

# 26V, 4-Channel Voltage Bus and 4-Channel High-Side Current Shunt Monitor

## NCP45491

The NCP45491 is a high-performance monolithic IC which can be used to monitor bus voltage and current on four high-voltage power supplies simultaneously. The HV bus voltages and currents are translated to a low-voltage power domain and multiplexed onto a single differential output for measurement externally by common ADCs. The device is configurable to operate either standalone or as a pair, permitting up to eight separate HV power supplies to be monitored and measured.

### Features

- Translates and Scales Shunt and Bus Voltages up to 26 V
- Single Device Monitors Four Supplies
- May Be Paired for Monitoring Up To Eight Supplies
- Very Low Powerdown Current
- All Channels Individually Gain Programmable by External Resistor Selection
- Fast Settling Time
- Real-Time Indication of All Bus Voltages Valid
- Adjustable Output Common-Mode Voltage Adapts to Most External ADCs
- Lead-Free Device

### Applications

- Computers/Notebooks
- Graphical Cards
- Power Management/Power Control Loops
- Battery Chargers

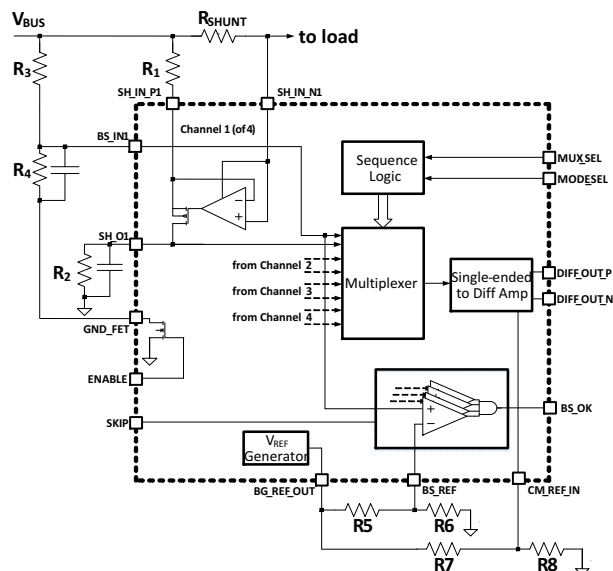
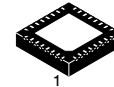


Figure 1. Block Diagram



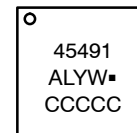
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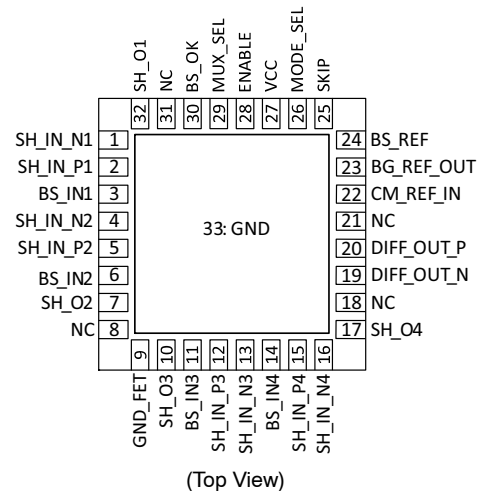
QFN32 4x4  
CASE 485CD

### MARKING DIAGRAM



45491 = Specific Device Code  
A = Assembly Location  
L = Wafer Lot  
Y = Year  
W = Work Week  
▪ = Pb-Free Package  
CCCCC = Country of Assembly

### PIN CONFIGURATION



### ORDERING INFORMATION

| Device         | Package            | Shipping†             |
|----------------|--------------------|-----------------------|
| NCP45491XMNTWG | QFN32<br>(Pb-Free) | 4000 /<br>Tape & Reel |

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

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**Table 1. PIN DESCRIPTION**

| Pin           | Name       | I/O | Function   |
|---------------|------------|-----|--|
| 2, 5, 12, 15  | SH_IN_Px   | AI  | Shunt Resistor Sense +, High Voltage                             |
| 1, 4, 13, 16  | SH_IN_Nx   | AI  | Shunt Resistor Sense -, High Voltage                             |
| 32, 7, 10, 17 | SH_Ox      | AO  | Shunt Voltage Gain Set / Filter, Current Output                  |
| 3, 6, 11, 14  | BS_INx     | AI  | Bus Voltage Sense, High Impedance Input                          |
| 20            | DIFF_OUT_P | AO  | Differential Output, Positive                                    |
| 19            | DIFF_OUT_N | AO  | Differential Output, Negative                                    |
| 22            | CM_REF_IN  | AI  | Common-Mode Reference for Differential Output                    |
| 29            | MUX_SEL    | DI  | Multiplexer Select Input   |
| 24            | BS_REF     | AI  | Bus OK Reference Input   |
| 30            | BS_OK      | DO  | Bus OK output (open-drain; high impedance = BUS OK)              |
| 28            | ENABLE     | DI  | Device Enable. When high, places device in low-power state       |
| 23            | BG_REF_OUT | AO  | Buffered Bandgap Voltage Output                                  |
| 9             | GND_FET    | AO  | Low-side GND ref for resistor dividers (open drain type)         |
| 25            | SKIP       | DI  | Skip Function control (see description)                          |
| 26            | MODE_SEL   | AI  | Multi-level Input for single-device, device A, or device B modes |
| 8, 18, 21, 31 | NC         |     | Pins must be floated   |
| 27            | VCC        | PWR | Device Power   |
| PAD           | GND        | GND | Device Ground  |

