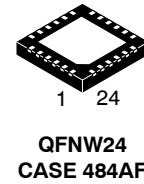
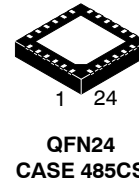


# High Efficiency Buck Dual LED Driver with Integrated Current Sensing for Automotive Front Lighting NCV78723



The NCV78723 is a single-chip and high efficient Buck Dual LED Driver designed for automotive front lighting applications like high beam, low beam, DRL (daytime running light), turn indicator, fog light, static cornering, etc. The NCV78723 is in particular designed for high current LEDs and provides a complete solution to drive 2 LED strings of up-to 60 V. It includes 2 independent current regulators for the LED strings and required diagnostic features for automotive front lighting with a minimum of external components – the chip doesn't need any external sense resistor for the buck current regulation. The available output current and voltages can be customized per individual LED string. When more than 2 LED channels are required on 1 module, then 2, 3 or more devices NCV78723 can be combined; also with NCV78713 device – the derivative of the NCV78723 incorporating Buck Single LED Driver. Thanks to the SPI programmability, one single hardware configuration can support various application platforms.

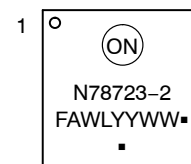
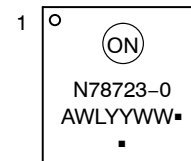
## Features

- Single Chip
- Buck Topology
- 2 LED Strings up-to 60 V
- High Current Capability up to 1.6 A DC per Output
- High Overall Efficiency
- Minimum of External Components
- Integrated High Accuracy Current Sensing
- Integrated Switched Mode Buck Current Regulator
- Average Current Regulation through the LEDs
- High Operating Frequencies to Reduce Inductor Sizes
- Low EMC Emission for LED Switching and Dimming
- SPI Interface for Dynamic Control of System Parameters
- Fail Safe Operating (FSO) Mode, Stand-Alone Mode
- These Devices are Pb-Free, Halogen Free/BFR Free and are RoHS Compliant

## Typical Applications

- High Beam
- Low Beam
- DRL
- Position or Park Light
- Turn Indicator
- Fog
- Static Cornering

## MARKING DIAGRAMS



N78723-0 = Specific Device Code  
 N78723-2 = Specific Device Code  
 F = Fab Indicator  
 A = Assembly Location  
 WL = Wafer Lot  
 YY = Year  
 WW = Work Week  
 ■ = Pb-Free Package

(Note: Microdot may be in either location)

## ORDERING INFORMATION

See detailed ordering and shipping information on page 31 of this data sheet.

# NCV78723

## TYPICAL APPLICATION SCHEMATIC

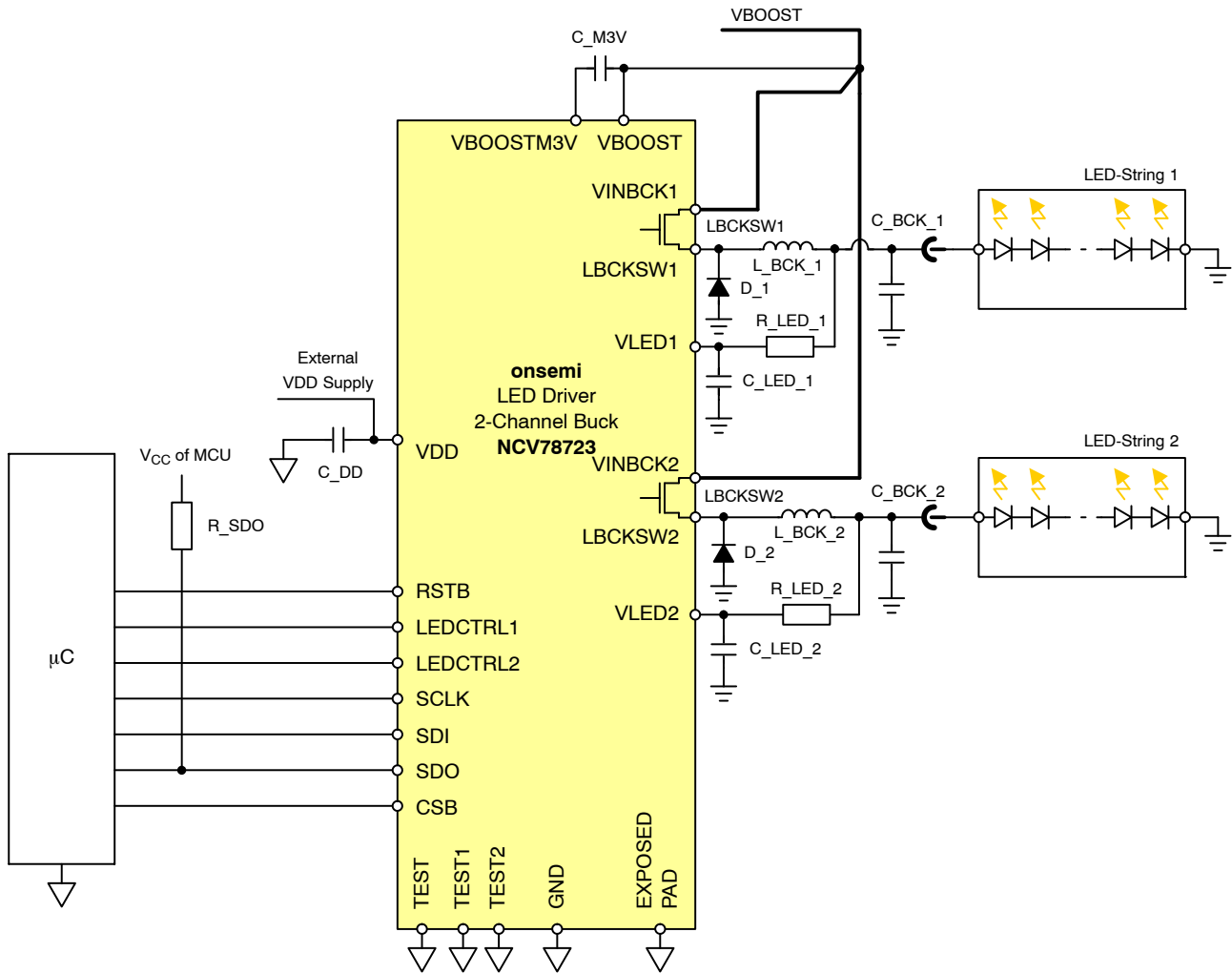


Figure 1. Typical Application Schematic

Table 1. EXTERNAL COMPONENTS

| Component | Function   | Typical Value             | Unit |
|-----------|--|---------------------------|------|
| L_BCK_x   | Buck Regulator Coil (see Buck Regulator Chapter for Details)             | 47                        | µH   |
| C_BCK_x   | Buck Regulator Output Capacitor (see Buck Regulator Chapter for Details) | 220                       | nF   |
| C_M3V     | Capacitor for M3V Regulator  | (see Table 6 – VBOOSTM3V) | nF   |
| C_DD      | V <sub>DD</sub> Decoupling Capacitor                                     | 470                       | nF   |
| C_LED_x   | Optional VLEDx Pin Filter Capacitor (Note 2)                             | 1                         | nF   |
| R_LED_x   | VLEDx Pin Serial Resistor (Notes 2 and 3)                                | Min. 1                    | kΩ   |
| R_SDO     | SPI Pull-Up Resistor   | 1                         | kΩ   |
| D_x       | Buck Regulator Free-Wheeling Diode                                       | e.g. MBR52H100T3G         |      |

1. Pin TEST has to be connected to ground. TEST1 and TEST2 pins can be connected to ground or left floating.
2. C\_LED\_x is optional. If used, time constant of the C\_LED\_x and R\_LED\_x filter has to be lower than minimal LEDCTRLx ON time in PWM dimming for proper VLED measurement.
3. R\_LED\_x is necessary to ensure Absolute Maximum Ratings of IVLEDx current (see Table 3).

# NCV78723

## BLOCK DIAGRAM

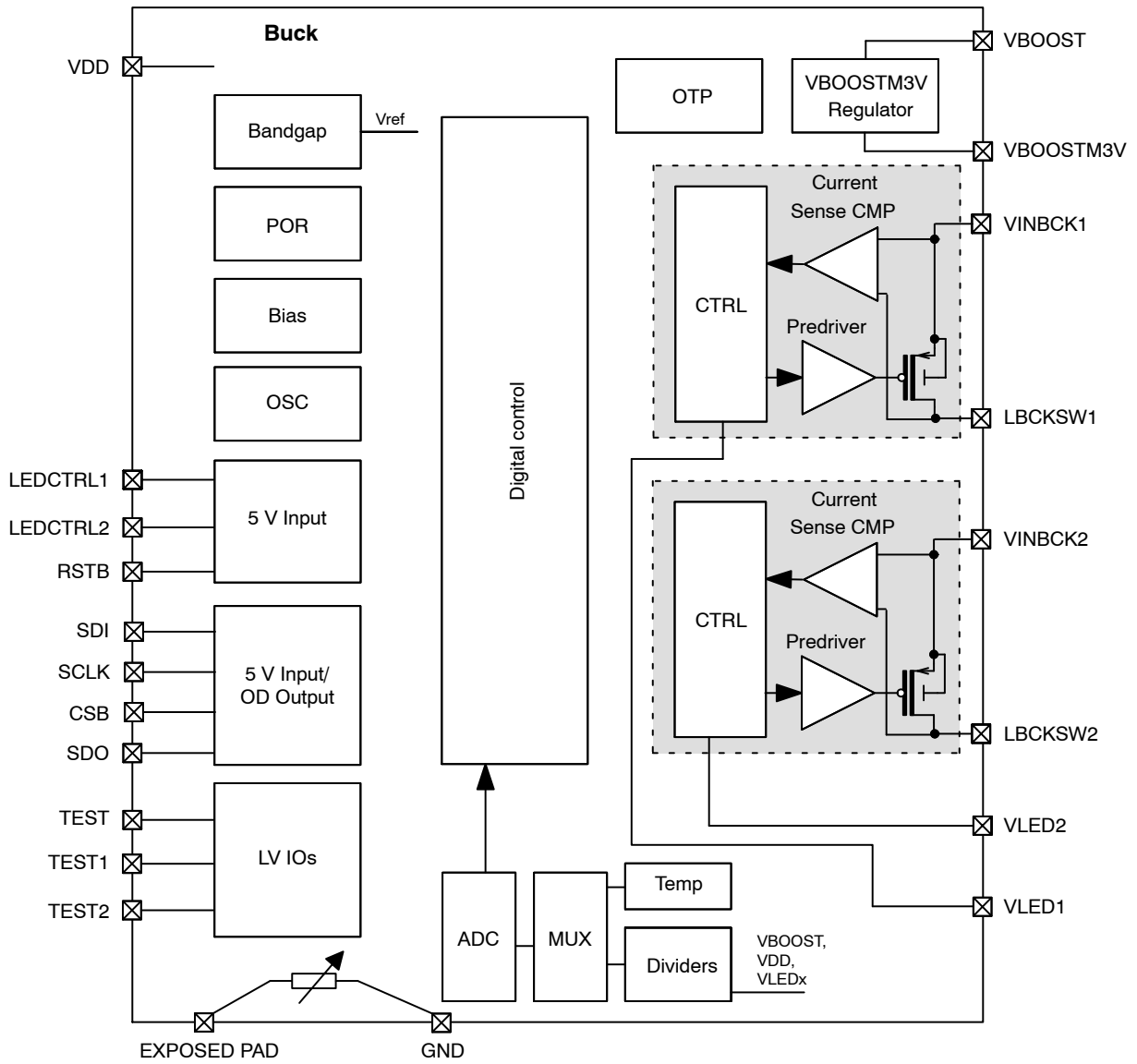


Figure 2. Block Diagram

# NCV78723

## ESD SCHEMATIC

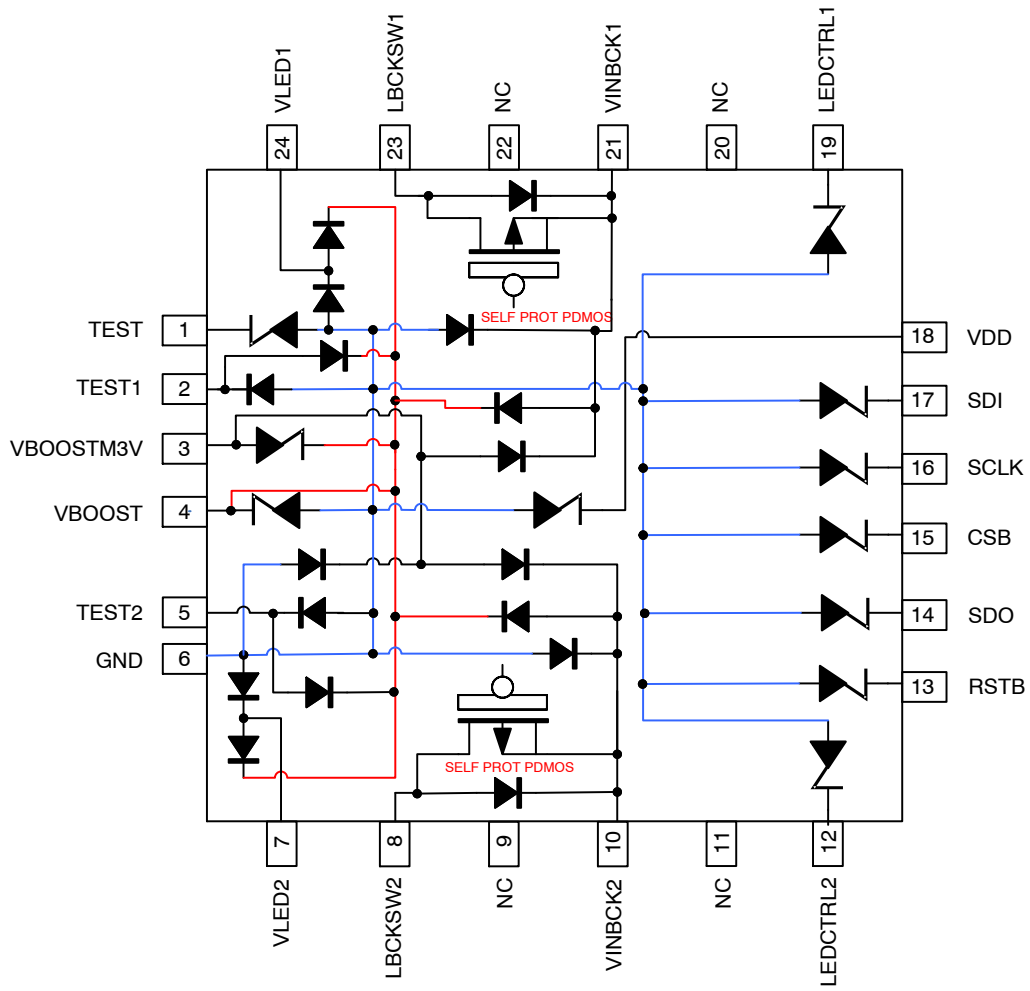


Figure 3. ESD Schematic

# NCV78723

## PACKAGE AND PIN DESCRIPTION

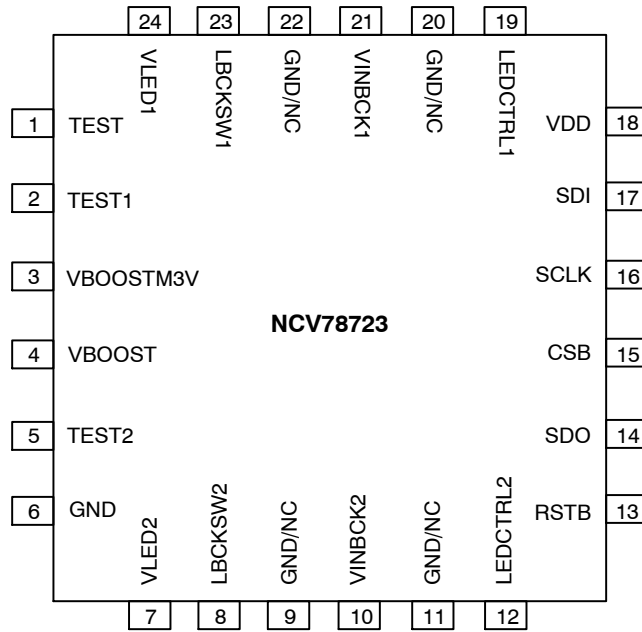


Figure 4. Pin Connections

Table 2. PIN DESCRIPTION

| Pin No.       | Pin Name  | Description                              | I/O Type              |
|---------------|-----------|--|-----------------------|
| 1             | TEST      | Test Pin                                 | LV In                 |
| 2             | TEST1     | Test Pin                                 | LV IN/OUT HV Tolerant |
| 3             | VBOOSTM3V | VBOOSTM3V Regulator Output Pin           | HV OUT (Supply)       |
| 4             | VBOOST    | Booster Input Voltage Pin                | HV Supply             |
| 5             | TEST2     | Test Pin                                 | LV IN/OUT HV Tolerant |
| 6             | GND       | Ground                                   | Ground                |
| 7             | VLED2     | LED String 2 Forward Voltage Sense Input | HV IN                 |
| 8             | LBCKSW2   | Buck 2 Switch Output                     | HV OUT                |
| 9, 11, 20, 22 | GND/NC    | GND/NC Connection in Application         | NC                    |
| 10            | VINBCK2   | Buck 2 High Voltage Supply               | HV Supply             |
| 12            | LEDCTRL2  | LED String 2 Enable                      | MV IN                 |
| 13            | RSTB      | External Reset Signal                    | MV IN                 |
| 14            | SDO       | SPI Data Output                          | MV Open-Drain         |
| 15            | CSB       | SPI Chip Select (Chip Select Bar)        | MV IN                 |
| 16            | SCLK      | SPI Clock                                | MV IN                 |
| 17            | SDI       | SPI Data Input                           | MV IN                 |
| 18            | VDD       | 3 V Logic Supply                         | LV Supply             |
| 19            | LEDCTRL1  | LED String 1 Enable                      | MV IN                 |
| 21            | VINBCK1   | Buck 1 High Voltage Supply               | HV Supply             |
| 23            | LBCKSW1   | Buck 1 Switch Output                     | HV OUT                |
| 24            | VLED1     | LED String 1 Forward Voltage Sense Input | HV IN                 |

**Table 3. ABSOLUTE MAXIMUM RATINGS**

| Characteristic                                       | Symbol               | Minimum                               | Maximum                             | Unit |
|--|----------------------|---------------------------------------|-------------------------------------|------|
| VBOOST Supply Voltage                                | V <sub>BOOST</sub>   | -0.3                                  | +68                                 | V    |
| VINBCKx Supply Voltage (Note 4)                      | VINBCKx              | Max of VBOOSTM3V - 0.3, -0.3          | Min of V <sub>BOOST</sub> + 0.3, 68 | V    |
| VBOOSTM3V Supply Voltage (Note 5)                    | VBOOSTM3V            | Max of V <sub>BOOST</sub> - 3.6, -0.3 | Min of V <sub>BOOST</sub> + 0.3, 68 | V    |
| VLED Sense Voltage                                   | VLEDx                | -0.3                                  | Min of V <sub>BOOST</sub> + 0.3, 68 | V    |
| Logic Supply Voltage (Note 6)                        | V <sub>DD</sub>      | -0.3                                  | 3.6                                 | V    |
| Medium Voltage IO Pins (Note 7)                      | IOMV                 | -0.3                                  | 7.0                                 | V    |
| Test Pins (Note 8)                                   | TESTx                | -0.3                                  | Min of V <sub>BOOST</sub> + 0.3, 68 | V    |
| Buck Switch Low Side (Note 4)                        | LBCKSWx              | -2.0                                  | VINBCKx + 0.3                       | V    |
| VLED Sink/Source Current                             | IVLEDx               | -30                                   | 30                                  | mA   |
| Storage Temperature (Note 9)                         | T <sub>STRG</sub>    | -50                                   | 150                                 | °C   |
| The Exposed Pad (Note 10)                            | EXPAD                | GND - 0.3                             | GND + 0.3                           | V    |
| Electrostatic Discharge on Component Level (Note 11) |                      |                                       |                                     |      |
| Human Body Model                                     | V <sub>ESD_HBM</sub> | -2                                    | +2                                  | kV   |
| Charge Device Model                                  | V <sub>ESD_CDM</sub> | -500                                  | +500                                | V    |

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.

