# MAX40016

# 4-Decade Current Sense Amplifier with Internal $R_{SENSE}$

## General Description

The MAX40016 is a very wide range current sense amplifier (CSA) with internal sense element that senses from less than 300µA to greater than 3A current range. The 4-decade sensed current functions with 1% (typical) gain error and offers three, multiplexed programmable output ranges in order to interface with 12-bit ADCs. Having an integrated sense element has the extra advantage that the entire current measuring path can be factory-trimmed, saving the user from having to calibrate independent sense resistors and CSAs. The MAX40016 drops a typical of 60mV at 3A from the voltage input to load output.

The MAX40016's integrated current-sensing element saves the space and cost of an external high-power, precision current sense resistor. The MAX40016 is offered in an ultra-tiny, 1.98mm x 1.31mm, 15-bump wafer-level package (WLP), further reducing board space.

The MAX40016 operates with a supply voltage from 2.5V to 5.5V. The device features a low-power mode in which the current-sensing element remains on, but the outputs are turned off to reduce the total supply current below 10µA (max).

The MAX40016 also includes a committed on-board amplifier with an internal gain of 1.5V/V. The MAX40016 operates over the -40°C to +125°C temperature range.

## Applications

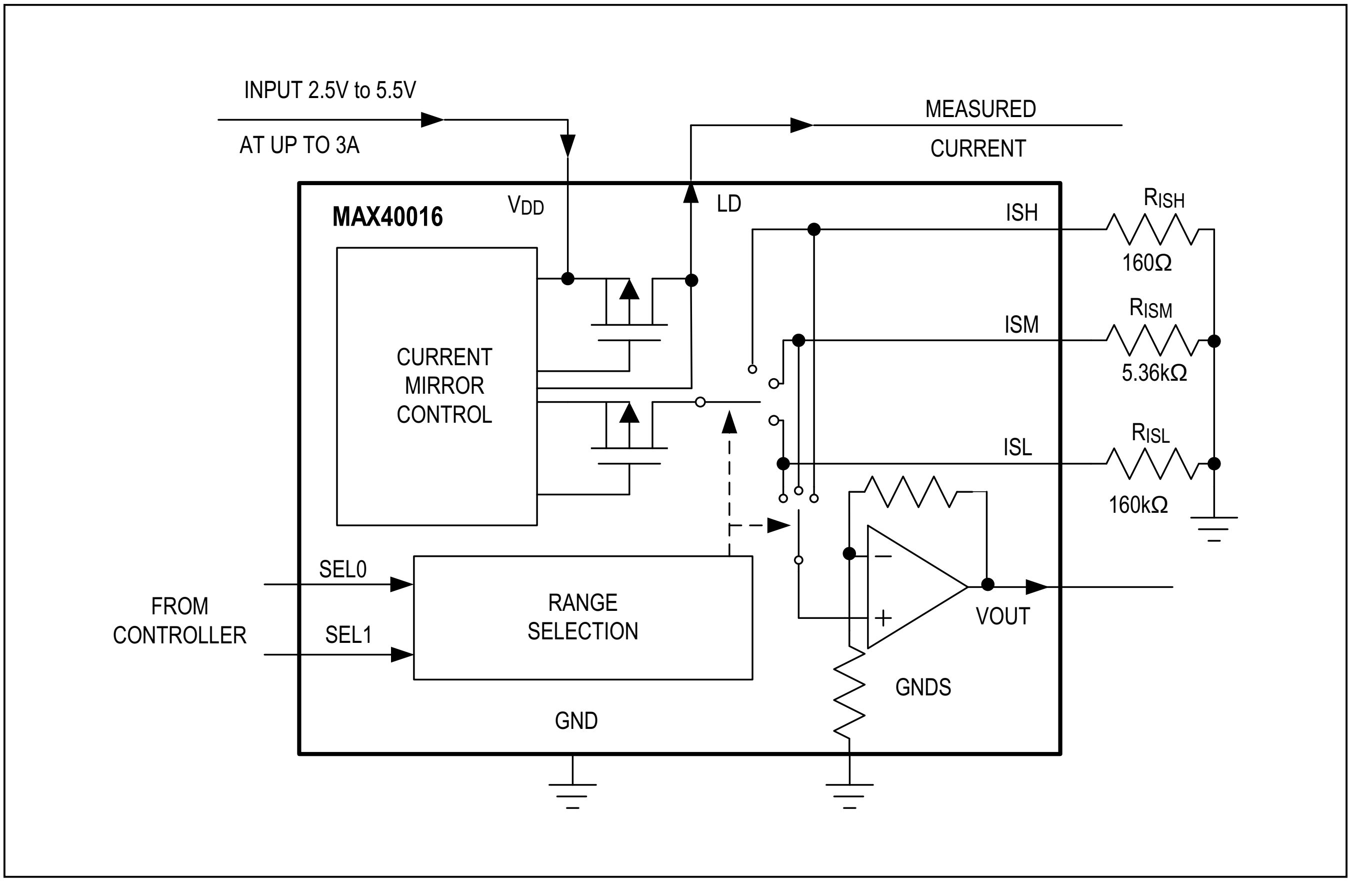
- Mobile Devices
- RF Power Monitoring
- Portable Instruments

## Benefits and Features

- Integrated Current Sense Element Saves The Space and Cost of Expensive Precision Sense Resistors
- 4-Decade Measurement Range
  - Maintains Accuracy from < 300µA to > 3A
- Withstands Overloads to 4A
- Low Voltage Drop Across Sense Element
  - 60mV (Active Mode, 3A Load)
  - 35mV (Low Power Mode, 3A Load)
- Three Multiplexed Scaling Resistor Outputs Allow Full Dynamic Range while Interfaced to 12-bit ADCs
- +2.5V to +5.5V Input Supply Voltage Range
- Low Power Mode Reduces Supply Current to 10µA Max
- Tiny 1.98mm x 1.31mm, 15-Bump, WLP
- -40°C to +125°C Operating Temperature Range

*Ordering Information appears at end of data sheet.*

## Simplified Block Diagram



## Absolute Maximum Ratings

$V_{DD}$ to GND ........................................................-0.3V to +6V
GND to GNDS ....................................................-0.3V to +0.3V
SEL0, SEL1, ISL, ISM, ISH, $V_{OUT}$ to GND ..-0.3V to $V_{DD}$+0.3V
$V_{DD}$ to LD............................................................-0.3V to 0.3V
LD to GND....................................... $V_{DD}$ - 0.3V to $V_{DD}$ + 0.3V
Maximum Current
( All pins except $V_{DD}$, LD, continuous)..........................20mA
Current from $V_{DD}$ to LD (Continuous)....................................4A
Continuous Power Dissipation (Multilayer Board) ($T_A$ = +70°C, derate 14.39mW/°C above +70°C)........................1151.2mW
Operating Temperature Range......................... -40°C to +125°C
Junction Temperature....................................................+150°C
Storage Temperature Range........................... -65°C to +150°C
Soldering Temperature (reflow).....................................+260°C

*Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

## Package Information

### 6 WLP

| PACKAGE CODE | N151B1+1 |
|---|---|
| Outline Number | 21-100213 |
| Land Pattern Number | Refer to Application Note 1891 |
| **THERMAL RESISTANCE, SINGLE-LAYER BOARD:** | |
| Junction to Ambient ($\theta_{JA}$) | 69.5°C/W |
| Junction to Ambient ($\theta_{JC}$) | N/A |

For the latest package outline information and land patterns (footprints), go to www.maximintegrated.com/packages. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to www.maximintegrated.com/thermal-tutorial.

## Electrical Characteristics

($V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10µF, SEL0 = $V_{DD}$, SEL1 = $V_{DD}$ (ISH range is selected), $T_A$ = $T_{MIN}$ to $T_{MAX}$, unless otherwise noted. Typical values are at $T_A$ = +25°C (Note 1))

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| **CURRENT SENSING** | | | | | | |
| Supply Voltage | $V_{DD}$ | Guaranteed by PSRR | 2.5 | | 5.5 | V |
| Supply Current (Active) | $I_{DD}$ | No $I_{LD}$ current, $V_{ISX}$ = 0V | | 0.8 | 1.2 | mA |
| Supply Current (Low-Power Mode) | $I_{DD\_LP}$ | Low-power mode (SEL0 = 0V, SEL1 = 0V), no $I_{LD}$ current, $V_{ISX}$ = 0V | | 5 | 10 | µA |
| Power-Up Time | | Measure at 50% of VOUT. | | 100 | | µs |
| Power Supply Rejection Ratio | PSRR | ΔGain Error/Δ$V_{DD}$, measured at ISX (Note 2) | -0.6 | +0.2 | +0.6 | %/V |

## Electrical Characteristics (continued)

($V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10μF, SEL0 = $V_{DD}$, SEL1 = $V_{DD}$ (ISH range is selected), $T_A$ = $T_{MIN}$ to $T_{MAX}$, unless otherwise noted. Typical values are at $T_A$ = +25°C (Note 1))

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| Voltage Drop ($V_{DD}$ to LD) | | Active mode, $I_{LD}$ = 3A (Note 6) | -40°C < $T_A$ < +85°C | | 60 | 90 | mV |
| | | | -40°C < $T_A$ < +125°C | | | 100 | |
| | | Active mode, $I_{LD}$ = 2A | -40°C < $T_A$ < +85°C | | 50 | 80 | |
| | | | -40°C < $T_A$ < +125°C | | | 95 | |
| | | Low power mode, $I_{LD}$ = 3A (Note 6) | -40°C < $T_A$ < +85°C | | 35 | 50 | |
| | | Low power mode, $I_{LD}$ = 3A (Note 6) | -40°C < $T_A$ < +125°C | | | 55 | |
| | | Low power mode, $I_{LD}$ = 2A | -40°C < $T_A$ < +85°C | | 23 | 35 | |
| | | Low power down mode, $I_{LD}$ = 2A | -40°C < $T_A$ < +125°C | | | 35 | |
| Current Gain | $G_I$ | $I_{ISX}/I_{LD}$, measured at ISX | | | 2 | | mA/A |
| Current Gain Error | $G_{I\_ERR}$ | $R_{ISX}$ = 160Ω, $I_{LD}$ = 3A (Note 6) | -40°C < $T_A$ < +85°C | -3.5 | +0.9 | +3.5 | % |
| | | | -40°C < $T_A$ < +125°C | -4 | | +4 | |
| | | $R_{ISX}$ = 160Ω, $I_{LD}$ = 300mA | -40°C < $T_A$ < +85°C | -3.5 | +0.9 | +3.5 | |
| | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 300mA | -40°C < $T_A$ < +125°C | -4 | | +4 | |
| | | $R_{ISX}$ = 5.36kΩ, $I_{LD}$ = 30mA | -40°C < $T_A$ < +85°C | -3.5 | +0.7 | +3.5 | |
| | | | -40°C < $T_A$ < +125°C | -4 | | +4 | |
| | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 3mA | -40°C < $T_A$ < +85°C | -6 | +1.4 | +6 | |
| | | | -40°C < $T_A$ < +125°C | -7 | | +7 | |
| | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 1mA | -40°C < $T_A$ < +85°C | -12 | +1.7 | +12 | |
| | | | -40°C < $T_A$ < +125°C | -15 | | +15 | |
| | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 300μA | -40°C < $T_A$ < +85°C | -25 | +2.8 | +25 | |
| | | | -40°C < $T_A$ < +125°C | -30 | | +30 | |
| Nonlinearity Current Gain Error | $G_{I\_ERR(NON)}$ | Measured at ISX | $R_{ISX}$ = 160Ω, $I_{LD}$ = 30mA to 3A | | 0.4 | | % |
| | | | $R_{ISX}$ = 5.36kΩ, $I_{LD}$ = 3mA to 30mA | | 0.8 | | |
| | | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 300μA to 3mA | | 1.7 | | |