**Table 2. MAXIMUM RATINGS**

| Rating  | Pins   | Condition | Symbol               | Value       | Unit |
|---|--|-----------|----------------------|-------------|------|
| Supply Voltage Range  | V <sub>CC</sub>  | GND = 0 V | V <sub>CC</sub>      | -0.3 to 5.5 | V    |
| Shunt Input Voltage Range                                     | SH_IN_Px, SH_IN_Nx   | GND = 0 V | V <sub>SH_IN_X</sub> | -0.3 to 30  | V    |
| Bus Input Voltage Range                                       | BS_INx   | GND = 0 V | V <sub>BS_IN</sub>   | -0.3 to 30  | V    |
| Grounding FET Range   | GND_FET  | GND = 0 V | V <sub>GND_FET</sub> | -0.3 to 30  | V    |
| Shunt Output Voltage Range                                    | SH_Ox  | GND = 0 V | V <sub>SH_Ox</sub>   | -0.3 to 5.5 | V    |
| Digital Input Voltage Range                                   | MUX_SEL, ENABLE, SKIP, MODE_SEL  | GND = 0 V | V <sub>EN</sub>      | -0.3 to 5.5 | V    |
| Low Voltage I/O Range   | BS_REF, CM_REF_IN, MODE_SEL, DIFF_OUT_P, DIFF_OUT_N, BS_OK, BG_REF_OUT | GND = 0 V | V <sub>LV</sub>      | -0.3 to 5.5 | V    |
| Thermal Resistance, Junction-to-Air                           |  |           | R <sub>θJA</sub>     | 40          | °C/W |
| Thermal Resistance, Junction-to-Case (V <sub>IN</sub> Paddle) |  |           | R <sub>θJC</sub>     | 5           | °C/W |
| Operating Temperature Range                                   |  |           | T <sub>A1</sub>      | -40 to 105  | °C   |
| Functional Temperature Range                                  |  |           | T <sub>A2</sub>      | -40 to 125  | °C   |
| Maximum Junction Temperature                                  |  |           | T <sub>J</sub>       | 125         | °C   |
| Storage Temperature Range                                     |  |           | T <sub>STG</sub>     | -40 to 150  | °C   |
| Lead Temperature, Soldering (10 sec.)                         |  |           | T <sub>SLD</sub>     | 260         | °C   |
| Moisture Sensitivity Level                                    |  |           | MSL                  | 1           | -    |

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

**Table 3. ESD RATINGS**

| Rating  | Symbol             | Value | Unit |
|---|--------------------|-------|------|
| ESD Capability, Human Body Model (Note 1)     | ESD <sub>HBM</sub> | >2.0  | kV   |
| ESD Capability, Charged Device Model (Note 1) | ESD <sub>CDM</sub> | >0.5  | kV   |
| Latch-up Immunity (Note 1)                    | I <sub>LU</sub>    | 100   | mA   |

1. Tested by the following methods @ T<sub>A</sub> = 25°C:  
 ESD Human Body Model tested per AEC-Q100-002 (EIA/JESD22-A114).  
 ESD Charged Device Model per JESD22-C101.  
 Latch-up testing per JEDEC78E.

**Table 4. RECOMMENDED OPERATING RANGES**

| Rating   | Symbol               | Min | Max | Unit |
|--|----------------------|-----|-----|------|
| Supply Voltage Range   | V <sub>CC</sub>      | 2.8 | 3.8 | V    |
| Shunt Input Voltage Range  | V <sub>SH_IN_X</sub> | 5   | 26  | V    |
| Shunt Output Voltage Range (operating)                               | V <sub>SH_Ox</sub>   | 0   | 0.5 | V    |
| Shunt Output Voltage Range (floating)                                | V <sub>SH_Ox</sub>   | 2.8 | 3.8 | V    |
| Bus Input Pin Voltage Range (Standby Mode)                           | V <sub>BS_INX</sub>  | 0   | 26  | V    |
| Bus Input Pin Voltage Range (Full Function or Limited Function Mode) | V <sub>BS_INX</sub>  | 0   | 0.5 | V    |
| Grounding FET Range  | V <sub>GND_FET</sub> | 0   | 26  | V    |
| Low Voltage I/O Range  | V <sub>LV</sub>      | 0   | 3.8 | V    |
| Ambient Temperature  | T <sub>A</sub>       | -40 | 85  | °C   |
| Junction Temperature   | T <sub>J</sub>       | -40 | 125 | °C   |

Functional operation above the stresses listed in the Recommended Operating Ranges is not implied. Extended exposure to stresses beyond the Recommended Operating Ranges limits may affect device reliability.