4. V(VINBCKx - LBCKSWx) < 70 V, the driver in off state.
5. The VBOOSTM3V regulator in off state.
6. Absolute maximum rating for pins: VDD, TEST. Also valid for relative difference V<sub>BOOST</sub> - VBOOSTM3V.
7. Absolute maximum rating for pins: SCLK, CSB, SDI, SDO, LEDCTRL1, LEDCTRL2, RSTB. The µC interface pins (the IOMV pins) accept 5 V while the device is in the power-off mode (V<sub>DD</sub> = 0 V).
8. Absolute maximum rating for pins: TEST1, TEST2.
9. For limited time up to 100 hours. Otherwise the max storage temperature is 85°C.
10. The exposed pad must be hard wired to GND pin in an application to ensure both electrical and thermal connection.
11. This device series incorporates ESD protection and is tested by the following methods:  
 ESD Human Body Model tested per AEC - Q100 - 002 (EIA/JESD22 - A114)  
 ESD Charge Device Model tested per EIA/JESD22 - C101  
 Latch-up Current Maximum Rating: ≤100 mA per JEDEC standard: JESD78

Operating ranges define the limits for functional operation and parametric characteristics of the device. A mission profile (Note 12) is a substantial part of the

operation conditions; hence the Customer must contact **onsemi** in order to mutually agree in writing on the allowed missions profile(s) in the application.

**Table 4. RECOMMENDED OPERATING RANGES**

| Characteristic   | Symbol              | Min                      | Typ                | Max                      | Unit |
|--|---------------------|--------------------------|--------------------|--------------------------|------|
| Boost Supply Voltage<br>N78723-0 Device<br>N78723-2 Device | V <sub>BOOST</sub>  | +8<br>+6                 |                    | +67<br>+67               | V    |
| VINBCKx Supply Voltage (Note 13)                           | VINBCKx             | V <sub>BOOST</sub> - 0.1 | V <sub>BOOST</sub> | V <sub>BOOST</sub> + 0.1 | V    |
| Low Voltage Supply   | V <sub>DD</sub>     | 3.05                     | 3.3                | 3.6                      | V    |
| Buck Switch Output Current                                 | I <sub>LBCKSW</sub> |                          |                    | 1.9                      | A    |
| Functional Operating Junction Temperature Range (Note 14)  | T <sub>JF</sub>     | -40                      |                    | 155                      | °C   |
| Parametric Operating Junction Temperature Range (Note 15)  | T <sub>JP</sub>     | -40                      |                    | 150                      | °C   |
| The Exposed Pad Connection (Note 16)                       | EXPOSED_PAD         | GND - 0.1                | GND                | GND + 0.1                | V    |

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.

12. A mission profile describes the application specific conditions such as, but not limited to, the cumulative operating conditions over life time, the system power dissipation, the system's environmental conditions, the thermal design of the customer's system, the modes, in which the device is operated by the customer, etc. No more than 100 cumulated hours in life time above T<sub>TW</sub>.
13. Hard connection of VINBCKx to VBOOST on PCB.
14. The circuit functionality is not guaranteed outside the functional operating junction temperature range. Also please note that the device is verified on bench for operation up to 170°C but that the production test guarantees 155°C only.
15. The parametric characteristics of the circuit are not guaranteed outside the Parametric operating junction temperature range.
16. The exposed pad must be hard wired to GND pin in an application to ensure both electrical and thermal connection.

**Table 5. THERMAL RESISTANCE**

| Characteristic                                       | Package   | Symbol            | Min | Typ | Max | Unit |
|--|-----------|-------------------|-----|-----|-----|------|
| Thermal Resistance Junction to Exposed Pad (Note 17) | QFN24 5x5 | R <sub>thjp</sub> | –   | 5   | –   | °C/W |

17. Includes also typical solder thickness under the Exposed Pad (EP).

**Table 6. ELECTRICAL CHARACTERISTICS**

(All Min and Max parameters are guaranteed over full junction temperature (T<sub>JP</sub>) range (–40°C; 150°C), unless otherwise specified)

| Characteristic | Symbol | Condition | Min | Typ | Max | Unit |
|----------------|--------|-----------|-----|-----|-----|------|
|----------------|--------|-----------|-----|-----|-----|------|

**VDD: 3 V LOW VOLTAGE ANALOG AND DIGITAL SUPPLY**

|                                 |                        |  |      |     |      |    |
|---------------------------------|------------------------|--|------|-----|------|----|
| The VDD Current Consumption     | I <sub>VDD</sub>       |  | –    | –   | 6    | mA |
| POR Toggle Level on VDD Rising  | POR <sub>3V_H</sub>    |  | 2.7  | –   | 3.05 | V  |
| POR Toggle Level on VDD Falling | POR <sub>3V_L</sub>    |  | 2.45 | –   | 2.8  | V  |
| POR Hysteresis                  | POR <sub>3V_HYST</sub> |  | 0.01 | 0.2 | 0.75 | V  |
| OTP UV Toggle Level on VBOOST   | OTP_UV                 |  | 13   | –   | 15   | V  |
| OTP UV Toggle Level Hysteresis  | OTP_UV_HYST            |  | 0.01 | 0.2 | 0.75 | V  |

**VBOOSTM3V: HIGH SIDE AUXILIARY SUPPLY**

|  |                          |                      |      |      |                   |    |
|--|--------------------------|----------------------|------|------|-------------------|----|
| VBSTM3 Regulator Output Voltage                  | V <sub>BSTM3</sub>       | Referenced to VBOOST | –3.6 | –3.3 | –3.0              | V  |
| DC Output Current Consumption<br>N78723–0 Device | M3V_IOUT                 |                      | –    | 5    | 28<br>(Note 18)   | mA |
| N78723–2 Device                                  |                          |                      | –    | 5    | 22.5<br>(Note 19) |    |
| Output Current Limitation                        | M3V_ILIM                 |                      | –    | –    | 200               | mA |
| VBSTM3 External Decoupling Cap.                  | C <sub>VBSTM3V</sub>     | Referenced to VBOOST | 0.3  | –    | 2.2               | µF |
| VBSTM3 Ext. Decoupling Cap. ESR                  | C <sub>VBSTM3V_ESR</sub> | Referenced to VBOOST | –    | –    | 200               | mΩ |
| VBOOST POR Level on N78723–2 Device (Note 20)    | M3V_VBSTPOR              |                      | 3.5  | –    | 5.5               | V  |

**OSC10M: SYSTEM OSCILLATOR CLOCK**

|                             |         |  |   |    |    |     |
|-----------------------------|---------|--|---|----|----|-----|
| System Oscillator Frequency | FOSC10M |  | 8 | 10 | 12 | MHz |
|-----------------------------|---------|--|---|----|----|-----|

**ADC FOR MEASURING V<sub>BOOST</sub>, V<sub>DD</sub>, V<sub>LED1</sub>, V<sub>LED2</sub>, TEMP**

|   |                    |                                   |              |        |              |      |
|---|--------------------|-----------------------------------|--------------|--------|--------------|------|
| ADC Resolution  | ADC_RES            |                                   | –            | 8      | –            | Bits |
| Nonlinearity<br>Integral (INL)<br>Differential (DNL)  | ADC_INL<br>ADC_DNL | Best Fitting Straight Line Method | –1.5<br>–2.0 | –<br>– | +1.5<br>+2.0 | LSB  |
| Full Path Gain Error for Measurements of V <sub>DD</sub> , V <sub>LEDx</sub> , V <sub>BOOST</sub> | ADC_GAINER         |                                   | –3.25        | –      | 3.25         | %    |
| Offset at Output of ADC   | ADC_OFFSET         |                                   | –2           | –      | 2            | LSB  |
| Time for 1 SAR Conversion   | ADC_CONV           | Full Conversion of 8 Bits         | 6.67         | 8      | 10           | µs   |
| ADC Full Scale for V <sub>DD</sub> Measurement  | ADCFS_VDD          |                                   | 3.87         | 4      | 4.13         | V    |

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.

18. V<sub>BOOST</sub> = 68 V, V<sub>LED1,2</sub> = 34 V, f<sub>BUCK</sub> = 2 MHz, maximum total gate charge for both activated BUCK channels Q<sub>GATE</sub> = 14 nC.

19. V<sub>BOOST</sub> = 68 V, V<sub>LED1,2</sub> = 34 V, f<sub>BUCK</sub> = 1.61 MHz, maximum total gate charge for both activated BUCK channels Q<sub>GATE</sub> = 14 nC.

20. On N78723–2 device, the Buck switch is switched off when VBOOST drops below M3V\_VBSTPOR level. When VBOOST returns back above M3V\_VBSTPOR level, normal operation is restored.

# NCV78723

**Table 6. ELECTRICAL CHARACTERISTICS** (continued)

(All Min and Max parameters are guaranteed over full junction temperature (T<sub>JP</sub>) range (-40°C; 150°C), unless otherwise specified)

| Characteristic   | Symbol   | Condition  | Min                                  | Typ                  | Max                                  | Unit |
|--|--|--|--------------------------------------|----------------------|--------------------------------------|------|
| <b>ADC FOR MEASURING V<sub>BOOST</sub>, V<sub>DD</sub>, V<sub>LED1</sub>, V<sub>LED2</sub>, TEMP</b> |  |  |                                      |                      |                                      |      |
| ADC Full Scale for V <sub>LEDx</sub> Measurement   | ADCFS_VLED00<br>ADCFS_VLED01<br>ADCFS_VLED10<br>ADCFS_VLED11 | The V <sub>LED</sub> Range Code is "00"<br>The V <sub>LED</sub> Range Code is "01"<br>The V <sub>LED</sub> Range Code is "10"<br>The V <sub>LED</sub> Range Code is "11" | 67.725<br>48.375<br>38.700<br>29.025 | 70<br>50<br>40<br>30 | 72.275<br>51.625<br>41.300<br>30.975 | V    |
| ADC Full Scale for V <sub>BOOST</sub> Measurement  | ADCFS_VBST   |  | 67.725                               | 70                   | 72.275                               | V    |
| ADC Full Scale for Temp. Measurement<br>N78723-0 Device<br>N78723-2 Device                           | ADCFS_TEMP   |  | 193.5<br>190                         | 200<br>200           | 206.5<br>210                         | °C   |
| TSD Threshold Level  | ADC_TSD  | ADC Measurement of Junction Temperature  | 163                                  | 169                  | 175                                  | °C   |
| Temperature Measurement Accuracy at Hot  | ADC_TEMPHOT  | t = 125°C  | -8                                   | -                    | 8                                    | °C   |
| Temperature Measurement Accuracy at Cold   | ADC_TEMPCOLD   | t = -40°C  | -15                                  | -                    | 15                                   | °C   |
| V <sub>LEDx</sub> Input Impedance<br>N78723-0 Device<br>N78723-2 Device                              | VLED_RES   |  | 210<br>280                           | -<br>-               | 650<br>790                           | kΩ   |
| <b>BUCK REGULATOR - SWITCH</b>   |  |  |                                      |                      |                                      |      |
| On Resistance, Range 1   | Rdson1   | At Room-Temperature,<br>I(VINBCKx) = 0.18 A,<br>V(BOOST - VINBCKx) ≤ 0.2 V   | -                                    | -                    | 5.2                                  | Ω    |
| On Resistance at Hot, Range 1  | Rdson1_hot   | At T <sub>j</sub> = 150 °C,<br>I(VINBCKx) = 0.18 A,<br>V(BOOST - VINBCKx) ≤ 0.2 V  | -                                    | -                    | 7.2                                  | Ω    |
| On Resistance, Range 2   | Rdson2   | At Room-Temperature,<br>I(VINBCKx) = 0.375 A,<br>V(BOOST - VINBCKx) ≤ 0.2 V  | -                                    | -                    | 2.6                                  | Ω    |
| On Resistance at Hot, Range 2  | Rdson2_hot   | At T <sub>j</sub> = 150 °C,<br>I(VINBCKx) = 0.375 A,<br>V(BOOST - VINBCKx) ≤ 0.2 V   | -                                    | -                    | 3.6                                  | Ω    |
| On Resistance, Range 3   | Rdson3   | At Room-Temperature,<br>I(VINBCKx) = 0.75 A,<br>V(BOOST - VINBCKx) ≤ 0.2 V   | -                                    | -                    | 1.3                                  | Ω    |
| On Resistance at Hot, Range 3  | Rdson3_hot   | At T <sub>j</sub> = 150 °C,<br>I(VINBCKx) = 0.75 A,<br>V(BOOST - VINBCKx) ≤ 0.2 V  | -                                    | -                    | 1.8                                  | Ω    |
| On Resistance, Range 4   | Rdson4   | At Room-Temperature,<br>I(VINBCKx) = 1.5 A,<br>V(BOOST - VINBCKx) ≤ 0.2 V  | -                                    | -                    | 0.65                                 | Ω    |
| On Resistance at Hot, Range 4  | Rdson4_hot   | At T <sub>j</sub> = 150 °C,<br>I(VINBCKx) = 1.5 A,<br>V(BOOST - VINBCKx) ≤ 0.2 V   | -                                    | -                    | 0.9                                  | Ω    |
| Switching Slope – ON Phase (Note 21)   | T <sub>RISE</sub>  |  | -                                    | 3                    | -                                    | V/ns |
| Switching Slope – OFF Phase (Notes 21 and 22)  | T <sub>FALL</sub>  |  | -                                    | 3                    | -                                    | V/ns |
| <b>BUCK REGULATOR - CURRENT REGULATION</b>   |  |  |                                      |                      |                                      |      |
| Current Sense Threshold Level, Range 1, Min Value  | ITHR1_000  | [BUCKx_VTHR = 00000000]<br>End of the BUCK ON-Phase  | 23.905                               | 28.125               | 32.344                               | mA   |

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.

21. When DRV\_SLOW\_EN bit is 1 on N78723-2 device, the switching slopes are typically by 30% slower.

22. Falling switching slope depends on used current (range, current sense threshold level) and free-wheeling diode capacitance.



**Table 6. ELECTRICAL CHARACTERISTICS** (continued)

(All Min and Max parameters are guaranteed over full junction temperature (T<sub>JP</sub>) range (-40°C; 150°C), unless otherwise specified)

| Characteristic   | Symbol      | Condition  | Min      | Typ     | Max      | Unit |
|--|-------------|--|----------|---------|----------|------|
| <b>BUCK REGULATOR – CURRENT REGULATION</b>   |             |  |          |         |          |      |
| Current Sense Threshold Level, Range 1, Spec. Value  | ITHR1_110   | [BUCKx_VTHR = 01101110]<br>End of the BUCK ON-Phase.<br>Min. Value for Specified Precision                 | -        | 112.5   | -        | mA   |
| Current Sense Threshold Level, Range 1, Max Value  | ITHR1_255   | [BUCKx_VTHR = 11111111]<br>End of the BUCK ON-Phase  | -        | 224.15  | -        | mA   |
| Current Sense Threshold Level, Range 2, Min Value  | ITHR2_000   | [BUCKx_VTHR = 00000000]<br>End of the BUCK ON-Phase  | 47.813   | 56.25   | 64.688   | mA   |
| Current Sense Threshold Level, Range 2, Spec. Value  | ITHR2_110   | [BUCKx_VTHR = 01101110]<br>End of the BUCK ON-phase.<br>Min. Value for Specified Precision                 | -        | 225     | -        | mA   |
| Current Sense Threshold Level, Range 2, Max Value  | ITHR2_255   | [BUCKx_VTHR = 11111111]<br>End of the BUCK ON-Phase  | -        | 448.3   | -        | mA   |
| Current Sense Threshold Level, Range 3, Min Value  | ITHR3_000   | [BUCKx_VTHR = 00000000]<br>End of the BUCK ON-Phase  | 95.625   | 112.5   | 129.375  | mA   |
| Current Sense Threshold Level, Range 3, Spec. Value  | ITHR3_110   | [BUCKx_VTHR = 01101110]<br>End of the BUCK ON-Phase.<br>Min. Value for Specified Precision                 | -        | 450     | -        | mA   |
| Current Sense Threshold Level, Range 3, Max Value  | ITHR3_255   | [BUCKx_VTHR = 11111111]<br>End of the BUCK ON-phase  | -        | 896.6   | -        | mA   |
| Current Sense Threshold Level, Range 4, Min Value  | ITHR4_000   | [BUCKx_VTHR = 00000000]<br>End of the BUCK ON-Phase  | 191.25   | 225     | 258.75   | mA   |
| Current Sense Threshold Level, Range 4, Spec. Value  | ITHR4_110   | [BUCKx_VTHR = 01101110]<br>End of the BUCK ON-Phase.<br>Min. Value for Specified Precision                 | -        | 900     | -        | mA   |
| Current Sense Threshold Level, Range 4, Max Value  | ITHR4_255   | [BUCKx_VTHR = 11111111]<br>End of the BUCK ON-Phase  | -        | 1791.75 | -        | mA   |
| Current Sense Threshold Increase per Code, Range 1   | ΔITHR1      | 8 Bit, Linear Increase   | -        | 0.77    | -        | mA   |
| Current Sense Threshold Increase per Code, Range 2   | ΔITHR2      | 8 Bit, Linear Increase   | -        | 1.54    | -        | mA   |
| Current Sense Threshold Increase per Code, Range 3   | ΔITHR3      | 8 Bit, Linear Increase   | -        | 3.08    | -        | mA   |
| Current Sense Threshold Increase per Code, Range 4   | ΔITHR4      | 8 Bit, Linear Increase   | -        | 6.15    | -        | mA   |
| Current Threshold Accuracy Only with Trimming Constant for the Highest Range (Note 23)<br>N78723-0<br>N78723-2 | ITHR_ERR_DD | Specified for BUCKx_VTHR ≥ 01101110, without the Delta of the Trimming Code and without Temp. Compensation | -8<br>-9 | -<br>-  | +8<br>+9 | %    |
| Current Threshold Accuracy without Temperature Compensation (Note 23)<br>N78723-0<br>N78723-2                  | ITHR_ERR_D  | Specified for BUCKx_VTHR ≥ 01101110, with the Delta of the Trimming Code and without Temp. Compensation    | -6<br>-7 | -<br>-  | +6<br>+7 | %    |
| Current Threshold Accuracy (Note 23)<br>N78723-0<br>N78723-2   | ITHR_ERR    | Specified for BUCKx_VTHR ≥ 01101110, the Delta of the Trimming Code and Temp. Compensation                 | -3<br>-4 | -<br>-  | +3<br>+4 | %    |

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.