## Electrical Characteristics (continued)

($V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10µF, SEL0 = $V_{DD}$, SEL1 = $V_{DD}$ (ISH range is selected), $T_A$ = $T_{MIN}$ to $T_{MAX}$, unless otherwise noted. Typical values are at $T_A$ = +25°C (Note 1))

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| CMRR_ISX (Note 3) | | Measured at ISX, 0V < $V_{ISX}$ < 1.1V | $R_{ISX}$ = 160Ω, $I_{LD}$ = 2A | | 0.02 | | %/V |
| | | | $R_{ISX}$ = 5.36kΩ, $I_{LD}$ = 100mA | | 0.02 | | |
| | | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 1mA | | 0.06 | | |
| ISX Residual Current | | $I_{LD}$ = 0 | | | 20 | | nA |
| **AMPLIFIER/DC CHARACTERISTICS** | | | | | | | |
| Typical Input Voltage | | Guaranteed by Output Amplifier Gain Error | | | 0.01 to 1.0 | | V |
| Offset Voltage | $V_{OS}$ | Input referred (Note 4) | | | 20 | | µV |
| PSRR_VOUT | | $\Delta V_{OUT}/\Delta V_{DD}$, $V_{ISX}$ = 1.0V, 2.5V < $V_{DD}$ < 5.5V | | | 0.2 | | mV/V |
| Output Amplifier Gain | $G_V$ | | | | 1.5 | | V/V |
| Output Amplifier Gain Error | $G_{V\_ERR}$ | 0.01V < $V_{ISX}$ < 1V | | -1 | +0.2 | +1 | % |
| Output Load Regulation | | $\Delta V_{OUT}/\Delta I_{OUT}$, sourcing 0 and 2mA, $V_{ISX}$ = 1.0V, | | | 0.1 | 1 | Ω |
| | | $\Delta V_{OUT}/\Delta I_{OUT}$, sinking 0 and 500µA, $V_{ISX}$ = 10mV | | | 0.1 | 1 | |
| Leakage Current Into $V_{OUT}$ (Low Power Mode) | | SEL0 = 0V, SEL1 = 0V, at $V_{OUT}$ = 1.5V | | | 5 | 100 | nA |
| Max Sink Current | | $V_{ISX}$ = 0V, $V_{OUT}$ = 1.65V, pulsed test | | | 28 | | mA |
| Max Source Current | | $V_{ISX}$ = 1.1V, $V_{OUT}$ = 0V, pulsed test | | | 28 | | mA |
| Total Transimpedance Gain | | $R_{ISX}$ connected to ISX pins | | | 0.003 x $R_{ISX}$ | | |
| Total Transimpedance Gain Error (Measured at $V_{OUT}$) | | $R_{ISX}$ = 160Ω, $I_{LD}$ = 3A (Note 6) | -40°C < $T_A$ < +85°C | -3.5 | 1 | +3.5 | % |
| | | | -40°C < $T_A$ < +125°C | -4 | | +4 | |
| | | $R_{ISX}$ = 160Ω, $I_{LD}$ = 300mA | -40°C < $T_A$ < +85°C | -3.5 | 1 | +3.5 | |
| | | | -40°C < $T_A$ < +125°C | -4 | | +4 | |
| | | $R_{ISX}$ = 5.36kΩ, $I_{LD}$ = 30mA | -40°C < $T_A$ < +85°C | -3.5 | +0.8 | +3.5 | |
| | | | -40°C < $T_A$ < +125°C | -4 | | +4 | |
| | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 3mA | -40°C < $T_A$ < +85°C | -6 | +1.5 | +6 | |
| | | | -40°C < $T_A$ < +125°C | -7 | | +7 | |
| | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 1mA | -40°C < $T_A$ < +85°C | -12 | +1.8 | +12 | |
| | | | -40°C < $T_A$ < +125°C | -15 | | +15 | |
| | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 300µA | -40°C < $T_A$ < +85°C | -25 | +3 | +25 | |
| | | | -40°C < $T_A$ < +125°C | -30 | | +30 | |

## Electrical Characteristics (continued)

($V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10μF, SEL0 = $V_{DD}$, SEL1 = $V_{DD}$ (ISH range is selected), $T_A$ = $T_{MIN}$ to $T_{MAX}$, unless otherwise noted. Typical values are at $T_A$ = +25°C (Note 1))

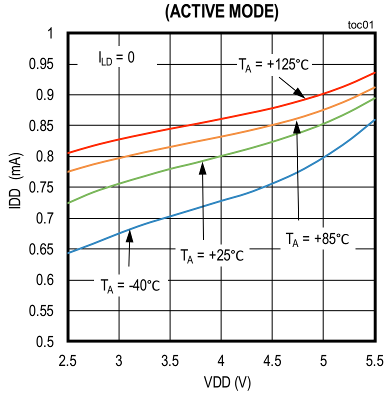
| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| Nonlinearity Total Transimpedance Gain Error (Measured at $V_{OUT}$) | | $R_{ISX}$ = 160Ω, $I_{LD}$ = 100mA to 3A | | 0.4 | | % |
| | | $R_{ISX}$ = 5.36kΩ, $I_{LD}$ = 3mA to 100mA | | 0.8 | | |
| | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 300μA to 3mA | | 1.7 | | |
| **AMPLIFIER/AC CHARACTERISTICS** | | | | | | |
| Small Signal Bandwidth | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 3mA DC and 30μ$A_{PP}$, $C_{LD}$ = 0 | | 1 | | MHz |
| | | $R_{ISX}$ = 160Ω, $I_{LD}$ = 300mA_DC and 3m$A_{PP}$, $C_{LD}$ = 0 | | 0.7 | | |
| Large Signal Bandwidth | | $R_{ISX}$ = 160Ω, $I_{LD}$ = 2A_DC and 1$A_{PP}$, $C_{LD}$ = 0 | | 300 | | kHz |
| Load Transient Response Time | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 1mA ↔ 2mA | | 220 | | μs |
| | | $R_{ISX}$ = 5.36kΩ, $I_{LD}$ = 30mA ↔ 60mA | | 70 | | μs |
| | | $R_{ISX}$ = 160Ω, $I_{LD}$ = 1A ↔ 2A | | 60 | | μs |
| Output Noise 1/f | | 0.1Hz to 10Hz | | 25 | | μ$V_{PP}$ |
| Output Integrated Noise | | 100Hz to 10kHz | | 11 | | μ$V_{RMS}$ |
| **RANGE SELECT INPUTS (SEL0, SEL1)** | | | | | | |
| Input High Level | $V_{IH}$ | SEL0 and SEL1 | 1 | | | V |
| Input Low Level | $V_{IL}$ | SEL0 and SEL1 | | | 0.5 | V |
| Input Current | $I_{IH}$ | $V_{IH}$ = $V_{VDD}$, SEL0 and SEL1 have weak pulldowns | | | 0.5 | μA |
| | $I_{IL}$ | $V_{IL}$ = 0V, SEL0 and SEL1 have weak pulldowns | | | 0.5 | |
| Low Power Mode, Sleep Delay | $t_{DIS}$ | $I_{LD}$ = 30mA (Note 5) | | 5 | | μs |
| Low Power Mode, Waking Delay | $t_{EN}$ | $R_{ISX}$ = 160Ω, $I_{LD}$ = 300mA (Note 5) | | 30 | | μs |
| | | $R_{ISX}$ = 5.36kΩ, $I_{LD}$ = 30mA (Note 5) | | 50 | | |
| | | $R_{ISX}$ = 160kΩ, $I_{LD}$ = 1mA (Note 6) | | 550 | | |
| Range Control Delay | | Measured from 50% level of SEL0 or SEL1 to the 50% rise of the ISX current | | 6 | | μs |

**Note 1:** Limits are 100% tested at $T_A$ = +25°C. Limits over the temperature range and relevant supply voltage range are guaranteed by design and characterization.
**Note 2:** ISX is any one of the ISL, ISM or ISH pins.
**Note 3:** CMRR_ISX is calculated as ($\Delta I_{ISX}$ / $I_{ISX}$) / $\Delta V_{ISX}$.
**Note 4:** Guaranteed by circuit architecture.
**Note 5:** Measured from 50% level of SEL0 or SEL1 edge to 50% reduction in the ISX current.
**Note 6:** Guaranteed by design.

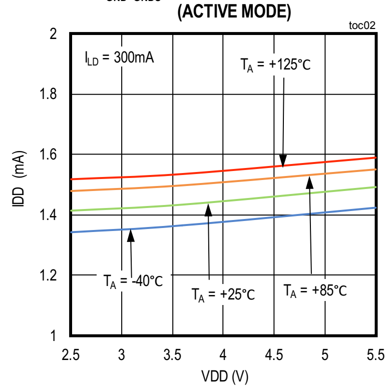
## Typical Operating Characteristics

$V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10µF, $R_{OUT}$ = 10kΩ, $C_{OUT}$ = 10pF, $R_{ISH}$ = 160Ω, $R_{ISM}$ = 5.36kΩ, $R_{ISL}$ = 160kΩ (per the MAX40016 EV kit). Typical values are at $T_A$ = +25°C, unless otherwise noted.

