

Improving feedback current accuracy when using H-Bridges for closed loop motor control

1 Introduction

Many applications use DC motors that require real-time current feedback from the load. Real-time current feedback enables the monitoring of current consumption and provides a means of implementing diagnostics that detect abnormal loading conditions. In some applications, highly accurate current measurement may be critical to implementing safety mechanisms in a system.

This document presents a simplified system level method for improving the accuracy of feedback current measurements when using NXP H-Bridge motor drivers, including the MC33926, MC33931, MC33932, MC34931S, and the MC34932S.

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2 Feedback (FB)

To facilitate closed-loop operation for motor speed and torque control, NXP's H-Bridge motor drivers (MC33926, MC33931, MC33932, MC34931S, and MC34932S) have feedback outputs (FB) for real time monitoring of H-Bridge high-side FET currents. The FB pin provides current sensing feedback of the H-Bridge high-side drivers. When running in the forward or reverse direction, a ground-referenced 0.24 % of load current comes out of the FB pin. By using an external resistor to ground, the proportional feedback current can be converted to a proportional voltage equivalent and the controlling microcontroller can 'read' the current proportional voltage with its analog-to-digital converter (ADC). This provides the user with only first-order motor current feedback for motor torque control. The resistance range for the linear operation of the FB pin is $100 \Omega < R_{FB}$ resistor to ground for spike suppression.

If Pulse Width Modulation (PWM) is implemented using the disable pin input (D1 only), a small filter capacitor ($\sim 1.0 \mu\text{F}$) may be required in parallel with the R_{FB} resistor to ground for spike suppression.

The architecture diagram of the part is shown in [Figure 1](#) with the shaded section showing the current feedback circuit.

