# MAX5823/MAX5824/ MAX5825

# Ultra-Small, Octal Channel, 8-/10-/12-Bit Buffered Output DACs with Internal Reference and I²C Interface

## General Description

The MAX5823/MAX5824/MAX5825 8-channel, low-power, 8-/10-/12-bit, voltage-output digital-to-analog converters (DACs) include output buffers and an internal 3ppm/°C reference that is selectable to be 2.048V, 2.500V, or 4.096V. The MAX5823/MAX5824/MAX5825 accept a wide supply voltage range of 2.7V to 5.5V with extremely low power (6mW) consumption to accommodate most low-voltage applications. A precision external reference input allows rail-to-rail operation and presents a 100kΩ (typ) load to an external reference.

The MAX5823/MAX5824/MAX5825 have an I²C-compatible, 2-wire interface that operates at clock rates up to 400kHz. The DAC output is buffered and has a low supply current of less than 250µA per channel and a low offset error of ±0.5mV (typ). On power-up, the MAX5823/MAX5824/MAX5825 reset the DAC outputs to zero or mid-scale based on the status of M/Z logic input, providing flexibility for a variety of control applications. The internal reference is initially powered down to allow use of an external reference. The MAX5823/MAX5824/MAX5825 allow simultaneous output updates using software LOAD commands or the hardware load DAC logic input (LDAC).

The MAX5823/MAX5824/MAX5825 feature a watchdog function which can be enabled to monitor the I/O interface for activity and integrity.

A clear logic input (CLR) allows the contents of the CODE and the DAC registers to be cleared asynchronously and simultaneously sets the DAC outputs to the programmable default value. The MAX5823/MAX5824/MAX5825 are available in a 20-pin TSSOP and an ultra-small, 20-bump WLP package and are specified over the -40°C to +125°C temperature range.

## Applications

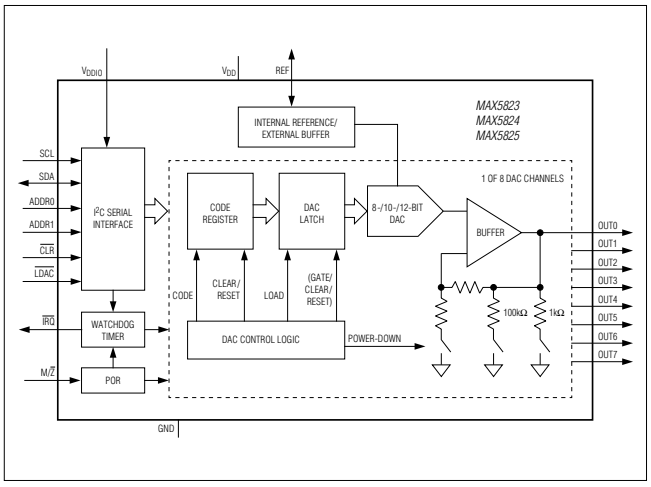
- Programmable Voltage and Current Sources
- Gain and Offset Adjustment
- Automatic Tuning and Optical Control
- Power Amplifier Control and Biasing
- Process Control and Servo Loops
- Portable Instrumentation

***Ordering Information* appears at end of data sheet.**

## Benefits and Features

- Eight High-Accuracy DAC Channels
  - 12-Bit Accuracy Without Adjustment
  - ±1 LSB INL Buffered Voltage Output
  - Guaranteed Monotonic Over All Operating Conditions
  - Independent Mode Settings for Each DAC
- Three Precision Selectable Internal References
  - 2.048V, 2.500V, or 4.096V
- Internal Output Buffer
  - Rail-to-Rail Operation with External Reference
  - 4.5µs Settling Time
  - Outputs Directly Drive 2kΩ Loads
- Small 6.5mm x 4.4mm 20-Pin TSSOP or Ultra-Small 2.5mm x 2.3mm 20-Bump WLP Package
- Wide 2.7V to 5.5V Supply Range
- Separate 1.8V to 5.5V $V_{DDIO}$ Power-Supply Input
- Fast 400kHz I²C-Compatible, 2-Wire Serial Interface
- Pin-Selectable Power-On-Reset to Zero-Scale or Midscale DAC Output
- $\overline{LDAC}$ and $\overline{CLR}$ For Asynchronous DAC Control
- Three Software-Selectable Power-Down Output Impedances
  - 1kΩ, 100kΩ, or High Impedance

## Functional Diagram



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## Absolute Maximum Ratings

$V_{DD}$, $V_{DDIO}$ to GND .....-0.3V to +6V
OUT_, REF to GND....0.3V to the lower of ($V_{DD}$ + 0.3V) and +6V
SCL, SDA, $\overline{IRQ}$, M/$\overline{Z}$, $\overline{LDAC}$, $\overline{CLR}$ to GND .....-0.3V to +6V
ADDR_ to GND.....-0.3V to the lower of ($V_{DDIO}$ + 0.3V) and +6V
Continuous Power Dissipation ($T_A$ = +70°C)
TSSOP (derate at 13.6mW/°C above 70°C).....1084mW
WLP (derate at 21.3mW/°C above 70°C).....1700mW
Maximum Continuous Current into Any Pin ..... ±50mA
Operating Temperature..... -40°C to +125°C
Storage Temperature ..... -65°C to +150°C
Lead Temperature (TSSOP only)(soldering, 10s).....+300°C
Soldering Temperature (reflow) ..... +260°C

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

## Package Thermal Characteristics (Note 1

TSSOP
Junction-to-Ambient Thermal Resistance ($\theta_{JA}$) .....73.8°C/W
Junction-to-Case Thermal Resistance ($\theta_{JC}$) .....20°C/W

WLP
Junction-to-Ambient Thermal Resistance ($\theta_{JA}$)
(Note 2) .....47°C/W

**Note 1:** Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to **www.maximintegrated.com/thermal-tutorial**.

**Note 2:** Visit **www.maximintegrated.com/app-notes/index.mvp/id/1891** for information about the thermal performance of WLP packaging.

## Electrical Characteristics

($V_{DD}$ = 2.7V to 5.5V, $V_{DDIO}$ = 1.8V to 5.5V, $V_{GND}$ = 0V, $C_L$ = 200pF, $R_L$ = 2kΩ, $T_A$ = -40°C to +125°C, unless otherwise noted.) (Note 3)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| **DC PERFORMANCE (Note 4)** | | | | | | |
| Resolution and Monotonicity | N | MAX5823 | 8 | | | Bits |
| | | MAX5824 | 10 | | | |
| | | MAX5825 | 12 | | | |
| Integral Nonlinearity (Note 5) | INL | MAX5823 | -0.25 | ±0.05 | +0.25 | LSB |
| | | MAX5824 | -0.5 | ±0.2 | +0.5 | |
| | | MAX5825 | -1 | ±0.5 | +1 | |
| Differential Nonlinearity (Note 5) | DNL | MAX5823 | -0.25 | ±0.05 | +0.25 | LSB |
| | | MAX5824 | -0.5 | ±0.1 | +0.5 | |
| | | MAX5825 | -1 | ±0.2 | +1 | |
| Offset Error (Note 6) | OE | | -5 | ±0.5 | +5 | mV |
| Offset Error Drift | | | | ±10 | | µV/°C |
| Gain Error (Note 6) | GE | | -1.0 | ±0.1 | +1.0 | %FS |
| Gain Temperature Coefficient | | With respect to $V_{REF}$ | | ±3.0 | | ppm of FS/°C |
| Zero-Scale Error | | | 0 | | +10 | mV |
| Full-Scale Error | | With respect to $V_{REF}$ | -0.5 | | +0.5 | %FS |

## Electrical Characteristics (continued)

($V_{DD}$ = 2.7V to 5.5V, $V_{DDIO}$ = 1.8V to 5.5V, $V_{GND}$ = 0V, $C_L$ = 200pF, $R_L$ = 2kΩ, $T_A$ = -40°C to +125°C, unless otherwise noted.) (Note 3)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| **DAC OUTPUT CHARACTERISTICS** | | | | | | | |
| Output Voltage Range (Note 7) | | No load | | 0 | | $V_{DD}$ | V |
| | | 2kΩ load to GND | | 0 | | $V_{DD}$ - 0.2 | |
| | | 2kΩ load to $V_{DD}$ | | 0.2 | | $V_{DD}$ | |
| Load Regulation | | $V_{OUT}$ = $V_{FS}$/2 | $V_{DD}$ = 3V ±10%, $\|I_{OUT}\| \le$ 5mA | | 300 | | µV/mA |
| | | | $V_{DD}$ = 5V ±10%, $\|I_{OUT}\| \le$ 10mA | | 300 | | |
| DC Output Impedance | | $V_{OUT}$ = $V_{FS}$/2 | $V_{DD}$ = 3V ±10%, $\|I_{OUT}\| \le$ 5mA | | 0.3 | | Ω |
| | | | $V_{DD}$ = 5V ±10%, $\|I_{OUT}\| \le$ 10mA | | 0.3 | | |
| Maximum Capacitive Load Handling | $C_L$ | | | | 500 | | pF |
| Resistive Load Handling | $R_L$ | | | 2 | | | kΩ |
| Short-Circuit Output Current | | $V_{DD}$ = 5.5V | Sourcing (output shorted to GND) | | 30 | | mA |
| | | | Sinking (output shorted to $V_{DD}$) | | 50 | | |
| DC Power-Supply Rejection | | $V_{DD}$ = 3V ±10% or 5V ±10% | | | 100 | | µV/V |
| **DYNAMIC PERFORMANCE** | | | | | | | |
| Voltage-Output Slew Rate | SR | Positive and negative | | | 1.0 | | V/µs |
| Voltage-Output Settling Time | | ¼ scale to ¾ scale, to ≤ 1 LSB, MAX5823 | | | 2.2 | | µs |
| | | ¼ scale to ¾ scale, to ≤ 1 LSB, MAX5824 | | | 2.6 | | |
| | | ¼ scale to ¾ scale, to ≤ 1 LSB, MAX5825 | | | 4.5 | | |
| DAC Glitch Impulse | | Major code transition (code x7FF to x800) | | | 7 | | nV*s |
| Channel-to-Channel Feedthrough (Note 8) | | Internal reference | | | 3.3 | | nV*s |
| | | External reference | | | 4.07 | | |
| Digital Feedthrough | | Midscale code, all digital inputs from 0V to $V_{DDIO}$ | | | 0.2 | | nV*s |
| Power-Up Time | | Startup calibration time (Note 9) | | | 200 | | µs |
| | | From power-down | | | 50 | | µs |