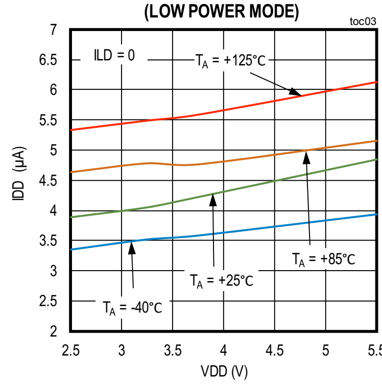
IDD vs. VDD vs. TEMPERATURE
(ACTIVE MODE)



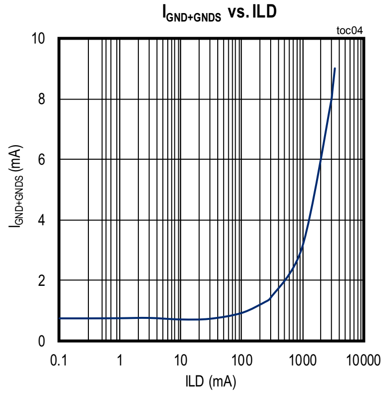

IGND+GNDS vs. VDD vs. TEMPERATURE
(ACTIVE MODE)



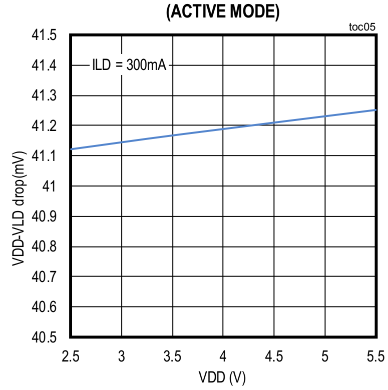

IDD vs. VDD vs. TEMPERATURE
(LOW POWER MODE)



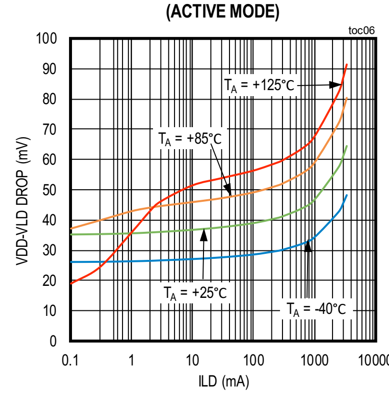

IGND+GNDS vs. ILD



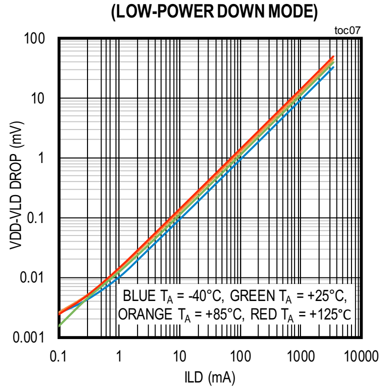

VDD-VLD DROP vs. VDD
(ACTIVE MODE)



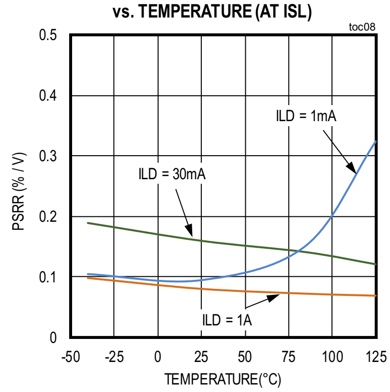

VDD-VLD DROP vs. ILD
(ACTIVE MODE)



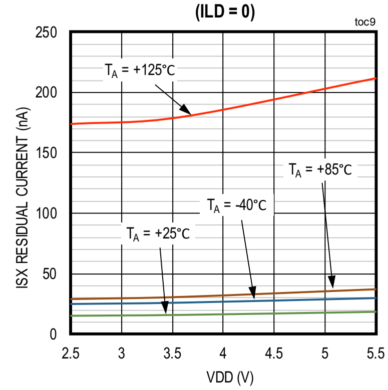

VDD-VLD DROP vs. ILD
(LOW-POWER DOWN MODE)




PSRR (ΔCURRENT GAIN ERROR/ΔVDD)
vs. TEMPERATURE (AT ISL)



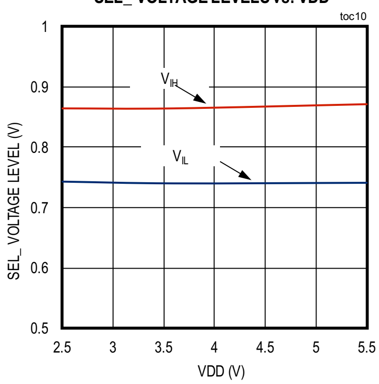

ISX RESIDUAL CURRENT vs. VDD
(ILD = 0)



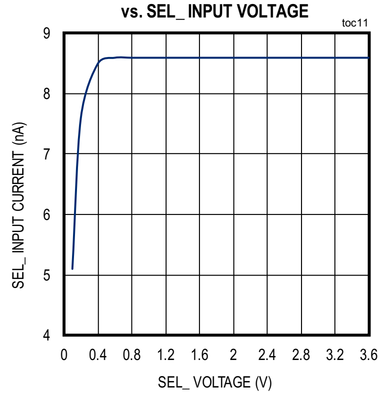
## Typical Operating Characteristics (continued)

$V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10µF, $R_{OUT}$ = 10kΩ, $C_{OUT}$ = 10pF, $R_{ISH}$ = 160Ω, $R_{ISM}$ = 5.36kΩ, $R_{ISL}$ = 160kΩ (per the MAX40016 EV kit). Typical values are at $T_A$ = +25°C, unless otherwise noted.

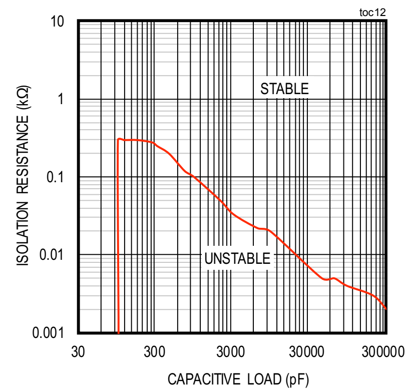
**SEL_ VOLTAGE LEVELS vs. VDD**



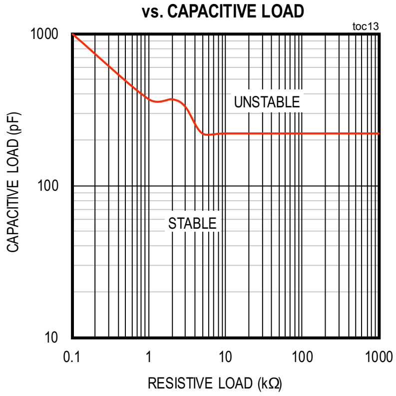

**SEL_ INPUT CURRENT vs. SEL_ INPUT VOLTAGE**



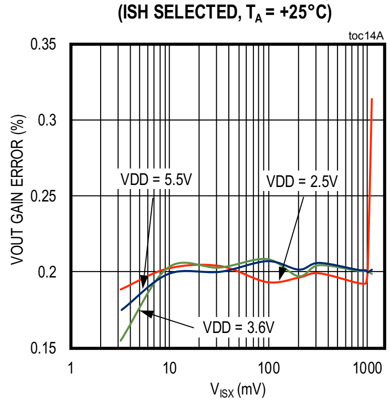

**BUFFER STABILITY vs. CAPACITIVE LOAD AND SERIES ISOLATION RESISTOR**



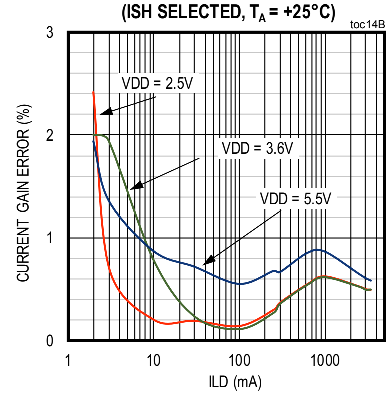

**BUFFER STABILITY RESISTIVE LOAD vs. CAPACITIVE LOAD**



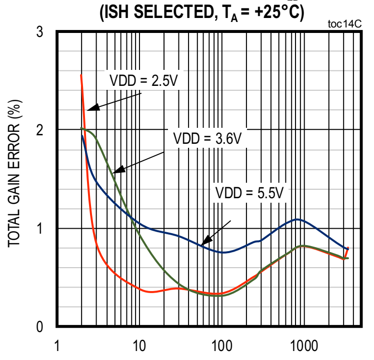

**BUFFER GAIN ERROR vs. $V_{ISX}$ (ISH SELECTED, $T_A$ = +25°C)**



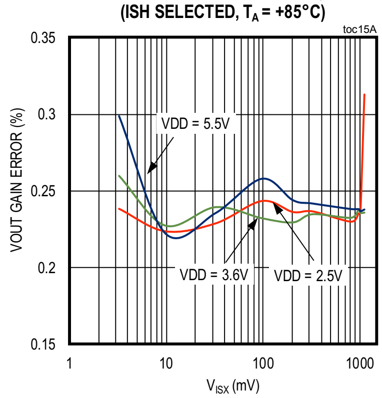

**CURRENT GAIN ERROR vs. $I_{LD}$ (ISH SELECTED, $T_A$ = +25°C)**



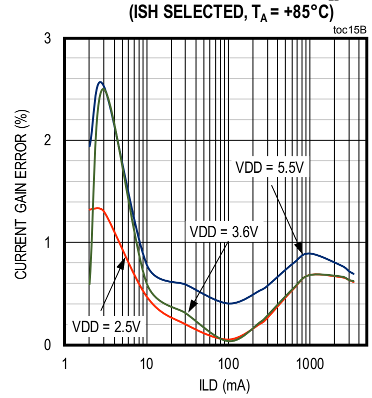

**TOTAL GAIN ERROR vs. $I_{LD}$ (ISH SELECTED, $T_A$ = +25°C)**




**BUFFER GAIN ERROR vs. $V_{ISX}$ (ISH SELECTED, $T_A$ = +85°C)**



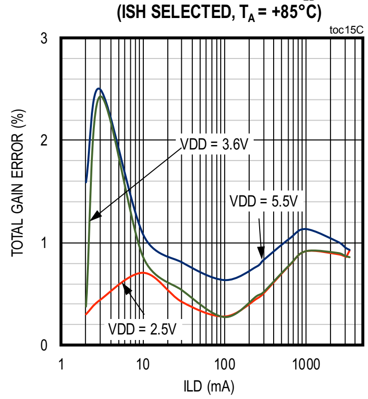

**CURRENT GAIN ERROR vs. $I_{LD}$ (ISH SELECTED, $T_A$ = +85°C)**



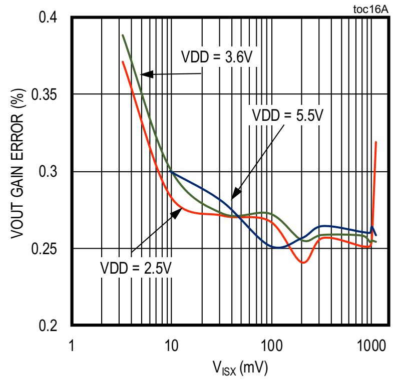
## Typical Operating Characteristics (continued)

$V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10µF, $R_{OUT}$ = 10kΩ, $C_{OUT}$ = 10pF, $R_{ISH}$ = 160Ω, $R_{ISM}$ = 5.36kΩ, $R_{ISL}$ = 160kΩ (per the MAX40016 EV kit). Typical values are at $T_A$ = +25°C, unless otherwise noted.