23. Measured as comparator DC threshold value, without comparator delay and switch falling slope.

# NCV78723

**Table 6. ELECTRICAL CHARACTERISTICS** (continued)

(All Min and Max parameters are guaranteed over full junction temperature (T<sub>J</sub>) range (-40°C; 150°C), unless otherwise specified)

| Characteristic  | Symbol       | Condition  | Min      | Typ        | Max        | Unit |
|---|--------------|--|----------|------------|------------|------|
| <b>BUCK REGULATOR – CURRENT REGULATION</b>  |              |  |          |            |            |      |
| Offset of Peak Current Comparator on N78723–2 Device  | CMP_OFFSET   |  | -10      | -          | +10        | mV   |
| Over-Current Detection Level, Range 1   | OCDR1        | Typ. $1.5 \times I_{THR1\_255}$  | 286      | -          | 388        | mA   |
| Over-Current Detection Level, Range 2   | OCDR2        | Typ. $1.5 \times I_{THR2\_255}$  | 573      | -          | 776        | mA   |
| Over-Current Detection Level, Range 3   | OCDR3        | Typ. $1.5 \times I_{THR3\_255}$  | 1148     | -          | 1553       | mA   |
| Over-Current Detection Level, Range 4   | OCDR4        | Typ. $1.5 \times I_{THR4\_255}$  | 2295     | -          | 3105       | mA   |
| Time Constant for Longest Off Time  | TC_00        | [BUCKx_TOFF = 00000]   | -        | 50         | -          | μs-V |
| Time Constant for Shortest Off Time   | TC_31        | [BUCKx_TOFF = 11111]   | -        | 5          | -          | μs-V |
| T <sub>OFF</sub> Time Relative Error  | TOFF_ERR     | TC = T <sub>OFF</sub> × V <sub>LED</sub><br>@ V <sub>LED</sub> > 2 V,<br>T <sub>OFF</sub> > 350 ns | -10      | -          | +10        | %    |
| T <sub>OFF</sub> Time Absolute Error  | TOFF_ERR_ABS | TC = T <sub>OFF</sub> × V <sub>LED</sub><br>@ V <sub>LED</sub> > 2 V,<br>T <sub>OFF</sub> ≤ 350 ns | -35      | -          | +35        | ns   |
| Time Constant Decrease per Code   | δTC          | 5 Bits, Exponential Decrease   | -        | 7.16       | -          | %    |
| Detection Level of V <sub>LED</sub> to be Too Low   | VLED_LMT     |  | 1.62     | 1.8        | 1.98       | V    |
| T <sub>OFF</sub> Time for Low V <sub>LED</sub> Voltages<br>N78723–0 Device<br>N78723–2 Device (Note 24) | TC_LOW       | VLED < VLED_LMT  | 78<br>72 | 105<br>105 | 120<br>140 | μs   |
| The Zero-cross Detection Threshold Level (Note 25)  | TC_ZCD       |  | -0.125   | -          | -0.005     | V    |
| The Zero-cross Detection Filter Time  | TC_ZCD_FT    |  | 20       | -          | 350        | ns   |
| OpenLEDx Detection Time   | TON_OPEN     |  | 40       | 50         | 60         | μs   |
| Buck Minimum T <sub>ON</sub> Time   | TON_MIN      | For<br>VINBCKx – LBCKSWx < 2.4 V,<br>No Failure at LBCKSWx Pin                                     | 50       | -          | 250        | ns   |
| Delay from BUCKx ISENS Comparator Input Voltage Balance to BUCKx Switch Going OFF                       | ISENSCMP_DEL | ISENS Cmp. Over-Drive<br>ramp > 1 mV/10 ns   | -        | 70         | -          | ns   |

**5 V TOLERANT DIGITAL INPUTS (SCLK, CSB, SDI, LEDCTRL1, LEDCTRL2, RSTB)**

|                                     |                   |   |     |     |      |    |
|-------------------------------------|-------------------|---|-----|-----|------|----|
| High-Level Input Voltage            | VINHI             |   | 2   | -   | -    | V  |
| Low-Level Input Voltage             | VINLO             |   | -   | -   | 0.8  | V  |
| Pull Resistance (Note 26)           | R <sub>PULL</sub> |   | 40  | -   | 160  | kΩ |
| LED PWM Propagation Delay (Note 27) | BUCKx_SW_DEL      | Activation Time of the BUCKx Switch from the LEDCTRLx Pin | 4.4 | 5.5 | 6.95 | μs |
| Sampling Resolution                 | LEDCTRL_SR        |   | -   | 100 | 125  | ns |
| RSTB Debouncer Time                 | RSTB_DEB          |   | -   | 100 | 200  | ns |

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.

24. Unless zero-cross detection stops the TOFF time on N78723–2 device.

25. The voltage at LBCKSWx pin when the comparator toggles, rising edge.

26. Pull down resistor (R<sub>PD</sub>) for RSTB, LEDCTRLx, SDI and SCLK, pull up resistor (R<sub>PJ</sub>) for CSB to VDD.

27. Jitter is present due to the internal resynchronization.

**Table 6. ELECTRICAL CHARACTERISTICS** (continued)

(All Min and Max parameters are guaranteed over full junction temperature (T<sub>J</sub>P) range (-40°C; 150°C), unless otherwise specified)

| Characteristic                                      | Symbol             | Condition   | Min | Typ | Max | Unit |
|---|--------------------|---|-----|-----|-----|------|
| <b>5 V TOLERANT OPEN-DRAIN DIGITAL OUTPUT (SDO)</b> |                    |   |     |     |     |      |
| Low-Voltage Output Voltage                          | V <sub>OUTLO</sub> | I <sub>OUT</sub> = -10 mA<br>(Current Flows into the Pin)   | -   | -   | 0.4 | V    |
| Equivalent Output Resistance                        | R <sub>DSON</sub>  | Low-Side Switch   | -   | 10  | 40  | Ω    |
| SDO Pin Leakage Current                             | SDO_ILEAK          |   | -   | -   | 2   | μA   |
| SDO Pin Capacitance                                 | SDO_C              |   | -   | -   | 10  | pF   |
| CLK to SDO Propagation Delay                        | SDO_DL             | Low-Side Switch Activation/<br>Deactivation Time; @ 1 kΩ to<br>5 V, 100 pF to GND, for Falling<br>Edge V(SDO) Goes below<br>0.5 V | -   | -   | 60  | ns   |

**3 V DIGITAL INPUTS (TEST, TEST1, TEST2)**

|                          |                    |                      |     |   |     |    |
|--------------------------|--------------------|----------------------|-----|---|-----|----|
| High-Level Input Voltage | V <sub>IN3HI</sub> |                      | 2.3 | - | -   | V  |
| Low-Level Input Voltage  | V <sub>IN3LO</sub> |                      | -   | - | 0.8 | V  |
| Pull Resistance          | R <sub>PD3</sub>   | Pull-Down Resistance | -   | - | 60  | kΩ |

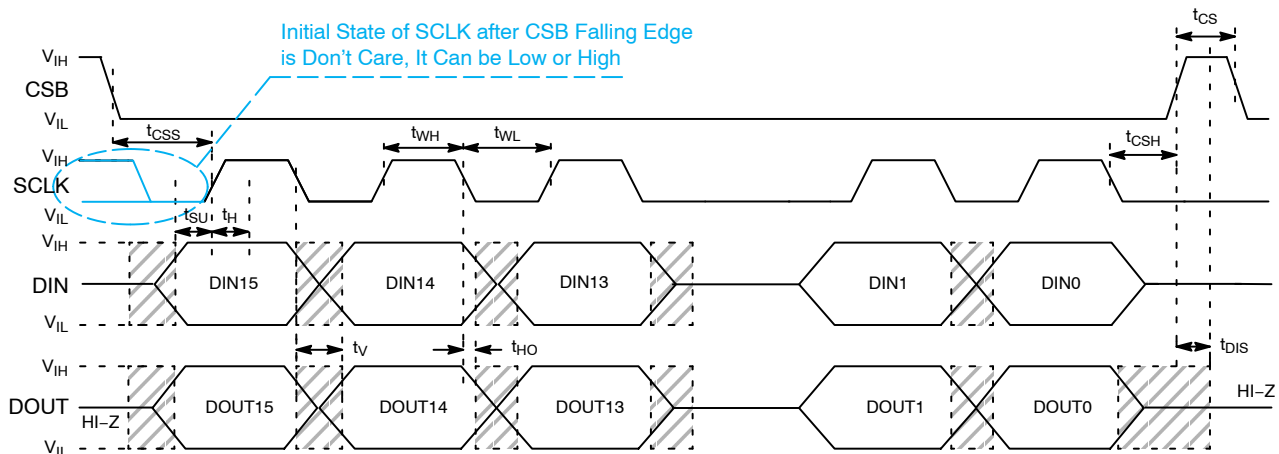
**SPI INTERFACE**

|  |                   |  |       |   |                             |    |
|--|-------------------|--|-------|---|-----------------------------|----|
| CSB Setup Time   | t <sub>CSS</sub>  |  | 0.5   | - | -                           | μs |
| CSB Hold Time  | t <sub>CSH</sub>  |  | 0.25  | - | -                           | μs |
| SCLK Low Time  | t <sub>WL</sub>   |  | 0.5   | - | -                           | μs |
| SCLK High Time   | t <sub>WH</sub>   |  | 0.5   | - | -                           | μs |
| Data-In (DIN) Setup Time,<br>Valid Data before Rising Edge<br>of CLK | t <sub>SU</sub>   |  | 0.25  | - | -                           | μs |
| Data-In (DIN) Hold Time, Hold<br>Data after Rising Edge of CLK       | t <sub>H</sub>    |  | 0.275 | - | -                           | μs |
| Output (DOUT) Disable Time<br>(Note 28)                              | t <sub>DIS</sub>  |  | 0.08  | - | 0.32                        | μs |
| Output (DOUT) Valid<br>(Note 28)                                     | t <sub>V1→0</sub> |  | -     | - | 0.32                        | μs |
| Output (DOUT) Valid<br>(Note 29)                                     | t <sub>V0→1</sub> |  | -     | - | 0.32 +<br>t <sub>(RC)</sub> | μs |
| Output (DOUT) Hold Time  | t <sub>HO</sub>   |  | 0.01  | - | -                           | μs |
| CSB High Time  | t <sub>CS</sub>   |  | 1     | - | -                           | μs |

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.

28. SDO low-side switch activation time.

29. Time depends on the SDO load and pull-up resistor.



**Figure 5. SPI Communication Timing**

TYPICAL CHARACTERISTICS

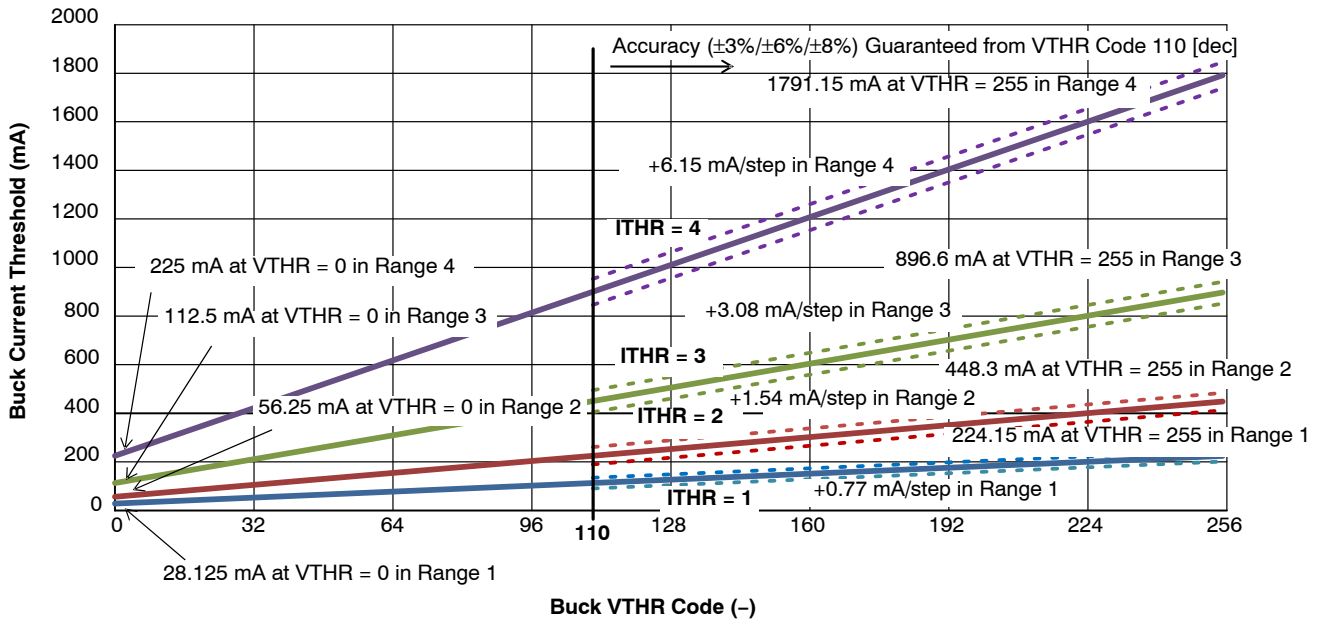


Figure 6. Buck Peak Current vs. Ranges and VTNR Code

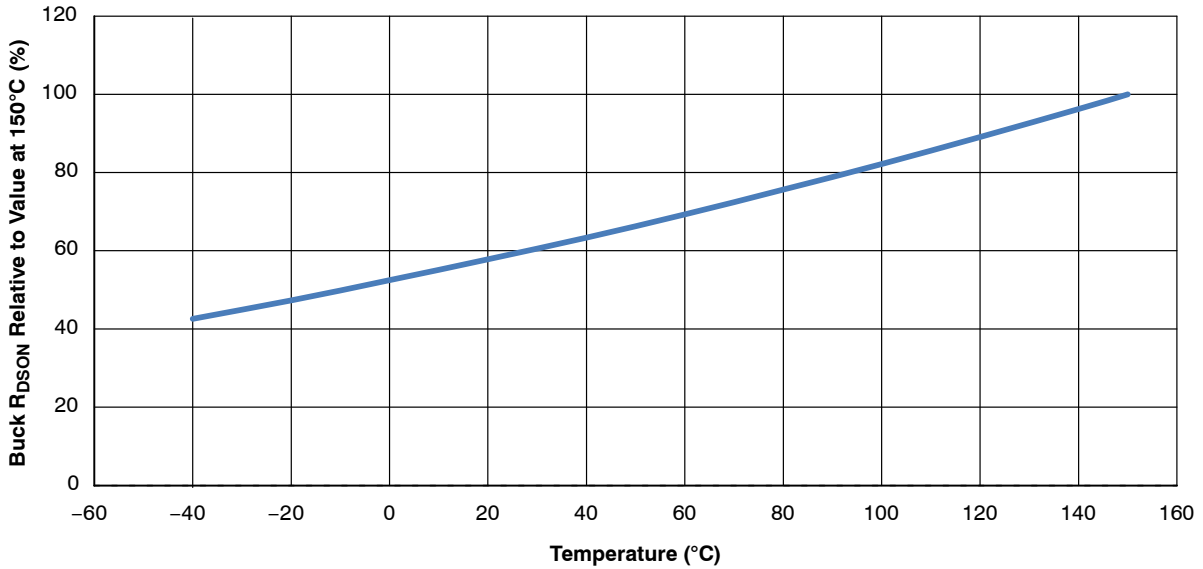


Figure 7. Typical Temperature Behavior of Buck Switch R<sub>DSON</sub> Relative to the Value at 150°C

TYPICAL CHARACTERISTICS

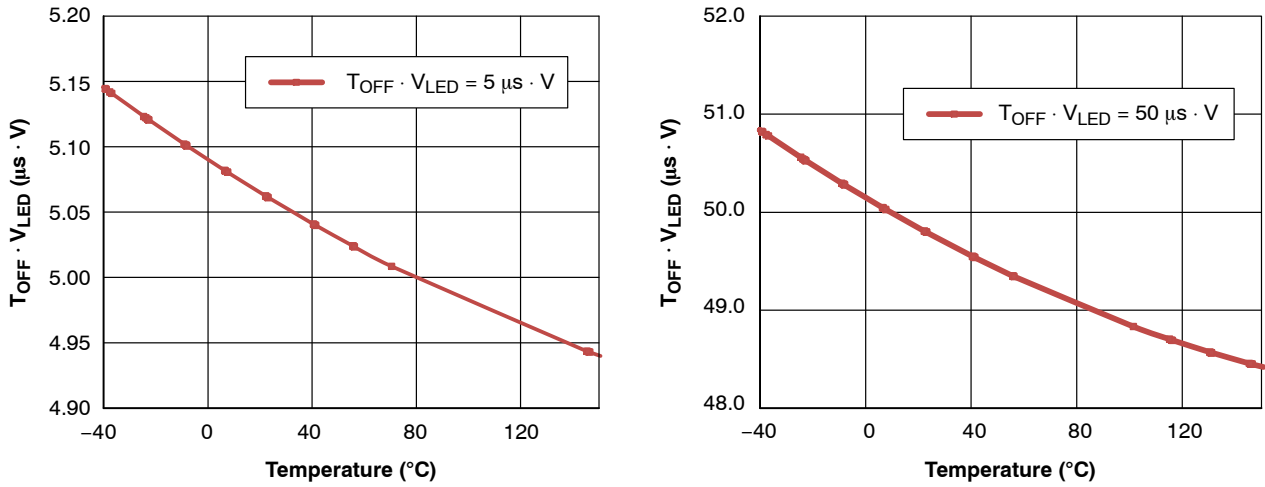
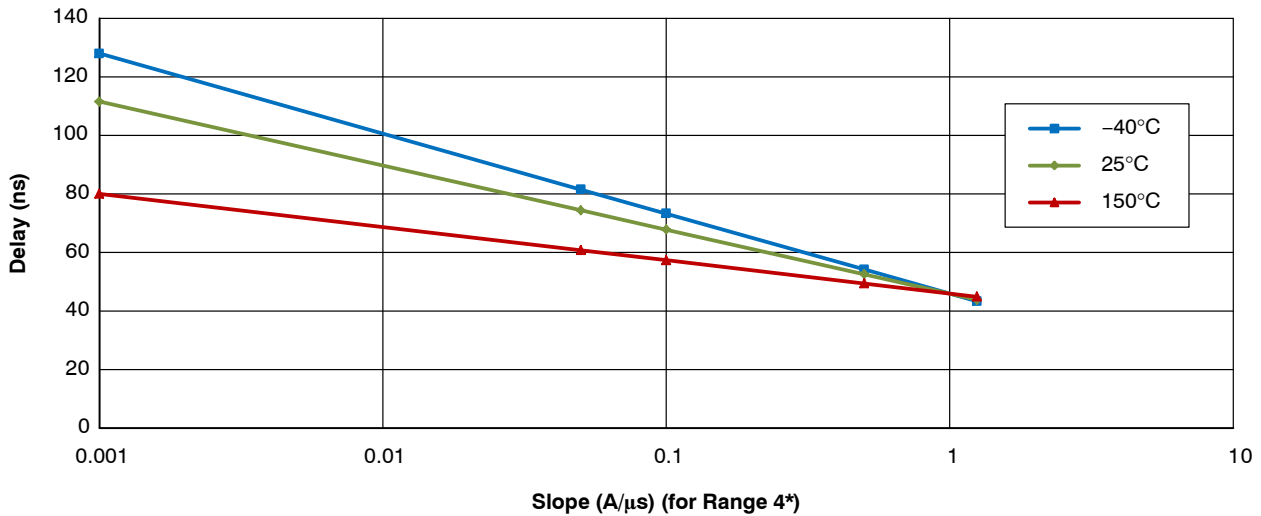


Figure 8. Typical Temperature Dependency of  $T_{OFF} \cdot V_{LED}$  Constant (Shortest  $T_{OFF} \cdot V_{LED} = 5 \mu s \cdot V$  and Longest  $T_{OFF} \cdot V_{LED} = 50 \mu s \cdot V$ )



\* In lower ranges, the same current slope (A/s) translates into a higher voltage slope (V/s) at the input of the comparator, because of the higher  $R_{DSON}$ . Resulting equations for all ranges:

Range 4: Comp. Delay [ns] =  $(0.0365 \cdot \text{Temp } [^{\circ}\text{C}] - 10.41) \cdot \ln(\text{Slope } [\text{A}/\mu\text{s}, \text{Range 4}]) + 46$

Range 3: Comp. Delay [ns] =  $(0.0365 \cdot \text{Temp } [^{\circ}\text{C}] - 10.41) \cdot \ln(\text{Slope} \cdot 2 [\text{A}/\mu\text{s}, \text{Range 4}]) + 46$

Range 2: Comp. Delay [ns] =  $(0.0365 \cdot \text{Temp } [^{\circ}\text{C}] - 10.41) \cdot \ln(\text{Slope} \cdot 4 [\text{A}/\mu\text{s}, \text{Range 4}]) + 46$

Range 1: Comp. Delay [ns] =  $(0.0365 \cdot \text{Temp } [^{\circ}\text{C}] - 10.41) \cdot \ln(\text{Slope} \cdot 8 [\text{A}/\mu\text{s}, \text{Range 4}]) + 46$

Figure 9. Typical Comparator Delay vs. Slope

DETAILED OPERATING DESCRIPTION

**Supply Concept in General**

Two voltages have to be supplied to the NCV78723 chip – low voltage VDD logic supply and high voltage VBOOST for providing energy to the buck regulators. More detailed description follows.