## Electrical Characteristics (continued)

($V_{DD}$ = 2.7V to 5.5V, $V_{DDIO}$ = 1.8V to 5.5V, $V_{GND}$ = 0V, $C_L$ = 200pF, $R_L$ = 2kΩ, $T_A$ = -40°C to +125°C, unless otherwise noted.) (Note 3)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| Output Voltage-Noise Density (DAC Output at Midscale) | | External reference | f = 1kHz | | 90 | | nV/√Hz |
| | | | f = 10kHz | | 82 | | |
| | | 2.048V internal reference | f = 1kHz | | 112 | | |
| | | | f = 10kHz | | 102 | | |
| | | 2.5V internal reference | f = 1kHz | | 125 | | |
| | | | f = 10kHz | | 110 | | |
| | | 4.096V internal reference | f = 1kHz | | 160 | | |
| | | | f = 10kHz | | 145 | | |
| Integrated Output Noise (DAC Output at Midscale) | | External reference | f = 0.1Hz to 10Hz | | 12 | | $\mu V_{P-P}$ |
| | | | f = 0.1Hz to 10kHz | | 76 | | |
| | | | f = 0.1Hz to 300kHz | | 385 | | |
| | | 2.048V internal reference | f = 0.1Hz to 10Hz | | 14 | | |
| | | | f = 0.1Hz to 10kHz | | 91 | | |
| | | | f = 0.1Hz to 300kHz | | 450 | | |
| | | 2.5V internal reference | f = 0.1Hz to 10Hz | | 15 | | |
| | | | f = 0.1Hz to 10kHz | | 99 | | |
| | | | f = 0.1Hz to 300kHz | | 470 | | |
| | | 4.096V internal reference | f = 0.1Hz to 10Hz | | 16 | | |
| | | | f = 0.1Hz to 10kHz | | 124 | | |
| | | | f = 0.1Hz to 300kHz | | 490 | | |
| Output Voltage-Noise Density (DAC Output at Full Scale) | | External reference | f = 1kHz | | 114 | | nV/√Hz |
| | | | f = 10kHz | | 99 | | |
| | | 2.048V internal reference | f = 1kHz | | 175 | | |
| | | | f = 10kHz | | 153 | | |
| | | 2.5V internal reference | f = 1kHz | | 200 | | |
| | | | f = 10kHz | | 174 | | |
| | | 4.096V internal reference | f = 1kHz | | 295 | | |
| | | | f = 10kHz | | 255 | | |
| Integrated Output Noise (DAC Output at Full Scale) | | External reference | f = 0.1Hz to 10Hz | | 13 | | $\mu V_{P-P}$ |
| | | | f = 0.1Hz to 10kHz | | 94 | | |
| | | | f = 0.1Hz to 300kHz | | 540 | | |
| | | 2.048V internal reference | f = 0.1Hz to 10Hz | | 19 | | |
| | | | f = 0.1Hz to 10kHz | | 143 | | |
| | | | f = 0.1Hz to 300kHz | | 685 | | |
| | | 2.5V internal reference | f = 0.1Hz to 10Hz | | 21 | | |
| | | | f = 0.1Hz to 10kHz | | 159 | | |
| | | | f = 0.1Hz to 300kHz | | 705 | | |
| | | 4.096V internal reference | f = 0.1Hz to 10Hz | | 26 | | |
| | | | f = 0.1Hz to 10kHz | | 213 | | |
| | | | f = 0.1Hz to 300kHz | | 750 | | |

## Electrical Characteristics (continued)

($V_{DD}$ = 2.7V to 5.5V, $V_{DDIO}$ = 1.8V to 5.5V, $V_{GND}$ = 0V, $C_L$ = 200pF, $R_L$ = 2kΩ, $T_A$ = -40°C to +125°C, unless otherwise noted.) (Note 3)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| **REFERENCE INPUT** | | | | | | | |
| Reference Input Range | $V_{REF}$ | | | 1.24 | | $V_{DD}$ | V |
| Reference Input Current | $I_{REF}$ | $V_{REF}$ = $V_{DD}$ = 5.5V | | | 55 | 74 | µA |
| Reference Input Impedance | $R_{REF}$ | | | 75 | 100 | | kΩ |
| **REFERENCE OUTPUT** | | | | | | | |
| Reference Output Voltage | $V_{REF}$ | $V_{REF}$ = 2.048V, $T_A$ = +25°C | | 2.043 | 2.048 | 2.053 | V |
| | | $V_{REF}$ = 2.5V, $T_A$ = +25°C | | 2.494 | 2.500 | 2.506 | |
| | | $V_{REF}$ = 4.096V, $T_A$ = +25°C | | 4.086 | 4.096 | 4.106 | |
| Reference Temperature Coefficient (Note 10) | | MAX5825A | | | ±3 | ±10 | ppm/°C |
| | | MAX5823/MAX5824/MAX5825B | | | ±10 | ±25 | |
| Reference Drive Capacity | | External load | | | 25 | | kΩ |
| Reference Capacitive Load Handling | | | | | 200 | | pF |
| Reference Load Regulation | | $I_{SOURCE}$ = 0 to 500µA | | | 2 | | mV/mA |
| Reference Line Regulation | | | | | 0.05 | | mV/V |
| **POWER REQUIREMENTS** | | | | | | | |
| Supply Voltage | $V_{DD}$ | $V_{REF}$ = 4.096V | | 4.5 | | 5.5 | V |
| | | All other options | | 2.7 | | 5.5 | |
| I/O Supply Voltage | $V_{DDIO}$ | | | 1.8 | | 5.5 | V |
| Supply Current (Note 11) | $I_{DD}$ | Internal reference | $V_{REF}$ = 2.048V | | 1.6 | 2 | mA |
| | | | $V_{REF}$ = 2.5V | | 1.7 | 2.1 | |
| | | | $V_{REF}$ = 4.096V | | 2.0 | 2.5 | |
| | | External reference | $V_{REF}$ = 3V | | 1.6 | 2.0 | |
| | | | $V_{REF}$ = 5V | | 1.9 | 2.5 | |
| Power-Down Mode Supply Current | $I_{PD}$ | All DACs off, internal reference ON | | | 140 | | µA |
| | | All DACs off, internal reference OFF, $T_A$ = -40°C to +85°C | | | 0.7 | 2 | |
| | | All DACs off, internal reference OFF, $T_A$ = +125°C | | | 2 | 4 | |
| Digital Supply Current | $I_{DDIO}$ | Static logic inputs, all outputs unloaded | | | | 1 | µA |
| **DIGITAL INPUT CHARACTERISTICS (SCL, SDA, ADDR0, ADDR1, $\overline{LDAC}$, $\overline{CLR}$, M/$\overline{Z}$)** | | | | | | | |
| Input High Voltage (Note 11) | $V_{IH}$ | (All inputs except M/$\overline{Z}$) | 2.2V < $V_{DDIO}$ < 5.5V | 0.7 x $V_{DDIO}$ | | | V |
| | | | 1.8V < $V_{DDIO}$ < 2.2V | 0.8 x $V_{DDIO}$ | | | V |
| | | 2.7V < $V_{DD}$ < 5.5V (for M/$\overline{Z}$) | | 0.7 x $V_{DD}$ | | | |

## Electrical Characteristics (continued)

($V_{DD}$ = 2.7V to 5.5V, $V_{DDIO}$ = 1.8V to 5.5V, $V_{GND}$ = 0V, $C_L$ = 200pF, $R_L$ = 2kΩ, $T_A$ = -40°C to +125°C, unless otherwise noted.) (Note 3)

| PARAMETER | SYMBOL | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| Input Low Voltage (Note 11) | $V_{IL}$ | (All inputs except M/$\overline{Z}$) | 2.2V < $V_{DDIO}$ < 5.5V | | | 0.3 x $V_{DDIO}$ | V |
| | | | 1.8V < $V_{DDIO}$ < 2.2V | | | 0.2 x $V_{DDIO}$ | V |
| | | 2.7V < $V_{DD}$ < 5.5V (for M/$\overline{Z}$) | | | | 0.3 x $V_{DD}$ | |
| Input Leakage Current | $I_{IN}$ | $V_{IN}$ = 0V or $V_{DDIO}$, all inputs except M/$\overline{Z}$ (Note 11) | | | ±0.1 | ±1 | µA |
| | | $V_{IN}$ = 0V or $V_{DD}$, for M/$\overline{Z}$ (Note 11) | | | | | |
| Input Capacitance (Note 10) | $C_{IN}$ | | | | | 10 | pF |
| Hysteresis Voltage | $V_H$ | | | | 0.15 | | V |
| ADDR_ Pullup/Pulldown Strength | $R_{PU}$, $R_{PD}$ | (Note 12) | | 30 | 50 | 90 | kΩ |
| **DIGITAL OUTPUT (SDA, $\overline{IRQ}$)** | | | | | | | |
| Output Low Voltage | $V_{OL}$ | $I_{SINK}$ = 3mA | | | | 0.2 | V |
| Output Inactive Leakage | $I_{OFF}$ | $\overline{IRQ}$ only, see $I_{IN}$ for SDA | | | ±0.1 | ±1 | µA |
| Output Inactive Capacitance | $C_{OFF}$ | $\overline{IRQ}$ only, see $C_{IN}$ for SDA | | | | 10 | pF |
| **WATCHDOG TIMER CHARACTERISTICS** | | | | | | | |
| Watchdog Timer Period | $t_{WDOSC}$ | $V_{DD}$ = 3V, $T_A$ = +25°C | | 0.95 | 1 | 1.05 | ms |
| Watchdog Timer Period Supply Drift | | $V_{DD}$ = 2.7V to 5.5V, $T_A$ = +25°C | | | 0.6 | | %/V |
| Watchdog Timer Period Temperature Drift | | $V_{DD}$ = 3V | | | 0.0375 | | %/°C |
| **I²C TIMING CHARACTERISTICS (SCL, SDA, $\overline{LDAC}$, $\overline{CLR}$)** | | | | | | | |
| SCL Clock Frequency | $f_{SCL}$ | | | | | 400 | kHz |
| Bus Free Time Between a STOP and a START Condition | $t_{BUF}$ | | | 1.3 | | | µs |
| Hold Time Repeated for a START Condition | $t_{HD;STA}$ | | | 0.6 | | | µs |
| SCL Pulse Width Low | $t_{LOW}$ | | | 1.3 | | | µs |
| SCL Pulse Width High | $t_{HIGH}$ | | | 0.6 | | | µs |
| Setup Time for Repeated START Condition | $t_{SU;STA}$ | | | 0.6 | | | µs |
| Data Hold Time | $t_{HD;DAT}$ | | | 0 | | 900 | ns |
| Data Setup Time | $t_{SU;DAT}$ | | | 100 | | | ns |
| SDA and SCL Receiving Rise Time | $t_R$ | | | 20 + $C_B$/10 | | 300 | ns |
| SDA and SCL Receiving Fall Time | $t_F$ | | | 20 + $C_B$/10 | | 300 | ns |