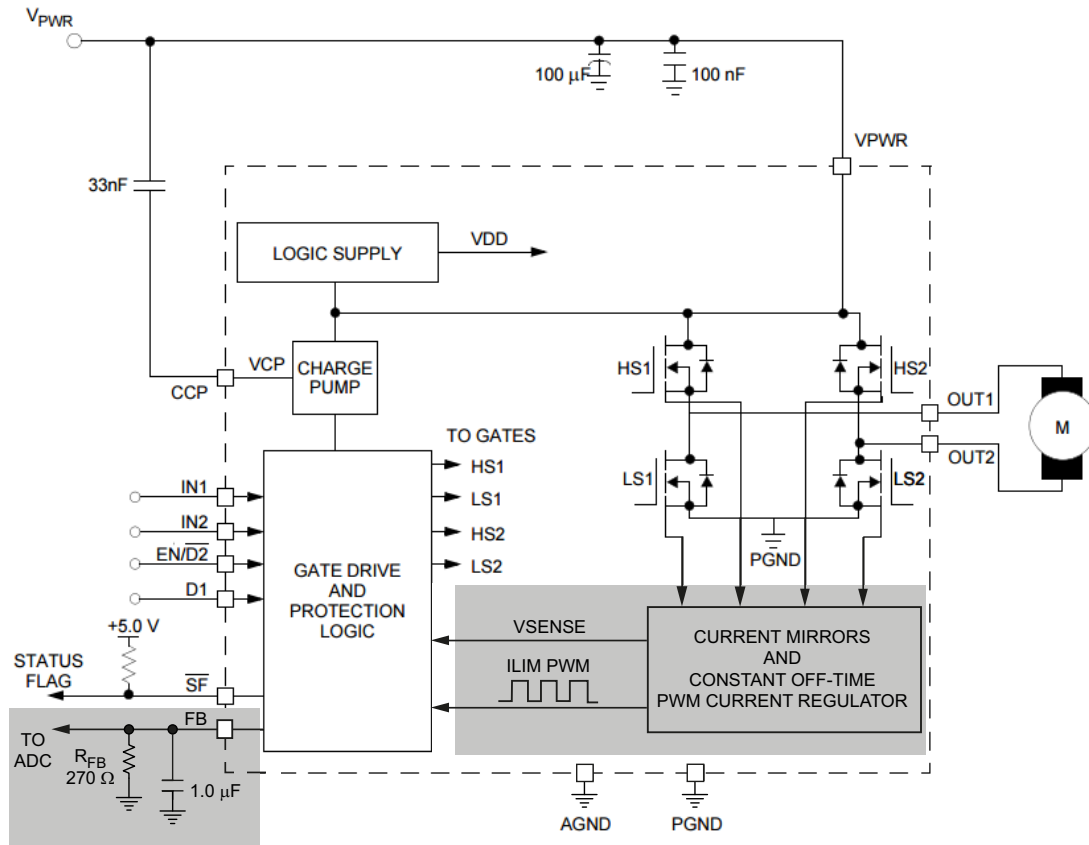


Figure 1. Architecture diagram with FB circuit highlighted

The scaled down current out of the FB pin is the summation of current from both high-side FETs. This is important to know, because if the device is used as two separate high-side switches, the current out of the FB pin represents the combined current of both high-side switches when operating simultaneously. [Figure 2](#) shows the configuration and the architecture of the current feedback circuit.

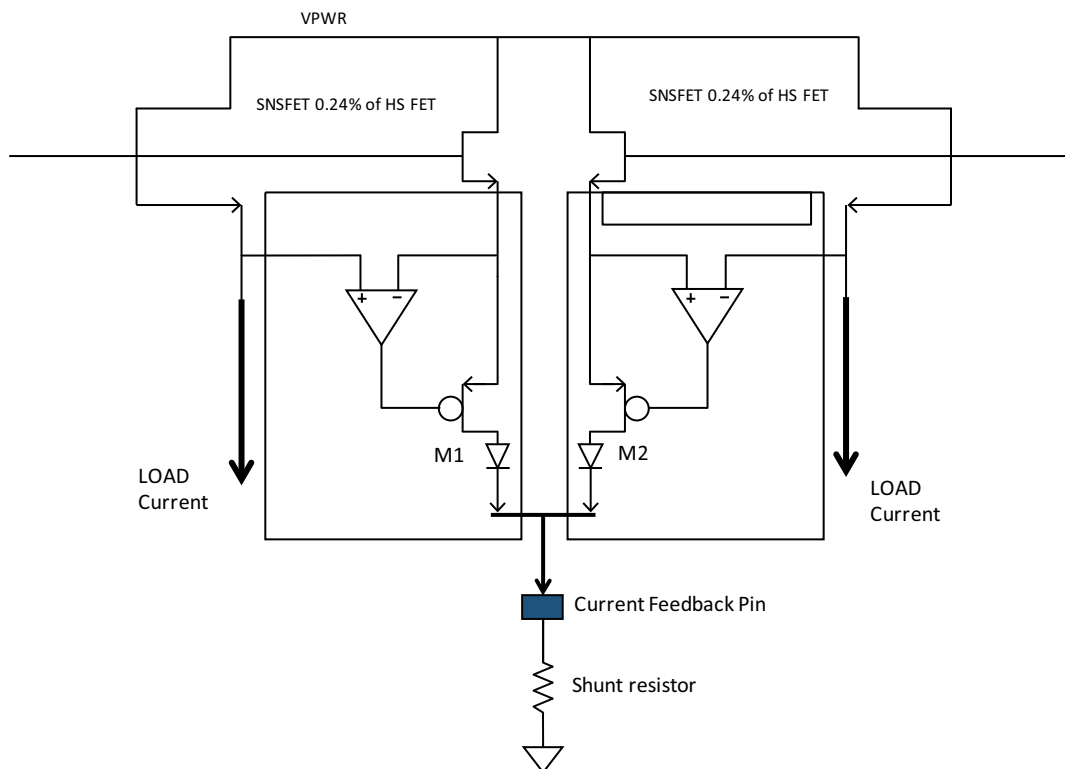


Figure 2. Current feedback circuit configuration

3 Specification

The current feedback feature scales the load current down to 0.24 % of the load current which flows through the high-side FETs. The accuracy is higher for load current above 1.5 A. This is because with higher load current, the amplifier offset current becomes a smaller portion of the total current from the current mirror circuit which comes out of the FB pin. (Most applications using these devices drive inductive loads in the 1.5 A to 6.0 A range.)