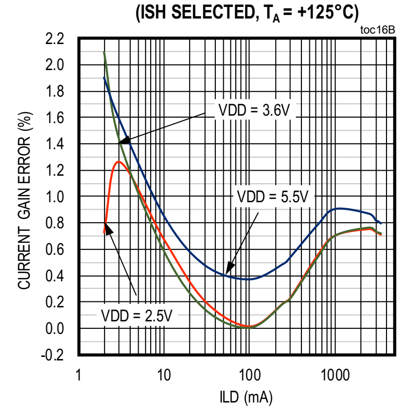
**TOTAL GAIN ERROR vs. $I_{LD}$ (ISH SELECTED, $T_A$ = +85°C)**



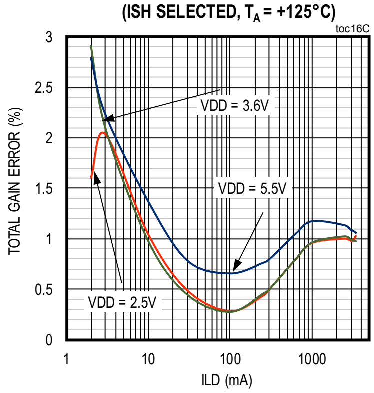

**BUFFER GAIN ERROR vs. $V_{ISX}$ (ISH SELECTED, $T_A$ = +125°C)**



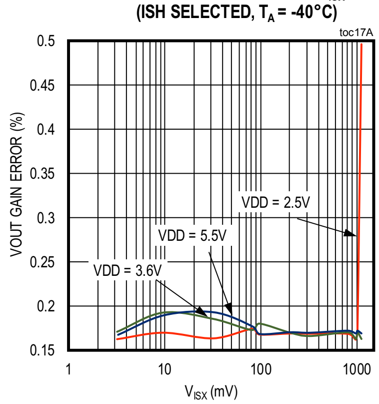

**CURRENT GAIN ERROR vs. $I_{LD}$ (ISH SELECTED, $T_A$ = +125°C)**



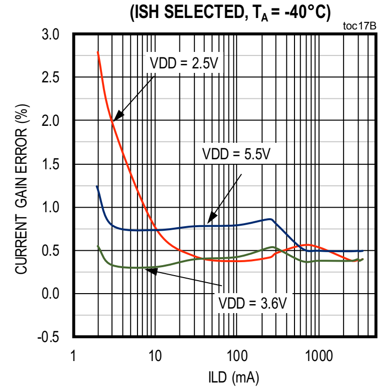

**TOTAL GAIN ERROR vs. $I_{LD}$ (ISH SELECTED, $T_A$ = +125°C)**



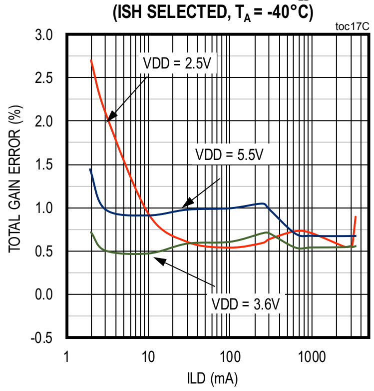

**BUFFER GAIN ERROR vs. $V_{ISX}$ (ISH SELECTED, $T_A$ = -40°C)**



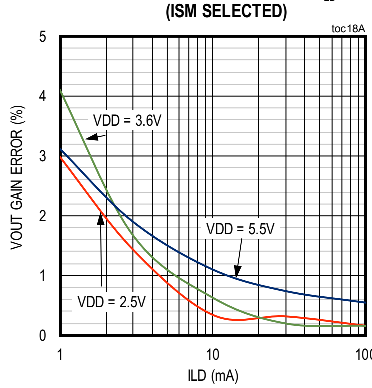

**CURRENT GAIN ERROR vs. $I_{LD}$ (ISH SELECTED, $T_A$ = -40°C)**



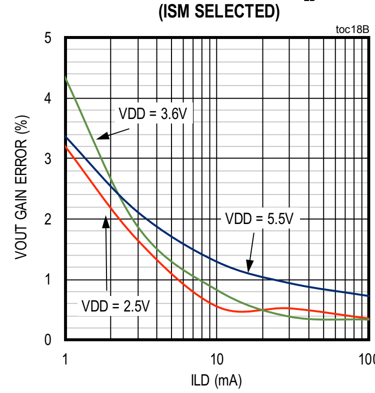

**TOTAL GAIN ERROR vs. $I_{LD}$ (ISH SELECTED, $T_A$ = -40°C)**




**CURRENT GAIN ERROR vs. $I_{LD}$ (ISM SELECTED)**

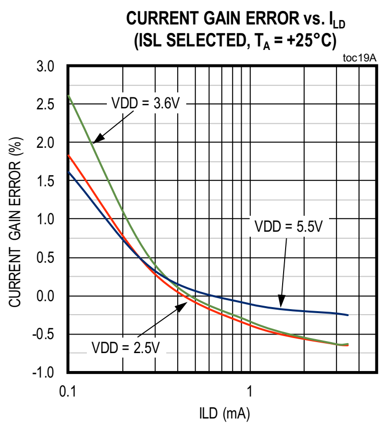


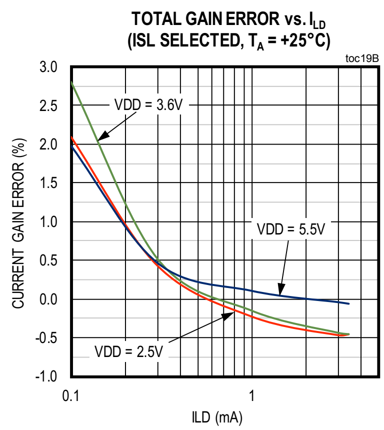

**TOTAL GAIN ERROR vs. $I_{LD}$ (ISM SELECTED)**

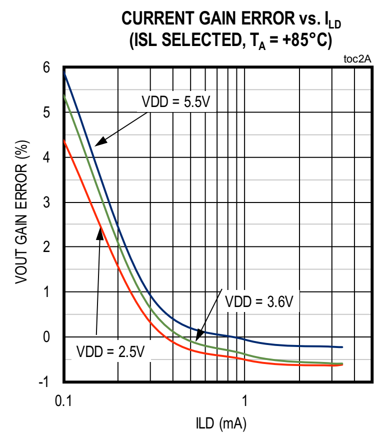


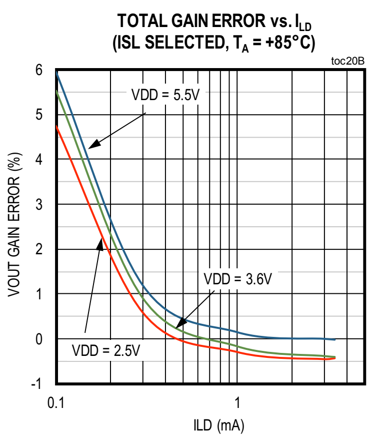
## Typical Operating Characteristics (continued)

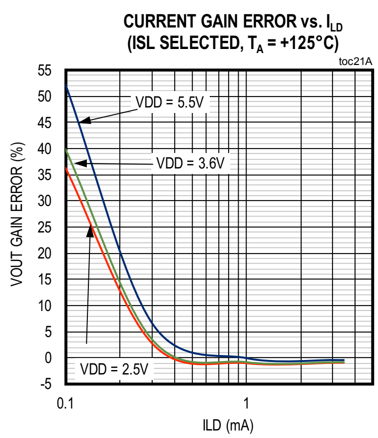
$V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10µF, $R_{OUT}$ = 10kΩ, $C_{OUT}$ = 10pF, $R_{ISH}$ = 160Ω, $R_{ISM}$ = 5.36kΩ, $R_{ISL}$ = 160kΩ (per the MAX40016 EV kit). Typical values are at $T_A$ = +25°C, unless otherwise noted.

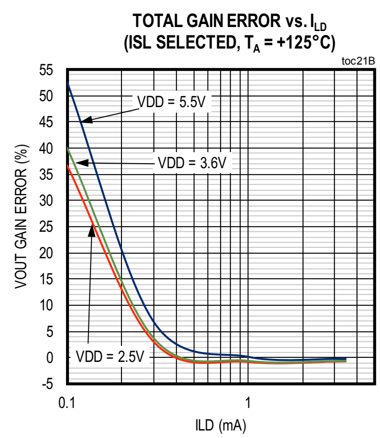


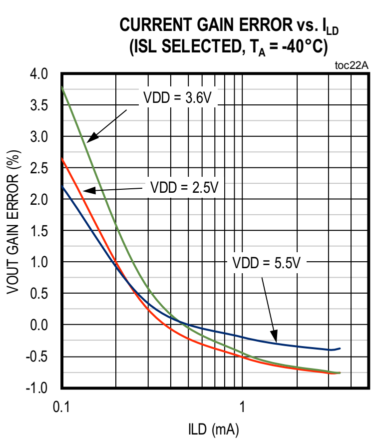



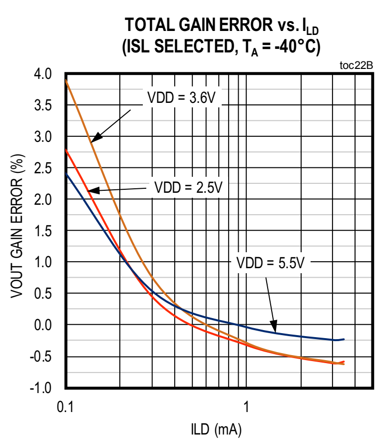



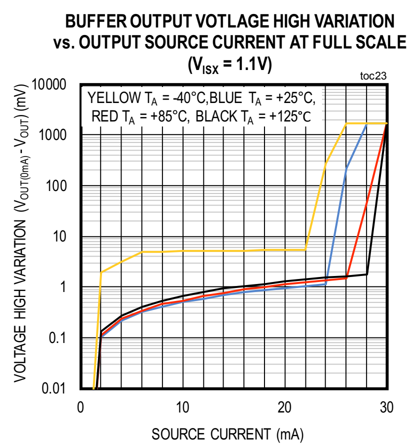



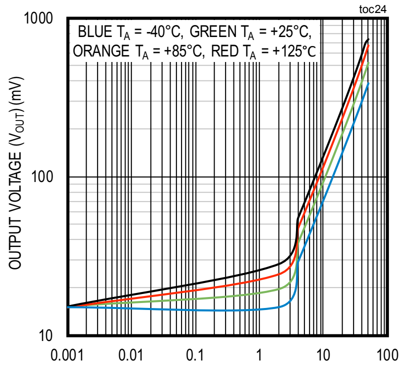



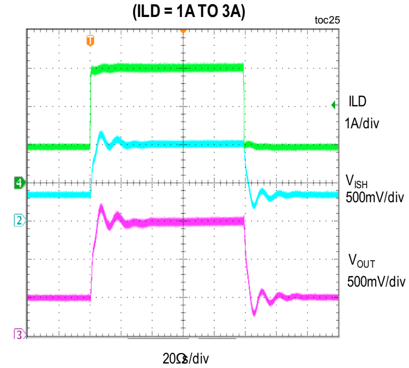
## Typical Operating Characteristics (continued)

$V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10µF, $R_{OUT}$ = 10kΩ, $C_{OUT}$ = 10pF, $R_{ISH}$ = 160Ω, $R_{ISM}$ = 5.36kΩ, $R_{ISL}$ = 160kΩ (per the MAX40016 EV kit). Typical values are at $T_A$ = +25°C, unless otherwise noted.