**VDD Supply**

The VDD supply is the low voltage digital and analog supply for the chip. NCV78723 does not contain internal VDD regulator and this voltage is supposed to be provided externally by a dedicated voltage regulator that fulfills specified voltage and current needs or can be supplied from the NCV78702/NCV78703 VDD pin.

The Power-On-Reset circuit (POR) monitors the VDD voltage and RSTB pin to control the out-of-reset and reset entering state. At power-up, the chip will exit from reset state when  $VDD > POR3V\_H$  and RSTB pin is in “log. 1”. No SPI communication is possible in reset state.

**VBOOST Supply**

The VBOOST supply voltage is the main high voltage supply for the chip. The voltage is supposed to be provided by booster chip such as NCV78702/NCV78703 or NCV878763 in an application. VINBCKx pins have to be connected by low impedance track to this supply to ensure proper buck performance.

The VBOOST voltage is monitored by under-voltage comparator to check sufficient zapping voltage at VBOOST pin during OTP programming operation.

**VBOOSTM3V Supply**

The VBOOSTM3V is the high side auxiliary supply for the gate drive of the buck regulators’ integrated high-side P-MOSFET switches. This supply receives energy directly from the VBOOST pin.

**Internal Clock Generation – OSC10M**

An internal RC clock named OSC10M is used to run all the digital functions in the chip. The clock is trimmed in the factory prior to delivery. Its accuracy is guaranteed under full operating conditions and is independent from external component selection (refer to Table 6 – OSC10M: System Oscillator Clock for details). All timings depend on OSC10M accuracy.

**Buck Regulator**

**General**

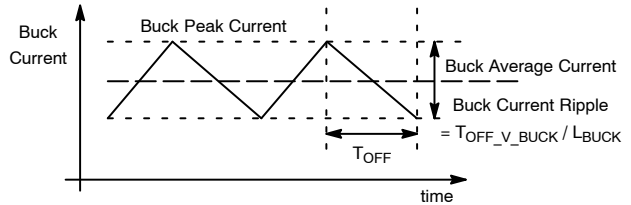
The NCV78723 contains two high-current integrated buck current regulators, which are the sources for the LED strings. The bucks are powered from the external booster regulator.

**Buck Current Regulation Principle**

Each buck controls the individual inductor peak current ( $I_{BUCKpeak}$ ) and incorporates a constant ripple ( $\Delta I_{BUCKpkpk}$ ) control circuit to ensure also stable average current through the LED string, independently from the string voltage. The buck average current is in fact described by the formula:

$$I_{BUCKAVG} = I_{BUCKpeak} - \frac{\Delta I_{BUCKpkpk}}{2} \tag{eq. 1}$$

This is graphically exemplified by Figure 10.



**Figure 10. Buck Regulator Controlled Average Current**

The parameter  $I_{BUCKpeak}$  is programmable through the device by means of the internal registers for range selection BUCKx\_ISENS\_THR[1:0] and code BUCKx\_VTHR[7:0].

The formula that defines the total ripple current over the buck inductor is also hereby reported:

$$\begin{aligned} \Delta I_{BUCKpkpk} &= \frac{T_{OFF} \cdot (V_{LED} + V_{DIODE})}{L_{BUCK}} \equiv \\ &\equiv \frac{T_{OFF} \cdot V_{LED}}{L_{BUCK}} = \frac{T_{OFF\_V_{LED\_iSPI}}}{L_{BUCK}} \end{aligned} \tag{eq. 2}$$

In the formula above,  $T_{OFF}$  represents the buck switch off time,  $V_{LED}$  is the LED voltage feedback sensed at the NCV78723 VLEDx pin and  $L_{BUCK}$  is the buck inductance value. The parameter  $T_{OFF\_V_{LED\_iSPI}}$  is programmable by SPI (BUCKx\_TOFF[4:0] register), with values related to Table 6 – Buck Regulator – Current Regulation. In order to achieve a constant ripple current value, the device varies the  $T_{OFF}$  time inversely proportional to the  $V_{LED}$  sensed at the device pin, according to the selected factor  $T_{OFF\_V_{LED\_iSPI}}$ . As a consequence to the constant ripple control and variable off time, the buck switching frequency depends on the boost voltage and LED voltage in the following way:

$$\begin{aligned} f_{BUCK} &= \frac{(V_{BOOST} - V_{LED})}{V_{BOOST}} \cdot \frac{1}{T_{OFF}} = \\ &= \frac{(V_{BOOST} - V_{LED})}{V_{BOOST}} \cdot \frac{V_{LED}}{T_{OFF\_V_{LED\_iSPI}}} \end{aligned} \tag{eq. 3}$$

The LED average current in time (DC) is equal to the buck time average current. Therefore, to achieve a given LED current target, it is sufficient to know the buck peak current and the buck current ripple. A rule of thumb is to count a minimum of 50% ripple reduction by means of the capacitor

$C_{BUCK}$  and this is normally obtained with a low cost ceramic component ranging from 100 nF to 470 nF (such values are typically used at connector sides anyway, so this is included in a standard BOM). The following figure reports a typical example waveform:

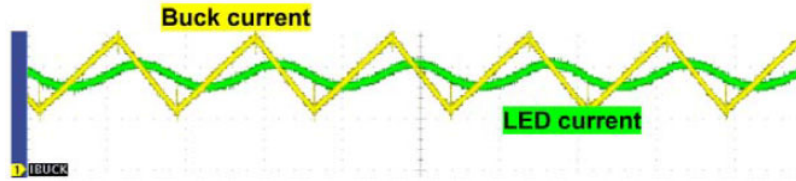


Figure 11. LED Current AC Components Filtered Out by Output Impedance (Oscilloscope Snapshot)

The use of  $C_{BUCK}$  is a cost effective way to improve EMC performances without the need to increase the value of

$L_{BUCK}$ , which would be certainly a far more expensive solution.

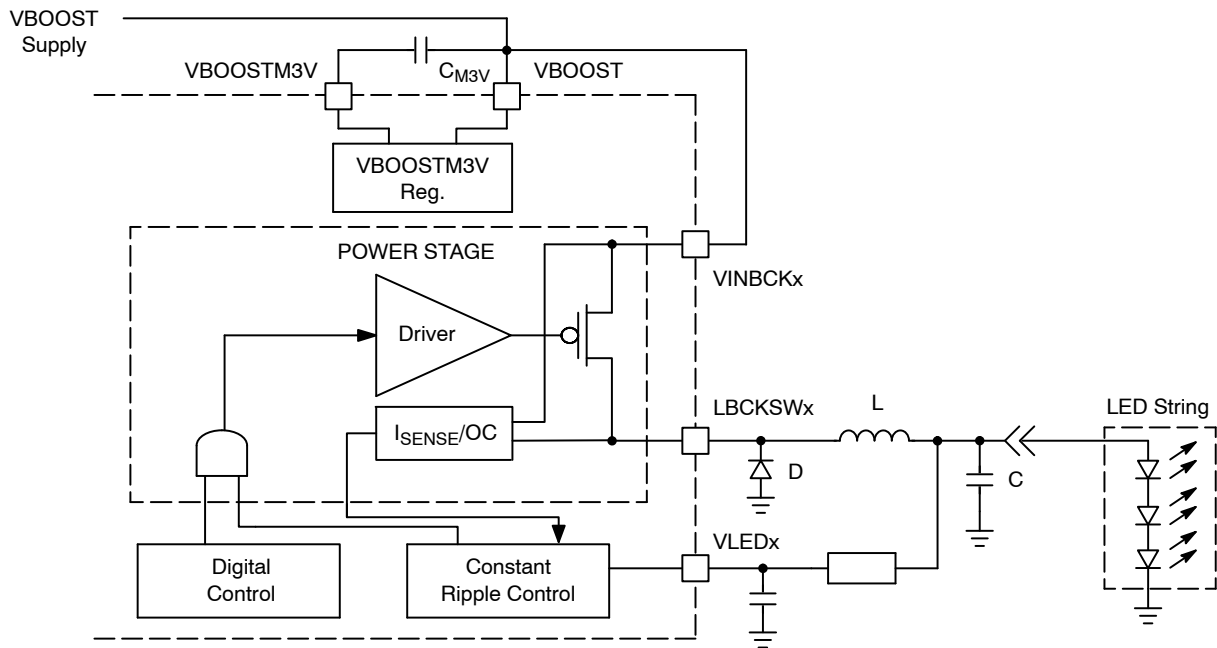


Figure 12. Buck Regulator Circuit Diagram

**Buck Offset Compensation**

The N78723-2 device features a peak current offset compensation that can be disabled by the corresponding BUCK<sub>x</sub>\_OFF\_CMP\_DIS SPI bit. When this bit is “0” (offset compensation is enabled), the offset changes polarity each buck period, so that the average effect over time on the peak current is minimized (ideally zero). As a consequence

of the polarity change, the peak current is toggling between two threshold values, one high value and one low, as shown in the picture below. The related sub-harmonic frequency (half the buck switching frequency) will appear in the spectrum. This has to be taken into account from EMC point of view. The use of the offset cancellation is very effective in case of high precision levels for low currents.



Figure 13. Buck Offset Compensation Feature

**SW Compensation of the Buck Current Accuracy**

In order to ensure buck current accuracy as specified in Table 6 – Buck Regulator – Current Regulation, set of constants trimmed during manufacturing process is available. Microcontroller should use them in the following way:

To Reach ±8% (±9% for N78723-2) Accuracy (±6% for Range 4) Over Whole Temperature Operating Range:

All ranges:  $BUCKx\_ISENS\_TRIM[6:0] = BUCKx\_ISENS\_RNG[6:0]$

BUCKx\_ISENS\_RNG[6:0] is trimming constant for the highest current range (Range 4) at hot temperature.

BUCKx\_ISENS\_RNG[6:0] constant is loaded into BUCKx\_ISENS\_TRIM[6:0] register automatically after the reset of the device.

To Reach ±6% (±7% for N78723-2) Accuracy Over Whole Temperature Operating Range:

BUCKx\_ISENS\_Dx[3:0] registers, meaning delta of the trimming constant with respect to the higher current range at hot temperature, have to be used. Trimming constant for the particular range at hot temperature can be then calculated as:

Range 4:  $BUCKx\_R4\_trim\_hot = BUCKx\_ISENS\_RNG[6:0]$ ,

Range 3:  $BUCKx\_R3\_trim\_hot = BUCKx\_ISENS\_RNG[6:0] + BUCKx\_ISENS\_D3[3:0]$ ,

Range 2:  $BUCKx\_R2\_trim\_hot = BUCKx\_ISENS\_RNG[6:0] + BUCKx\_ISENS\_D3[3:0] + BUCKx\_ISENS\_D2[3:0]$ ,

Range 1:  $BUCKx\_R1\_trim\_hot = BUCKx\_ISENS\_RNG[6:0] + BUCKx\_ISENS\_D3[3:0] + BUCKx\_ISENS\_D2[3:0] + BUCKx\_ISENS\_D1[3:0]$ ,

where:

delta of the trimming constant BUCKx\_ISENS\_Dx[3:0] is signed, coded as two's complement. Range of this constant is decadic <-8; 7>, binary <1000; 0111>.

Calculated trimming constant has to be then written into trimming SPI register:

$BUCKx\_ISENS\_TRIM[6:0] = BUCKx\_Ry\_trim\_hot$

To Reach ±3% (±4% for N78723-2) Accuracy Over Whole Temperature Operating Range:

In addition to BUCKx\_ISENS\_Dx[3:0] registers, the BUCK\_ISENS\_TCx[3:0] registers, meaning temperature coefficients for the appropriate ranges, have to be used.

When TC\_VERSION = 0, trimming value for a certain temperature should be calculated as:

Range 4:  $BUCKx\_R4\_trim = BUCKx\_R4\_trim\_hot + k_{L3} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

Range 3:  $BUCKx\_R3\_trim = BUCKx\_R3\_trim\_hot + k_{L2} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

Range 2:  $BUCKx\_R2\_trim = BUCKx\_R2\_trim\_hot + k_{L1} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

Range 1:  $BUCKx\_R1\_trim = BUCKx\_R1\_trim\_hot + k_{L0} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

When TC\_VERSION = 1, trimming value for a certain temperature should be calculated as:

Range 4:  $BUCK2\_R4\_trim = BUCK2\_R4\_trim\_hot + k_{L3} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

Range 3:  $BUCK2\_R3\_trim = BUCK2\_R3\_trim\_hot + k_{L3} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

Range 2:  $BUCK2\_R2\_trim = BUCK2\_R2\_trim\_hot + k_{L2} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

Range 1:  $BUCK2\_R1\_trim = BUCK2\_R1\_trim\_hot + k_{L2} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

Range 4:  $BUCK1\_R4\_trim = BUCK1\_R4\_trim\_hot + k_{L1} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

Range 3:  $BUCK1\_R3\_trim = BUCK1\_R3\_trim\_hot + k_{L1} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

Range 2:  $BUCK1\_R2\_trim = BUCK1\_R2\_trim\_hot + k_{L0} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

Range 1:  $BUCK1\_R1\_trim = BUCK1\_R1\_trim\_hot + k_{L0} \cdot (Tj - Thot) + k_Q \cdot (Tj - Thot)^2$ ,

where:

buck temperature coefficient BUCK\_ISENS\_TCx[3:0] is signed, coded as two's complement. Range of this constant is decadic <-8; 7>, binary <1000; 0111>,

$k_{Lx}$  is linear coefficient for each current range calculated:  $k_{Lx} = (BUCK\_ISENS\_TCx[3:0] - k_Q \cdot (170^\circ C)^2) / (-170^\circ C)$  [code/°C] when TC\_VERSION = 0

$k_{Lx}$  is linear coefficient for each current range calculated:  $k_{Lx} = (BUCK\_ISENS\_TCx[3:0] - k_Q \cdot (200^\circ C)^2) / (-200^\circ C)$  [code/°C] when TC\_VERSION = 1

$k_Q$  is quadratic constant for all current ranges:  $k_Q = 2.18 \cdot 10^{-4}$  [code/(°C)<sup>2</sup>]

$Tj$  is junction temperature in °C calculated from VTEMP[7:0] SPI register value according to the equation defined in chapter

ADC: Device Temperature ADC:  $V_{TEMP}$

$Thot$  temperature is constant equal to 125°C when TC\_VERSION = 0

$Thot$  temperature is constant equal to 155°C when TC\_VERSION = 1.



Calculated trimming constant has to be then written into trimming SPI register:

$$BUCKx\_ISENS\_TRIM[6:0] = BUCKx\_Ry\_trim$$

**Note:** The BUCKx\_ISENS\_TRIM[6:0] SPI register allows compensation of the peak current app. in range  $\pm 40\%$  from actual value according to the following equation:

$$IBUCKx = (ITHRx\_000 + \delta ITHRx \cdot BUCKx\_VTHR[7:0]) \cdot (1 + 0.4 \cdot ((BUCKx\_ISENS\_TRIM[6:0] - 63)/63)),$$

where:

ITHRx\_000 is current for VTHR code 0 in ITHRx range (see Table 6 – Buck Regulator – Current Regulation),  
 $\delta ITHRx$  code step in range ITHRx (see Table 6 – Buck Regulator – Current Regulation).

**Paralleling the Bucks for Higher Current Capability**

Different buck channels can be paralleled at the module output (after the buck inductors) for *higher current capability* on a unique channel, summing up together the individual DC currents.

**Buck Overcurrent Protection**

Being a current regulator, the NCV78723 buck is by nature preventing overcurrent in all normal situations. However, in order to protect the system from overcurrent even in case of failures, protection mechanism is available.

This protection is based on internal sensing over the buck switch: when the peak current rises above the maximum limit (OCDRx level, see see Table 6 – Buck Regulator – Current Regulation), an internal counter starts to increment at each period, until the count written in BUCKx\_OC\_OCCMP\_THR[1:0] + 1 is attained. The count is reset if the current drops below OCDRx level or the buck channel is disabled and also at each dimming cycle. From the moment the count is reached onwards, the buck is kept continuously off, until the SPI error flag OCLEDx is read. After reading the flag, the buck channel “x” is automatically re-enabled and will try to regulate the current again.

**Dimming**

The NCV78723 supports both analog and digital dimming (or so called PWM dimming). Analog dimming is performed by controlling the LED amplitude current during operation. This can be done by means of changing the peak current level and/or the  $T_{OFF\_VLED\_ISPI}$  constants by SPI commands (see Buck Regulator section).

In this section, we only describe PWM dimming as this is the preferred method to maintain the desired LED color temperature for a given current rating. In PWM dimming, the LED current waveform frequency is constant and the duty cycle is set according to the required light intensity. In order to avoid the beats effect, the dimming frequency should be set at “high enough” values, typically above 300 Hz.

PWM dimming is controlled externally by means of LEDCTRLx inputs.

**Digital Dimming**

The two independent control inputs LEDCTRLx handle the dimming signals for the related channel “x”. In digital dimming, the buck activation is transparently linked to the

logic status of the LEDCTRLx pins. The only difference is the controlled phase shift of typical 5.5  $\mu s$  (Table 6 – 5 V Tolerant Digital Inputs) that allows synchronized measurements of the VLEDx pins via the ADC (see dedicated section for more details). As the phase shift is applied both to rising edges and falling edges, with a very limited jitter, the PWM duty cycle is not affected. Apart from the phase shift and the system clock OSC10M, there is no limitation to the PWM duty cycle values or resolutions at the bucks, which is a copy of the reference provided at the inputs.