**Table 5. AC CHARACTERISTICS** (V<sub>SH\_IN\_X</sub> = 15 V, V<sub>EN</sub> = 0 V, V<sub>CC</sub> = 3.3 V, unless indicated otherwise. Min and Max values are valid for temperature range -40°C ≤ T<sub>J</sub> ≤ +105°C unless noted otherwise and are guaranteed by test, design, characterization, or statistical correlation. Typical values are referenced to T<sub>J</sub> = 25°C)

| Parameter  | Symbol              | Min   | Typ | Max | Unit |
|--|---------------------|-------|-----|-----|------|
| Multiplexer Settling Time (to 9.375 mV)                      | T <sub>STAB1</sub>  |       |     | 100 | ns   |
| Multiplexer Settling Time (to 3.125 mV)                      | T <sub>STAB2</sub>  |       |     | 300 | ns   |
| MUX_SEL Period (normal operation)                            | T <sub>MSP</sub>    | 0.185 |     | 11  | μs   |
| MUX_SEL Reset Period   | T <sub>RP</sub>     | 35    |     |     | μs   |
| Power-up Time (STANDBY or Limited Function to Full Function) | T <sub>PWR_UP</sub> |       |     | 40  | μs   |
| Differential Amplifier Capacitive Load Capability (Note 2)   | C <sub>DIFF</sub>   |       |     | 82  | pF   |

2. Differential Output C<sub>LOAD</sub> (i.e.: DIFF\_OUT\_x to GND) appears as a series RC with lumped equivalent R (0.86–8.6 Ω) and C (8.2–82 pF).

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**Table 6. DC CHARACTERISTICS** ( $V_{SH\_IN\_X} = 15\text{ V}$ ,  $V_{EN} = 0\text{ V}$ ,  $V_{CC} = 3.3\text{ V}$ , unless indicated otherwise. Min and Max values are valid for temperature range  $-40^{\circ}\text{C} \leq T_J \leq +105^{\circ}\text{C}$  unless noted otherwise and are guaranteed by test, design, characterization, or statistical correlation. Typical values are referenced to  $T_J = 25^{\circ}\text{C}$ )

| Parameter   | Symbol            | Min   | Typ | Max       | Unit                           |
|---|-------------------|-------|-----|-----------|--------------------------------|
| MUX_SEL, SKIP, MODE_SEL, ENABLE Logic High  | $V_{IH}$          | 1.4   |     |           | V                              |
| MUX_SEL, SKIP, MODE_SEL, ENABLE Logic Low   | $V_{IL}$          |       |     | 0.4       | V                              |
| Input Impedance (MODE_SEL, ENABLE pins)   | $R_{FLOAT}$       | 100k  |     |           | $\Omega$                       |
| SH_O Pin Current Source Capability  | $I_{SH\_O\_MAX}$  |       |     | 5         | mA                             |
| Fixed Current for Detection of SH_Ox Open   | $I_{SH\_LEAK}$    |       |     | 1         | $\mu\text{A}$                  |
| GND_FET ON Resistance (measured @ 1 mA)   | $R_{GND\_FET}$    |       |     | 10        | $\Omega$                       |
| BG_REF_OUT Voltage  | $V_{BG}$          | 1.274 | 1.3 | 1.326     | V                              |
| BG_REF_OUT Load   | $I_{V_{BG\_OUT}}$ |       |     | 100       | $\mu\text{A}$                  |
| BS_OK Logic Low Impedance   | $R_{BS\_OK}$      |       |     | 300       | $\Omega$                       |
| VCC range for BS_OK low impedance   | $V_{LI}$          | 1     |     | 3.8       | V                              |
| VCC Threshold Reference for BS_OK Input (POR) (Note 3)  | $V_{BS\_TH}$      | 2.6   |     | 2.8       | V                              |
| Shunt Monitor Offset Voltage (Note 4)   | $V_{SM\_OV}$      |       |     | $\pm 150$ | $\mu\text{V}$                  |
| Shunt Monitor Offset Voltage Drift (Note 4)   | $SM\_VD$          |       |     | 2         | $\mu\text{V}/^{\circ}\text{C}$ |
| Shunt Monitor CMRR ( $V_{SH\_IN\_Px}$ in valid range, see above) (Note 5)                                   | $SM\_CMRR$        | 80    |     |           | dB                             |
| Valid SH_O resistance   | $R_{SH\_O}$       |       |     | 2000      | $\Omega$                       |
| Differential Amp Input Offset Voltage, room temperature (Note 6)  | $V_{D\_OVRT}$     |       |     | $\pm 2$   | mV                             |
| Differential Amp Input Offset Voltage Drift, $-40^{\circ}\text{C}$ to $+105^{\circ}\text{C}$ (Note 6)       | $V_{D\_OVT}$      |       |     | $\pm 6$   | mV                             |
| Differential Amp PSRR ( $V_{CC} = 2.8\text{ V}$ to $3.8\text{ V}$ )   | $DA\_PSRR$        | 60    |     |           | dB                             |
| Differential Amp Common-Mode Voltage  | $V_{CM}$          | 565   |     | 885       | mV                             |
| Differential Amp Closed Loop Gain   | $G_{DA}$          |       | 2   |           | V/V                            |
| Differential Full Scale Output  | $V_{FSO}$         |       |     | 800       | mV <sub>pp</sub>               |
| $I_{VCC}$ (Fully Functional, $V_{EN} = 0$ , $V_{CC}$ must be $2.8\text{ V} - 3.8\text{ V}$ )                | $I_{VCC\_F}$      |       |     | 1.5       | mA                             |
| $I_{VCC}$ (Limited Function, $V_{EN} = \text{Tri-state}$ , $V_{CC}$ must be $2.8\text{ V} - 3.8\text{ V}$ ) | $I_{VCC\_L}$      |       |     | 400       | $\mu\text{A}$                  |
| $I_{VCC}$ (STANDBY) (Note 7)  | $I_{VCC\_S}$      |       |     | 180       | $\mu\text{A}$                  |
| $I_{SHO}$ (STANDBY, non-floated SH_Ox pin) (Note 7)   | $I_{SHO\_S}$      |       |     | 100       | $\mu\text{A}$                  |
| $I_{SH\_IN\_N}$ (VBUS current in Full Function) (Note 8)  | $I_{VBUS}$        |       |     | 300       | $\mu\text{A}$                  |