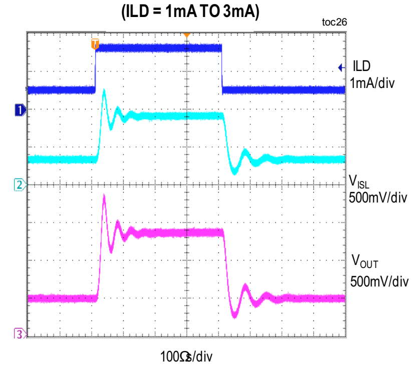
BUFFER OUTPUT VOTLAGE LOW vs. OUTPUT SINK CURRENT ($V_{ISX}$ = 10mV)



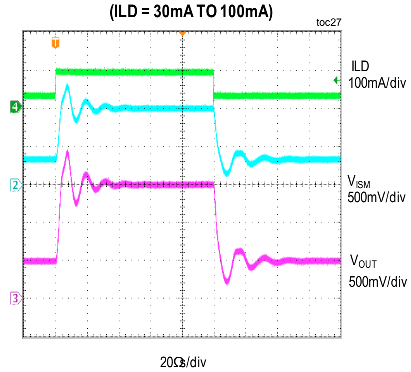

ISH LOAD TRANSIENT RESPONSE (ILD = 1A TO 3A)



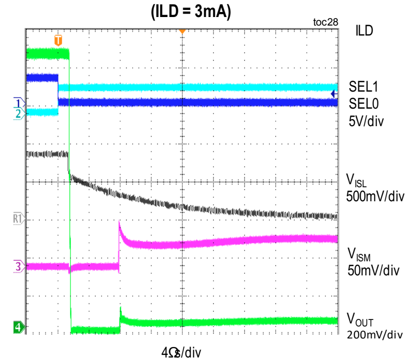

ISL LOAD TRANSIENT RESPONSE (ILD = 1mA TO 3mA)



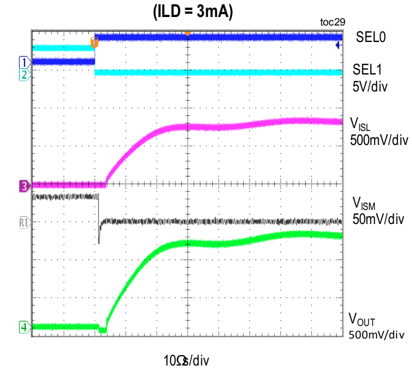

ISM LOAD TRANSIENT RESPONSE (ILD = 30mA TO 100mA)



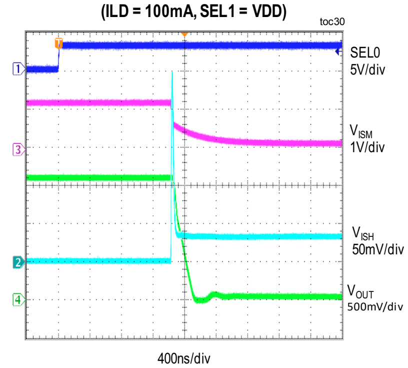

ISL-TO-ISM RANGE-SWITCH RESPONSE (ILD = 3mA)



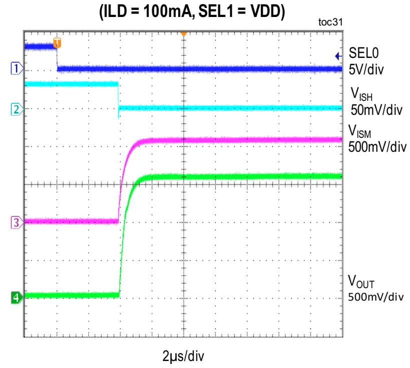

ISM-TO-ISL RANGE-SWITCH RESPONSE (ILD = 3mA)



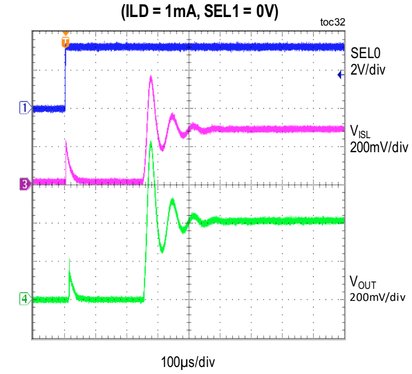

ISM-TO-ISH RANGE-SWITCH RESPONSE (ILD = 100mA, SEL1 = VDD)




ISH-TO-ISM RANGE-SWITCH RESPONSE (ILD = 100mA, SEL1 = VDD)



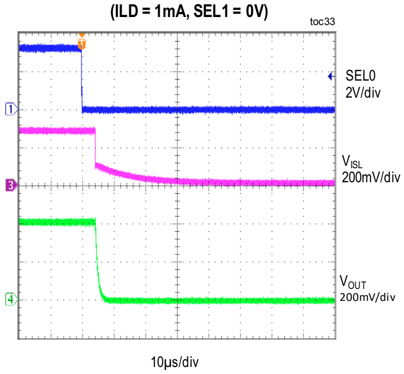

ISL ENABLE DELAY (ILD = 1mA, SEL1 = 0V)



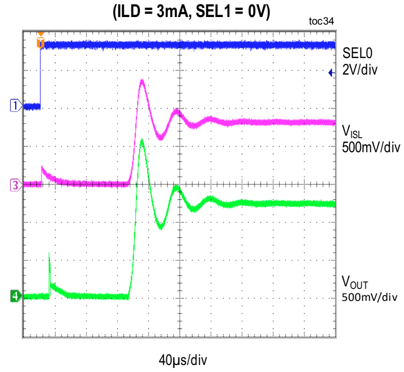
## Typical Operating Characteristics (continued)

$V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10µF, $R_{OUT}$ = 10kΩ, $C_{OUT}$ = 10pF, $R_{ISH}$ = 160Ω, $R_{ISM}$ = 5.36kΩ, $R_{ISL}$ = 160kΩ (per the MAX40016 EV kit). Typical values are at $T_A$ = +25°C, unless otherwise noted.

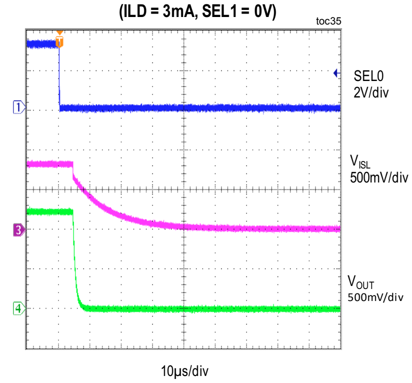
ISL DISABLE DELAY
(ILD = 1mA, SEL1 = 0V)



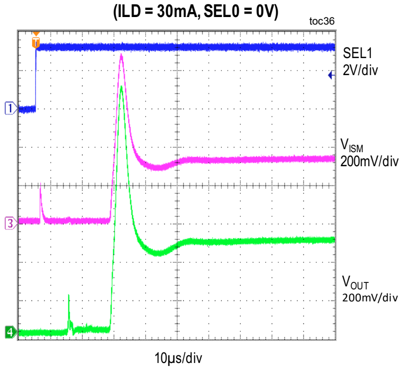

ISL ENABLE DELAY
(ILD = 3mA, SEL1 = 0V)



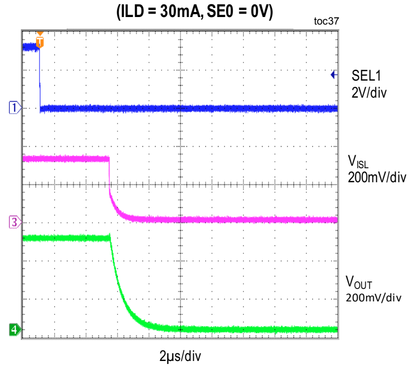

ISL DISABLE DELAY
(ILD = 3mA, SEL1 = 0V)



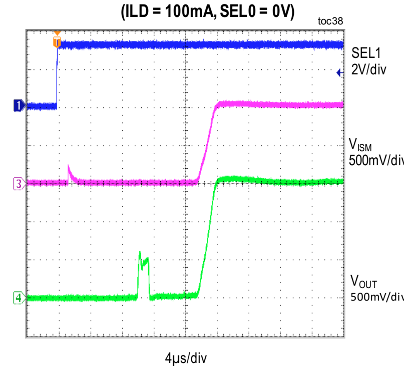

ISM ENABLE DELAY
(ILD = 30mA, SEL0 = 0V)



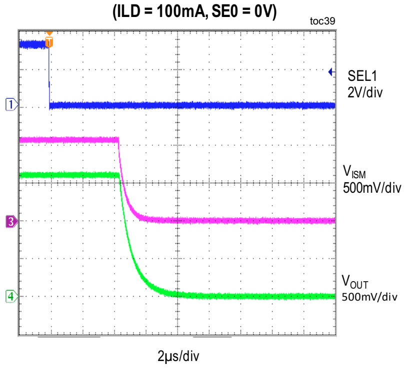

ISM DISABLE DELAY
(ILD = 30mA, SE0 = 0V)



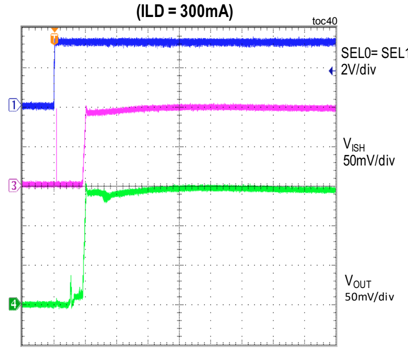

ISM ENABLE DELAY
(ILD = 100mA, SEL0 = 0V)



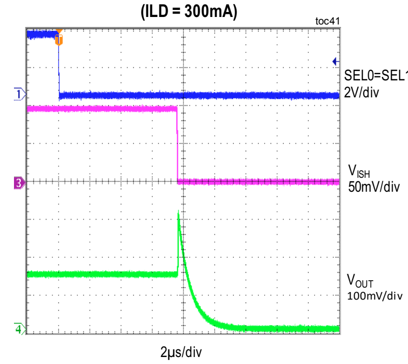

ISM DISABLE DELAY
(ILD = 100mA, SE0 = 0V)




ISH ENABLE DELAY
(ILD = 300mA)



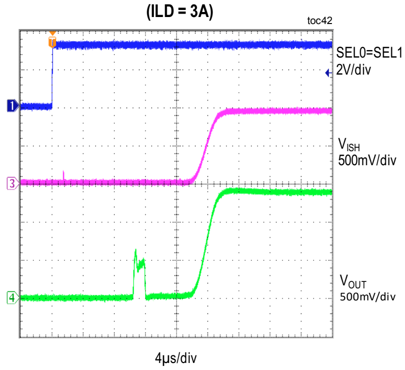

ISH DISABLE DELAY
(ILD = 300mA)



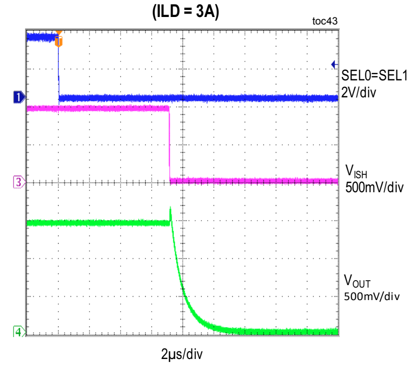
## Typical Operating Characteristics (continued)

$V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10µF, $R_{OUT}$ = 10kΩ, $C_{OUT}$ = 10pF, $R_{ISH}$ = 160Ω, $R_{ISM}$ = 5.36kΩ, $R_{ISL}$ = 160kΩ (per the MAX40016 EV kit). Typical values are at $T_A$ = +25°C, unless otherwise noted.