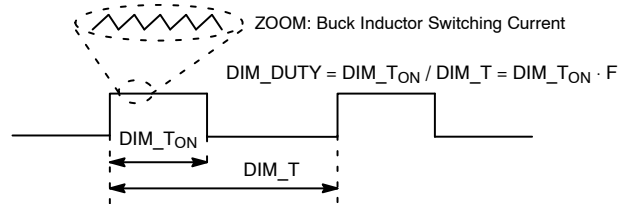


Figure 14. Buck Current Digital or PWM Dimming

**ADC**

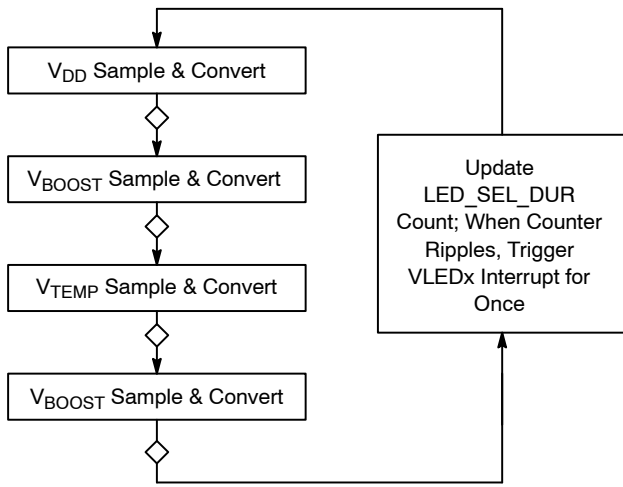
**General**

The built-in analog to digital converter (ADC) is an 8-bit successive approximation register (SAR). This embedded peripheral can be used to provide the following measurements to the external Micro Controller Unit (MCU):

- VBOOST Voltage: Sampled at the VBOOST Pin
- VDD Voltage: Sampled at the VDD Pin
- VLED1ON, VLED2ON Voltages
- VLED1 and VLED2 Voltages
- VTEMP Measurement (Chip Temperature)

The internal NCV78723 ADC state machine samples all the above channels automatically, taking care for setting the analog MUX and storing the converted values in memory. The external MCU can read out all ADC measured values via the SPI interface, in order to take application specific decisions. Please note that none of the MCU SPI commands interfere with the internal ADC state machine sample and conversion operations: the MCU will always get the last available data at the moment of the register read.

The state machine sampling and conversion scheme is represented in the figure below.



**Figure 15. ADC Sample and Conversion Main Sequence**

Referring to the figure above, the typical rate for a full SAR plus digital conversion per channel is 8 μs (Table 6 – ADC for Measuring VBOOST, VDD, VLED1, VLED2, TEMP). For instance, each new VBOOST ADC converted sample occurs at 16 μs typical rate, whereas for both the VDD and VTEMP channel the sampling rate is typically 32 μs, that is to say a complete cycle of the depicted sequence. This time is referred to as T<sub>ADC\_SEQ</sub>.

If the SPI setting LED\_SEL\_DUR[8:0] is not zero, then interrupts for the VLEDx measurements are allowed at the points marked with a rhombus, with a minimum cadence corresponding to the number of the elapsed ADC sequences (forced interrupt). In formulas:

$$T_{VLEDx\_INT\_Forced} = LED\_SEL\_DUR[8 : 0] \cdot T_{ADC\_SEQ} \quad (\text{eq. 4})$$

In general, prior to the forced interrupt status, the VLEDx<sub>ON</sub> ADC interrupts are generated when a falling edge on the control line for the buck channel “x” is detected by the device. In case of *digital dimming*, this interrupt start signal corresponds to the LEDCTRLx falling edge together with a controlled phase delay (Table 6 – 5 V Tolerant Digital Inputs). The purpose of the phase delay is to allow completion the ongoing ADC conversion before starting the one linked to the VLEDx interrupt: if at the moment of the conversion LEDCTRLx pin is logic high, then the updated registers are VLEDxON[7:0] and VLEDx[7:0]; otherwise, if LEDCTRLx pin is logic low, the only register refreshed is VLEDx[7:0]. This mechanism is handled automatically by the NCV78723 logic without need of intervention from the user, thus drastically reducing the MCU cycles and embedded firmware and CPU cycles overhead that would be otherwise required.

To avoid loss of data linked to the ADC main sequence, one LED channel is served at a time also when interrupt requests from both channels are received in a row and a full sequence is required to go through to enable a new interrupt VLEDx. In addition, possible conflicts are solved by using a defined priority (channel pre-selection). Out of reset, the

default selection is given to channel “1”. Then an internal flag keeps priority tracking, toggling at each time between channels pre-selection. Therefore, up to two dimming periods will be required to obtain a full measurement update of the two channels. This is not considered however a limitation, as typical periods for dimming signals are in the order of 1 ms period, thus allowing very fast failure detection.

A flow chart referring to the ADC interrupts is also displayed.



**Figure 16. ADC VLEDx Interrupt Sequence**

All NCV78723 ADC registers data integrity is protected by ODD parity on the bit 8 (that is to say the 9th bit if counting from the LSbit named “0”). Please refer to the SPI map section for further details.

**Logic Supply Voltage ADC: V<sub>DD</sub>**

The logic supply voltage is sampled at VDD pin. The (8-bit) conversion ratio is 4/255 (V/dec) = 0.0157 (V/dec) typical. The converted value can be found in the SPI register VDD[7:0], protected with ODD parity bit.

**Boost Voltage ADC: V<sub>BOOST</sub>**

This measurement refers to the boost voltage at the VBOOST pin, with an 8 bit conversion ratio of 70/255 (V/dec) = 0.274 (V/dec) typical, result can be found inside the SPI register VBOOST[7:0]. The value is protected by ODD parity bit. This measurement can be used by the MCU for diagnostics and booster control loop monitoring.

**Device Temperature ADC: V<sub>TEMP</sub>**

By means of the VTEMP measurement, the MCU can monitor the device junction temperature (T<sub>J</sub>) over time. The conversion formula is:

$$T_J = (VTEMP[7 : 0] - 50.5)/0.805 \quad (\text{eq. 5})$$

VTEMP[7:0] is the value read out directly from the related 8bit-SPI register (please refer to the SPI map). The value is also used internally by the device for the *thermal warning* and *thermal shutdown* functions. More details on these two can be found in the dedicated sections in this document. The value is protected by ODD parity bit.

**LED String Voltages ADC: V<sub>LEDx</sub>, V<sub>LEDxON</sub>**

The voltage at the pins VLEDx (1, 2) is measured. There are 4 ranges available, that can be selected by means of ADC\_VLEDx\_RNG\_SEL[1:0] register, to obtain higher resolution for LED voltage measurement.

Conversion ratios in dependency on selected range are:

- 0x0: 70/255 (V/dec) = 0.274 (V/dec);
- 0x1: 50/255 (V/dec) = 0.196 (V/dec);
- 0x2: 40/255 (V/dec) = 0.157 (V/dec);
- 0x3: 30/255 (V/dec) = 0.118 (V/dec).

This information, found in registers VLEDxON[7:0] and VLEDx[7:0], can be used by the MCU to infer about the LED string status, for example, individual shorted LEDs. As for the other ADC registers, the values are protected by ODD parity.

Please note that in the case of constant LEDCTRLx inputs and no dimming (in other words dimming duty cycle equals to 0% or 100%) the VLEDx interrupt is forced with a rate equal to T<sub>VLEDx\_INT\_forced</sub>, given in the ADC general section. This feature can be exploited by MCU embedded algorithm diagnostics to read the LED channels voltage even when in OFF state, before module outputs activation (module startup pre-check).

**Diagnostics**

The NCV78723 features a wide range of embedded diagnostic features. Their description follows. Please also refer to the previous SPI section for more details.

**Diagnostic Description**

- *Thermal Warning:* this mechanism detects a user-programmable junction temperature which is in principle close, but lower, to the chip maximum allowed, thus providing the information that some action (power de-rating) is required to prevent overheating that would cause Thermal Shutdown. A typical power de-rating technique consists in reducing the output dimming duty cycle in function of the temperature: the higher the temperature above the thermal warning, the lower the duty cycle. The thermal warning flag (TW) is given in status register 0x14 and is latched. When VTEMP[7:0] raises to or above THERMAL\_WARNING\_THR[7:0] threshold, the TW flag is set. At power up the default thermal warning threshold is typically 159°C (SPI code 179).
- *Thermal Shutdown:* this safety mechanism intends to protect the device from damage caused by overheating, by disabling the both buck channels. The diagnostic is displayed per means of the TSD bit in status register 0x14

(latched). Once occurred, the thermal shutdown condition is exited when the temperature drops below the thermal warning level, thus providing hysteresis for thermal shutdown recovery process. Outputs are re-enabled automatically if BUCKx\_TSD\_AUT\_RCRV\_EN = 1, or they are re-enabled by rising edge on BUCKx\_EN if BUCKx\_TSD\_AUT\_RCRV\_EN = 0. The application thermal design should be made as such to avoid the thermal shutdown in the worst case conditions. The thermal shutdown level is not user programmable and is factory trimmed (see ADC\_TSD in Table 6 – Buck Regulator – Switch).

- *SPI Error:* in case of SPI communication errors the SPIERR bit in status register 0x14 is set. The bit is latched. For more details, please refer to section “SPI protocol: Framing and Parity Error”.
- *Open LEDx String:* individual open LED diagnostic flags indicate whether the “x” string is detected open. The detection is based on a counter overflow of typical 50 μs when the related channel is activated. Both OPENLED1 and OPENLED2 flags (latched) are contained in status register 0x13. Please note that the open detection does not disable the buck channel(s).
- *Short LEDx String:* a short circuit detection is available independently for each LED channel per means of the flag SHORTLEDx (latched, status register 0x13). The detection is based on the voltage measured at the VLEDx pins via a dedicated internal comparator: when the voltage drops below the VLED\_LMT minimum threshold (typical 1.8 V, see Table 6 – Buck Regulator – Current Regulation) the related flag is set. Together with the detection, a fixed TOFF is used. On N78723–2 device, TOFF time is terminated immediately when the inductor current reaches zero. This improves the dimming behavior via external short switches (pixel control).
- *Overcurrent on Channel x:* this diagnostics protects the LEDx and the buck channel x electronics from overcurrent. As the overcurrent is detected, the OCLEDx flag (latched, status register 0x13) is raised and the related buck channel is disabled. More details about the detection mechanisms and parameters are given in section “Buck Overcurrent Protection”.
- *Buckx Status:* register BUCKx\_STATUS shows the actual status of Buckx output. When BUCKx\_STATUS is 1, the corresponding output regulates current to the LED.
- *LEDCTRLx Pin Status:* SPI registers LED1VAL resp. LED2VAL indicate the actual logic level of the debounced LEDCTRLx pins. These signals follow the output of 200 ns digital debouncers implemented on LEDCTRLx pins.
- *Buckx Running at Minimum TON Time:* register BUCKx\_MIN\_TON (latched) indicates that minimal TON time is detected on the corresponding channel. It is clear by read flag. This information can be used for

detection of transition period during which the BUCKx output current decreases due to the change of BUCKx\_VTHR code or BUCKx\_ISENS\_THR range.

- *Buckx TON Time Duration:* SPI register BUCKx\_TON\_DUR[7:0] reflects the last measured Buckx TON time (1LSB = 200 ns) on the corresponding channel. When Buckx runs with TON time < typ. 200 ns, the BUCKx\_TON\_DUR[7:0] SPI register returns value 0x00. When Buckx is stopped, the

BUCKx\_TON\_DUR[7:0] register keeps the last measured TON time.

- *HW Reset:* the out of reset condition is reported through the HWR bit (latched). This bit is set only at each Power On Reset (POR) and indicates the device is ready to operate.

A short summary table of the main diagnostic bits related to the LED outputs follows.

Table 7. LED OUTPUT DIAGNOSTIC SUMMARY

| Diagnose  |                          | Detection Level           | LED Output  | Latched |
|-----------|--------------------------|---------------------------|---|---------|
| Flag      | Description              |                           |   |         |
| TW        | Thermal Warning          | SPI Register Programmable | Not Disabled<br>(If No TSD, otherwise Disabled)   | Yes     |
| TSD       | Thermal Shutdown         | Factory Trimmed           | Disabled<br>(Automatically Re-Enabled when Temp Falls below TW and BUCKx_TSD_AUT_RCVR_EN = 1) | Yes     |
| SPIERR    | SPI Error                | (See SPI Section)         | Not Disabled  | Yes     |
| OPENLEDx  | LED String Open Circuit  | Buck on Time > TON_OPEN   | Not Disabled  | Yes     |
| SHORTLEDx | LED String Short Circuit | VLEDx < VLED_LMT          | Not Disabled<br>(Fixed Buck TOFF or Zero Cross TOFF Applied when output is On)                | Yes     |
| OCLEDx    | LED String Overcurrent   | lbuckx > OCDR{1..4}       | Disabled  | Yes     |

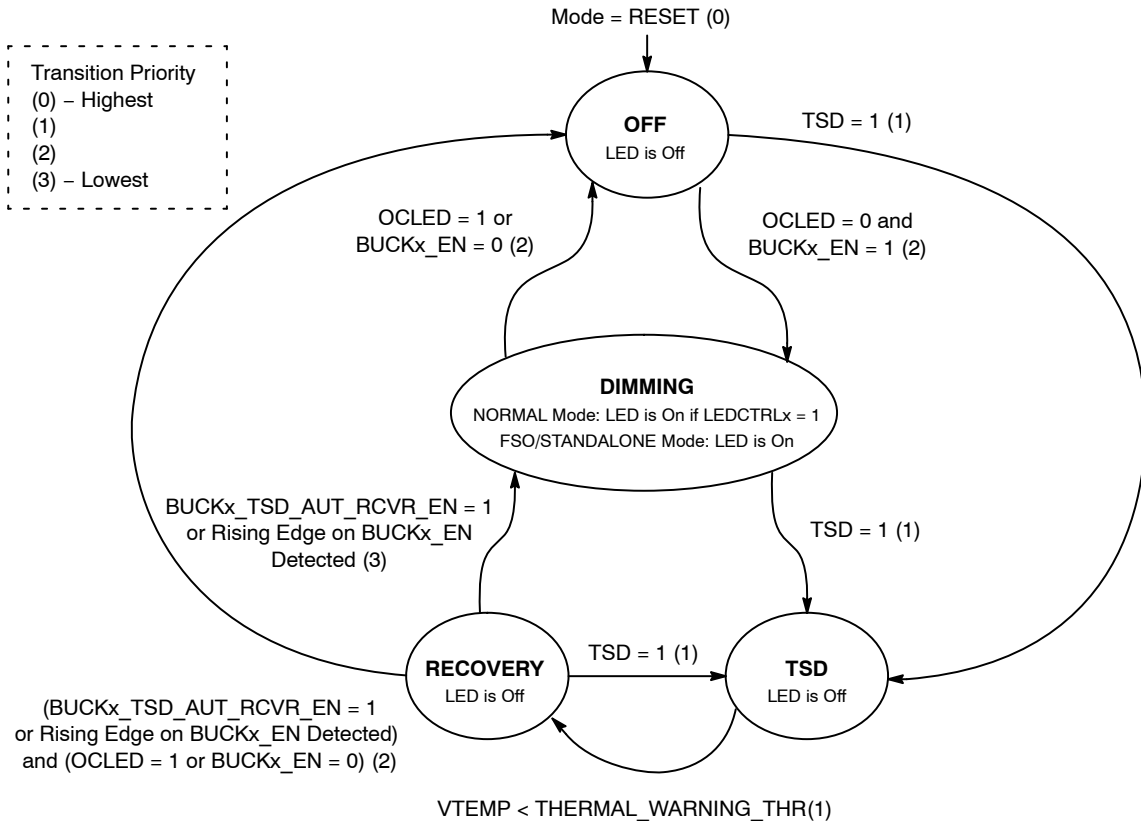


Figure 17. LED Dimming State Diagram

**Functional Mode Description**

Overview of all functional modes is in accordance to the state diagram on Figure 18. Individual states are described below.

Transition Condition (Priority Level)  
 Action Executed when Transition is Performed

Transition Priority:  
 (0) – Highest  
 (1)  
 (2) – Lowest

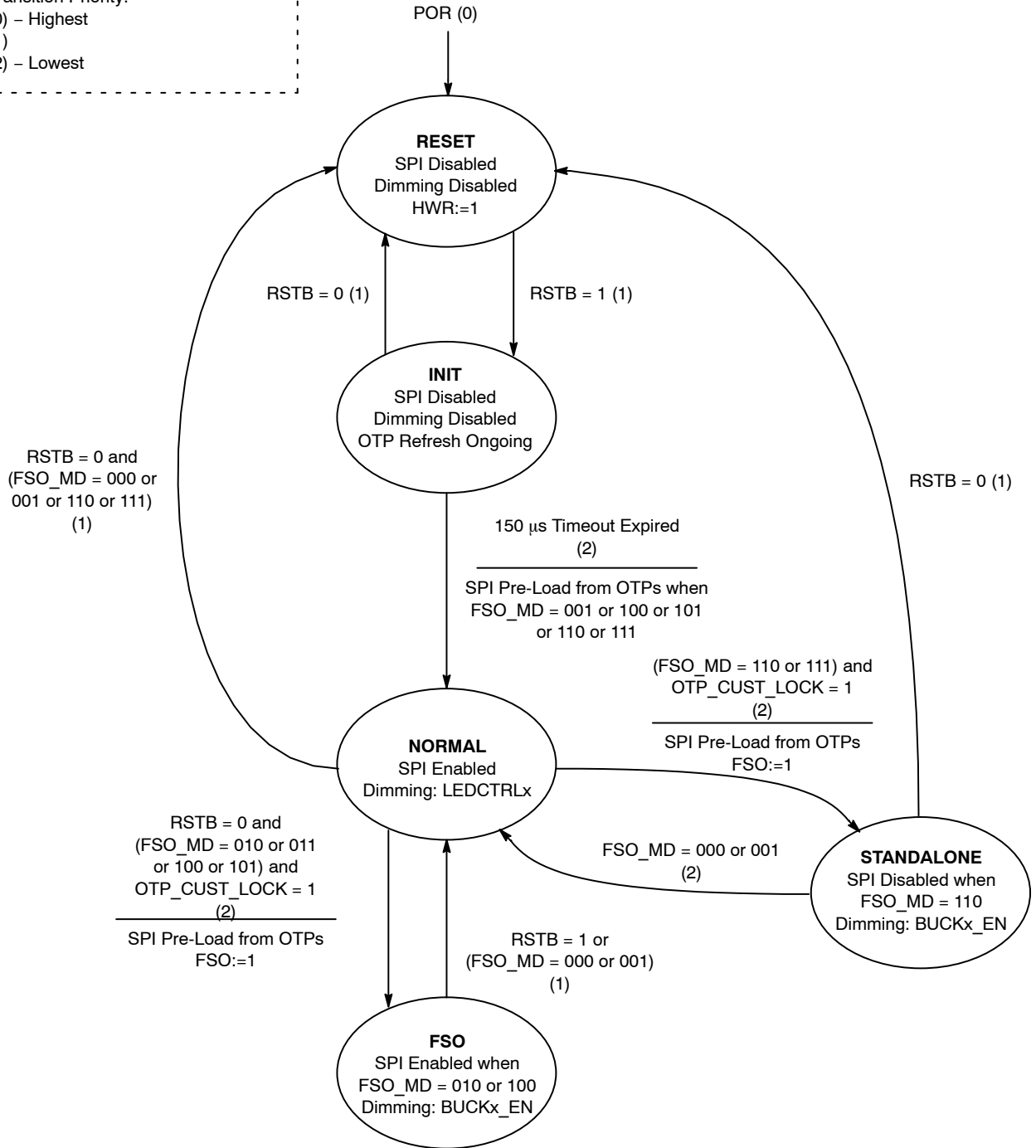


Figure 18. Functional Modes State Diagram

**Reset**

Asynchronous reset is caused either by POR (POR always causes asynchronous reset – transition to reset state) or by falling edge on RSTB pin (in normal/stand-alone mode, when FSO\_MD[2:0] = 000 or 001 or 110 or 111).