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

3. Vcc detection for BS\_OK must trip in this range. Device can be either operational or not operational in this range.

4. Shunt Monitor Offset Voltage and Offset Voltage Drift are referred to the SH\_IN\_Px and SH\_IN\_Nx pins.

5. Input Offset voltage at  $T_J = 25^{\circ}\text{C}$ .

6. Differential Amplifier Offset Voltage and Offset Voltage Drift are referred to the multiplexer input pins (e.g. BS\_INx or SH\_Ox).

7.  $V_{EN} = V_{CC}$ ; Total  $V_{CC}$  standby current is  $I_{VCC\_S}$  plus an additional  $I_{SHO\_S}$  for every SH\_Ox channel that is not floating.

8. Specifications for  $V_{BUS}$  current draw are only applicable when  $V_{CC} = 2.8\text{ V}$  to  $3.8\text{ V}$ .

## APPLICATIONS INFORMATION

**Differential Output Amplifier**

A differential output amplifier provides a scaled representation of multiple bus voltages and currents to an external device on the DIFF\_OUT\_P and DIFF\_OUT\_N pins. These voltages and currents are presented *sequentially* (under control of the Sequence Logic block) via the Multiplexer. The common-mode voltage of the differential output amplifier is established by the voltage on the CM\_REF\_IN pin.

**Current Shunt Monitor (one of four identical instances)**

The differential voltage across an external shunt resistor (R<sub>SHUNT</sub>) is converted to a current by a transconductor stage implemented by an op-amp and external resistor R1. This current is supplied to the SH\_Ox pin where it is converted back to a ground-referenced voltage by external resistor R2. The conversion gain from differential voltage across the shunt resistor to that ground-referred voltage on SH\_Ox may then be set directly as the ratio of R<sub>SHUNT</sub> to R1. A capacitor may be connected across R2 in order to provide noise filtering if required in the application. Note that bias current for the op-amp is taken from the “load” side of the shunt resistor so that it is included in the load current measurement.

**Current Shunt Resistors**

The external resistors labeled R<sub>SHUNT</sub>, R1, and R2 in Figure 1 are used to define the full dynamic range of the shunt current monitoring and are user application dependent. Resistors R<sub>SHUNT</sub> and R1 are chosen based on the maximum load current (I<sub>LOAD</sub>) to define the SH\_Ox current (I<sub>SH\_Ox</sub>) using the equation;

$$I_{SH\_Ox} = \frac{R_{SHUNT}}{R_1} I_{LOAD} \quad (\text{eq. 1})$$

I<sub>SH\_Ox</sub> is also user defined and is not to exceed I<sub>SH\_O\_MAX</sub>. Ideally, the SH\_Ox current is around 2 mA. The resistance of R2 is found with the relationship;

$$R_2 = \frac{V_{SH\_Ox}}{I_{SH\_Ox}} \quad (\text{eq. 2})$$

Regardless of the values of I<sub>LOAD</sub> or I<sub>SH\_Ox</sub>, the maximum voltage of the SH\_Ox pin shall not exceed V<sub>SH\_Ox</sub>, indicated in the operating range table.

**Bus Voltage Monitor (one of four identical instances)**

An external voltage divider is used to scale the voltage on the BS\_INx pin to an appropriate full-scale range for the differential output amplifier. Resistors R3 and R4 form a resistor divider to define the full dynamic range of the bus voltage monitor with;

$$\frac{R_4}{R_3 + R_4} \times V_{BUS} = V_{BS\_INx} \quad (\text{eq. 3})$$

**Multiplexer Select**

The multiplier selection is controlled by a single digital input (MUX\_SEL pin). The device will monitor this pin and cycle through the different measured parameters in a fixed sequence. The sequence will repeat cycle as shown in the tables until either a timeout condition is detected or the device is disabled. The MUX\_SEL pin needs to be pulsed at least once before normal MUX\_SEL cycles begin. The delay between the falling edge of the last initial MUX\_SEL pulse and the first rising edge of the normal MUX\_SEL cycle needs to be 14.75 μs > T<sub>d</sub> > 24.25 μs.

**Operating Modes**

There are two operating modes – stand-alone (one to four channels) and paired operation (up to eight channels). In paired operation, MODE\_SEL is used to designate a “Device A” and “Device B” of a pair. When paired, the differential output amplifiers of the two devices are expected to be “wire-or’ed” together, and the table logic insures that only one device will actively drive DIFF\_OUT\_P and DIFF\_OUT\_N at any given time. See description in the Auxiliary Functions section for details. Additionally, devices can be configured to operate with a reduced channel count. See description in the Auxiliary Functions section for details.