Table 1. Load current (I_{OUT}) vs. feedback current (I_{FB})

Load current flowing between the two outputs (I_{OUT}) ^(Notes)	Feedback current (I_{FB})			
	Min.	Typ.	Max.	Unit
0 mA	0	—	50	μ A
300 mA	0	270	750	μ A
500 mA	0.35	0.775	1.56	mA
1.5 A	2.86	3.57	4.28	mA
3.0 A	5.71	7.14	8.57	mA
6.0 A	11.43	14.29	17.15	mA

Notes

1. Accuracy is better than 20 % from 0.5 A to 6.0 A. Recommended terminating resistor value: $R_{FB} = 270 \Omega$

4 Improving accuracy in feedback current measurement

The following method describes how to improve feedback current measurement accuracy using a simple linear model that incorporates data collected at different temperatures for all six data points in the specification. The method involves capturing FB current for load current values in the specification at hot, room and cold temperatures. These values are then used to create a linear model based on the measured versus the target value of the load current.

4.1 Measurements at various ambient temperatures (T_A)

This section shows the average of ten FB current measurements taken at hot temperature, room temperature, and cold temperatures in the lab to compensate for variation in feedback current over different temperatures. Feedback current measurement for OUT1 and OUT2 is achieved by measuring both the load current and the current through the FB pin in forward and reverse directions respectively. This data was used to create a simple first and second order mathematical model to improve the FB current measurement accuracy.

Table 2. Target vs. measured FB current on OUTx at $T_A = 105\text{ }^\circ\text{C}$

OUT1 current (mA)	FB current (mA), 0.24 % of OUTX current		OUT2 current (mA)	FB current (mA), 0.24 % of OUTX current	
	Target	Measured		Target	Measured
0	0	0.02	0	0	0.02
300	0.72	0.20	300	0.72	0.20
500	1.2	0.70	500	1.2	0.70
1500	3.6	3.26	1500	3.6	3.26
3000	7.2	7.14	3000	7.2	7.14
6000	14.4	14.78	6000	14.4	14.78

Table 3. Target vs. measured FB current on OUTx at $T_a = 85\text{ }^\circ\text{C}$

OUT1 current (mA)	FB current (mA), 0.24 % of OUTX current		OUT2 current (mA)	FB current (mA), 0.24 % of OUTX current	
	Target	Measured		Target	Measured
0	0	0.02	0	0	0.03
300	0.72	0.21	300	0.72	0.21
500	1.2	0.71	500	1.2	0.71
1500	3.6	3.27	1500	3.6	3.27
3000	7.2	7.14	3000	7.2	7.14
6000	14.4	14.86	6000	14.4	14.86

Table 4. Target vs. measured FB current on OUTx at $T_A = 25\text{ }^\circ\text{C}$

OUT1 current (mA)	FB current (mA), 0.24 % of OUTX current		OUT2 current (mA)	FB current (mA), 0.24 % of OUTX current	
	Target	Measured		Target	Measured
0	0	0.03	0	0	0.04
300	0.72	0.24	300	0.72	0.24
500	1.2	0.74	500	1.2	0.75
1500	3.6	3.31	1500	3.6	3.31
3000	7.2	7.18	3000	7.2	7.17
6000	14.4	14.96	6000	14.4	14.95

Table 5. Target vs. measured FB current on OUTx at $T_a = -40\text{ }^\circ\text{C}$