**Init and Normal Mode**

Normal mode is entered through Init state after internal delay of 150 μs. In Init state, OTP refresh is performed. If OTP bits for FSO\_MD[2:0] register and *OTP Lock Bit* are programmed, transition to FSO/SA mode is possible.

**FSO/Stand-Alone Mode**

FSO (Fail-Safe Operation)/Stand-Alone modes can be used for two main purposes:

- Default power-up operation of the chip (**Stand-Alone** functionality without external microcontroller or preloading of the registers with default content for default operation before microcontroller starts sending SPI commands for chip settings)
- **Fail-Safe** functionality (chip functionality definition in fail-safe mode when the external microcontroller functionality is not guaranteed)

FSO/stand-alone function is controlled according to Table 8. Entrance into FSO/Stand-alone mode is possible only after customer OTP zapping when *OTP Lock Bit* is set. After FSO mode activation, the FSO bit in status register is set. FSO register is cleared by read register.

When FSO/Stand-Alone mode is activated, content of the following SPI registers is preloaded from OTP memory:

- BUCK1\_VTHR[7:0],
- BUCK1\_ISENS\_THR[1:0],
- BUCK2\_VTHR[7:0],
- BUCK2\_ISENS\_THR[1:0],
- BUCK1\_TOFF[4:0],
- BUCK2\_TOFF[4:0],
- BUCK1\_EN,
- BUCK2\_EN,
- FSO\_MD[2:0],
- BUCK1\_TSD\_AUT\_RCVR\_EN,
- BUCK2\_TSD\_AUT\_RCVR\_EN,
- BUCKx\_OC\_OCCMP\_THR[1:0]].

BUCKx\_ISENS\_TRIM[6:0] register is preloaded from corresponding BUCKx\_ISENS\_RNG[6:0] register.

In FSO (entered via falling edge on RSTB pin) and Stand-Alone modes, **BUCK1\_EN** & **BUCK2\_EN** are controlled from SPI register map (SPI registers are updated from OTP's after entrance into these modes).

BUCK1\_EN and BUCK2\_EN are supposed to be set ‘1’ for the BUCKx operation in the FSO/stand-alone mode.

When control registers are pre-loaded from OTP's after POR and FSO mode is not entered (valid for FSO\_MD[2:0] = 100 or 101), BUCK1\_EN and BUCK2\_EN are kept inactive (‘0’) until the first valid SPI operation is finished to avoid potential activation of buck regulators immediately after POR (to prevent undefined state of LEDCTRLx pins in case MCU leaves POR later than NCV78723).

In FSO and Stand-Alone modes, the logic level at **LEDCTRLx** pins is ignored and digital PWM dimming with LEDCTRLx pins is not available. The outputs can be dimmed only by means of BUCKx\_EN register.

A falling edge on RSTB pin may trigger either entrance into FSO mode or reset in dependency on FSO\_MD[2:0] register value. Please refer to Table 8 and Figure 18 for more details.

Once FSO mode is entered via falling edge on RSTB pin, reset function of RSTB pin is blocked until FSO mode is exited. FSO mode can be exited by the rising edge on RSTB pin or by writing FSO\_MD[2:0] = 000 or 001 (possible only in FSO modes, where SPI control register update is allowed: FSO\_MD[2:0] = 011 or 101).

In stand-alone mode (FSO\_MD[2:0] = 110 or 111), RSTB has always reset functionality.

During entrance into FSO mode, value of FSO\_MD[2:0] SPI register (preloaded from OTP at power-up only) is latched into internal register and all FSO related functions are then controlled according to it. Purpose is to avoid the reset of the device when FSO mode is active and FSO\_MD[2:0] is changed to value corresponding to stand-alone mode, where RSTB pin has reset functionality. The internal register is cleared after POR or when FSO mode is exited.

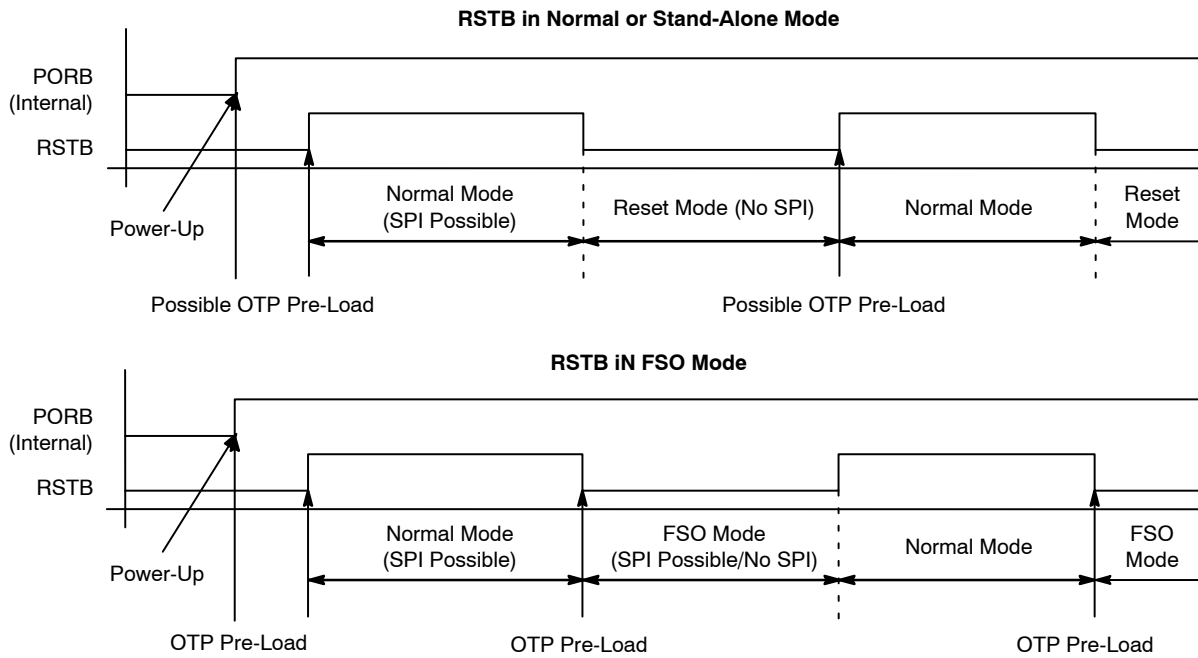


Figure 19. RSTB Pin Functionality in Normal, Stand-Alone and FSO Modes

Table 8. FSO MODES

| FSO_MD[2:0]          | Description  |
|----------------------|--|
| 000 <sub>b</sub> = 0 | <p><b>FSO Mode Disabled, Registers are Loaded with Safe Value = 0x00h after POR, Default</b></p> <ul style="list-style-type: none"> <li>After the reset, control registers are loaded with 0x00h value.</li> <li>Entrance into FSO mode is not possible unless dedicated SPI write command to change FSO_MD[2:0] value is sent</li> <li>RSTB pin has <b>reset</b> functionality</li> <li>LEDCTRLx pins are functional (buck enable/disable, digital PWM dimming available)</li> </ul>  |
| 001 <sub>b</sub> = 1 | <p><b>FSO Mode Disabled, Registers are Loaded with Data from OTP Memory after POR</b></p> <ul style="list-style-type: none"> <li>After the reset, control registers are loaded with data stored in OTP memory (device's OTP memory has to be programmed, <i>OTP Lock Bit</i> has to be set). It reduces number of SPI transfers needed to configure the device after the reset.</li> <li>Entrance into FSO mode is not possible</li> <li>RSTB pin has <b>reset</b> functionality</li> <li>LEDCTRLx pins are functional (buck enable/disable, digital PWM dimming available)</li> </ul>   |
| 010 <sub>b</sub> = 2 | <p><b>FSO Entered after Falling Edge on RSTB Pin, Registers (except FSO_MD[2:0]) are Loaded with Safe Value = 0x00h after POR</b></p> <ul style="list-style-type: none"> <li>After FSO mode activation, control registers are loaded with data stored in OTP memory.</li> <li>SPI register update (SPI write/read operation) in FSO mode is <b>disabled</b> (SPI write operation is blocked; clearing of SPI registers is blocked; in case of invalid SPI frame, SPIERR flag is set).</li> <li>RSTB pin serves to enter/exit FSO mode.</li> <li>LEDCTRLx pins are not functional (buck enable/disable only by means of BUCKx_EN SPI/OTP bits, digital PWM dimming not available).</li> </ul> |
| 011 <sub>b</sub> = 3 | <p><b>FSO Entered after Falling Edge on RSTB Pin, Registers (except FSO_MD[2:0]) are Loaded with Safe Value = 0x00h after POR</b></p> <ul style="list-style-type: none"> <li>After FSO mode activation, control registers are loaded with data stored in OTP memory.</li> <li>SPI register update (SPI write/read operation) in FSO mode is <b>enabled</b></li> <li>FSO mode can be exited by writing FSO_MD[2:0] = 000 or 001</li> <li>RSTB pins serves to enter/exit FSO mode.</li> <li>LEDCTRLx pins are not functional (buck enable/disable only by means of BUCKx_EN SPI/OTP bits, digital PWM dimming not available).</li> </ul>   |
| 100 <sub>b</sub> = 4 | <p><b>FSO Entered after Falling Edge on RSTB Pin, Registers are Loaded with Data from OTP Memory after POR</b></p> <ul style="list-style-type: none"> <li>After FSO mode activation, control registers are loaded with data stored in OTP memory.</li> <li>SPI register update (SPI write/read operation) in FSO mode is <b>disabled</b> (SPI write operation is blocked; clearing of SPI registers is blocked; in case of invalid SPI frame, SPIERR flag is set).</li> <li>RSTB pin serves to enter/exit FSO mode.</li> <li>LEDCTRLx pins are not functional (buck enable/disable only by means of BUCKx_EN SPI/OTP bits, digital PWM dimming not available).</li> </ul>                    |

Table 8. FSO MODES (continued)

| FSO_MD[2:0]          | Description  |
|----------------------|--|
| 101 <sub>b</sub> = 5 | <p><b>FSO Entered after Falling Edge on RSTB Pin, Registers are Loaded with Data from OTP Memory after POR</b></p> <ul style="list-style-type: none"> <li>After FSO mode activation, control registers are loaded with data stored in OTP memory.</li> <li>SPI register update (SPI write/read operation) in FSO mode is <b>enabled</b></li> <li>FSO mode can be exited by writing FSO_MD[2:0] = 000 or 001</li> <li>RSTB pin serves to enter/exit FSO mode.</li> <li>LEDCTRLx pins are not functional (buck enable/disable only by means of BUCKx_EN SPI/OTP bits, digital PWM dimming not available).</li> </ul>   |
| 110 <sub>b</sub> = 6 | <p><b>SA (Stand-Alone)/FSO Entered after POR (RSTB Pin Rising Edge), Registers are Loaded with Data from OTP Memory</b></p> <ul style="list-style-type: none"> <li>After FSO/SA mode activation, control registers are loaded with data from OTP memory</li> <li>SPI register update (SPI write/read operation) in SA/FSO mode is <b>disabled</b> (SPI write operation is blocked; clearing of SPI registers is blocked; in case of invalid SPI frame, SPIERR flag is set).</li> <li>RSTB pin has <b>reset</b> functionality</li> <li>LEDCTRLx pins are not functional (buck enable/disable only by means of BUCKx_EN SPI/OTP bits, digital PWM dimming not available).</li> </ul> |
| 111 <sub>b</sub> = 7 | <p><b>SA (Stand-Alone)/FSO Entered after POR (RSTB Pin Rising Edge), Registers are Loaded with Data from OTP Memory</b></p> <ul style="list-style-type: none"> <li>After SA/FSO mode activation, control registers are loaded with data from OTP memory</li> <li>SPI register update (SPI write/read operation) in SA/FSO mode is <b>enabled</b></li> <li>FSO mode can be exited by writing FSO_MD[2:0] = 000 or 001</li> <li>RSTB pin has <b>reset</b> functionality</li> <li>LEDCTRLx pins are not functional (buck enable/disable only by means of BUCKx_EN SPI/OTP bits, digital PWM dimming not available).</li> </ul>  |

**SPI Interface**

**General**

The serial peripheral interface (SPI) is used to allow an external microcontroller (MCU) to communicate with the device. NCV78723 acts always as a slave and it cannot initiate any transmission. The operation of the device is configured and controlled by means of SPI registers, which are observable for read and/or write from the master. The NCV78723 SPI transfer size is 16 bits.

During an SPI transfer, the data is simultaneously transmitted (shifted out serially) and received (shifted in serially). A serial clock line (SCLK) synchronizes shifting and sampling of the information on the two serial data lines: SDO and SDI. The SDO signal is the output from the Slave (NCV78723), and the SDI signal is the output from the Master.

A slave or chip select line (CSB) allows individual selection of a slave SPI device in a time multiplexed multiple-slave system.

The CSB line is active low. If an NCV78723 is not selected, SDO is in high impedance state and it does not interfere with SPI bus activities. Since the NCV78723 always clocks data out on the falling edge and samples data in on rising edge of clock, the MCU SPI port must be configured to match this operation.

The implemented SPI allows connection to multiple slaves by means of star connection (CSB per slave) or by means of daisy chain.

An SPI star connection requires a bus = (3 + N) total lines, where N is the number of Slaves used, the SPI frame length is 16 bits per communication.

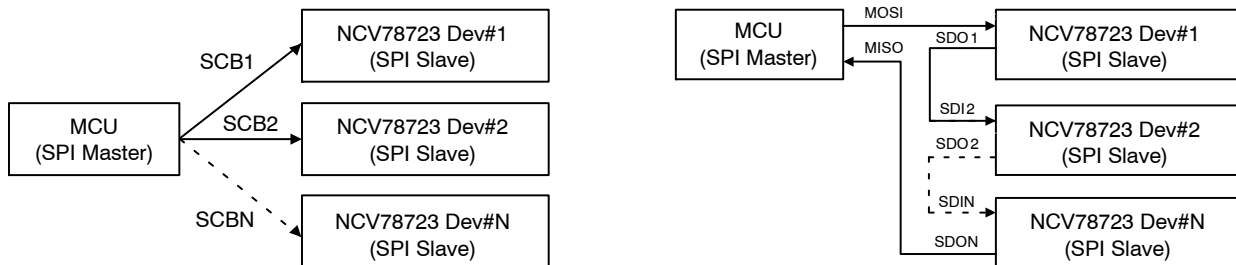


Figure 20. SPI Star vs. Daisy Chain Connection

**SPI Daisy Chain Mode**

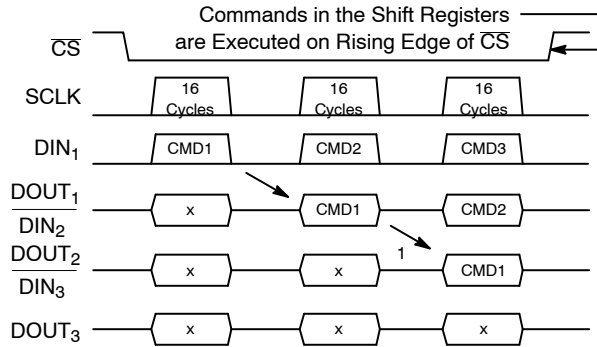
SPI daisy chain connection bus width is always four lines independently on the number of slaves. However, the SPI transfer frame length will be a multiple of the base frame length so  $N \times 16$  bits per communication: the data will be

interpreted and read in by the devices at the moment the CSB rises.

A diagram showing the data transfer between devices in daisy chain connection is given further: CMDx represents



the 16-bit command frame on the data input line transmitted by the Master, shifting via the chips' shift registers through the daisy chain. The chips interpret the command once the chip select line rises.



**Figure 21. SPI Daisy Chain Data Shift between Slaves. The Symbol 'x' Represents the Previous Content of the SPI Shift Register Buffer**

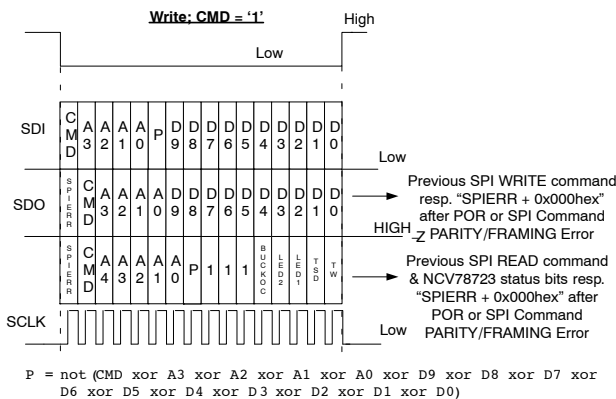
The NCV78723 default power up communication mode is "star". In order to enable daisy chain mode, a multiple of 16 bits clock cycles must be sent to the devices, while the SDI line is left to zero.

NOTE: To come back to star mode the NOP register (address 0x0000) must be written with all ones, with the proper data parity bit and parity framing bit: see SPI protocol for details about parity and write operation.

**SPI Transfer Format**

Two types of SPI commands (to SDI pin of NCV78723) from the micro controller can be distinguished: "Write to a control register" and "Read from register (control or status)".

The frame protocol for the write operation:



**Figure 22. SPI Write Frame**

Referring to the previous picture, the write frame coming from the master (into the SDI) is composed from the following fields:

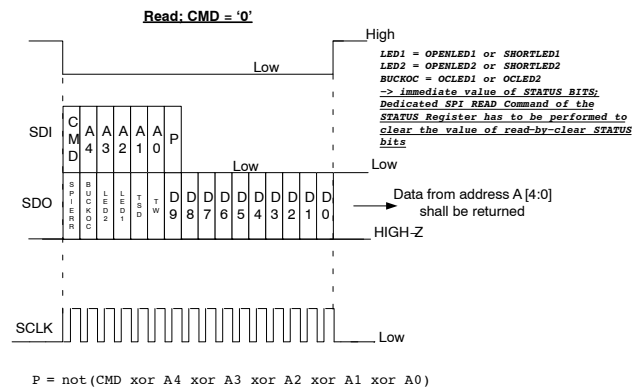
- Bit[15] (MSB): CMD bit = 1 for write operation,
- Bits[14:11]: 4 bits WRITE ADDRESS field,
- Bit[10]: frame parity bit. It is ODD parity formed by the negated XOR of all other bits in the frame,
- Bits[9:0]: 10 bit DATA to write

Device in the same time replies to the master (on the SDO):

- If the previous command was a write and no SPI error had occurred, a copy of the command, address and data written fields,
- If the previous command was a read, the response frame summarizes the address used and an overall diagnostic check (copy of the main detected errors, see Figures 22 and 23 for details),
- In case of previous SPI error or after power-on-reset, only the MSB bit will be 1, followed by zeros.

If parity bit in the frame is wrong, device will not perform command and <SPI> flag will be set.