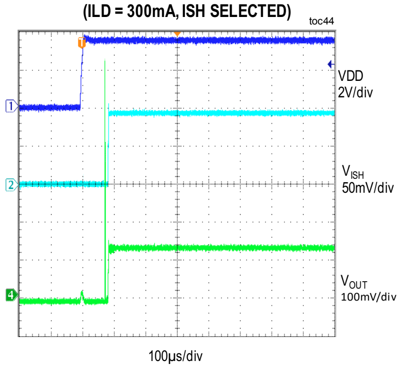
ISH ENABLE DELAY (ILD = 3A)



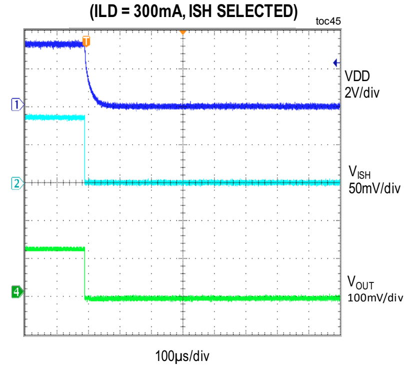

ISH DISABLE DELAY (ILD = 3A)



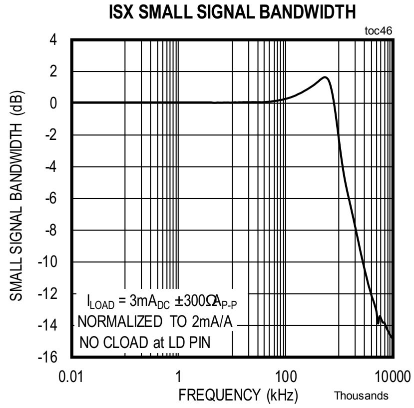

POWER-UP TIME (ILD = 300mA, ISH SELECTED)



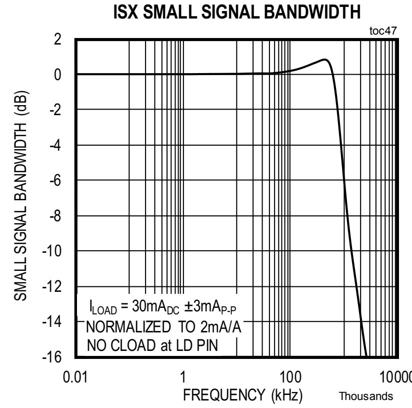

POWER-DOWN TIME (ILD = 300mA, ISH SELECTED)




ISX SMALL SIGNAL BANDWIDTH

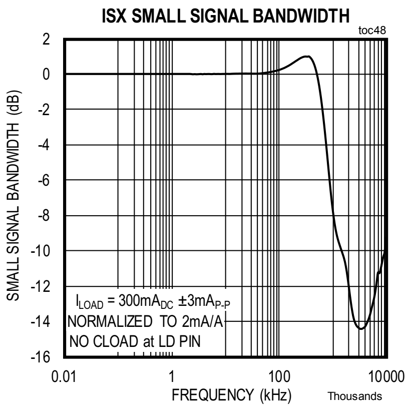


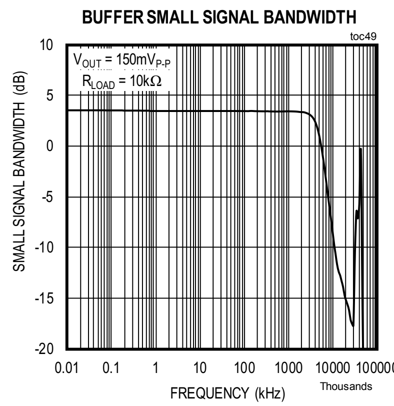

ISX SMALL SIGNAL BANDWIDTH

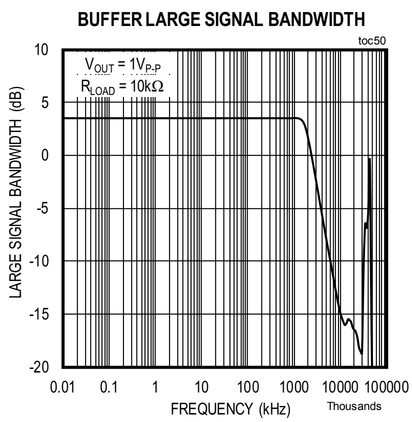


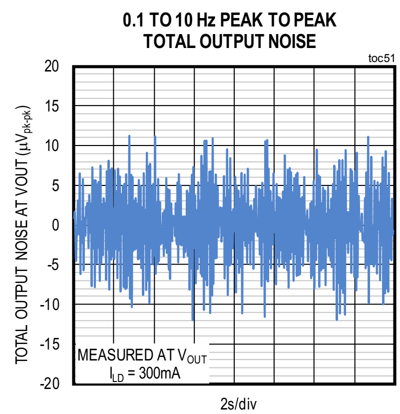
## Typical Operating Characteristics (continued)

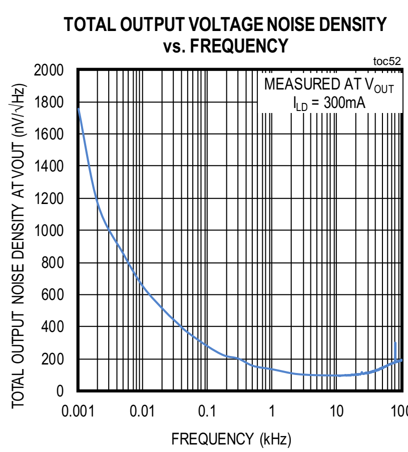
$V_{DD}$ = 3.6V, $I_{LD}$ = 300mA, $C_{LD}$ = 10µF, $R_{OUT}$ = 10kΩ, $C_{OUT}$ = 10pF, $R_{ISH}$ = 160Ω, $R_{ISM}$ = 5.36kΩ, $R_{ISL}$ = 160kΩ (per the MAX40016 EV kit). Typical values are at $T_A$ = +25°C, unless otherwise noted.



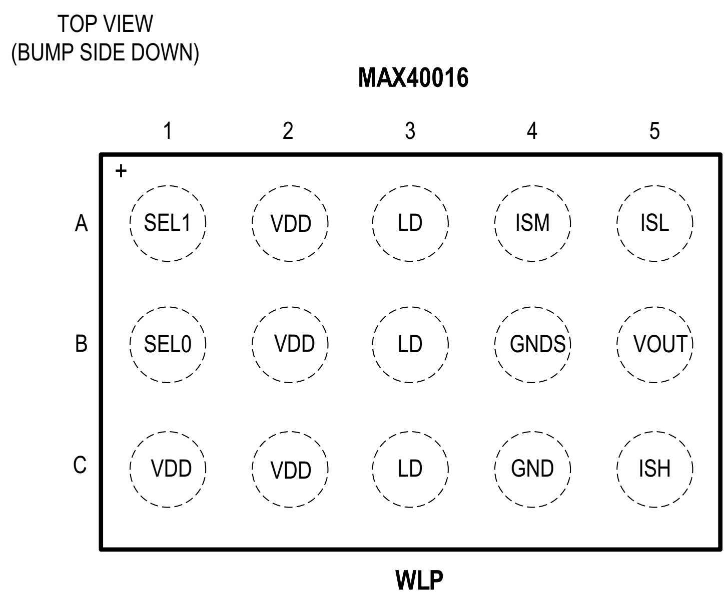



## Pin Configuration




## Pin Description

| PIN | NAME | FUNCTION |
|---|---|---|
| C1, A2, B2, C2 | $V_{DD}$ | Device $V_{DD}$ Supply and Measured Current Input. Bypass $V_{DD}$ to GND with a 0.1μF and a 10μF ceramic capacitors in parallel as close to the device as possible. |
| A3, B3, C3 | LD | Measured Current Output. Connect LD to the load side. Bypass LD to GND with a 10μF ceramic capacitor. |
| C5 | ISH | High Current Range Output. Connect a resistor from ISH to GND to scale the $V_{OUT}$ range. |
| A4 | ISM | Middle Current Range Output. Connect a resistor from ISM to GND to scale the $V_{OUT}$ range. |
| A5 | ISL | Low Current Range Output. Connect a resistor from ISL to GND to scale the $V_{OUT}$ range. |
| B4 | GNDS | Ground. Return of the output amplifier's gain setting network. Connect GNDS to GND. |
| C4 | GND | Circuit Ground. All signals are referenced to GND. |
| B1 | SEL0 | Logic Selection Input 0 (see Table 1). |
| A1 | SEL1 | Logic Selection Input 1 (see Table 1). |
| B5 | $V_{OUT}$ | Amplifier Output Voltage. $V_{OUT}$ is proportional to the $V_{DD}$ to $I_{LD}$ current. The scaling factor depends on the resistor values on the ISL, ISM, and ISH inputs. |

## Detailed Description

The MAX40016 CSA contains an integrated current-sensing element saving the space and cost of an external sense resistor. Having an integrated sense element has the extra advantage that the entire current measuring path can be factory trimmed, saving the user from having to calibrate independent sense resistors and CSAs.

The CSA has a low power mode in which the current-sensing element remains on, but the output and internal circuitry are turned off to bring the total supply current well below 10μA. In this mode, the pass element is turned fully on and will therefore drop slightly less voltage than while it is measuring current. Low power mode is selected by applying a logic-low to both SEL0 and SEL1 (see Table 1).

Three multiplexed scaling outputs from the wide range CSA allow the use of different scaling resistors so that a 12-bit ADC can be sufficient with simple resistor range selection. If only one output is used, an ADC with at least 15 bits of resolution will be needed to realize the full dynamic range of the CSA. See the applications section for details. Each of the scaled outputs are available as a voltage from the $V_{OUT}$ pin.