OUT1 current (mA)	FB current (mA), 0.24 % of OUTX current		OUT2 current (mA)	FB current (mA), 0.24 % of OUTX current	
	Target	Measured		Target	Measured
0	0	0.03	0	0	0.04
300	0.72	0.28	300	0.72	0.28
500	1.2	0.79	500	1.2	0.79
1500	3.6	3.35	1500	3.6	3.35
3000	7.2	7.22	3000	7.2	7.22
6000	14.4	15.00	6000	14.4	14.99

5 Mathematical model for 0 A to 6.0 A current range

Figure 3 illustrates a linear model showing the calculated load current with respect to the actual output current. This model is based on the data in Section 4, Improving accuracy in feedback current measurement, page 4, and provides a very good approximation of the load current derived by measuring the current out of the FB pin. This improves the feedback current measurement accuracy when compared to direct conversion using the feedback current ratio.

5.1 Linear model

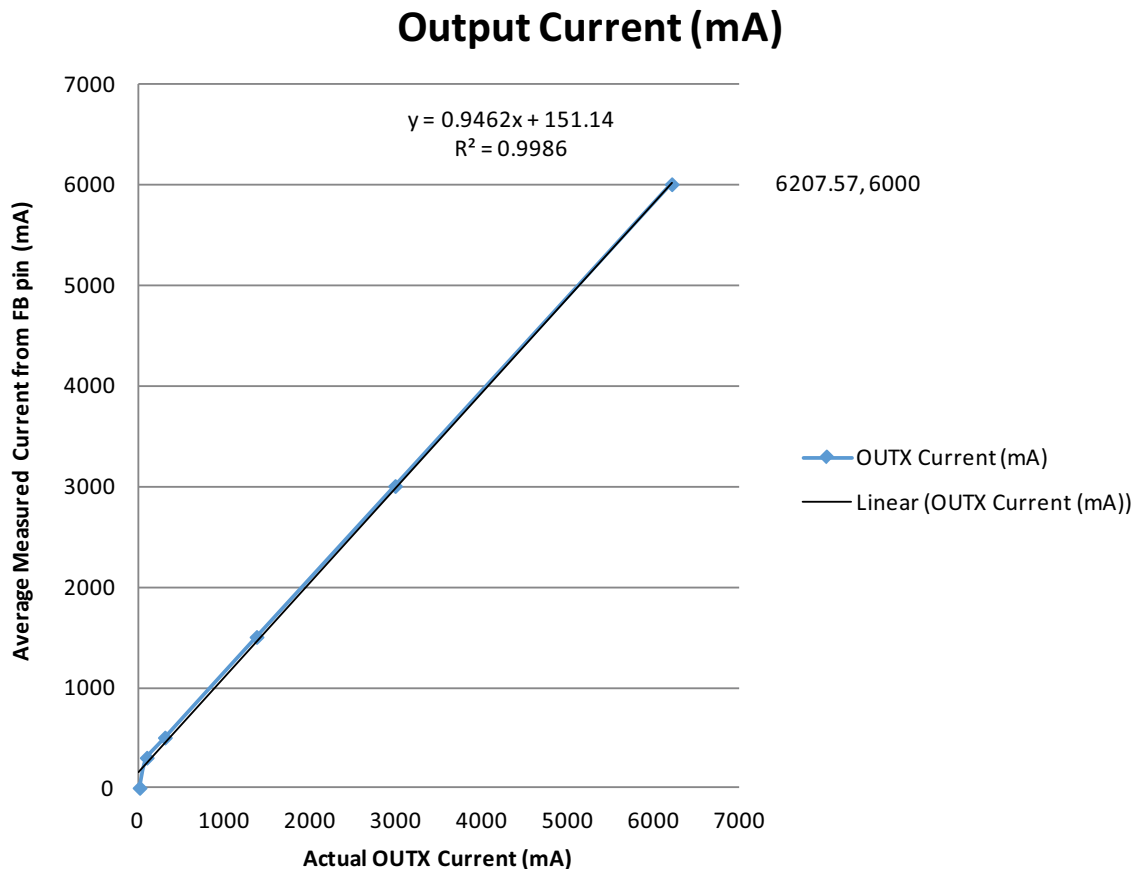


Figure 3. Linear model for 0 A to 6.0 A range

The Linear Current Model Equation for the 0 A to 6.0 A range is:

Linear: $y(t) = 0.9462x(t) + 151.14$

where t is the value at an instant in time

Table 6. Linear model data for 0 A to 6.0 A range

Actual OUTX current (mA)	Average measured current from FB pin (mA)	Average estimated OUTX current from FB pin (mA)	Adjusted measured OUTX current (mA)	% error after modeling
0	0.03	12.52	162.99	—
300	0.23	95.72	241.71	-9.43
500	0.74	306.62	441.26	-11.75
1500	3.30	1374.21	1451.42	-3.24
3000	7.17	2986.86	2977.30	-0.76
6000	14.90	6207.57	6024.74	-0.41

Implementing a second order model gives higher accuracy at load currents higher than 1.5 A. However, at load currents lower than 0.5 A, a slight increase in percentage error was observed. Table 7 clearly shows that, even with a better curve fit, the accuracy does not drastically increase at higher load current data points when compared with the simpler linear model. Implementing a second order model may increase the accuracy of the feedback current measurement at the expense of increasing the processing load on the MCU. Consider the trade-off between the computation demand on the MCU and the feedback current measurement accuracy requirement when making such decisions.

5.2 Second order model

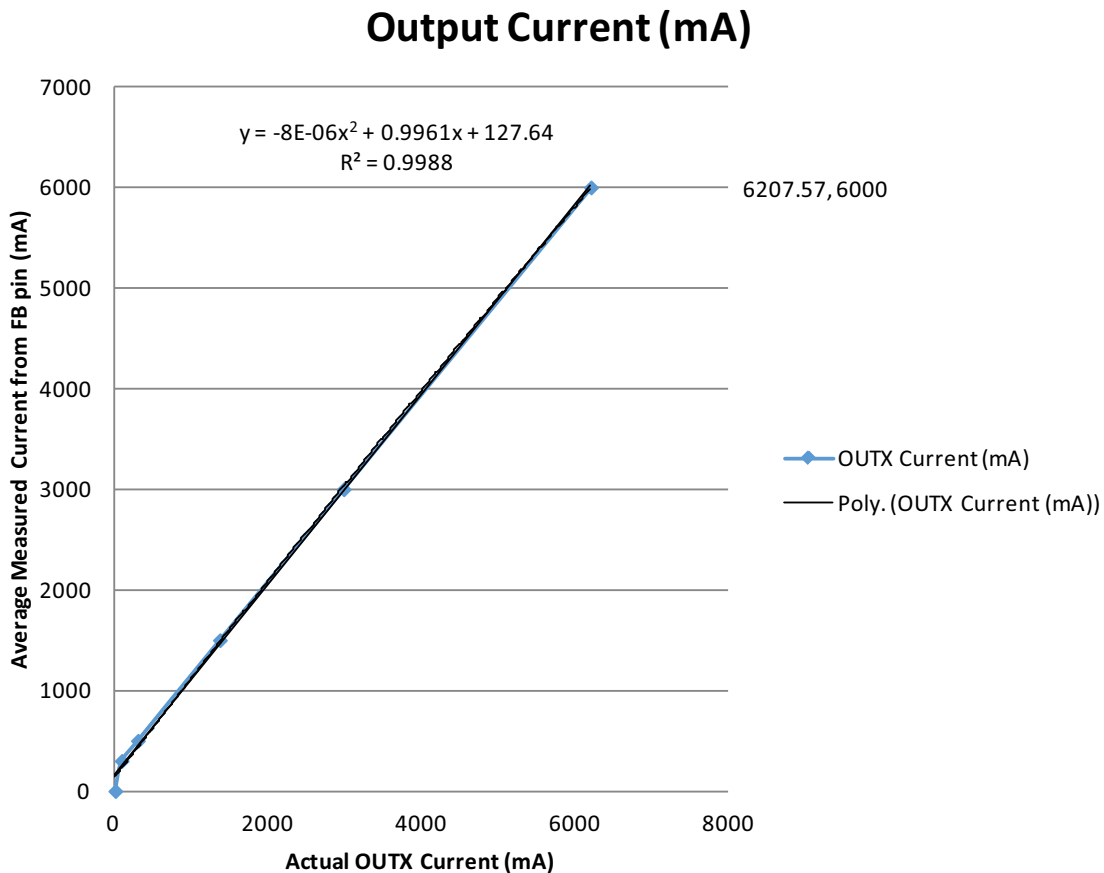


Figure 4. Second order model for 0 A to 6.0 A range

Mathematical model for 0 A to 6.0 A current range

The Second Order Current Model Equation for the 0 A to 6.0 A range is:

$$\text{Second Order: } y(t) = -8 \times 10^{-6}x(t)^2 + 0.9961x(t) + 127.64$$

where t is the value at an instant in time

Table 7. Second order model data for 0 A to 6.0 A range

Actual OUTX current (mA)	Average measured current from FB pin (mA)	Average estimated OUTX current from FB pin (mA)	Adjusted measured OUTX current (mA)	% error after modeling
0	0.03	12.52	140.11	—
300	0.23	95.72	222.91	-25.70
500	0.74	306.62	432.31	-13.54
1500	3.30	1374.21	1481.39	-1.24
3000	7.17	2986.86	3031.48	1.05
6000	14.90	6207.57	6002.73	0.05

6 Mathematical model for 1.5 A to 6.0 A current range

Many applications using MC33926, MC33931, MC33932, MC34931S, and MC34932S devices may operate in a continuous current operating range of 1.5 A to 6.0 A. In such cases, more accuracy may be expected from these devices when compared with models for the 0 A to 6.0 A range. A simple linear model was formed from the data in [Section 4, Improving accuracy in feedback current measurement, page 4](#) giving an almost perfect linear curve fit for 1.5 A to 6.0 A load current range. [Figure 5](#) shows a simple linear (First Order) model for measuring load feedback current using the FB pin.