**Power-up Sequence**

V<sub>BUS</sub> voltages must be applied before V<sub>CC</sub>. V<sub>CC</sub> must be applied (2.8 V – 3.8 V) for expected operation and current consumption. The enable signal must be held low while the V<sub>CC</sub> supply comes up. After both V<sub>BUS</sub> and V<sub>CC</sub> supplies are present, EN can then be pulled high or floated if standby mode or limited function mode is desired. Refer to auxiliary functions section for more information.

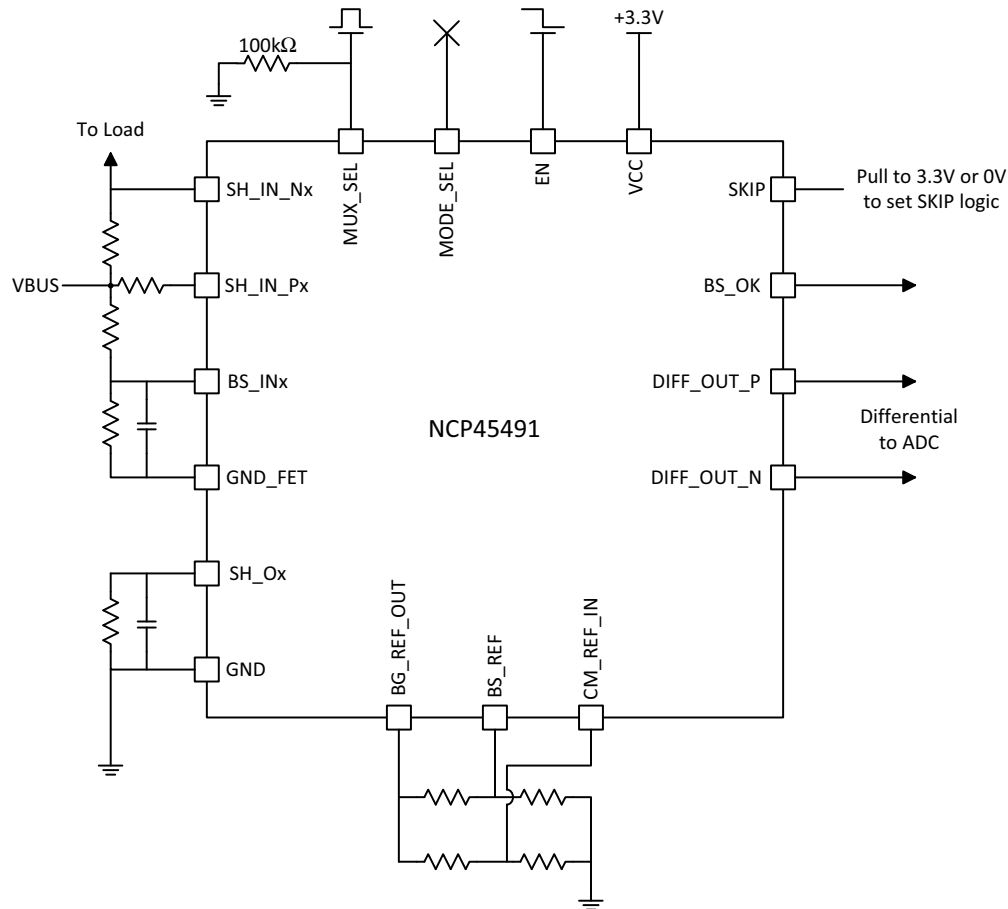
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| Four-Channel Stand-Alone Operation |                                     |
|------------------------------------|-------------------------------------|
| MUX_SEL Cycle                      | Differential Amp Output             |
| Standby                            | Hi-Z                                |
| 1                                  | Channel 1 Bus Voltage               |
| 2                                  | Channel 1 Shunt Current             |
| 3                                  | Channel 2 Bus Voltage               |
| 4                                  | Channel 2 Shunt Current             |
| 5                                  | Channel 3 Bus Voltage               |
| 6                                  | Channel 3 Shunt Current             |
| 7                                  | Channel 4 Bus Voltage               |
| 8                                  | Channel 4 Shunt Current             |
| 9→1                                | Channel 1 Bus Voltage               |
| 10→2                               | Channel 1 Shunt Current             |
| ....                               | Repeat cycle until reset or timeout |