## Electrical Characteristics (continued)

($V_{DD}$ = 2.7V to 5.5V, $V_{DDIO}$ = 1.8V to 5.5V, $V_{GND}$ = 0V, $C_L$ = 200pF, $R_L$ = 2kΩ, $T_A$ = -40°C to +125°C, unless otherwise noted.) (Note 3)

| PARAMETER | SYMBOL | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|
| SDA Transmitting Fall Time | $t_F$ | | 20 + $C_B$/10 | | 250 | ns |
| Setup Time for STOP Condition | $t_{SU;STO}$ | | 0.6 | | | µs |
| Bus Capacitance Allowed | $C_B$ | $V_{DD}$ = 2.7V to 5.5V | 10 | | 400 | pF |
| Pulse Width of Suppressed Spike | $t_{SP}$ | | | 50 | | ns |
| $\overline{CLR}$ Removal Time Prior to a Recognized START | $t_{CLRSTA}$ | | 100 | | | ns |
| $\overline{CLR}$ Pulse Width Low | $t_{CLPW}$ | | 20 | | | ns |
| $\overline{LDAC}$ Pulse Width Low | $t_{LDPW}$ | | 20 | | | ns |
| $\overline{LDAC}$ Fall to SCLK Rise Hold | $t_{LDH}$ | | 400 | | | ns |

**Note 3:** Electrical specifications are production tested at $T_A$ = +25°C. Specifications over the entire operating temperature range are guaranteed by design and characterization. Typical specifications are at $T_A$ = +25°C.

**Note 4:** DC performance is tested without load, $V_{REF} = V_{DD}$.

**Note 5:** Linearity is tested with unloaded outputs to within 20mV of GND and $V_{DD}$.

**Note 6:** Offset and gain calculated from measurements made with $V_{REF} = V_{DD}$ at code 30 and 4065 for MAX5825, code 8 and 1016 for MAX5824, and code 2 and 254 for MAX5823.

**Note 7:** Subject to zero- and full-scale error limits and $V_{REF}$ settings.

**Note 8:** Measured with all other DAC outputs at midscale with one channel transitioning 0 to full scale.

**Note 9:** On power-up, the device initiates an internal 200µs (typ) calibration sequence. All commands issued during this time will be ignored.

**Note 10:** Guaranteed by design.

**Note 11:** All channels active at $V_{FS}$, unloaded. Static logic inputs with $V_{IL} = V_{GND}$ and $V_{IH} = V_{DDIO}$ for all inputs .

**Note 12:** Unconnected conditions on the ADDR_ inputs are sensed through a resistive pullup and pulldown operation; for proper operation, ADDR_ inputs must be connected to $V_{DDIO}$, GND, or left unconnected with minimal capacitance.

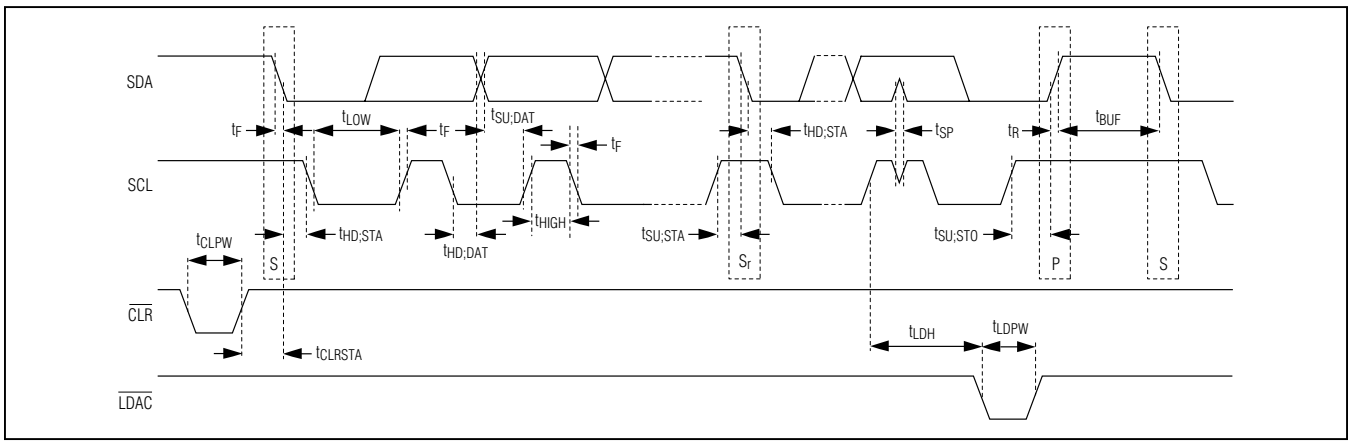
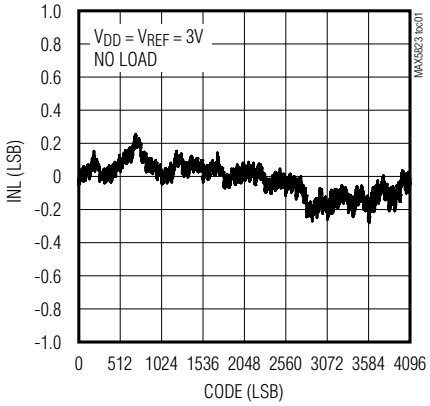



*Figure 1. I²C Serial Interface Timing Diagram*

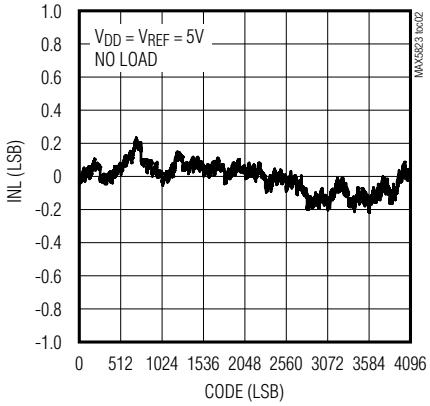
## Typical Operating Characteristics

(MAX5825, 12-bit performance, $T_A$ = +25°C, unless otherwise noted.)