The frame protocol for the read operation:



**Figure 23. SPI Read Frame**

Referring to the previous picture, the read frame coming from the master (into the SDI) is composed from the following fields:

- Bit[15] (MSB): CMD bit = 0 for read operation,
- Bits[14:10]: 5 bits READ ADDRESS field,
- Bit[10]: frame parity bit. It is ODD parity formed by the negated XOR of all other bits in the frame,
- Bits [8:0]: 9 bits zeroes field.

Device in the same frame provides to the master (on the SDO) data from the required address (in frame response), thus achieving the lowest communication latency.

**SPI Framing and Parity Error**

SPI communication framing error is detected by the NCV78723 in the following situations:

- Not an integer multiple of 16 CLK pulses are received during the active-low CSB signal;
- LSB bits (8..0) of a read command are not all zero;
- SPI parity errors, either on write or read operation.

Once an SPI error occurs, the <SPI> flag can be reset only by reading the status register in which it is contained (using in the read frame the right communication parity bit).

# NCV78723

## SPI ADDRESS MAP

**Table 9. NCV78723 SPI ADDRESS MAP**

| ADDR  | R/W | Bit 9                                       | Bit 8                       | Bit 7                    | Bit 6                   | Bit 5      | Bit 4               | Bit 3         | Bit 2              | Bit 1        | Bit 0        |            |
|-------|-----|---|-----------------------------|--------------------------|-------------------------|------------|---------------------|---------------|--------------------|--------------|--------------|------------|
| 0x00  | NA  | NOP Register (Read/Write Operation Ignored) |                             |                          |                         |            |                     |               |                    |              |              |            |
| 0x01  | R/W | BUCK1_ISENS_THR[1:0]                        |                             |                          | BUCK1_VTHR[7:0]         |            |                     |               |                    |              |              |            |
| 0x02  | R/W | BUCK2_ISENS_THR[1:0]                        |                             |                          | BUCK2_VTHR[7:0]         |            |                     |               |                    |              |              |            |
| 0x03  | R/W | BUCK1_TOFF[4:0]                             |                             |                          |                         |            | BUCK2_TOFF[4:0]     |               |                    |              |              |            |
| 0x04  | R/W | BUCK1_OFF_CMP_DIS (Note 31)                 | BUCK2_OFF_CMP_DIS (Note 31) | DRV_SLOW_EN (Note 31)    | BUCKx_OC_OCCMP_THR[1:0] |            | FSO_MD[2:0]         |               | BUCK1_EN           | BUCK2_EN     |              |            |
| 0x05  | R/W | BUCK1_TSD_AUT_RCVR_EN                       | BUCK2_TSD_AUT_RCVR_EN       | THERMAL_WARNING_THR[7:0] |                         |            |                     |               |                    |              |              |            |
| 0x06  | R/W | VTEMP_OFF_COMP_ODD_PAR (Note 30)            | LED_SEL_DUR[8:0]            |                          |                         |            |                     |               |                    |              |              |            |
| 0x07  | R/W | VTEMP_OFF_COMP[2:0] (Note 30)               |                             |                          | BUCK1_ISENS_TRIM[6:0]   |            |                     |               |                    |              |              |            |
| 0x08  | R/W | VTEMP_OFF_COMP[5:3] (Note 30)               |                             |                          | BUCK2_ISENS_TRIM[6:0]   |            |                     |               |                    |              |              |            |
| 0x09  | R/W | ADC_VLED1_RNG_SEL[1:0]                      |                             | ADC_VLED2_RNG_SEL[1:0]   | OTP_BIAS_H              | OTP_BIAS_L | OTP_ADDR[1:0]       |               | OTP_OPERATION[1:0] |              |              |            |
| 0x0A  | R   | 0x0   | ODD PARITY                  | VLED1ON[7:0]             |                         |            |                     |               |                    |              |              |            |
| 0x0B  | R   | 0x0   | ODD PARITY                  | VLED2ON[7:0]             |                         |            |                     |               |                    |              |              |            |
| 0x0C  | R   | 0x0   | ODD PARITY                  | VLED1[7:0]               |                         |            |                     |               |                    |              |              |            |
| 0x0D  | R   | 0x0   | ODD PARITY                  | VLED2[7:0]               |                         |            |                     |               |                    |              |              |            |
| 0x0E  | R   | 0x0   | ODD PARITY                  | VTEMP[7:0]               |                         |            |                     |               |                    |              |              |            |
| 0x0F  | R   | 0x0   | ODD PARITY                  | VBOOST[7:0]              |                         |            |                     |               |                    |              |              |            |
| 0x10  | R   | 0x0   | ODD PARITY                  | VDD[7:0]                 |                         |            |                     |               |                    |              |              |            |
| 0x11  | R   | 0x0   | ODD PARITY                  | BUCK1_TON_DUR[7:0]       |                         |            |                     |               |                    |              |              |            |
| 0x12  | R   | 0x0   | ODD PARITY                  | BUCK2_TON_DUR[7:0]       |                         |            |                     |               |                    |              |              |            |
| 0x13  | R   | 0x0   | ODD PARITY                  | 0x0                      | OPENLED1                | SHORTLED1  | OCLED1              | OPENLED2      | SHORTLED2          | OCLED2       |              |            |
| 0x14  | R   | 0x0   | ODD PARITY                  | OTP_FAIL                 | FSO                     | HWR        | LED1VAL             | LED2VAL       | SPIERR             | TSD          | TW           |            |
| 0x15  | R   | 0x0   | ODD PARITY                  | 0x0                      |                         |            | OTP_ACTIVE          | BUCK1_MIN_TON | BUCK2_MIN_TON      | BUCK1_STATUS | BUCK2_STATUS |            |
| 0x16  | R   | 0x0   | ODD PARITY                  | 0x0                      | BUCK1_ISENS_RNG[6:0]    |            |                     |               |                    |              |              |            |
| 0x17  | R   | 0x0   | ODD PARITY                  | 0x0                      | BUCK2_ISENS_RNG[6:0]    |            |                     |               |                    |              |              |            |
| 0x18  | R   | 0x0   | ODD PARITY                  | BUCK2_ISENS_D1[3:0]      |                         |            | BUCK1_ISENS_D1[3:0] |               |                    |              |              |            |
| 0x19  | R   | 0x0   | ODD PARITY                  | BUCK2_ISENS_D2[3:0]      |                         |            | BUCK1_ISENS_D2[3:0] |               |                    |              |              |            |
| 0x1A  | R   | 0x0   | ODD PARITY                  | BUCK2_ISENS_D3[3:0]      |                         |            | BUCK1_ISENS_D3[3:0] |               |                    |              |              |            |
| 0x1B  | R   | 0x0   | ODD PARITY                  | BUCK_ISENS_TC1[3:0]      |                         |            | BUCK_ISENS_TC0[3:0] |               |                    |              |              |            |
| 0x1C  | R   | 0x0   | ODD PARITY                  | BUCK_ISENS_TC3[3:0]      |                         |            | BUCK_ISENS_TC2[3:0] |               |                    |              |              |            |
| 0x1D  | R   | 0x0   | ODD PARITY                  | 0x0                      |                         |            |                     |               |                    |              |              | TC_VERSION |
| 0x1E  | R   | OTP_DATA[9:0]                               |                             |                          |                         |            |                     |               |                    |              |              |            |
| 0x1F  | R   | 0x0   |                             | REVID[7:0]               |                         |            |                     |               |                    |              |              |            |
| OTHER | R   | 0x0   |                             |                          |                         |            |                     |               |                    |              |              |            |

30. Read Only.

31. Available only on N78723-2 device.

Table 10. BIT DEFINITION

| Symbol   | MAP Position           | Description                                       |
|--|------------------------|---|
| <b>REGISTER 0X00 (CR): NOP REGISTER, RESET VALUE (POR) = 000000000<sub>2</sub></b>                 |                        |   |
| NOP  | Bits [9:0] – ADDR_0x00 | NOP Register (Read/Write Operation Ignored)       |
| <b>REGISTER 0X01 (CR): BUCK 1 PEAK CURRENT SETTINGS, RESET VALUE (POR) = 000000000<sub>2</sub></b> |                        |   |
| BUCK1_ISENS_THR[1:0]   | Bits [9:8] – ADDR_0x01 | Peak Current: Selection of the Range 1, 2, 3 or 4 |
| BUCK1_VTHR[7:0]  | Bits [7:0] – ADDR_0x01 | Peak Current Comparator Threshold Value           |
| <b>REGISTER 0X02 (CR): BUCK 2 PEAK CURRENT SETTINGS, RESET VALUE (POR) = 000000000<sub>2</sub></b> |                        |   |
| BUCK2_ISENS_THR[1:0]   | Bits [9:8] – ADDR_0x02 | Peak Current: Selection of the Range 1, 2, 3 or 4 |
| BUCK2_VTHR[7:0]  | Bits [7:0] – ADDR_0x02 | Peak Current Comparator Threshold Value           |
| <b>REGISTER 0X03 (CR): BUCK 1 AND 2 TOFF SETTINGS, RESET VALUE (POR) = 000000000<sub>2</sub></b>   |                        |   |
| BUCK1_TOFF[4:0]  | Bits [9:5] – ADDR_0x03 | Buck 1 TOFF-VLED Constant Settings                |
| BUCK2_TOFF[4:0]  | Bits [4:0] – ADDR_0x03 | Buck 2 TOFF-VLED Constant Settings                |
| <b>REGISTER 0X04 (CR): BUCK SETTINGS, RESET VALUE (POR) = 000000000<sub>2</sub></b>                |                        |   |
| BUCK1_OFF_CMP_DIS  | Bit 9 – ADDR_0x04      | Buck 1 Offset Cancellation Disable                |
| BUCK2_OFF_CMP_DIS  | Bit 8 – ADDR_0x04      | Buck 2 Offset Cancellation Disable                |
| DRV_SLOW_EN  | Bit 7 – ADDR_0x04      | Slow Driver Slope Enable                          |
| BUCKx_OC_OCCMP_THR[1:0]  | Bits [6:5] – ADDR_0x04 | Overcurrent Detection Settings                    |
| FSO_MD[2:0]  | Bits [4:2] – ADDR_0x04 | FSO Mode Selection                                |
| BUCK1_EN   | Bit 1 – ADDR_0x04      | Buck Regulator Channel 1 Enable Bit               |
| BUCK2_EN   | Bit 0 – ADDR_0x04      | Buck Regulator Channel 2 Enable Bit               |
| <b>REGISTER 0X05 (CR): BUCK SETTINGS, RESET VALUE (POR) = 0010110011<sub>2</sub></b>               |                        |   |
| BUCK1_TSD_AUT_RCVR_EN  | Bit 9 – ADDR_0x05      | Buck 1 Automatic Recovery after TSD               |
| BUCK2_TSD_AUT_RCVR_EN  | Bit 8 – ADDR_0x05      | Buck 2 Automatic Recovery after TSD               |
| THERMAL_WARNING_THR[7:0]   | Bits [7:0] – ADDR_0x05 | Thermal Warning Threshold Settings                |
| <b>REGISTER 0X06 (CR): BUCK SETTINGS, RESET VALUE (POR) = X00000000<sub>2</sub></b>                |                        |   |
| VTEMP_OFF_COMP ODD PAR.  | Bit 9 – ADDR_0x06      | ADC VTEMP Trimming Parity Bit                     |
| LED_SEL_DUR[8:0]   | Bits [8:0] – ADDR_0x06 | VLED Measurement Settings                         |
| <b>REGISTER 0X07 (CR): BUCK SETTINGS, RESET VALUE (POR) = XXX0000000<sub>2</sub></b>               |                        |   |
| VTEMP_OFF_COMP[2:0]  | Bits [9:7] – ADDR_0x07 | ADC VTEMP Trimming                                |
| BUCK1_ISENS_TRIM[6:0]  | Bits [6:0] – ADDR_0x07 | Compensation of the Buck 1 Peak Current           |
| <b>REGISTER 0X08 (CR): BUCK SETTINGS, RESET VALUE (POR) = XXX0000000<sub>2</sub></b>               |                        |   |
| VTEMP_OFF_COMP[5:3]  | Bits [9:7] – ADDR_0x08 | ADC VTEMP Trimming                                |
| BUCK2_ISENS_TRIM[6:0]  | Bits [6:0] – ADDR_0x08 | Compensation of the Buck 2 Peak Current           |
| <b>REGISTER 0X09 (CR): BUCK SETTINGS, RESET VALUE (POR) = 000000000<sub>2</sub></b>                |                        |   |
| ADC_VLED1_RNG_SEL[1:0]   | Bits [9:8] – ADDR_0x09 | Range Select for VLED ADC, Channel 1              |
| ADC_VLED2_RNG_SEL[1:0]   | Bits [7:6] – ADDR_0x09 | Range Select for VLED ADC, Channel 2              |
| OTP_BIAS_H   | Bit 5 – ADDR_0x09      | OTP Bias High                                     |
| OTP_BIAS_L   | Bit 4 – ADDR_0x09      | OTP Bias Low                                      |
| OTP_ADDR[1:0]  | Bits [3:2] – ADDR_0x09 | OTP Address                                       |
| OTP_OPERATION[1:0]   | Bits [1:0] – ADDR_0x09 | OTP Operation                                     |
| <b>REGISTER 0X0A (SR): VLED1ON, RESET VALUE (POR) = 010000000<sub>2</sub></b>                      |                        |   |
| ODD PARITY   | Bit 8 – ADDR_0x0A      | Odd Parity over Data                              |
| VLED1ON[7:0]   | Bits [7:0] – ADDR_0x0A | Output of VLED 1 ADC                              |
| <b>REGISTER 0X0B (SR): VLED2ON, RESET VALUE (POR) = 010000000<sub>2</sub></b>                      |                        |   |
| ODD PARITY   | Bit 8 – ADDR_0x0B      | Odd Parity over Data                              |
| VLED2ON[7:0]   | Bits [7:0] – ADDR_0x0B | Output of VLED 2 ADC                              |

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**Table 10. BIT DEFINITION** (continued)

| Symbol   | MAP Position           | Description                                    |
|--|------------------------|--|
| <b>REGISTER 0X0C (SR): VLED1, RESET VALUE (POR) = 010000000<sub>2</sub></b>            |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x0C      | Odd Parity over Data                           |
| VLED1[7:0]   | Bits [7:0] – ADDR_0x0C | Output of VLED 1 ADC                           |
| <b>REGISTER 0X0D (SR): VLED2, RESET VALUE (POR) = 010000000<sub>2</sub></b>            |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x0D      | Odd Parity over Data                           |
| VLED2[7:0]   | Bits [7:0] – ADDR_0x0D | Output of VLED 2 ADC                           |
| <b>REGISTER 0X0E (SR): VTEMP, RESET VALUE (POR) = 0XXXXXXX<sub>2</sub></b>             |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x0E      | Odd Parity over Data                           |
| VTEMP[7:0]   | Bits [7:0] – ADDR_0x0E | Output of VTEMP ADC                            |
| <b>REGISTER 0X0F (SR): VBOOST, RESET VALUE (POR) = 0XXXXXXX<sub>2</sub></b>            |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x0F      | Odd Parity over Data                           |
| VBOOST[7:0]  | Bits [7:0] – ADDR_0x0F | Output of VBOOST ADC                           |
| <b>REGISTER 0X10 (SR): VDD, RESET VALUE (POR) = 0XXXXXXX<sub>2</sub></b>               |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x10      | Odd Parity over Data                           |
| VDD[7:0]   | Bits [7:0] – ADDR_0x10 | Output of VDD ADC                              |
| <b>REGISTER 0X11 (SR): BUCK1_TON_DUR, RESET VALUE (POR) = 010000000<sub>2</sub></b>    |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x11      | Odd Parity over Data                           |
| BUCK1_TON_DUR[7:0]   | Bits [7:0] – ADDR_0x11 | Buck 1 Ton Duration                            |
| <b>REGISTER 0X12 (SR): BUCK2_TON_DUR, RESET VALUE (POR) = 010000000<sub>2</sub></b>    |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x12      | Odd Parity over Data                           |
| BUCK2_TON_DUR[7:0]   | Bits [7:0] – ADDR_0x12 | Buck 2 Ton Duration                            |
| <b>REGISTER 0X13 (SR): BUCK DIAGNOSTICS, RESET VALUE (POR) = 0X000X00X<sub>2</sub></b> |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x13      | Odd Parity over Data                           |
| OPENLED1   | Bit 5 – ADDR_0x13      | Buck 1 Open LED Flag, Latched                  |
| SHORTLED1  | Bit 4 – ADDR_0x13      | Buck 1 Short LED Flag, Latched                 |
| OCLED1   | Bit 3 – ADDR_0x13      | Buck 1 Overcurrent Flag, Latched               |
| OPENLED2   | Bit 2 – ADDR_0x13      | Buck 2 Open LED Flag, Latched                  |
| SHORTLED2  | Bit 1 – ADDR_0x13      | Buck 2 Short LED Flag, Latched                 |
| OCLED2   | Bit 0 – ADDR_0x13      | Buck 2 Overcurrent Flag, Latched               |
| <b>REGISTER 0X14 (SR): BUCK DIAGNOSTICS, RESET VALUE (POR) = 0X001XXXX<sub>2</sub></b> |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x14      | Odd Parity over Data                           |
| OTP_FAIL   | Bit 7 – ADDR_0x14      | OTP Failure Flag, Latched                      |
| FSO  | Bit 6 – ADDR_0x14      | Chip being in FSO Mode Flag, Non-Latched       |
| HWR  | Bit 5 – ADDR_0x14      | Hardware Reset Flag, Latched                   |
| LED1VAL  | Bit 4 – ADDR_0x14      | Actual Status of LEDCTRL1 Pin, Non-Latched     |
| LED2VAL  | Bit 3 – ADDR_0x14      | Actual Status of LEDCTRL2 Pin, Non-Latched     |
| SPIERR   | Bit 2 – ADDR_0x14      | SPI Error Flag, Latched                        |
| TSD  | Bit 1 – ADDR_0x14      | Thermal Shutdown Flag, Latched                 |
| TW   | Bit 0 – ADDR_0x14      | Thermal Warning Flag, Latched                  |
| <b>REGISTER 0X15 (SR): BUCK DIAGNOSTICS, RESET VALUE (POR) = 010000000<sub>2</sub></b> |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x15      | Odd Parity over Data                           |
| OTP_ACTIVE   | Bit 4 – ADDR_0x15      | OTP Active Flag, Non-Latched                   |
| BUCK1_MIN_TON  | Bit 3 – ADDR_0x15      | Minimal Ton Detected on Buck 1, Latched        |
| BUCK2_MIN_TON  | Bit 2 – ADDR_0x15      | Minimal Ton Detected on Buck 2, Latched        |
| BUCK1_STATUS   | Bit 1 – ADDR_0x15      | Actual Status of Buck 1 Regulator, Non-Latched |
| BUCK2_STATUS   | Bit 0 – ADDR_0x15      | Actual Status of Buck 2 Regulator, Non-Latched |