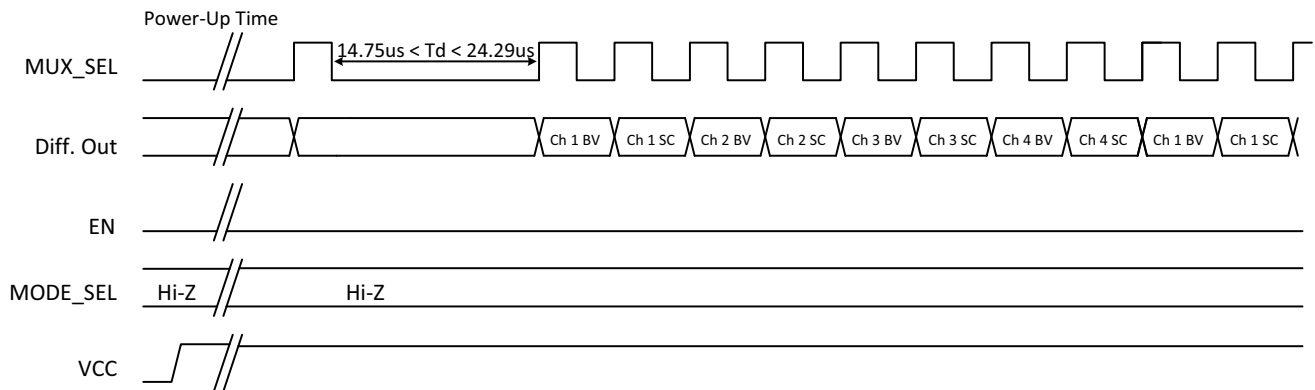
| Six-Channel Paired Operation |                                      |                                      |
|------------------------------|--------------------------------------|--------------------------------------|
| MUX_SEL Cycle                | Differential Amp Output (Device A)   | Differential Amp Output (Device B)   |
| Standby                      | Hi-Z                                 | Hi-Z                                 |
| 1                            | Ch 1 Bus Voltage                     | Hi-Z                                 |
| 2                            | Ch 1 Shunt Current                   | Hi-Z                                 |
| 3                            | Ch 2 Bus Voltage                     | Hi-Z                                 |
| 4                            | Ch 2 Shunt Current                   | Hi-Z                                 |
| 5                            | Ch 3 Bus Voltage                     | Hi-Z                                 |
| 6                            | Ch 3 Shunt Current                   | Hi-Z                                 |
| 7                            | Hi-Z                                 | Ch 1 Bus Voltage                     |
| 8                            | Hi-Z                                 | Ch 1 Shunt Current                   |
| 9                            | Hi-Z                                 | Ch 2 Bus Voltage                     |
| 10                           | Hi-Z                                 | Ch 2 Shunt Current                   |
| 11                           | Hi-Z                                 | Ch 3 Bus Voltage                     |
| 12                           | Hi-Z                                 | Ch 3 Shunt Current                   |
| 13→1                         | Ch 1 Bus Voltage                     | Hi-Z                                 |
| 14→2                         | Ch 1 Shunt Current                   | Hi-Z                                 |
| ....                         | Repeat cycle until re-set or timeout | Repeat cycle until re-set or timeout |