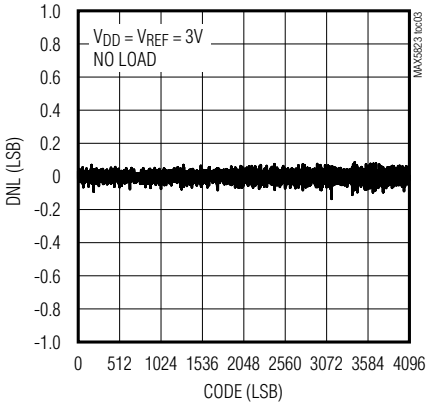
**INL vs. CODE**



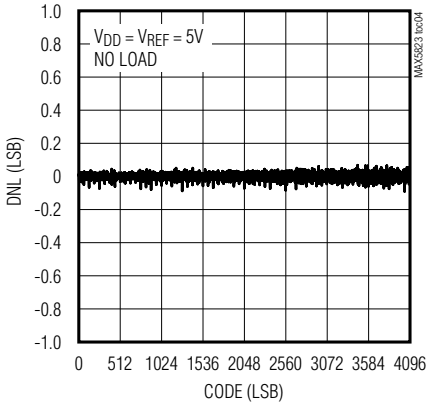

**INL vs. CODE**



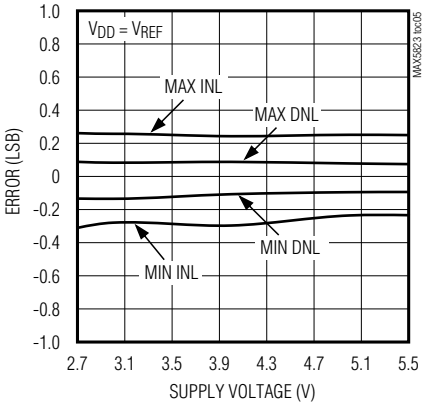

**DNL vs. CODE**



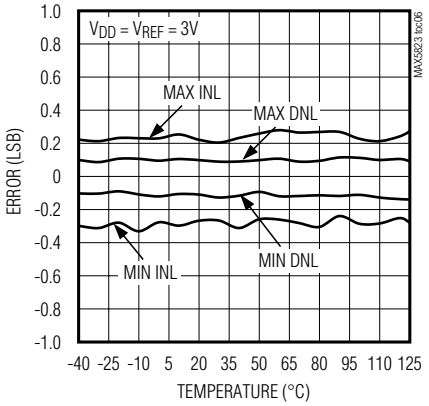

**DNL vs. CODE**



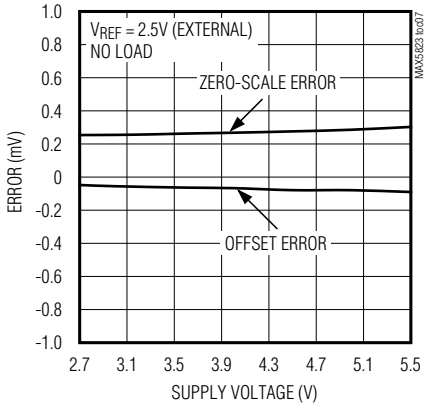

**INL AND DNL vs. SUPPLY VOLTAGE**



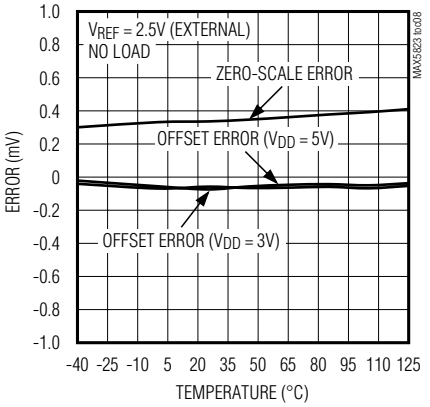

**INL AND DNL vs. TEMPERATURE**



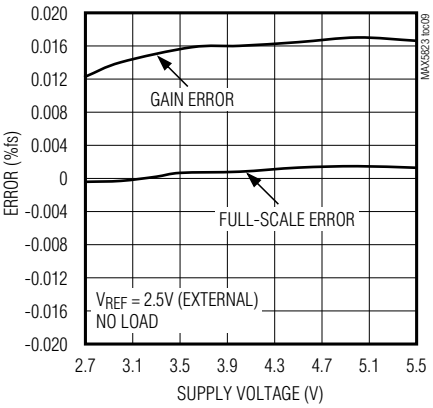

**OFFSET AND ZERO-SCALE ERROR vs. SUPPLY VOLTAGE**




**OFFSET AND ZERO-SCALE ERROR vs. TEMPERATURE**



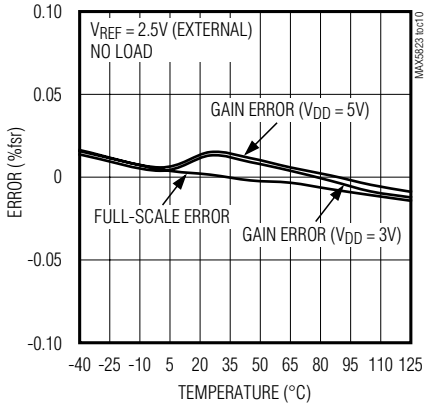

**FULL-SCALE ERROR AND GAIN ERROR vs. SUPPLY VOLTAGE**



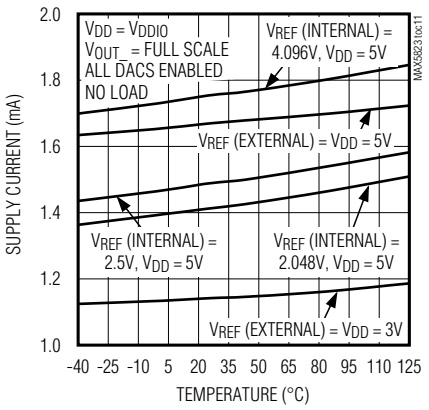
## Typical Operating Characteristics (continued)

(MAX5825, 12-bit performance, $T_A$ = +25°C, unless otherwise noted.)

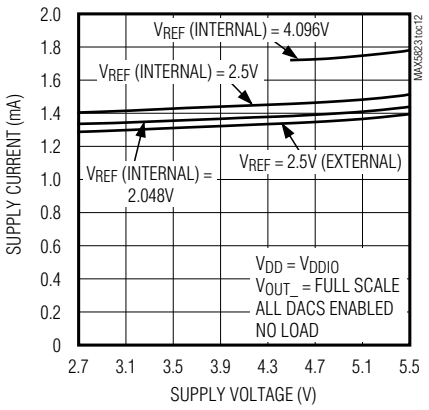
**FULL-SCALE ERROR AND GAIN ERROR vs. TEMPERATURE**



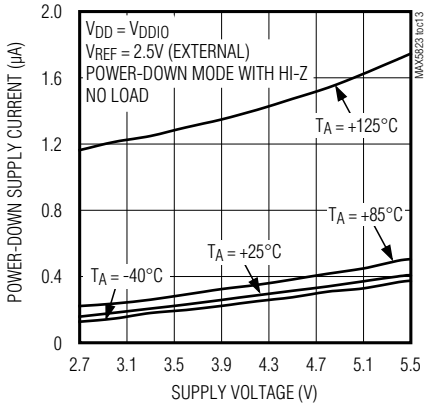

**SUPPLY CURRENT vs. TEMPERATURE**



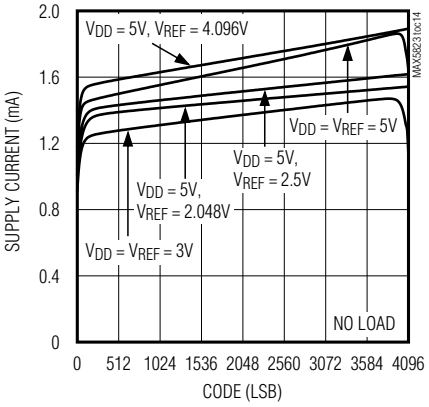

**SUPPLY CURRENT vs. SUPPLY VOLTAGE**



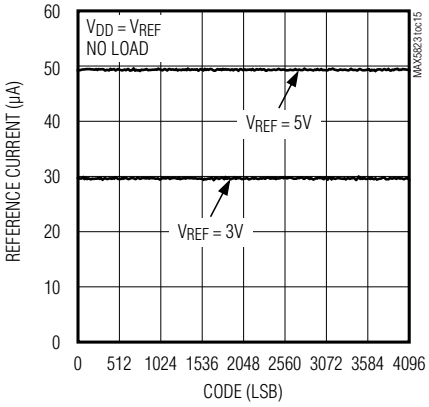

**POWER-DOWN MODE SUPPLY CURRENT vs. SUPPLY VOLTAGE**



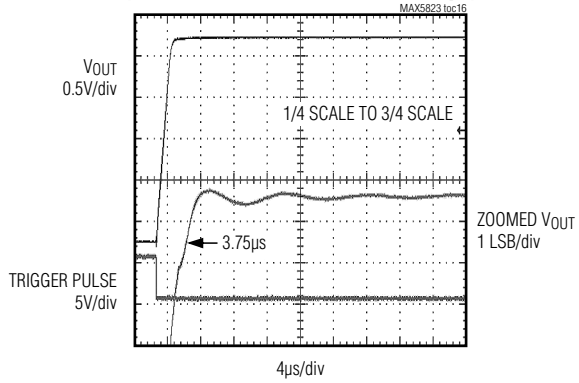

**IVDD vs. CODE**



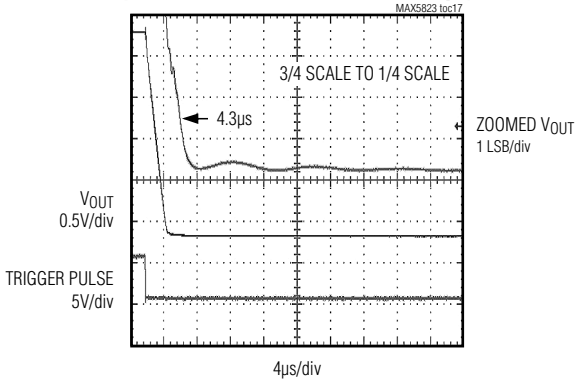

**IREF (EXTERNAL) vs. CODE**




**SETTLING TO ±1 LSB**
**(VDD = VREF = 5V, RL = 2kΩ, CL = 200pF)**



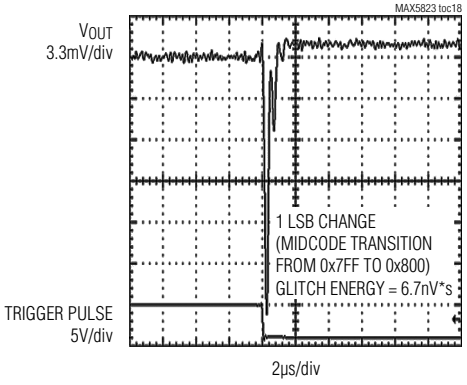

**SETTLING TO ±1 LSB**
**(VDD = VREF = 5V, RL = 2kΩ, CL = 200pF)**



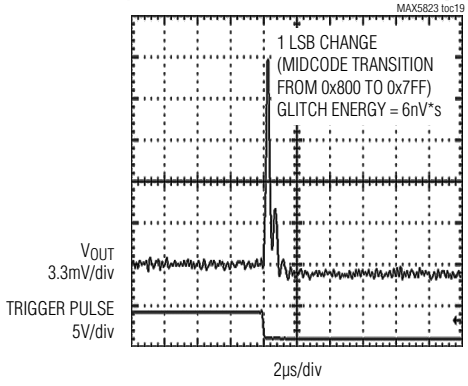
## Typical Operating Characteristics (continued)

(MAX5825, 12-bit performance, $T_A$ = +25°C, unless otherwise noted.)

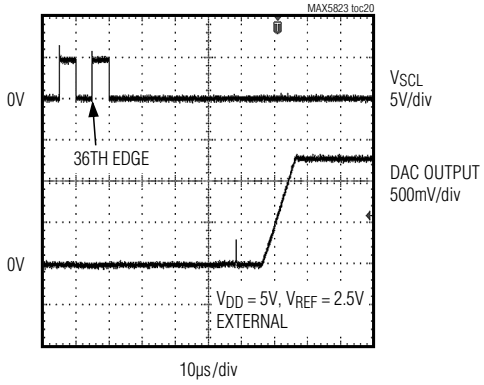
**MAJOR CODE TRANSITION GLITCH ENERGY**
**($V_{DD}$ = $V_{REF}$ = 5V, $R_L$ = 2kΩ, $C_L$ = 200pF)**