The $V_{OUT}$ amplifier output is capable of driving a wide range of ADCs and has a gain of 1.5V/V to provide a full-scale of 1.5V. Most of the values shown in this document are for a full-scale output of 1.5V, suited for 1.8V controllers with embedded 10 to 16-bit ADCs.

The MAX40016 senses from less than 300μA to greater than 3A current range. The output maintains less than 5% error specification over a 10,000:1 ratio. In theory, this requires an ADC with a resolution exceeding 13 bits to realize its full dynamic range. While such ADCs are readily available, the system microcontroller already has an embedded 12-bit ADC in many cases.

The three multiplexed scaling current outputs from MAX40016 allow the span to be divided into three ranges that are well within a lower-resolution ADC's capability. Note that it is the same current that is switched to one of the three outputs at a time. The ISH, ISM and ISL pin names are mainly to indicate which output pin is selected. The MAX40016 has its ranges selected using the SEL0 and SEL1 pins. See *Current Sense Range Selection (SEL0, SEL1)* section and (Table 1) for all the modes.

### Scaling Resistors

The multiplexed scaling resistors' values ($R_{ISH}$, $R_{ISM}$, $R_{ISL}$) should be chosen to suit the ADC's full-scale, usually defined by its reference voltage ($V_{REF}$). Care should be taken to account for all tolerances to avoid overloading the ADC. The typical current from the MAX40016's ISL, or ISM, or ISH pin is specified as 2mA/A. The internal amplifier has a gain of 1.5V/V. Resistors of 0.1% are readily available and so the nominal resistance value is given by:

$$R_{ISX} = \frac{VREF / 1.5}{\left(I_{FS} \times 0.002\right)} \ (\Omega)$$

The $R_{ISX}$ determined from the above equation, where the voltage across the scaling resistor should be limited to 1V, which corresponds to 1.5V full-scale after the amplifier. The closest E192 available value is 167Ω which gives very little over-current margin. A 160Ω $R_{ISX}$ value offers a little more margin towards a conservative design.

### Current Sense Range Selection (SEL0, SEL1)

SEL0 and SEL1 are digital inputs decoded to control the mirroring of the sense current on the $V_{DD}$ to LD path to one of three scaled current outputs (ISH, ISM, or ISL), as shown in Table 1. When both SEL0 and SEL1 are at logic 0, the MAX40016 enters its low power operating mode.

## Table 1. Current Sense Range Selection

| SEL0 | SEL1 | OPERATING MODE/RANGE |
|---|---|---|
| 0 | 0 | Low Power Mode is Enabled. $V_{OUT}$ is high impedance. In low power mode, the current-sensing element still passes current just as an external sense resistor would. There is no capability to turn off the current. |
| 0 | 1 | Middle Current Sense Range (ISM) is Enabled. The resistor $R_{ISM}$ connected at this current output terminal defines the full-scale voltage of 1V to the internal amplifier. |
| 1 | 0 | Low Current Sense Range (ISL) is Enabled. The resistor $R_{ISL}$ connected at this current output terminal defines the full-scale voltage of 1V to the internal amplifier. |
| 1 | 1 | High Current Sense Range (ISH) is Enabled. The resistor $R_{ISH}$ connected at this current output terminal defines the full-scale voltage of 1V to the internal amplifier. |

**Note:** *ISL, ISM, ISH can support all current range from low end to high end. The only difference is that they are selected by different SEL0/SEL1 combination.*

### Low Power Mode

The MAX40016 has a low power mode that is activated by pulling both SEL0 and SEL1 low. In this mode, all of the internal circuitry is shut down to save power. The output amplifier is placed in a high impedance state to allow multiplexing of the output line with another MAX40016 for example. In low power mode, the current-sensing element still passes current just as an external sense resistor would. There is no capability to turn off the current.

### ISX Residual Current

When at no load current ($I_{LD}$ = 0), there is a small internal residual current at ISX pin due to the internal current mirror block mechanism. This residual current is not an offset current and should not have effect when there is a load current being sensed. Refer to *Typical Operating Characteristics* for the typical information of this residual current over the the temperature range and $V_{DD}$ supply voltage range.

### Device Power Up

Initially, the MAX40016 powers up in low power mode, regardless of the state of SEL0 and SEL1. After the power-up delay time (100μs), the part reverts to the mode selected by SEL0 and SEL1.

## Applications Information

### ESD Clamps

The diagram shows the internal ESD clamping diodes that protect the MAX40016 against electrostatic discharge.

### Power Supplies and Bypassing

The MAX40016 operates from single supply voltage +2.5V to +5.5V. The $V_{DD}$ supply input is also the measured current input terminal. Pay extra attention to bypassing and grounding the MAX40016. Peak supply and measured output currents may exceed 3A when the load side experiences large current transients with large external capacitive loads. Supply drops and ground shifts may degrade the device performance. Ground shifts due to insufficient device grounding may also disturb other circuits sharing the same AC ground return path. Any series inductance in the $V_{DD}$, LD and/or GND paths can cause oscillations due to the very high di/dt when switching the MAX40016 with any capacitive load. Bypass $V_{DD}$ supply to ground with a 0.1μF in parallel with a 10μF ceramic capacitors as close as possible to the device. Bypass the measured current output, LD terminal, with a 10μF ceramic capacitor or larger depending on the sensing load current, additional bypassing may be needed to keep the device stable during large load output transitions.

### Layout Guidelines

Due to the high currents that may flow through the integrated sensing element based on the application, take care to eliminate solder and parasitic trace resistance from causing errors. Using thicker copper in the PCB construction for these high currents is recommended. Use of Kelvin (force and sense) PCB layout techniques or use of a multilayer PCB with separate ground, power supply and load planes is recommended for noisy digital environments (see the MAX40016EVKIT# data sheet for a layout example). Keep digital signals far away from the sensitive analog inputs. Unshielded long traces at the input and output sense terminals of the device can degrade performance due to noise pick-up.

## Application Information

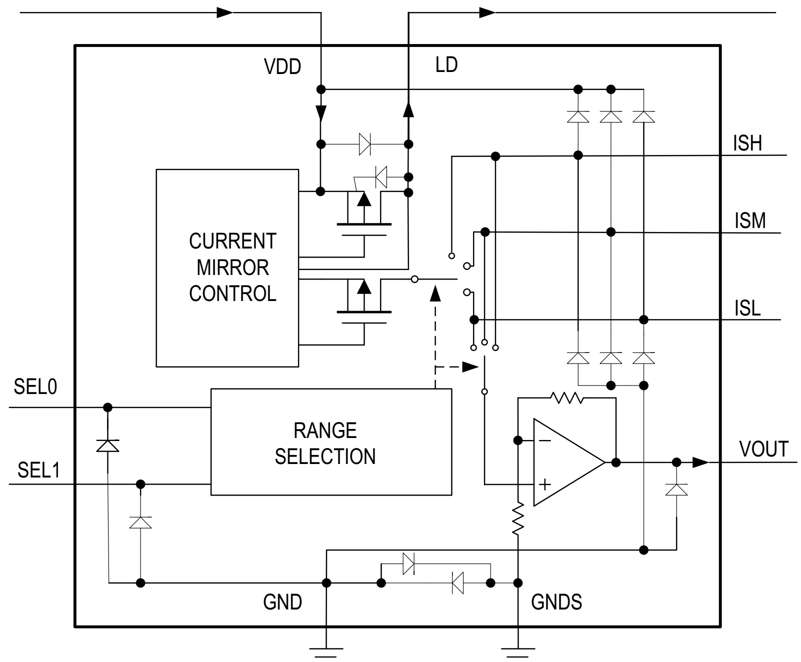



*Figure 1. Functional Diagram Showing ESD Clamps*

## Typical Application Circuits

When the chosen ADC has sufficient resolution to handle the MAX40016 full dynamic range (4-decade of sensing range), only the $R_{ISH}$ resistor is required (Figure 2). For a full-scale of 3A the value of $R_{ISH}$ is 160Ω for a 1V full-scale at the ISH pin, which corresponds to 1.5V output at $V_{OUT}$.

Determining the nominal value of $R_{ISH}$:

The amplifier has a nominal gain of 1.5V/V and the output full-scale voltage is optimized to be 1.5V. So the full-scale voltage across $R_{ISH}$ is 1V.

The current division factor $F_{DV}$ (from sensing channel to ISH) is 500 (i.e., 2mA/A).

The full-scale sensed current ($I_{FS}$) is divided by $F_{DV}$ and the divided current flows through $R_{ISH}$.

Thus, $I_{RSH} = I_{FS}/F_{DV}$, giving $R_{ISH} = F_{DV}/I_{FS}$.

Example #1: Using a MAX11214 (24-bit at 64ksps).

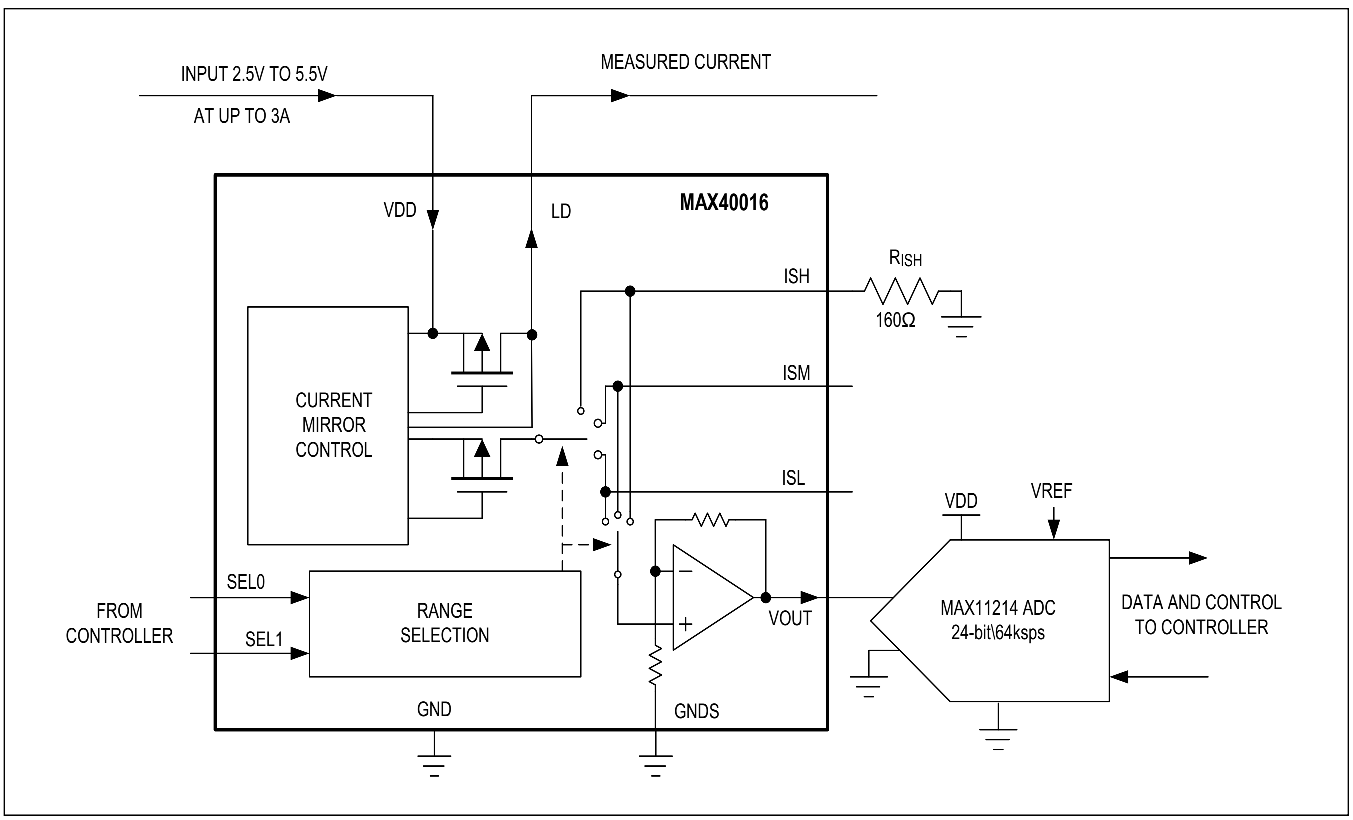



*Figure 2. Using the MAX40016 with MAX11214 24-Bit, 64ksps ADC (Single Scaling Resistor with Internal Buffer)*