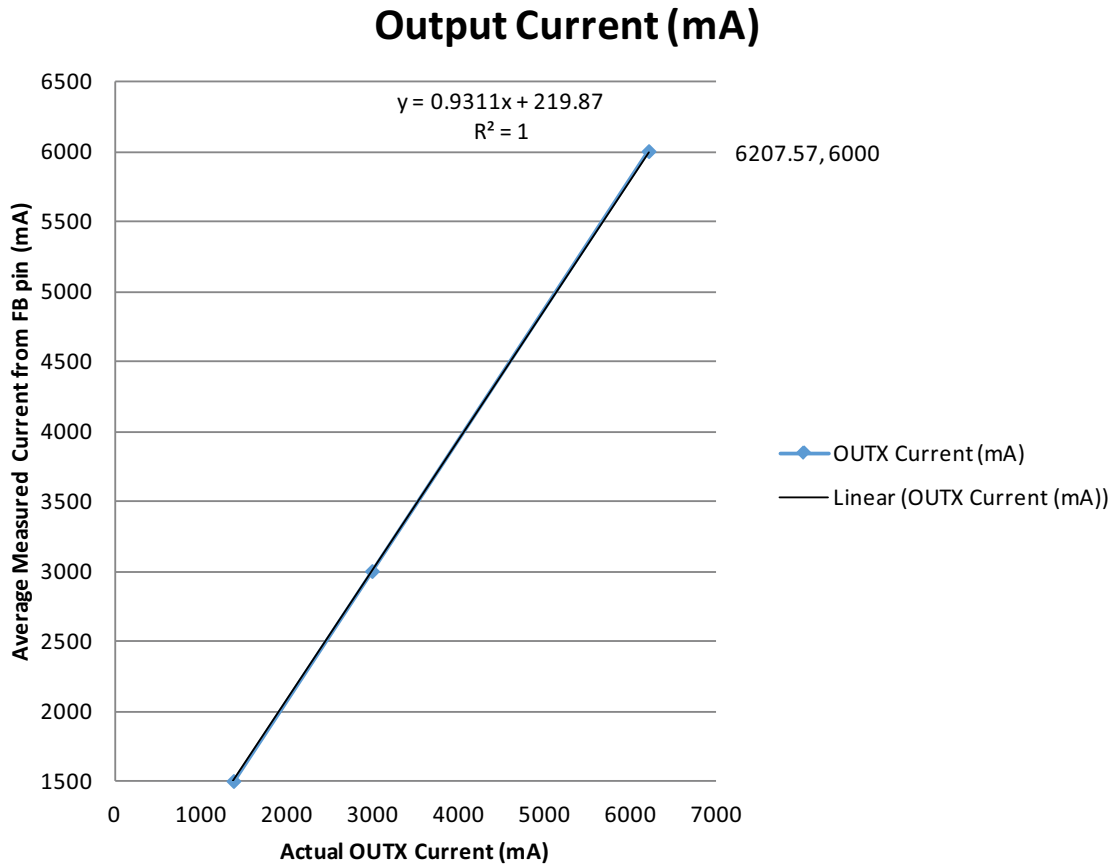


Figure 5. First order model for 1.5 A to 6.0 A range

Linear Current Model Equation for the 0 A to 6.0 A range:

Linear: $y(t) = 0.9311x(t) + 219.87$

where t is the value at an instant in time

Table 8. Linear model data for 1.5 A to 6.0 A range

Actual OUTX current (mA)	Average measured current from FB pin (mA)	Average estimated OUTX current from FB pin (mA)	Adjusted measured OUTX current (mA)	% error after modeling
1500	3.30	1374.21	1499.40	-0.04
3000	7.17	2986.86	3000.93	0.03
6000	14.90	6207.57	5999.74	0.00

Based on lab data from ten devices, [Table 8](#) clearly shows the percentage of error in measured feedback current using the linear model is very small. Operating in this range would give the best accuracy.

7 Measurement of feedback current

Feedback current is measured by adding a shunt resistor on the FB pin to convert the current from the FB pin to voltage within the detectable range of the ADC on the MCU.