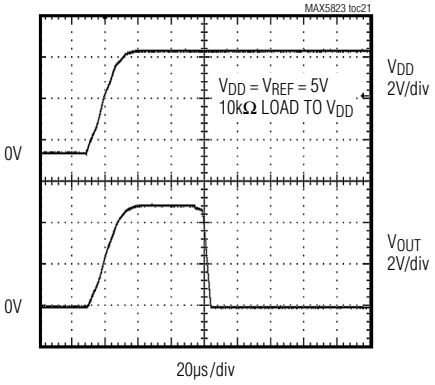

**MAJOR CODE TRANSITION GLITCH ENERGY**
**($V_{DD}$ = $V_{REF}$ = 5V, $R_L$ = 2kΩ, $C_L$ = 200pF)**



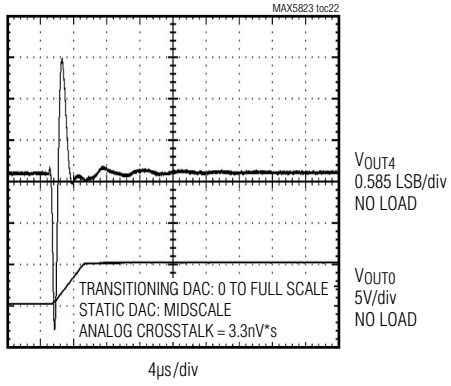

**$V_{OUT}$ vs. TIME TRANSIENT**
**EXITING POWER-DOWN**



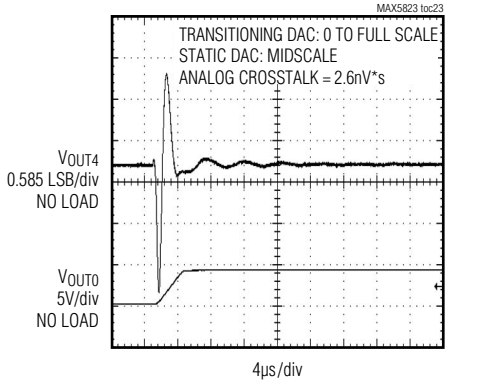

**POWER-ON RESET TO 0V**




**CHANNEL-TO-CHANNEL FEEDTHROUGH**
**($V_{DD}$ = $V_{REF}$ = 5V, $T_A$ = +25°C, NO LOAD)**



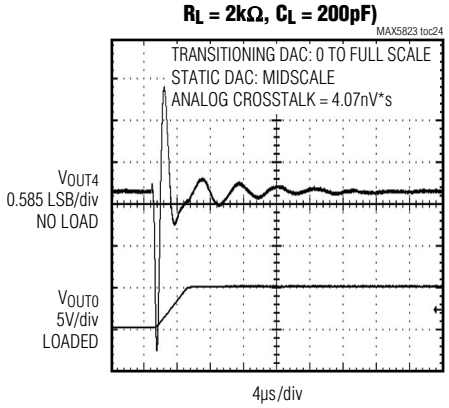

**CHANNEL-TO-CHANNEL FEEDTHROUGH**
**($V_{DD}$ = 5V, $V_{REF}$ = 4.096V, $T_A$ = +25°C, NO LOAD)**



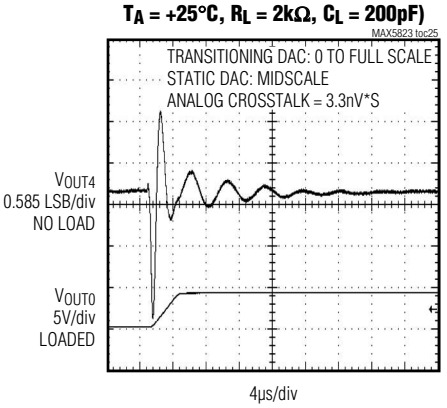
## Typical Operating Characteristics (continued)

(MAX5825, 12-bit performance, $T_A$ = +25°C, unless otherwise noted.)

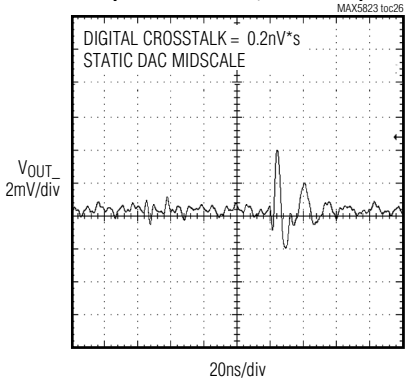
**CHANNEL-TO-CHANNEL FEEDTHROUGH**
**($V_{DD}$ = $V_{REF}$ = 5V, $T_A$ = +25°C, $R_L$ = 2kΩ, $C_L$ = 200pF)**



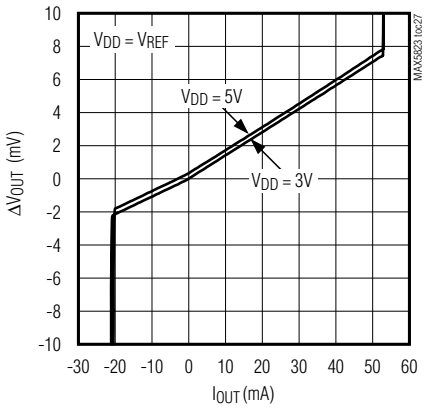

**CHANNEL-TO-CHANNEL FEEDTHROUGH**
**($V_{DD}$ = 5V, $V_{REF}$ = 4.096V (INTERNAL), $T_A$ = +25°C, $R_L$ = 2kΩ, $C_L$ = 200pF)**



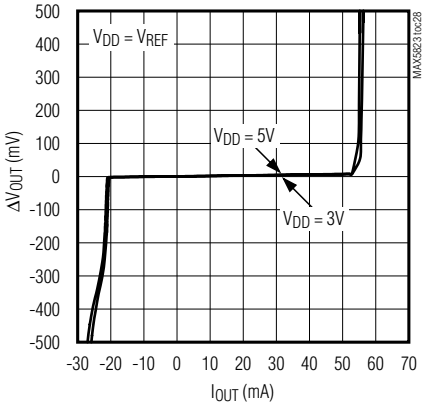

**DIGITAL FEEDTHROUGH**
**($V_{DD}$ = $V_{REF}$ = 5V, $R_L$ = 10kΩ)**



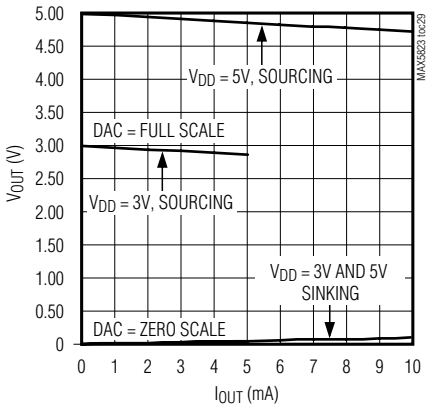

**OUTPUT LOAD REGULATION**



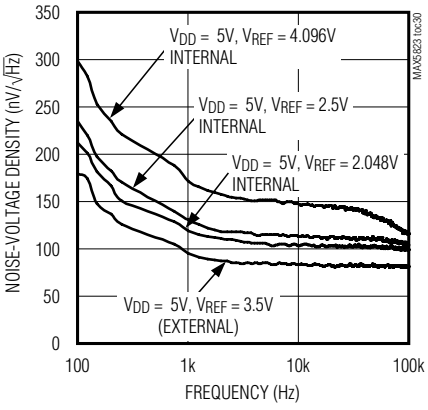

**OUTPUT CURRENT LIMITING**




**HEADROOM AT RAILS vs. OUTPUT CURRENT ($V_{DD}$ = $V_{REF}$)**



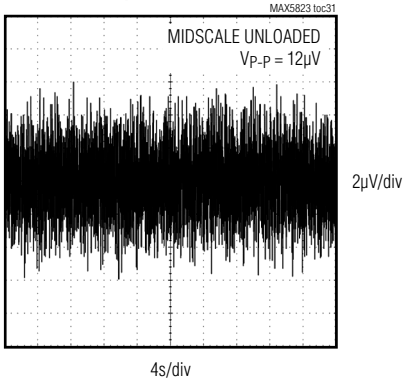

**NOISE-VOLTAGE DENSITY vs. FREQUENCY (DAC AT MIDSCALE)**



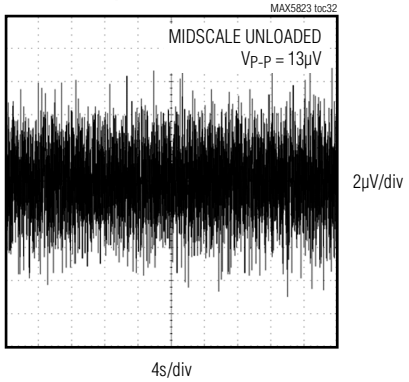
## Typical Operating Characteristics (continued)

(MAX5825, 12-bit performance, $T_A$ = +25°C, unless otherwise noted.)

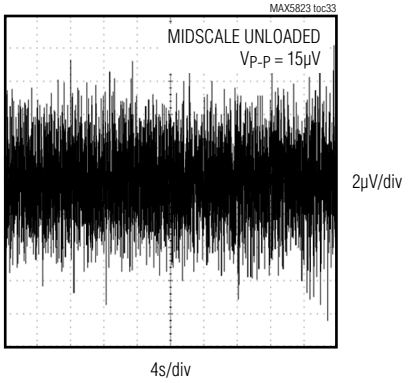
**0.1Hz TO 10Hz OUTPUT NOISE, EXTERNAL REFERENCE ($V_{DD}$ = 5V, $V_{REF}$ = 4.5V)**



