ISL28006: Measuring Common-Mode and Power Supply Rejection Ratio

Although the datasheet of a current-sense amplifier (such as ISL28006) showcases device performance in the form of its electrical specifications, occasionally customers require confirmation of electrical parameters through bench testing.

Of particular importance are the Common-Mode Rejection Ratio (CMRR) and the Power Supply Rejection Ratio (PSRR), these parameters quantify the ability of the device to do the following:

- Reject signals that are common to both the positive and negative inputs (CMRR)
- Suppress power supply variations to its output signal (PSRR)

This application note provides the test circuits, measurement instructions, and test results of practical measurements, and it gives two short explanations of CMRR and PSRR.

Contents

1. Test Setup and Instructions for Measuring CMRR and PSRR 2
1.1 Test Circuits 2
1.2 Measurement Instructions 2
1.3 Test Results for ISL28006-100 2
2. Common-Mode Rejection Ratio, CMRR 3
3. Power Supply Rejection Ratio, PSRR 4
4. Summary 4
5. Revision History 5

1. Test Setup and Instructions for Measuring CMRR and PSRR

1.1 Test Circuits

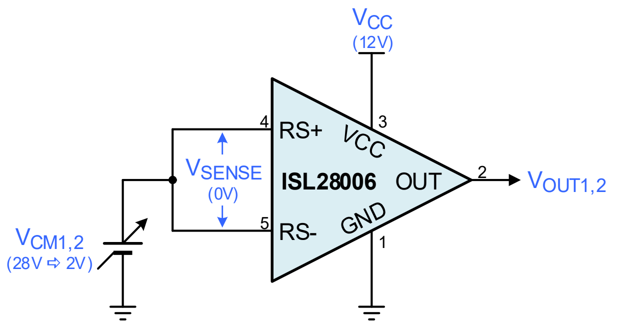

Figure 1. CMRR Bench Test Setup

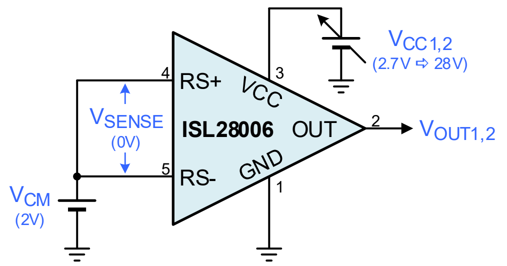

Figure 2. PSRR Bench Test Setup

1.2 Measurement Instructions

CMRR Measuring Steps:

1. Make $V_{CC} = 12V$
2. Make $V_{CM1} = 28V$
3. Measure V_{OUT1}
4. Make $V_{CM2} = 2V$
5. Measure V_{OUT2}
6. Calculate:

$$CMRR(dB) = 20\ Log_{10}\left(G \times \frac{V_{CM1} - V_{CM2}}{V_{OUT1} - V_{OUT2}}\right)$$

PSRR Measuring Steps:

1. Make $V_{CM} = 2V$
2. Make $V_{CC1} = 28V$
3. Measure V_{OUT1}
4. Make $V_{CC2} = 2.7V$
5. Measure V_{OUT2}
6. Calculate:

$$PSRR(dB) = 20\ Log_{10}\left(G \times \frac{V_{CC1} - V_{CC2}}{V_{OUT1} - V_{OUT2}}\right)$$

1.3 Test Results for ISL28006-100

CMRR Test Results

Voltage Applied:	V_{CM1} = 28.01948 V
Voltage Measured:	V_{OUT1} = 1.772mV
Voltage Applied:	V_{CM2} = 2.075959 V
Voltage Measured:	V_{OUT2} = 1.734mV
Fixed Internal Gain:	G = 100
CMRR Calculated:	CMRR = 157 dB
Min. CMRR Specified:	CMRR = 105 dB

PSRR Test Results

Voltage Applied:	V_{CC1} = 28.06254 V
Voltage Measured:	V_{OUT1} = 2.020mV
Voltage Applied:	V_{CC2} = 2.771867 V
Voltage Measured:	V_{OUT2} = 1.534mV
Fixed Internal Gain:	G = 100
PSRR Calculated:	PSRR = 134 dB
Min. PSRR Specified:	PSRR = 90 dB

2. Common-Mode Rejection Ratio, CMRR

The common-mode rejection ratio (CMRR) of a differential amplifier is a parameter that quantifies the ability of the device to reject common-mode signals, for example, those that appear simultaneously and in-phase at both inputs. An ideal differential amplifier would have an infinite CMRR. In practice, however, this is not achievable because of the slight mismatch of transistor parameters in the differential input stage.

This mismatch allows a change in common-mode voltage, ΔV_{CM}, to alter the operating points of the transistors differently, which creates a change in output voltage, ΔV_{OUT}, despite the lack of an input signal, $V_{IN} = 0$ (Figure 3). A differential amplifier therefore does amplify a small fraction of input common-mode voltage. This fraction can be modeled as an input voltage error, E_I, of the size ΔV_{CM}/CMRR. Per op-amp signal convention, this input error voltage is assigned to the non-inverting amplifier input (Figure 4).