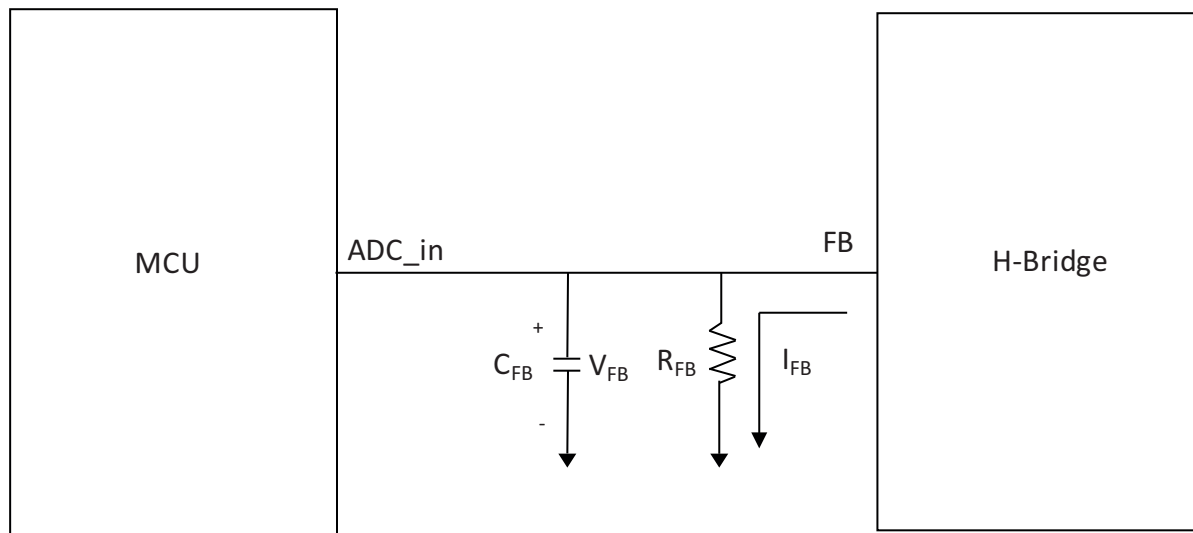


Figure 6. Measurement of feedback current using the MCU

Based on the R_{FB} selected, the measured voltage using the ADC across the shunt resistor gives a good estimate of the load current which can be used as feedback current to implement safety mechanisms and diagnostics for the system.

As an example, the linear models in [Section 5, Mathematical model for 0 A to 6.0 A current range, page 6](#) and [Section 6, Mathematical model for 1.5 A to 6.0 A current range, page 9](#) may be converted from a current model to a voltage model and then converted back to a current model to do the feedback current estimation.

7.1 The modified linear voltage model and estimated feedback current equations

Modified Linear Voltage Model Equation for 0 A to 6.0 A Range:

$$y(t) = 0.9462x(t) + 151.14 \times 0.0024 \times R_{FB}[\Omega]$$

Estimated Feedback Current (Load Current):

$$\frac{y(t)}{0.0024 \times R_{FB}[\Omega]}$$

Modified Linear Voltage Model Equation for 1.5 A to 6.0 A Range:

$$y(t) = 0.9311x(t) + 219.87 \times 0.0024 \times R_{FB}[\Omega]$$

Estimated Feedback Current (Load Current):

$$\frac{y(t)}{0.0024 \times R_{FB}[\Omega]}$$

where t is the value at an instant in time

A small capacitor (C_{FB}) may be added to filter out noise in the voltage signal across the shunt resistor (V_{FB}). Note that a large C_{FB} may cause excessive averaging of the signal and could prevent the MCU's ADC from detecting small current transients due to abnormal system operation. Hence, a small filter capacitor $C_{FB} \leq 1.0 \mu\text{f}$ is recommended parallel to R_{FB} .

8 Conclusion

The simple linear model demonstrated in [Section 5, Mathematical model for 0 A to 6.0 A current range, page 6](#) and [Section 6, Mathematical model for 1.5 A to 6.0 A current range, page 9](#) yields three to four times more accurate feedback current measurements than a direct conversion of FB pin current to feedback current using the 0.24 % factor. This model is well suited for implementing diagnostics, monitoring power consumption, detecting open loads, etc.

The models in this document are based on data from ten different devices. The models may need modification for some systems. Nonetheless, the methodology for increasing accuracy remains the same. Moreover, the 1.5 A to 6.0 A range model yields higher accuracy than the 0 A to 6.0 A range. Therefore, when making a decision on when and how to use these models, consider the system's operating range and application requirements.

9 References

Following are URLs where you can obtain information on related NXP products and application solutions:

Support pages	Description	URL
MC33926	Product Summary Page	www.nxp.com/webapp/sps/site/prod_summary.jsp?code=MC33926
MC33931	Product Summary Page	www.nxp.com/webapp/sps/site/prod_summary.jsp?code=MC33931
MC33932	Product Summary Page	www.nxp.com/webapp/sps/site/prod_summary.jsp?code=MC33932
MC34931S	Product Summary Page	www.nxp.com/webapp/sps/site/prod_summary.jsp?code=MC34931
MC34932S	Product Summary Page	www.nxp.com/webapp/sps/site/prod_summary.jsp?code=MC34932

10 Revision history

Revision	Date	Description
1.0	11/2015	<ul style="list-style-type: none">• Initial release
	7/2016	<ul style="list-style-type: none">• Updated to NXP document form and style

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