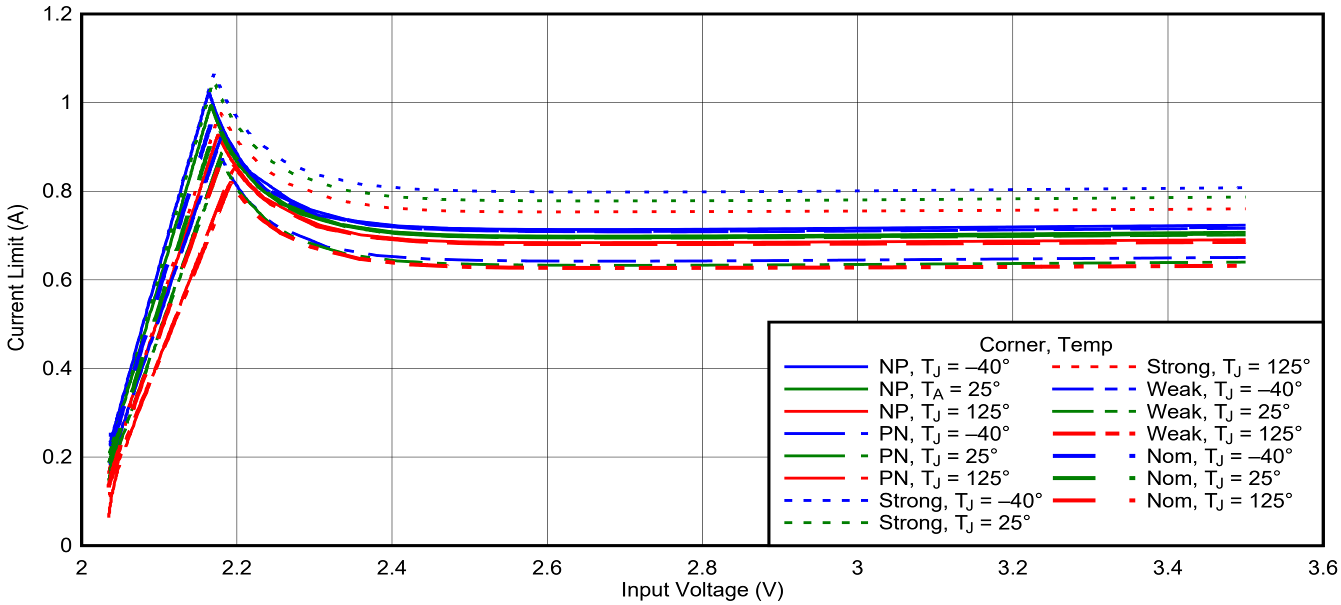
With process and temperature variation results from simulation, shown in Figure 2-7, the TLV758P was forced to a V_{OUT} of 4.0 V. When operating in the dropout region (V_{IN} is in a range between 4.1 V and 4.2 V) and V_{OUT} = 4.0 V, then the current limit value can increase to approximately 1.2 A. After that current limit engages, a regulated current limit range between 640 mA up to 810 mA which is within the range listed in the *Electrical Characteristics* table.

Similarly, Figure 2-8 shows simulation data for V_{OUT} = 2.5 V. When the input voltage (V_{IN}) is in deep dropout, the current limit value increases, in this case, close to 1.1 A. This reaction shows that the behavior is not dependent on the output voltage of the LDO regulator. After the input voltage starts increasing, the current limit returns to within the range between 620 mA and 800 mA showing that the device regulates the output current to a range within the TLV758P data sheet specifications.



$V_{OUT(nom)}$ = 4.0 V

Figure 2-7. Simulation Data for Current Limit vs Input Voltage



$V_{OUT(nom)}$ = 2.5 V

Figure 2-8. Simulation Data for Current Limit vs Input Voltage

3 Conclusion

This application report describes the current limit behavior for an LDO during dropout operation using the TLV758P device as an example. Based on the bench and simulation results for TLV758P, when kept out of dropout the current limit is within the range between 530 mA and 885 mA specified in the TLV758P data sheet. However, it was shown that due to the standard current limit circuit architecture, during dropout operation, the sense current decreases, therefore, increasing the trip point where the current limit circuit is enabled, while deep dropout operation results in an increase of current limit. This behavior comes into effect as the TLV758P is operated under the condition shown in Equation 2.

$$V_{IN} – V_{OUT} \le V_{DO} \tag{2}$$