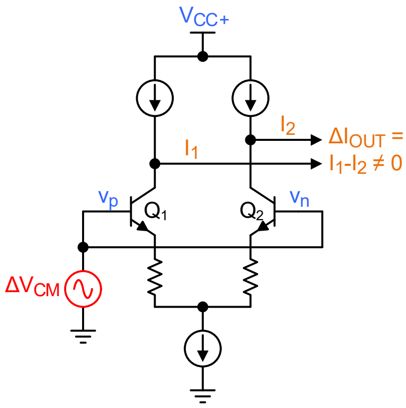

Figure 3. Differential Input Stage: ΔV_{CM} causes ΔI_{OUT} despite zero Input ($v_p = v_n$)

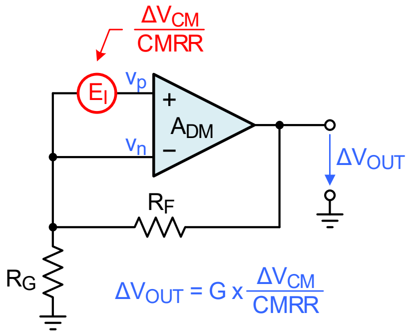

Figure 4. Practical Amplifier with Input Common-Mode Error Voltage $E_I = \Delta V_{CM}$/CMRR

(EQ. 1)
$$\Delta V_{OUT} = A_{DM}(v_p - v_n) = A_{DM}\left(\frac{\Delta V_{CM}}{CMRR} - \beta \times \Delta V_{OUT}\right) \text{ with } \beta = \frac{R_G}{R_G + R_F}$$

Then, solving for ΔV_{OUT} gives Equation 2.

(EQ. 2)
$$\Delta V_{OUT} = \frac{A_{DM}}{1 + A_{DM}} \times \frac{\Delta V_{CM}}{CMRR} = \frac{1}{1/A_{DM} + \beta} \times \frac{\Delta V_{CM}}{CMRR}$$

As the differential gain is much larger than one (A_{DM} >> 1), Equation 2 is reduced to:

(EQ. 3)
$$\Delta V_{OUT} = \frac{1}{\beta} \times \frac{\Delta V_{CM}}{CMRR} = G \times \frac{\Delta V_{CM}}{CMRR}$$

and solving for CMRR yields:

(EQ. 4)
$$CMRR = G \times \frac{\Delta V_{CM}}{\Delta V_{OUT}} = G \times \frac{V_{CM1} - V_{CM2}}{V_{OUT1} - V_{OUT2}}$$

ΔV_{CM} usually consists of two test voltages, one at the common-mode maximum (V_{CM1}), the other one at the common-mode minimum (V_{CM2}). At both test voltages, the corresponding output voltages, V_{OUT1} and V_{OUT2}, are recorded to calculate CMRR.

Although widely misused, the term CMRR only states the actual ratio of A_{DM}/A_{CM}. When expressing this ratio in dB, the correct term to be used is CMR, the common-mode rejection. Therefore:

(EQ. 5)
$$CMR(dB) = 20 \times Log_{10}\ CMRR = 20 \times Log_{10}\left(G \times \frac{V_{CM1} - V_{CM2}}{V_{OUT1} - V_{OUT2}}\right)$$

3. Power Supply Rejection Ratio, PSRR

The power supply rejection ratio (PSRR) is a parameter that quantifies the ability of an amplifier to reject changes in the power supply of the device. Similar to the common-mode phenomenon, variations in the power supply alter the operating points of the input transistors (Figure 5). Analogous to the CMRR, the PSRR can be modeled as an input error $E_I = \Delta V_S/PSRR$, which is assigned to the non-inverting input and is amplified with the non-inverting gain, $1/\beta$, (Figure 6).

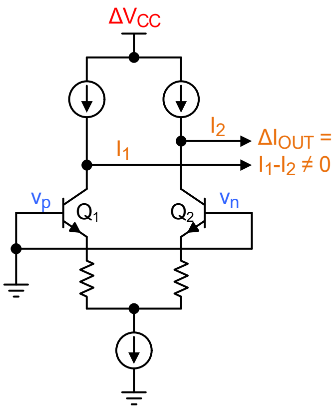

Figure 5. Differential Input Stage: ΔV_{CC} causes ΔI_{OUT} Despite Zero Input ($v_p = v_n$)

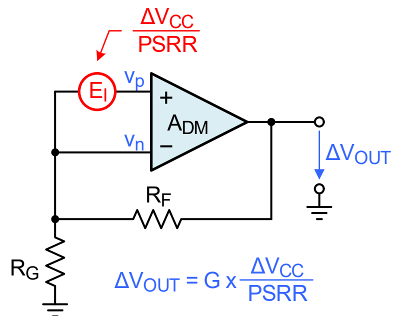

Figure 6. Practical Amplifier with Input Error Voltage because of Power Supply Variations: $E_I = \Delta V_{CC}/PSRR$

The resulting change in output voltage is derived in the same way as it is done for CMRR, although with a different input error term:

(EQ. 6)
$$\Delta V_{OUT} = G \times \frac{\Delta V_{CC}}{PSRR}$$

Then, solving for PSRR and considering two test points in form of a minimum supply, V_{CC1}, and a maximum supply, V_{CC2}, the corresponding output voltages, V_{OUT1} and V_{OUT2}, are recorded and PSRR is calculated using Equation 7.

(EQ. 7)
$$PSRR = 20 \times Log_{10}\left(G \times \frac{V_{CC1} - V_{CC2}}{V_{OUT1} - V_{OUT2}}\right)$$

4. Summary

The application note details the definition of CMRR and PSRR and how to measure both parameters. The practical measurements showed that the typical rejection ratios are more than 40dB (100x) higher than the specified minimum values in the data sheet.

5. Revision History

Revision	Date	Description
1.00	Mar 9, 2022	Initial release.

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