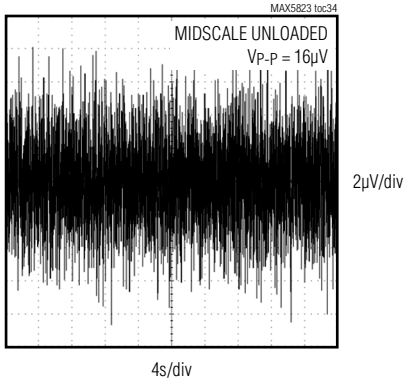

**0.1Hz TO 10Hz OUTPUT NOISE, INTERNAL REFERENCE ($V_{DD}$ = 5V, $V_{REF}$ = 2.048V)**



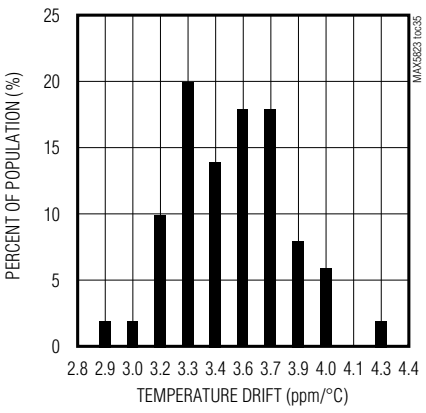

**0.1Hz TO 10Hz OUTPUT NOISE, INTERNAL REFERENCE ($V_{DD}$ = 5V, $V_{REF}$ = 2.5V)**



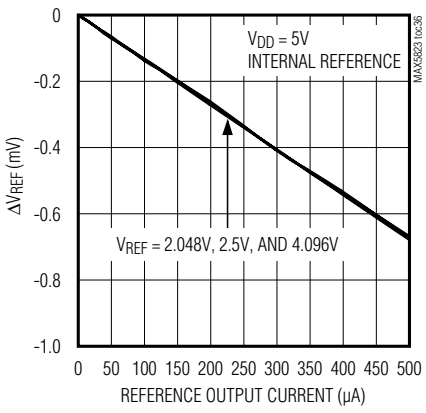

**0.1Hz TO 10Hz OUTPUT NOISE, INTERNAL REFERENCE ($V_{DD}$ = 5V, $V_{REF}$ = 4.096V)**



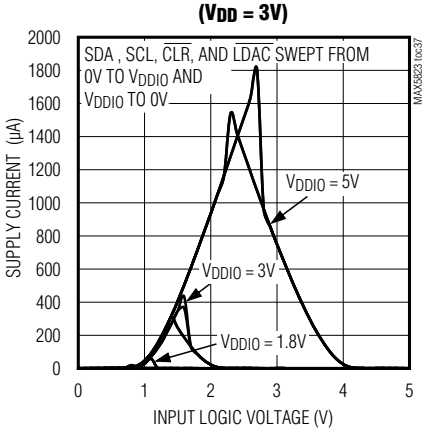

**$V_{REF}$ DRIFT vs. TEMPERATURE**




**REFERENCE LOAD REGULATION**



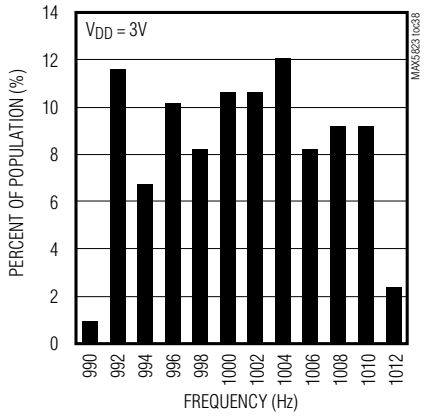

**SUPPLY CURRENT vs. INPUT LOGIC VOLTAGE ($V_{DD}$ = 3V)**



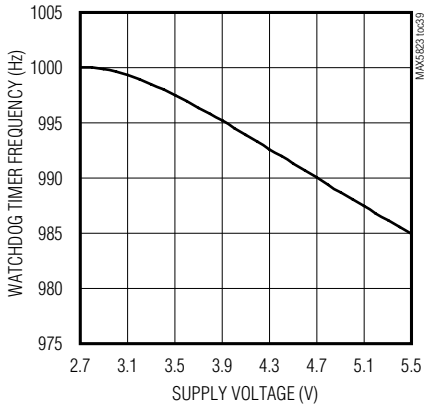
## Typical Operating Characteristics (continued)

(MAX5825, 12-bit performance, $T_A$ = +25°C, unless otherwise noted.)

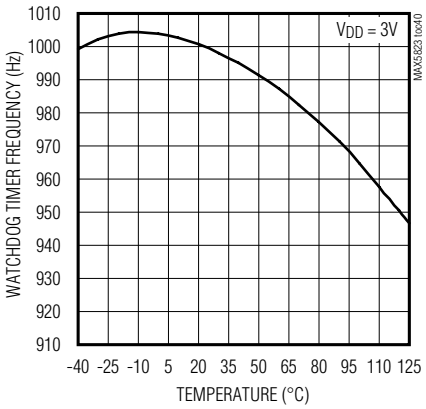
**WATCHDOG TIMER PERIOD HISTOGRAM**



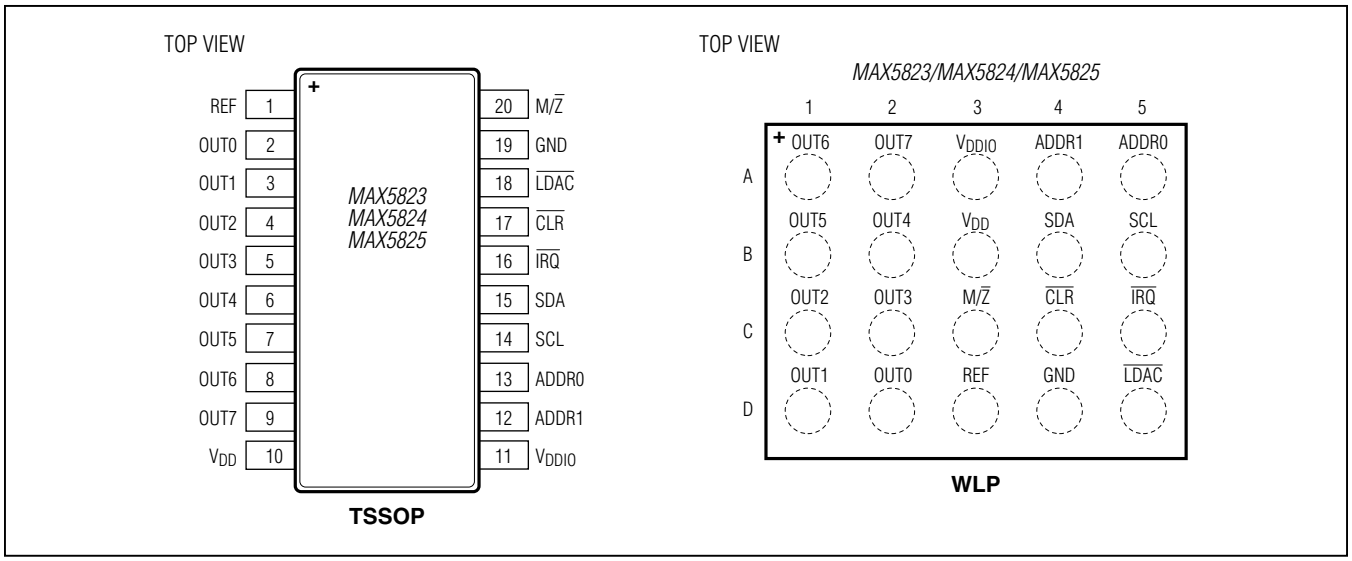

**WATCHDOG TIMER FREQUENCY vs. SUPPLY VOLTAGE**




**WATCHDOG TIMER FREQUENCY vs. TEMPERATURE**



## Pin Configurations




## Pin Description

| PIN | | NAME | FUNCTION |
|---|---|---|---|
| TSSOP | WLP | | |
| 1 | D3 | REF | Reference Voltage Input/Output |
| 2 | D2 | OUT0 | DAC Channel 0 Voltage Output |
| 3 | D1 | OUT1 | DAC Channel 1 Voltage Output |
| 4 | C1 | OUT2 | DAC Channel 2 Voltage Output |
| 5 | C2 | OUT3 | DAC Channel 3 Voltage Output |
| 6 | B2 | OUT4 | DAC Channel 4 Voltage Output |
| 7 | B1 | OUT5 | DAC Channel 5 Voltage Output |
| 8 | A1 | OUT6 | DAC Channel 6 Voltage Output |
| 9 | A2 | OUT7 | DAC Channel 7 Voltage Output |
| 10 | B3 | $V_{DD}$ | Analog Supply Voltage |
| 11 | A3 | $V_{DDIO}$ | Digital Supply Voltage |
| 12 | A4 | ADDR1 | I²C Address Selection Input Bit 1 |
| 13 | A5 | ADDR0 | I²C Address Selection Input Bit 0 |
| 14 | B5 | SCL | I²C Serial Data Clock Input |
| 15 | B4 | SDA | I²C Serial Data Bus Input/Output |
| 16 | C5 | $\overline{IRQ}$ | Active-Low Open Drain Interrupt Output. $\overline{IRQ}$ low indicates watchdog timeout. |
| 17 | C4 | $\overline{CLR}$ | Active-Low Asynchronous DAC Clear Input |
| 18 | D5 | $\overline{LDAC}$ | Active-Low Asynchronous DAC Load Input |
| 19 | D4 | GND | Ground |
| 20 | C3 | M/$\overline{Z}$ | DAC Output Reset Selection. Connect M/$\overline{Z}$ to GND for zero-scale and connect M/$\overline{Z}$ to $V_{DD}$ for midscale. |

## Detailed Description

The MAX5823/MAX5824/MAX5825 are 8-channel, low-power, 8-/10-/12-bit buffered voltage-output DACs. The 2.7V to 5.5V wide supply voltage range and low-power consumption accommodates most low-power and low-voltage applications. The devices present a 100kΩ load to the external reference. The internal output buffers allow rail-to-rail operation. An internal voltage reference is available with software selectable options of 2.048V, 2.500V, or 4.096V. The devices feature a fast 400kHz I²C-compatible interface. The MAX5823/MAX5824/MAX5825 include a serial-in/parallel-out shift register, internal CODE and DAC registers, a power-on-reset (POR) circuit to initialize the DAC outputs to zero scale (M/$\overline{Z}$ = 0) or midscale (M/$\overline{Z}$ = 1), and control logic.

$\overline{CLR}$ is available to asynchronously clear the DAC outputs to a user-programmable default value, independent of the serial interface. $\overline{LDAC}$ is available to simultaneously update selected DACs on one or more devices. The MAX5823/MAX5824/MAX5825 also feature user-configurable interface watchdog, with status indicated by the $\overline{IRQ}$ output.

### DAC Outputs (OUT_)

The MAX5823/MAX5824/MAX5825 include internal buffers on all DAC outputs, which provide improved load regulation for the DAC outputs. The output buffers slew at 1V/µs (typ) and drive as low as 2kΩ in parallel with 500pF. The analog supply voltage ($V_{DD}$) determines the maximum output voltage range of the devices since it powers the output buffers. Under no-load conditions, the output buffers drive from GND to $V_{DD}$, subject to offset and gain errors. With a 2kΩ load to GND, the output buffers drive from GND to within 200mV of $V_{DD}$. With a 2kΩ load to $V_{DD}$, the output buffers drive from $V_{DD}$ to within 200mV of GND.

The DAC ideal output voltage is defined by:

$$V_{OUT} = V_{REF} \times \frac{D}{2^N}$$

where D = code loaded into the DAC register, $V_{REF}$ = reference voltage, N = resolution.

### Internal Register Structure

The user interface is separated from the DAC logic to minimize digital feedthrough. Within the serial interface is an input shift register, the contents of which can be routed to control registers, individual, or multiple DACs as determined by the user command.

Within each DAC channel there is a CODE register followed by a DAC latch register (see the *Detailed Functional Diagram*). The contents of the CODE register hold pending DAC output settings which can later be loaded into the DAC registers. The CODE register can be updated using both CODE and CODE_LOAD user commands. The contents of the DAC register hold the current DAC output settings. The DAC register can be updated directly from the serial interface using the CODE_LOAD commands or can upload the current contents of the CODE register using LOAD commands or the $\overline{LDAC}$ logic input.

The contents of both CODE and DAC registers are maintained during power-down states, so that when the DACs are powered on, they return to their previously stored output settings. Any CODE or LOAD commands issued during power-down states continue to update the register contents.

Once the device is powered up, each DAC channel can be independently programmed with a desired RETURN value using the RETURN command. This becomes the value the CODE and DAC registers will use in the event of any watchdog, clear or gate activity, as selected by the DEFAULT command.

Hardware $\overline{CLR}$ operations and SW_CLEAR commands return the contents of all CODE and DAC registers to their user-selected defaults. SW_RESET commands will reset CODE and DAC register contents to their M/$\overline{Z}$ selected initial codes. A SW_GATE state can be used to momentarily hold selected DAC outputs in their DEFAULT positions. The contents of CODE and DAC registers can be manipulated by watchdog timer activity, enabling a variety of safety features.