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## APPLICATIONS DIAGRAMS

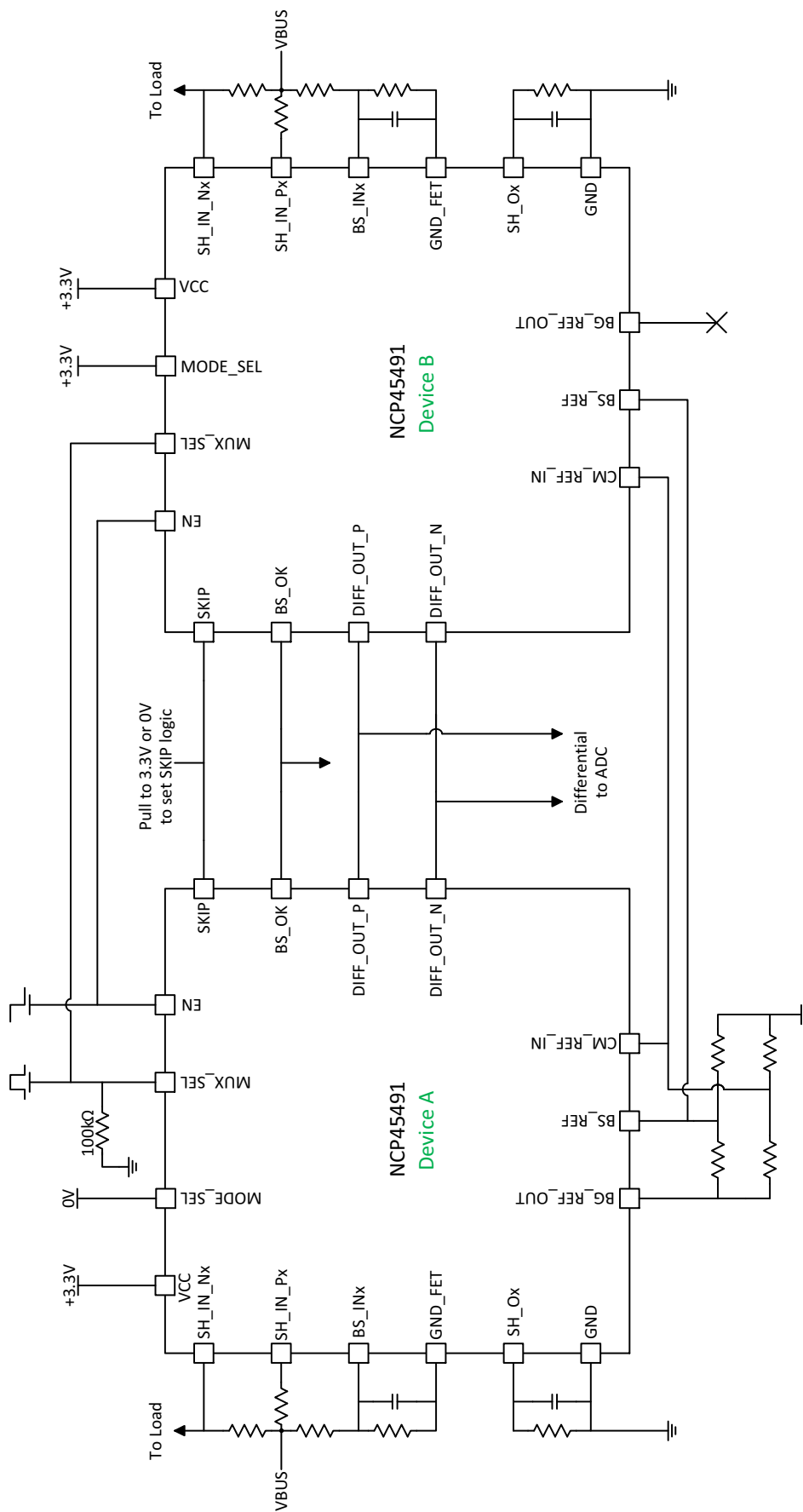


**Figure 2. Stand Alone Device Operation**



**Figure 3. Stand Alone Timing Characteristics**

**NCP45491**



### Figure 4. Six-Channel Paired Device Operation

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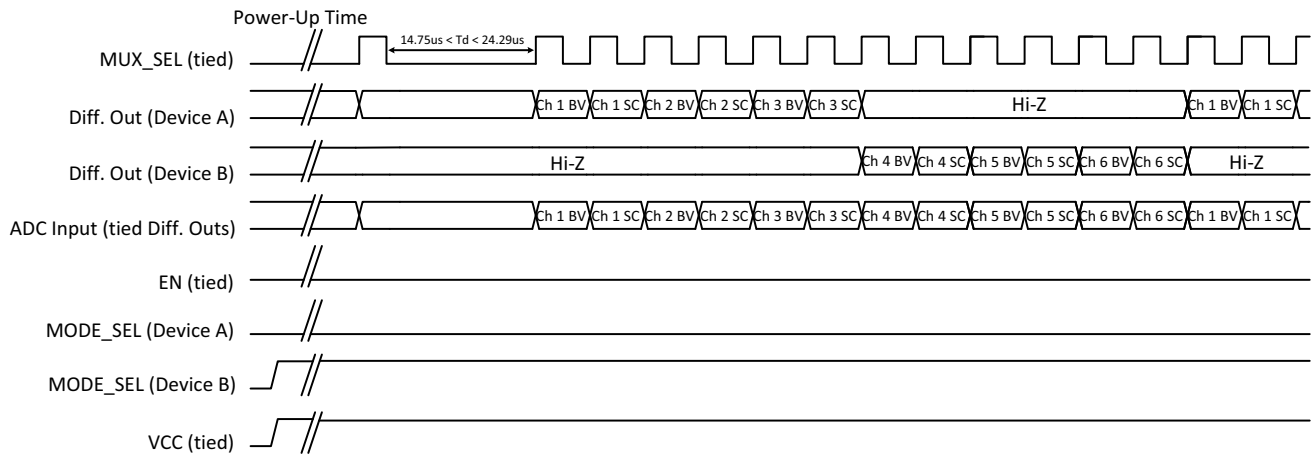


Figure 5. Six-Channel Paired Device Timing Characteristics

## AUXILIARY FUNCTIONS

**Bus Comparator (BS\_OK)**

A real-time indication that  $V_{CC}$  and all bus voltages (as measured on the BS\_INx pins) are valid is provided on the BS\_OK pin. BS\_OK remains low until all used BS\_INx pins are above a user-defined threshold voltage. The threshold voltage for the valid condition of BS\_INx pins is set by the voltage provided to the BS\_REF pin and must be less than 0.2 V. This can be done via an external resistor divider and the bandgap reference. If desired, the user can use the SKIP pin to modify the logic as shown in the corresponding table (H=high, L=low, Z=tristate, X=don't care). The SKIP pin can also be used to hold BS\_OK = L in the absence of VCC.

**Reset/Timeout**

Normal operation can be interrupted and device returned to standby mode by holding the MUX\_SEL pin HIGH or LOW longer than the reset period  $T_{RP}$ .

**Bandgap Reference**

The BG\_REF\_OUT pin provides a high-accuracy voltage from which BS\_REF and CM\_REF\_IN voltages can be supplied via external voltage dividers.

**Ground FET**

The GND\_FET pin is a switch that connects the bus voltage dividers to ground. In order that these voltage dividers not consume current when not needed (as in device shutdown), a low-impedance open-drain FET disconnects the low-side of these resistor dividers when the EN pin is at a logic HIGH level.

**Enable Function**

The EN pin controls device operation according to the corresponding table.

**Mode Select Function**

The MODE\_SEL pin controls multiplexer operation according to the corresponding table. Note that MODE\_SEL is left floating in stand-alone operation.