The high sampling rate of the MAX11214 renders an anti-aliasing filter unnecessary. Only the $R_{ISH}$ resistor is needed to define the gain and the internal programmable gain amplifier inside the ADC allows the selection of reference voltages to match with the 1.5V full-scale from MAX40016. Alternatively, the MAX40016's output buffer can be bypassed and the ADC can be connected directly to the ISH pin, to read the voltage across $R_{ISH}$ directly (see Figure 3). If the PCB layout requires a long distance between the MAX40016 and the ADC, the current output from ISH should be run across the PCB and the $R_{ISH}$ terminating resistor placed as close as possible to the ADC's input. This helps reduce errors caused by voltage drops across the PCB.

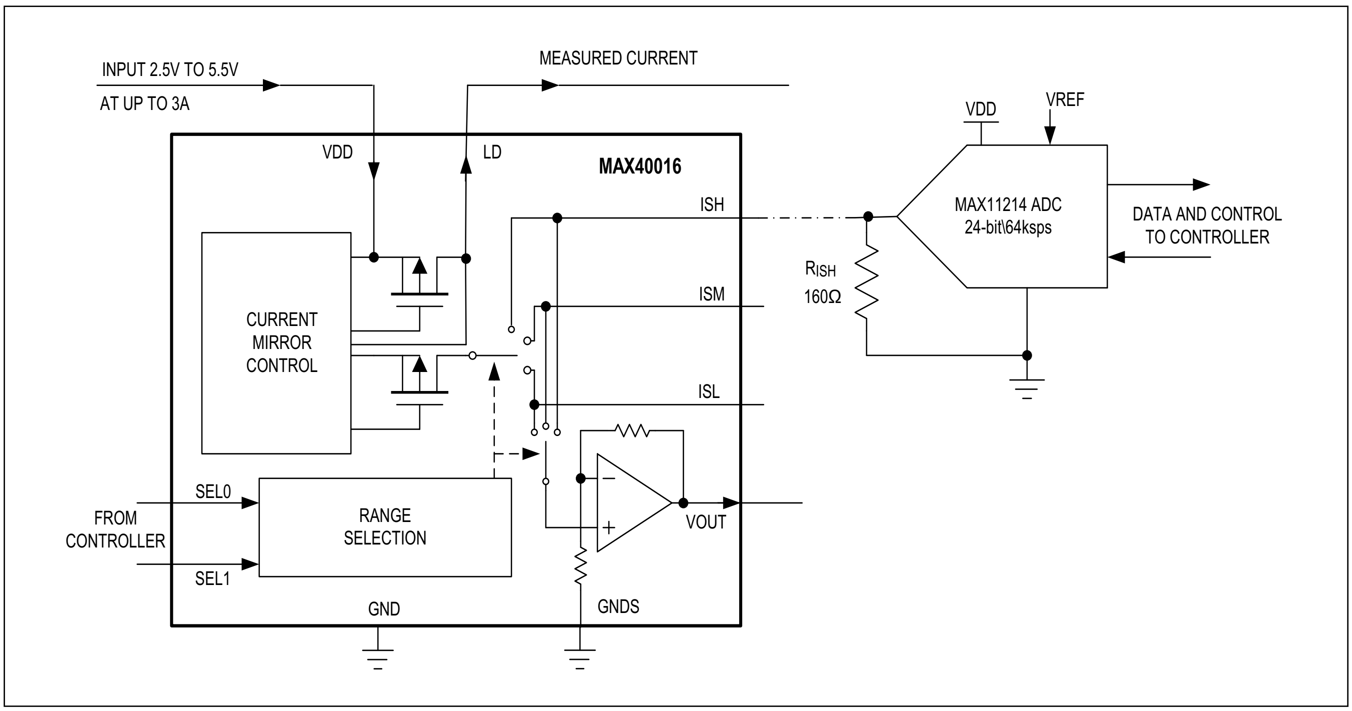



*Figure 3. Using the MAX40016 with MAX11214 24-Bit, 64ksps ADC (Single Scaling Resistor without Internal Buffer)*

### Implementation with Lower Resolution ADCs

When two or three ranges are required, as in the case of a 10-bit to 12-bit ADC, the higher range resistor ($R_{ISH}$) is calculated as described above. Calculating $R_{ISM}$ and or $R_{ISL}$ follows the same method with the only difference being the full-scale current is now the lower-range full-scale current. Exactly where it is optimum to arrange this current will depend on the system. Typically splitting the ranges in the region of 30:1 is suitable for most applications. Using $R_{ISH}$ = 160Ω, $R_{ISM}$ = 5.3kΩ and $R_{ISL}$ = 160kΩ to split the range up equally (Figure 4). However, this range transition value can be chosen such that the most commonly expected readings would have the better resolution. Selecting too low a transition point leads to more, presumably unnecessary, quantization noise in the higher range.

Example #2: Using an Embedded 12-bit ADC

While typical values for $R_{IN}$, $C_{IN}$, and $T_{ACQ}$ are 250Ω, 26pF and 350ns these values will vary for different ADCs. Care should be taken to keep all stray capacitance to a minimum.

When the ADC starts its acquisition phase, it suddenly loads the amplifier with $C_{IN}$ through $R_{IN}$. In cases where this loading causes the amplifier's output to ring, an impedance matching filter, $R_F$ and $C_F$ may be needed. These components' values should be kept low since they add to the total settling time. Note that Voltage at ISH, ISM, ISL pins should not exceed 1.1V for proper operation (see *Input Voltage Range Under Amplifier* section of the Electrical Characteristics table).

## Ordering Information

| PART | TEMP RANGE | PIN-PACKAGE | TOP MARK |
|---|---|---|---|
| MAX40016ANL+T | -40°C to +125°C | 15 WLP | +AAB |

*+Denotes a lead(Pb)-free/RoHS-compliant package.*
*T = Denotes tape-and-reel.*

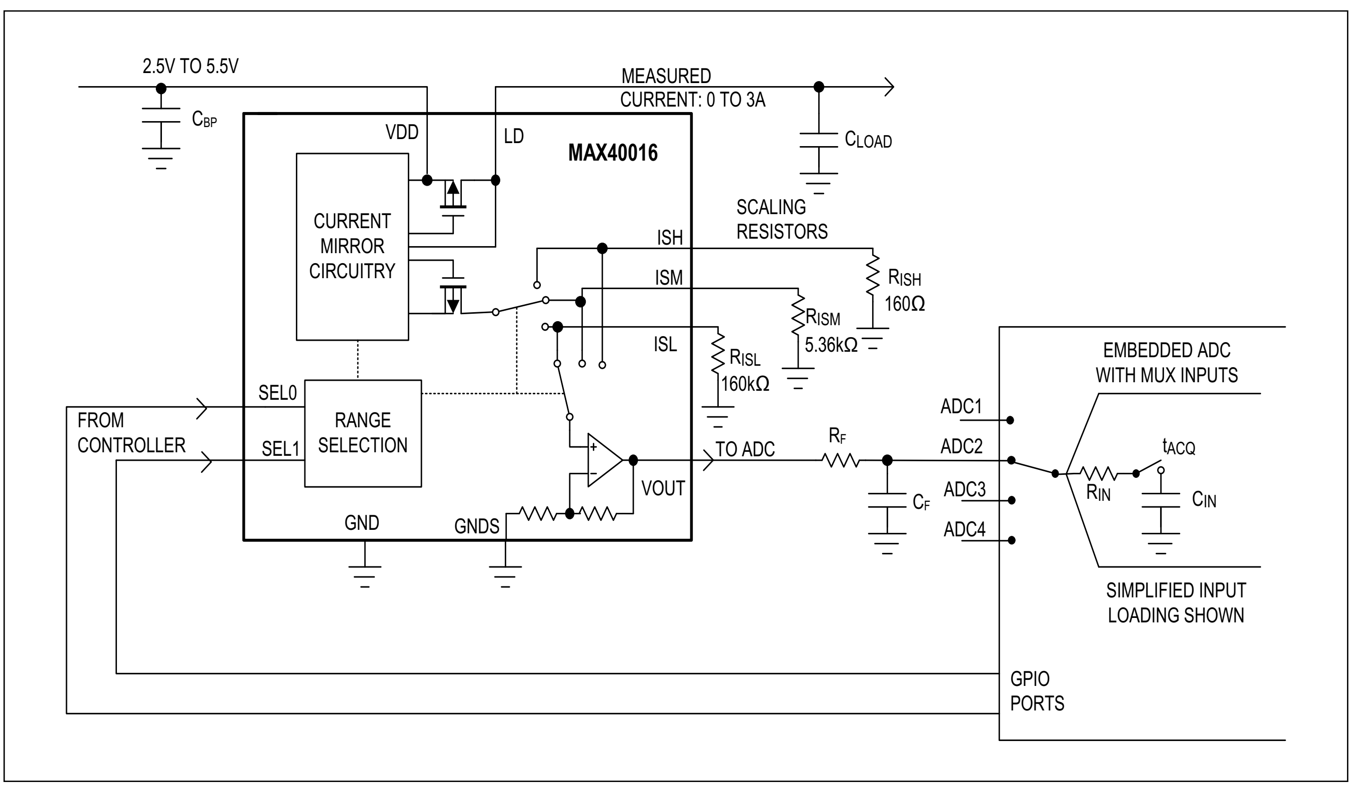



*Figure 4. Using the MAX40016 with an Embedded 12-Bit ADC*

## Revision History

| REVISION NUMBER | REVISION DATE | DESCRIPTION | PAGES CHANGED |
|---|---|---|---|
| 0 | 1/18 | Initial release | — |