### Internal Reference

The MAX5823/MAX5824/MAX5825 include an internal precision voltage reference that is software selectable to be 2.048V, 2.500V, or 4.096V. When an internal reference is selected, that voltage is available on the REF output for other external circuitry (see the *Typical Operating Circuits*) and can drive loads down to 25kΩ.

### External Reference

The external reference input has a typical input impedance of 100kΩ and accepts an input voltage from +1.24V to $V_{DD}$. Apply an external voltage between REF and GND to use an external reference. The MAX5823/MAX5824/MAX5825 power up and reset to external reference mode. Visit **www.maximintegrated.com/products/references** for a list of available external voltage-reference devices.

### M/$\overline{Z}$ Input

The MAX5823/MAX5824/MAX5825 feature a pin selectable DAC reset state using the M/$\overline{Z}$ input. Upon a power-on reset, all CODE and DAC data registers are reset to zero scale (M/$\overline{Z}$ = GND) or midscale (M/$\overline{Z}$ = $V_{DD}$). M/$\overline{Z}$ is referenced to $V_{DD}$ (not $V_{DDIO}$). In addition, M/$\overline{Z}$ must be valid at the time the device is powered up—connect M/$\overline{Z}$ directly to $V_{DD}$ or GND.

### Load DAC ($\overline{LDAC}$) Input

The MAX5823/MAX5824/MAX5825 feature an active-low asynchronous $\overline{LDAC}$ logic input that allows DAC outputs to update simultaneously. Connect $\overline{LDAC}$ to $V_{DDIO}$ or keep $\overline{LDAC}$ high during normal operation when the device is controlled only through the serial interface. Drive $\overline{LDAC}$ low to update the DAC outputs with data from the CODE registers. Holding $\overline{LDAC}$ low causes the DAC registers to become transparent and CODE data is passed through to the DAC registers immediately updating the DAC outputs. A software CONFIG command can be used to configure the $\overline{LDAC}$ operation of each DAC independently.

### Clear ($\overline{CLR}$) Input

The MAX5823/MAX5824/MAX5825 feature an asynchronous active-low $\overline{CLR}$ logic input that simultaneously sets all selected DAC outputs to their programmable DEFAULT states. Driving $\overline{CLR}$ low clears the contents of both the CODE and DAC registers and also ignores any on-going I²C command which modifies registers associated with a DAC configured to accept clear operations. To allow a new I²C command, drive $\overline{CLR}$ high, satisfying the $t_{CLRSTA}$ timing requirement. A software CONFIG command can be used to configure the clear operation of each DAC independently.

### Watchdog Feature

The MAX5823/MAX5824/MAX5825 feature an interface watchdog timer with programmable timeout duration. This monitors the I/O interface for activity and integrity. If the watchdog is enabled, the host processor must write a valid command to the device within the timeout period to prevent a timeout. If the watchdog is allowed to timeout, selected DAC outputs are returned to the programmable DEFAULT state, protecting the system against control faults.

By default, all watchdog features are disabled; users wishing to activate any watchdog feature must configure the device accordingly. Individual DAC channels can be configured using the CONFIG command to accept the watchdog alarm and to gate, clear, or hold their outputs in response to an alarm. A watchdog refresh event and watchdog behavior upon timeout is defined by a programmable safety level using the WDOG_CONFIG command.

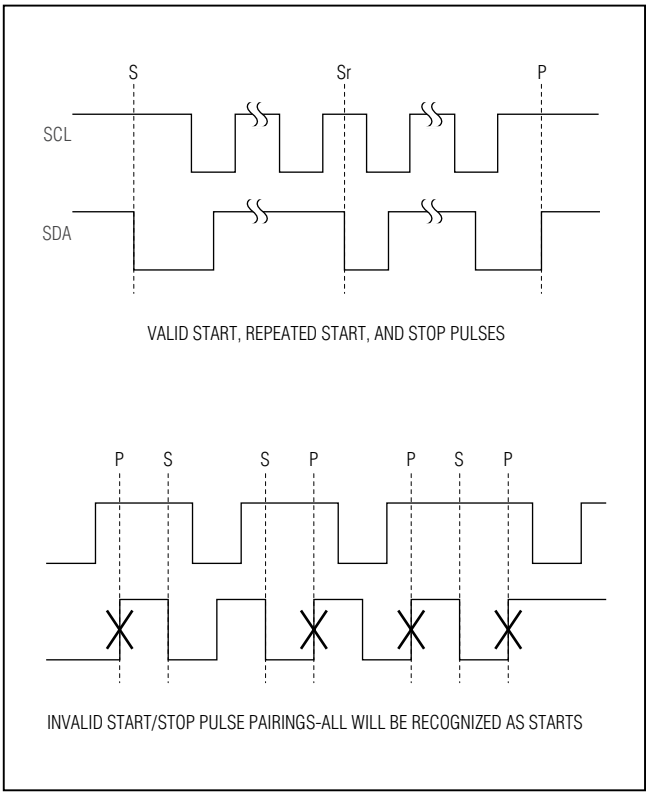



*Figure 2. I²C START, Repeated START, and STOP Conditions*

### $\overline{IRQ}$ Output

The MAX5823/MAX5824/MAX5825 feature an active-low open-drain interrupt output indicating to the host when a watchdog timeout has occurred.

### Interface Power Supply ($V_{DDIO}$)

The MAX5823/MAX5824/MAX5825 feature a separate supply input ($V_{DDIO}$) for the digital interface (1.8V to 5.5V). Connect $V_{DDIO}$ to the I/O supply of the host processor.

### I²C Serial Interface

The MAX5823/MAX5824/MAX5825 feature an I²C-/SMBus™-compatible, 2-wire serial interface consisting of a serial data line (SDA) and a serial clock line (SCL). SDA and SCL enable communication between the MAX5823/MAX5824/MAX5825 and the master at clock rates up to 400kHz. Figure 1 shows the 2-wire interface timing diagram. The master generates SCL and initiates data transfer on the bus. The master device writes data to the MAX5823/MAX5824/MAX5825 by transmitting the proper slave address followed by the command byte and then the data word. Each transmit sequence is framed by a START (S) or Repeated START (Sr) condition and a STOP (P) condition. Each word transmitted to the MAX5823/MAX5824/MAX5825 is 8 bits long and is followed by an acknowledge clock pulse. A master reading data from the MAX5823/MAX5824/MAX5825 must transmit the proper slave address followed by a series of nine SCL pulses for each byte of data requested. The MAX5823/MAX5824/MAX5825 transmit data on SDA in sync with the master-generated SCL pulses. The master acknowledges receipt of each byte of data. Each read sequence is framed by a START or Repeated START condition, a not acknowledge, and a STOP condition. SDA operates as both an input and an open-drain output. A pullup resistor, typically 4.7kΩ is required on SDA. SCL operates only as an input. A pullup resistor, typically 4.7kΩ, is required on SCL if there are multiple masters on the bus, or if the single master has an open-drain SCL output.

Series resistors in line with SDA and SCL are optional. Series resistors protect the digital inputs of the MAX5823/MAX5824/MAX5825 from high voltage spikes on the bus lines and minimize crosstalk and undershoot of the bus signals. The MAX5823/MAX5824/MAX5825 can accommodate bus voltages higher than $V_{DDIO}$ up to a limit of 5.5V; bus voltages lower than $V_{DDIO}$ are not recommended and may result in significantly increased interface currents. The MAX5823/MAX5824/MAX5825 digital inputs are double buffered. Depending on the command issued through the serial interface, the CODE register(s) can be loaded without affecting the DAC register(s) using the write command. To update the DAC registers, either drive the $\overline{LDAC}$ input low to simultaneously update all DAC outputs, or use the software LOAD command.

**Table 1. I²C Slave Address LSBs**

| ADDR1 | ADDR0 | A3 | A2 | A1 | A0 |
|---|---|---|---|---|---|
| $V_{DDIO}$ | $V_{DDIO}$ | 1 | 1 | 1 | 1 |
| $V_{DDIO}$ | N.C. | 1 | 1 | 1 | 0 |
| $V_{DDIO}$ | GND | 1 | 1 | 0 | 0 |
| N.C. | $V_{DD}$ | 1 | 0 | 1 | 1 |
| N.C. | N.C. | 1 | 0 | 1 | 0 |
| N.C. | GND | 1 | 0 | 0 | 0 |
| GND | $V_{DDIO}$ | 0 | 0 | 1 | 1 |
| GND | N.C. | 0 | 0 | 1 | 0 |
| GND | GND | 0 | 0 | 0 | 0 |

### I²C START and STOP Conditions

SDA and SCL idle high when the bus is not in use. A master initiates communication by issuing a START condition. A START condition is a high-to-low transition on SDA with SCL high. A STOP condition is a low-to-high transition on SDA while SCL is high (Figure 2). A START condition from the master signals the beginning of a transmission to the MAX5823/MAX5824/MAX5825. The master terminates transmission and frees the bus, by issuing a STOP condition. The bus remains active if a Repeated START condition is generated instead of a STOP condition.

### I²C Early STOP and Repeated START Conditions

The MAX5823/MAX5824/MAX5825 recognize a STOP condition at any point during data transmission except if the STOP condition occurs in the same high pulse as a START condition. Transmissions ending in an early STOP condition will not impact the internal device settings. If the STOP occurs during a readback byte, the transmission is terminated and a later read mode request will begin transfer of the requested register data from the beginning (this applies to combined format I²C read mode transfers only), interface verification mode transfers will be corrupted. See Figure 2.

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## I²C Slave Address

The slave address is defined as the seven most significant bits (MSBs) followed by the R/$\overline{W}$ bit. See Figure 4. The three most significant bits are 001 with the 4 LSBs determined by ADDR1 and ADDR0 as shown in Table 1. Setting the R/$\overline{W}$ bit to 1 configures the MAX5823/MAX5824/MAX5825 for read mode. Setting the R/$\overline{W}$ bit to 0 configures the MAX5823/MAX5824/MAX5825 for write mode. The slave address is the first byte of information sent to the MAX5823/MAX5824/MAX5825 after the START condition.

The MAX5823/MAX5824/MAX5825 has the ability to detect an unconnected (N.C.) state on the ADDR_ inputs for additional address flexibility; if disconnecting the ADDR_ inputs, be certain to minimize all loading on the ADDR_ inputs (i.e. provide a landing for ADDR_, but do not allow any board traces).