**Reduced Channel Count**

If an application requires less than 4 channels, then pins for unused channels must be connected in the following manner for correct operation of the BS\_OK output.

| PINS for Unused Channels | Connection                               |
|--------------------------|--|
| BS_INx                   | Connect to BS_IN pin of previous channel |
| SH_Ox                    | Float                                    |
| SH_IN_Px                 | Connect to VCC voltage or higher         |
| SH_IN_Nx                 | Connect to VCC voltage or higher         |

Note: "x" refers to the unused channel number

Connecting the SH\_IN\_Px and SH\_IN\_Nx pins for unused channels to the respective SH\_IN\_Px and SH\_IN\_Nx of previous active channels is an acceptable way to provide the bias voltages needed. If the SH\_Ox pin is left floating, then that channel and all subsequent channels will be skipped in the DIFF\_OUT readout. For example, if SH\_O3 is left floating, SH\_O3 and SH\_O4 will be bypassed. If devices are in paired mode, the number of unused channels on both devices must be matched. However, bus voltage on those unused channels (as measured on the BS\_INx pins) will still be compared to the BS\_REF voltage and included in the BS\_OK output logic. If SKIP = 0 V, then the BS\_INx voltages are ignored. In this case the unused BS\_INx pins can be tied to any voltage less than VCC.

| SKIP Logic |              |        |      |                |
|------------|--------------|--------|------|----------------|
| EN         | VCC          | BS_INx | SKIP | BS_OK          |
| X          | Z(unpowered) | X      | H    | L              |
| X          | L (POR)      | X      | X    | L              |
| H          | X            | X      | X    | L              |
| Z/L        | H            | L      | H    | L              |
| Z/L        | H            | H      | H    | H (open drain) |
| Z/L        | H            | X      | L    | H (open drain) |

| EN Logic             |  |
|----------------------|--|
| Level                | Device Operation   |
| LOW                  | Fully Functional   |
| Tri-state (floating) | Limited Function: BG_REF_OUT is valid, GND_FET is turned ON, BS_OK comparators and output are functional. All other functions to be disabled. DIFF_OUT to be Hi-Z and multiplexer select logic is held in reset. |
| HIGH                 | Standby: As described in Limited Function above with GND_FET turned OFF  |

| MODE_SEL Logic       |                       |
|----------------------|-----------------------|
| Level                | Multiplexer Operation |
| LOW                  | Device A              |
| Tri-state (floating) | Stand-Alone           |
| HIGH                 | Device B              |

## LAYOUT GUIDELINES

### Electrical Layout Considerations

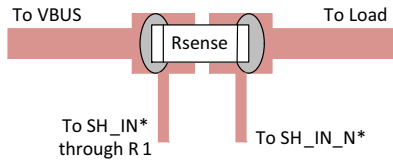
Correct physical layout is important for proper low noise accurate operation of the NCP45491.

**Power Paths:** Use wide and short traces for bus voltage source to load path to reduce parasitic resistance and loss of power through the primary current path. The load current (traveling from source to load through Rshunt) does not pass through the NCP45491, but careful consideration of this path is critical.

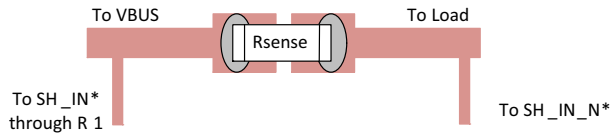
**Power Supply Decoupling:** A decoupling capacitor of 0.1  $\mu\text{F}$  from VCC to ground is recommended. Keep capacitor as close to the NCP45491 VCC pin as possible, with a direct connection to the GND pad.

**Rshunt layout:** A correct 4-wire Kelvin connection to the Rshunt resistor (also commonly known as the Rsense resistor) is critical to achieving accurate bus current and voltage measurements. The Rshunt resistor should have a low tolerance specification with adequate power ratings depending on the application. Any shared traces between the force and sense connections to the Rshunt resistor will result in additional un-accounted for resistance in the  $\text{m}\Omega$  that will add error to the bus current and voltage measurements. The figure below demonstrates correct Rshunt connection.

Correct layout:



Incorrect layout:



**Ground:** A solid connection to the back ground pad of the NCP45491 to a ground plane will help to reduce noise, in addition to the decoupling capacitor. Using the ground plane to shield sensitive analog signals is good practice.

**Differential Output:** To achieve a low noise result, the DIFF\_OUT\_P and the DIFF\_OUT\_N should be routed close together with matched lengths. Shielding these lines with GND will provide additional protection from noise. Minimizing the distance traveled by the differential output pair to get to the digitizing ADC is also a good way to avoid additional noise. The DIFF\_OUT\_x signals should not be routed in close proximity to other digital signals in the system application.

**Routing of Digital Signals:** MUX\_SEL, MODE\_SEL, SKIP, and ENABLE should be routed to avoid direct coupling with any of the analog input and output signals of the NCP45491. In most applications, these digital signals are static and are of lesser concern.

**References:** Connections to BS\_REF, BG\_REF\_OUT, and CM\_REF\_IN should be kept close to the NCP45491 for best noise performance.

**Thermal Layout Considerations:** As the load current does not flow through the NCP45491, thermal dissipation is of minimal concern. Connecting the GND pad on the back of the part to a ground plane is ample. Selection of R1, R2, R3, R4, and Rshunt may require higher power ratings above the 0.1W standard for small SMD passives.

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