Table 10. BIT DEFINITION (continued)

| Symbol   | MAP Position           | Description  |
|--|------------------------|--|
| <b>REGISTER 0X16: BUCK TRIMMING, RESET VALUE (POR) = 0X0XXXXXX<sub>2</sub></b> |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x16      | Odd Parity over Data   |
| BUCK1_ISENS_RNG[6:0]   | Bits [6:0] – ADDR_0x16 | Trimming Constant for Highest Range on Hot for Buck 1 Peak Current |
| <b>REGISTER 0X17: BUCK TRIMMING, RESET VALUE (POR) = 0X0XXXXXX<sub>2</sub></b> |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x17      | Odd Parity over Data   |
| BUCK2_ISENS_RNG[6:0]   | Bits [6:0] – ADDR_0x17 | Trimming Constant for Highest Range on Hot for Buck 2 Peak Current |
| <b>REGISTER 0X18: BUCK TRIMMING, RESET VALUE (POR) = 0XXXXXXX<sub>2</sub></b>  |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x18      | Odd Parity over Data   |
| BUCK2_ISENS_D1[3:0]  | Bits [7:4] – ADDR_0x18 | Delta Trimming Constant for Buck 2 Peak Current                    |
| BUCK1_ISENS_D1[3:0]  | Bits [3:0] – ADDR_0x18 | Delta Trimming Constant for Buck 1 Peak Current                    |
| <b>REGISTER 0X19: BUCK TRIMMING, RESET VALUE (POR) = 0XXXXXXX<sub>2</sub></b>  |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x19      | Odd Parity over Data   |
| BUCK2_ISENS_D2[3:0]  | Bits [7:4] – ADDR_0x19 | Delta Trimming Constant for Buck 2 Peak Current                    |
| BUCK1_ISENS_D2[3:0]  | Bits [3:0] – ADDR_0x19 | Delta Trimming Constant for Buck 1 Peak Current                    |
| <b>REGISTER 0X1A: BUCK TRIMMING, RESET VALUE (POR) = 0XXXXXXX<sub>2</sub></b>  |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x1A      | Odd Parity over Data   |
| BUCK2_ISENS_D3[3:0]  | Bits [7:4] – ADDR_0x1A | Delta Trimming Constant for Buck 2 Peak Current                    |
| BUCK1_ISENS_D3[3:0]  | Bits [3:0] – ADDR_0x1A | Delta Trimming Constant for Buck 1 Peak Current                    |
| <b>REGISTER 0X1B: BUCK TRIMMING, RESET VALUE (POR) = 0XXXXXXX<sub>2</sub></b>  |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x1B      | Odd Parity over Data   |
| BUCK_ISENS_TC1[3:0]  | Bits [7:4] – ADDR_0x1B | Temperature Coefficient Trimming Constant for Buck Peak Current    |
| BUCK_ISENS_TC0[3:0]  | Bits [3:0] – ADDR_0x1B | Temperature Coefficient Trimming Constant for Buck Peak Current    |
| <b>REGISTER 0X1C: BUCK TRIMMING, RESET VALUE (POR) = 0XXXXXXX<sub>2</sub></b>  |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x1C      | Odd Parity over Data   |
| BUCK_ISENS_TC3[3:0]  | Bits [7:4] – ADDR_0x1C | Temperature Coefficient Trimming Constant for Buck Peak Current    |
| BUCK_ISENS_TC2[3:0]  | Bits [3:0] – ADDR_0x1C | Temperature Coefficient Trimming Constant for Buck Peak Current    |
| <b>REGISTER 0X1D: BUCK TRIMMING, RESET VALUE (POR) = 0X000000X<sub>2</sub></b> |                        |  |
| ODD PARITY   | Bit 8 – ADDR_0x1D      | Odd Parity over Data   |
| TC_VERSION   | Bit 0 – ADDR_0x1D      | Usage of BUCK_ISENS_TCx[3:0] Constants                             |
| <b>REGISTER 0X1E: OTP DATA, RESET VALUE (POR) = 000000000<sub>2</sub></b>      |                        |  |
| OTP_DATA[9:0]  | Bits [9:0] – ADDR_0x1E | OTP Data   |
| <b>REGISTER 0X1F: REVID, RESET VALUE (POR) = 00000XXXXXX<sub>2</sub></b>       |                        |  |
| REVID[7:0]   | Bits [7:0] – ADDR_0x1F | Revision ID  |

POR values of status registers are shown in situation that FSO mode is not entered after POR. All latched flags are “cleared by read”. ‘x’ means that value after reset is defined during reset phase (diagnostics) or is trimmed during manufacturing process.

SPI register SPI\_REVID[7:0] is used to track the silicon version, following encoding mechanism is used:

- SPI\_REVID[7:6]: Constant 00 [binary]
- SPI\_REVID[5]: 713/723 Distinguishing Bit (REVID[5] = 0 means 723)

- SPI\_REVID[4:3]: Full Mask Version <0 to 3>
- SPI\_REVID[2]: N78723–0/N78723–2 Distinguishing Bit (REVID[2] = 0 means N78723–0)
- SPI\_REVID[1:0]: Metal Tune <0 to 3>

REVID[7:0] for N78723–0 device is 11hex (723 = 0, Full Mask Version = 2, N78723–0 = 0, Metal Tune = 1)

REVID[7:0] for N78723–2 device is 14hex (723 = 0, Full Mask Version = 2, N78723–2 = 1, Metal Tune = 0)

**OTP MEMORY**

**Description**

The OTP (Once Time Programmable) memory contains 40 bits which bear the most important application dependant parameters and is user programmable via SPI interface. The programming of these bits is typically done at the end of the module manufacturing line.

OTP memory serves to store configuration data for Fail-Safe or Stand-Alone functionality or default configuration of the chip after power-up.

The OTP bits can be programmed only once, this is ensured by dedicated *OTP Lock Bit* which is set during programming.

**Table 11. OTP MAP**

| OTP Bits   | Connection to SPI Register |
|------------|----------------------------|
| OTP[7:0]   | BUCK1_VTHR[7:0]            |
| OTP[9:8]   | BUCK1_ISENS_THR[1:0]       |
| OTP[17:10] | BUCK2_VTHR[7:0]            |
| OTP[19:18] | BUCK2_ISENS_THR[1:0]       |
| OTP[24:20] | BUCK1_TOFF[4:0]            |
| OTP[29:25] | BUCK2_TOFF[4:0]            |
| OTP[30]    | BUCK1_EN                   |
| OTP[31]    | BUCK2_EN                   |
| OTP[34:32] | FSO_MD[2:0]                |
| OTP[35]    | BUCK1_TSD_AUT_RCR_EN       |
| OTP[36]    | BUCK2_TSD_AUT_RCR_EN       |
| OTP[38:37] | BUCKx_OC_OCCMP_THR[1:0]    |
| OTP[39]    | OTP Lock Bit               |

The OTP bits addressed by SPI register OTP\_ADDR[1:0] are accessible (read only) in the SPI register OTP\_DATA[9:0] after OTP Refresh operation (OTP\_OPERATION[1:0] = 0x1) in the following way:

OTP\_ADDR[1:0] = 0x0: OTP\_DATA[9:0] = OTP[9:0]  
 OTP\_ADDR[1:0] = 0x1: OTP\_DATA[9:0] = OTP[19:10]  
 OTP\_ADDR[1:0] = 0x2: OTP\_DATA[9:0] = OTP[29:20]  
 OTP\_ADDR[1:0] = 0x3: OTP\_DATA[9:0] = OTP[39:30]

**OTP Operations**

The NCV78723 supports following operations with OTP memory:

- OTP\_OPERATION[1:0] = 0x0 or 0x3:  
**NOP** (no operation)
- OTP\_OPERATION[1:0] = 0x1:  
**OTP Refresh** – refresh of the whole OTP memory (40 bits). Data addressed by SPI register OTP\_ADDR[1:0] are available in SPI register OTP\_DATA[9:0] after the end of OTP Refresh operation
- OTP\_OPERATION[1:0] = 0x2:  
**OTP Zap** – data from SPI register (those listed in

Table 11) and *OTP Lock Bit* are programmed into OTP memory. OTP Zap operation is allowed to be performed only once – when *OTP Lock Bit* is unprogrammed

SPI status bit OTP\_ACTIVE is set to “log. 1” when an OTP operation is in progress.

**OTP Programming Procedure**

Following procedure should be applied to program OTP memory:

- VBOOST voltage has to be in range between 15 V and 20 V with current capability at least 50 mA
- VDD voltage has to be kept in range for normal mode operation
- The junction temperature has to stay in range from 0°C to 125°C during OTP programming
- SPI registers listed in Table 11 have to be written with required content
- Content of the SPI registers (those listed in Table 11) is programmed into the OTP memory by OTP\_OPERATION[1:0] = 0x2 SPI write command. *OTP Lock Bit* is programmed automatically at the same time to prevent any further OTP programming

**OTP Programming Verification**

OTP\_FAIL bit in the SPI status register is set when VBOOST under-voltage (see OTP\_UV parameter) is detected during OTP Zap operation. It is clear by read flag.

The OTP\_BIAS\_H and OTP\_BIAS\_L registers are used to check proper OTP programming. After OTP programming, the OTP content has to be the same as programmed when OTP is read with OTP\_BIAS\_H = 1 and OTP\_BIAS\_L = 1.

Following procedure should be applied to verify OTP content:

- VDD voltage has to be kept in range for normal mode operation
- Write SPI registers OTP\_BIAS\_L = 1 and OTP\_BIAS\_H = 0
- Write SPI register OTP\_OPERATION[1:0] = 0x1 (OTP Refresh) for all OTP\_ADDR[1:0] values and check corresponding OTP\_DATA[9:0] content which has to match with previously programmed data
- Write SPI registers OTP\_BIAS\_L = 0 and OTP\_BIAS\_H = 1
- Write SPI register OTP\_OPERATION[1:0] = 0x1 (OTP Refresh) for all OTP\_ADDR[1:0] values and check corresponding OTP\_DATA[9:0] content which has to match with previously programmed data
- Programming is considered as successful when no mismatch is observed

# NCV78723

**Table 12. ORDERING INFORMATION**

| Device**           | Marking  | Package*  | Shipping†           |
|--------------------|----------|---|---------------------|
| NCV78723MW0CR2G    | N78723-0 | QFN24 5 × 5 with Wettable Flank (Pb-Free)           | 5,000 / Tape & Reel |
| NCV78723MW0R2G     | N78723-0 | QFN24 5 × 5 with Wettable Flank (Pb-Free)           | 5,000 / Tape & Reel |
| NCV78723MW2R2G     | N78723-2 | QFNW24 5 × 5 with Step-cut Wettable Flank (Pb-Free) | 5,000 / Tape & Reel |
| NCV78723MW2AR2G*** | N78723-2 | QFNW24 5 × 5 with Step-cut Wettable Flank (Pb-Free) | 5,000 / Tape & Reel |

\*\* NCV78723MW2 & NCV78723MW0 have different package mold compound. Please contact **onsemi** for technical details.

\*For additional information on our Pb-Free strategy and soldering details, please download the **onsemi** Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

\*\*\* NCV78723MW2AR2G is recommended for new designs.

†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.

# MECHANICAL CASE OUTLINE

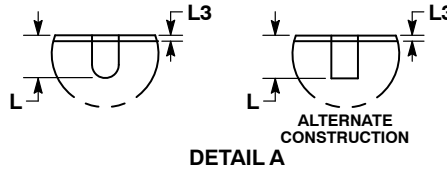
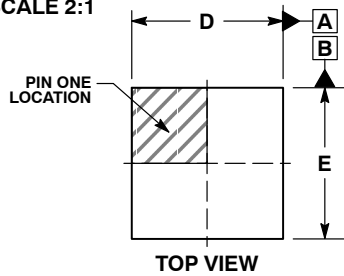
## PACKAGE DIMENSIONS



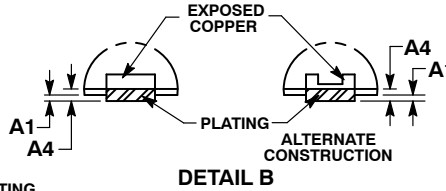
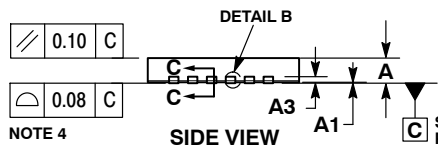
1 24  
SCALE 2:1

QFNW24 5x5, 0.65P  
CASE 484AF  
ISSUE A

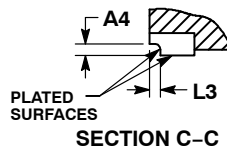
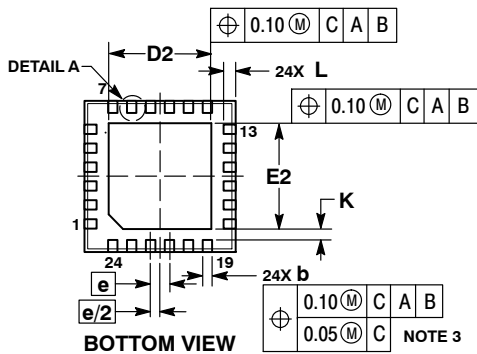
DATE 07 AUG 2018



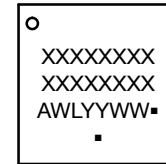
- NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
  2. CONTROLLING DIMENSION: MILLIMETERS.
  3. DIMENSION b APPLIES TO PLATED TERMINAL AND IS MEASURED BETWEEN 0.15 AND 0.30 MM FROM THE TERMINAL TIP.
  4. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS THE TERMINALS.



| MILLIMETERS |          |      |      |
|-------------|----------|------|------|
| DIM         | MIN      | NOM  | MAX  |
| A           | 0.80     | 0.85 | 0.90 |
| A1          | ----     | ---- | 0.05 |
| A3          | 0.20 REF |      |      |
| A4          | 0.10     | ---- | ---- |
| b           | 0.25     | 0.30 | 0.35 |
| D           | 4.90     | 5.00 | 5.10 |
| D2          | 3.40     | 3.50 | 3.60 |
| E           | 4.90     | 5.00 | 5.10 |
| E2          | 3.40     | 3.50 | 3.60 |
| e           | 0.65 BSC |      |      |
| K           | 0.35 REF |      |      |
| L           | 0.30     | 0.40 | 0.50 |
| L3          | 0.05 REF |      |      |



### GENERIC MARKING DIAGRAM\*

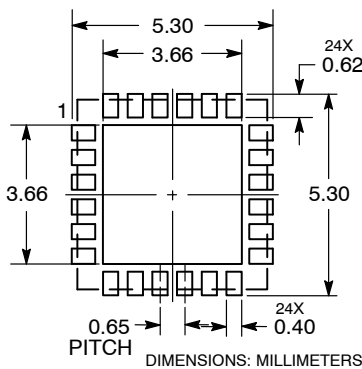


- XXXXXX = Specific Device Code
- A = Assembly Location
- WL = Wafer Lot
- YY = Year
- WW = Work Week
- = Pb-Free Package

(Note: Microdot may be in either location)

\*This information is generic. Please refer to device data sheet for actual part marking. Pb-Free indicator, "G" or microdot "▪", may or may not be present. Some products may not follow the Generic Marking.

### RECOMMENDED SOLDERING FOOTPRINT



|                  |                   |  |
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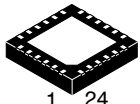
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# MECHANICAL CASE OUTLINE

## PACKAGE DIMENSIONS

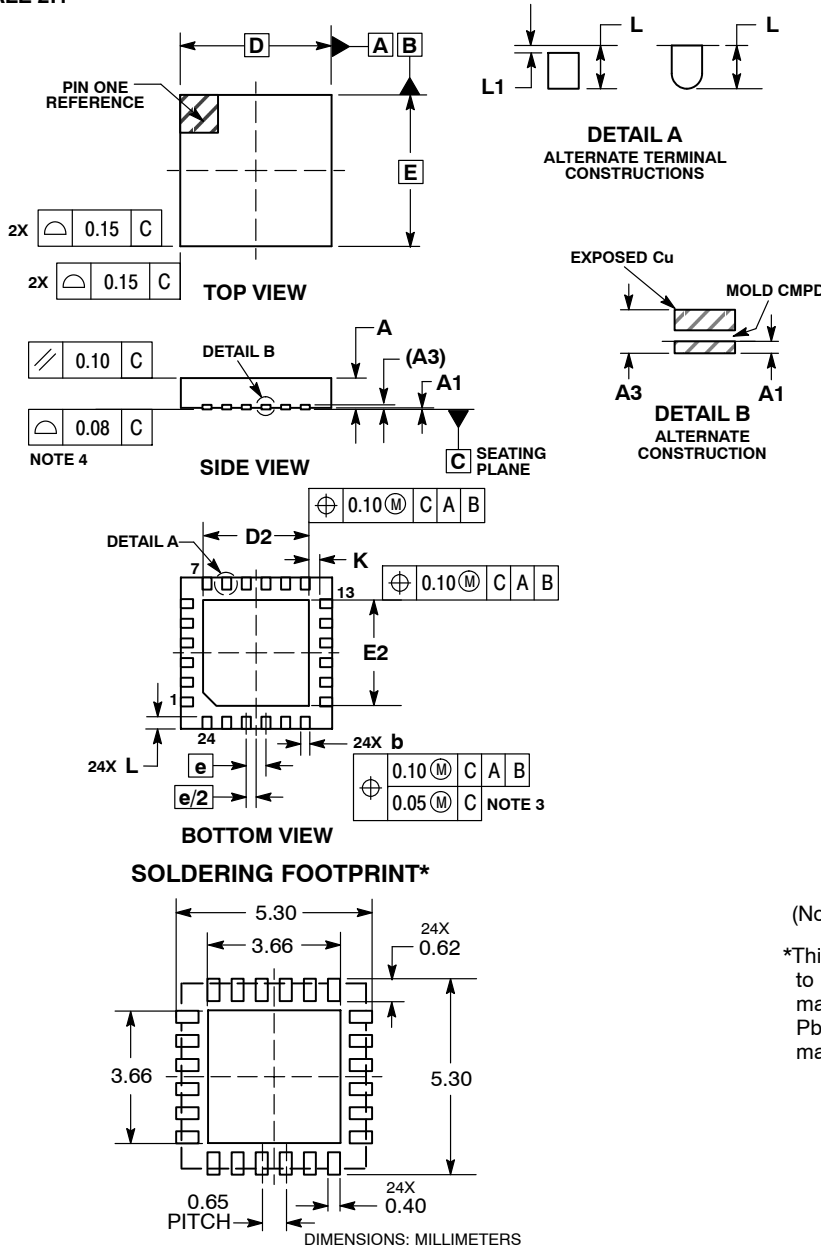
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1 24  
SCALE 2:1

QFN24 5x5, 0.65P  
CASE 485CS  
ISSUE O

DATE 24 OCT 2012

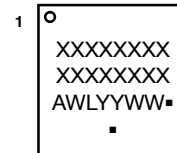


**NOTES:**

1. DIMENSIONS AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: MILLIMETERS.
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| MILLIMETERS |      |      |
|-------------|------|------|
| DIM         | MIN  | MAX  |
| A           | 0.80 | 0.90 |
| A1          | ---  | 0.05 |
| A3          | 0.20 | REF  |
| b           | 0.25 | 0.35 |
| D           | 5.00 | BSC  |
| D2          | 3.40 | 3.60 |
| E           | 5.00 | BSC  |
| E2          | 3.40 | 3.60 |
| e           | 0.65 | BSC  |
| K           | 0.20 | MIN  |
| L           | 0.30 | 0.50 |
| L1          | ---  | 0.15 |

**GENERIC MARKING DIAGRAM\***



- XXXXXX = Specific Device Code
- A = Assembly Location
- WL = Wafer Lot
- YY = Year
- WW = Work Week
- = Pb-Free Package

(Note: Microdot may be in either location)

\*This information is generic. Please refer to device data sheet for actual part marking.

Pb-Free indicator, "G" or microdot "▪", may or may not be present.

\*For additional information on our Pb-Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

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