## I²C Broadcast Address

A broadcast address is provided for the purpose of updating or configuring all MAX5823/MAX5824/MAX5825 devices on a given I²C bus. All MAX5823/MAX5824/MAX5825 devices acknowledge and respond to the broadcast device address 00101000, regardless of the state of the address pins. The broadcast mode is intended for use in write mode only (as indicated by R/$\overline{W}$ = 0 in the address given).

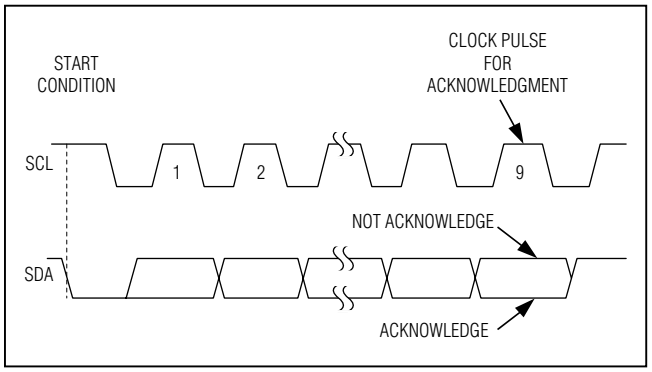



*Figure 3. I²C Acknowledge*

## I²C Acknowledge

In write mode, the acknowledge bit (ACK) is a clocked 9th bit that the MAX5823/MAX5824/MAX5825 use to handshake receipt of each byte of data as shown in Figure 3. The MAX5823/MAX5824/MAX5825 pull down SDA during the entire master-generated 9th clock pulse if the previous byte is successfully received. Monitoring ACK allows for detection of unsuccessful data transfers. An unsuccessful data transfer occurs if a receiving device is busy or if a system fault has occurred. In the event of an unsuccessful data transfer, the bus master will retry communication.

In read mode, the master pulls down SDA during the 9th clock cycle to acknowledge receipt of data from the MAX5823/MAX5824/MAX5825. An acknowledge is sent by the master after each read byte to allow data transfer to continue. A not-acknowledge is sent when the master reads the final byte of data from the MAX5823/MAX5824/MAX5825, followed by a STOP condition.

## I²C Command Byte and Data Bytes

A command byte follows the slave address. A command byte is typically followed by two data bytes unless it is the last byte in the transmission. If data bytes follow the command byte, the command byte indicates the address of the register that is to receive the following two data bytes. The data bytes are stored in a temporary register and then transferred to the appropriate register during the ACK periods between bytes. This avoids any glitching or digital feedthrough to the DACs while the interface is active.

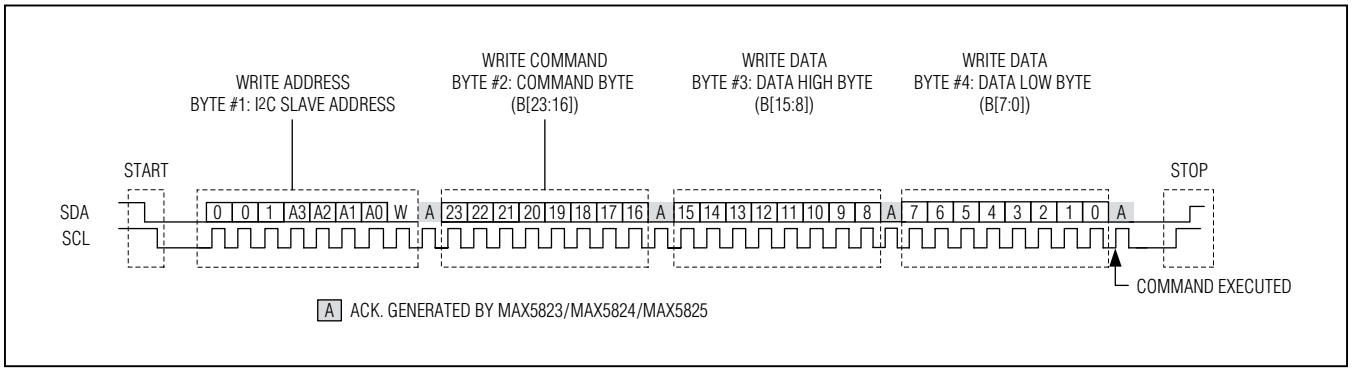



*Figure 4. I²C Single Register Write Sequence*

## I²C Write Operations

A master device communicates with the MAX5823/MAX5824/MAX5825 by transmitting the proper slave address followed by command and data words. Each transmit sequence is framed by a START or Repeated START condition and a STOP condition as described above. Each word is 8 bits long and is always followed by an acknowledge clock (ACK) pulse as shown in the Figure 4 and Figure 5. The first byte contains the address of the MAX5823/MAX5824/MAX5825 with R/$\overline{W}$ = 0 to indicate a write. The second byte contains the register (or command) to be written and the third and fourth bytes contain the data to be written. By repeating the register address plus data pairs (Byte #2 through Byte #4 in Figure 4 and Figure 5), the user can perform multiple register writes using a single I²C command sequence. There is no limit as to how many registers the user can write with a single command. The MAX5823/MAX5824/MAX5825 support this capability for all user-accessible write mode commands.

## Combined Format I²C Readback Operations

Each readback sequence is framed by a START or Repeated START condition and a STOP condition. Each word is 8 bits long and is followed by an acknowledge clock pulse as shown in Figure 6. The first byte contains the address of the MAX5823/MAX5824/MAX5825 with R/$\overline{W}$ = 0 to indicate a write. The second byte contains the register that is to be read back. There is a Repeated START condition, followed by the device address with R/$\overline{W}$ = 1 to indicate a read and an acknowledge clock. The master has control of the SCL line but the MAX5823/MAX5824/MAX5825 take over the SDA line. The final two bytes in the frame contain the register data readback followed by a STOP condition. If additional bytes beyond those required to readback the requested data are provided, the MAX5823/MAX5824/MAX5825 will continue to readback ones.

Readback of the WDOG command (B[23:20] = 0001) is directly supported, confirming the current watchdog timeout selection, mask status, and safety level.

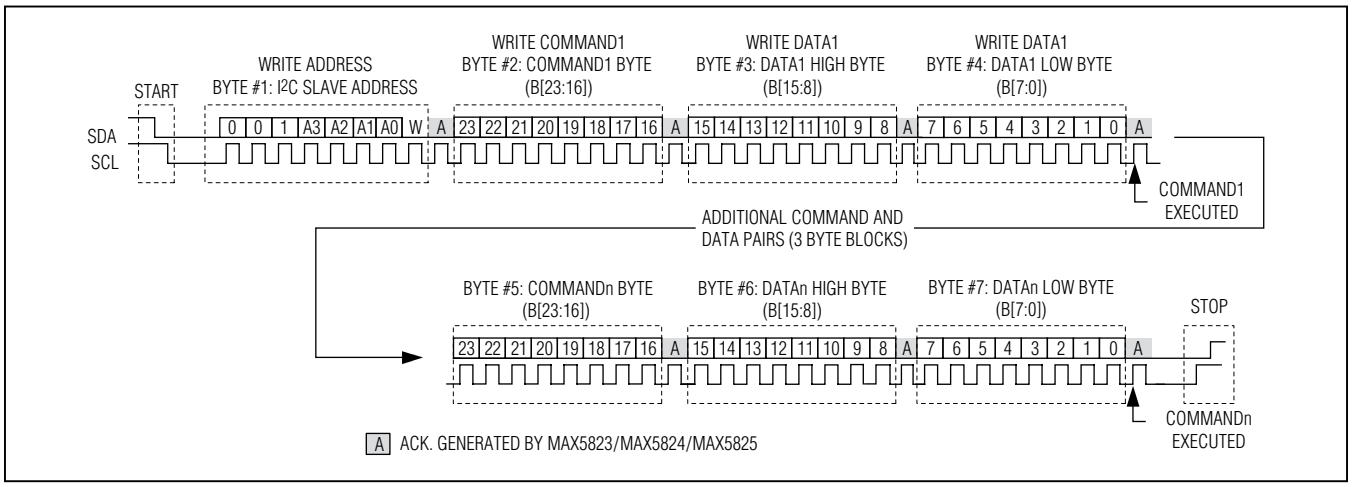



*Figure 5. Multiple Register Write Sequence (Standard I²C Protocol)*

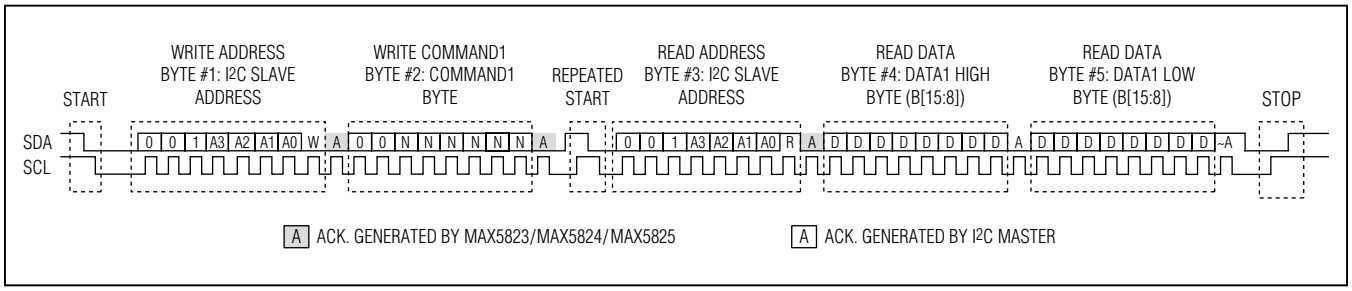



*Figure 6. Standard I²C Register Read Sequence*

Readback of individual RETURN registers is supported for RETURN commands (B[23:20] = 0111). For this command, which supports a DAC address, the requested channel RETURN register content will be returned, along with the selected DAC address. If all DACs are selected, readback will begin with RETURN0 content and will progress through the remaining DAC channels. The RETURN_ALL (B[23:16] = 11000011) command behaves identically to the RETURN command with all DACs selected.

Readback of individual CODE registers is supported for the CODE commands (B[23:20] = 1000). For this command, which supports a DAC address, the requested channel CODE register content will be returned, along with the selected DAC address. If all DACs are selected, readback will begin with CODE0 content and will progress through the remaining DAC channels. The CODE_ALL (B[23:16] = 11000000) command behaves identically to the CODE command with all DACs selected.

Readback of individual DAC registers is supported for all LOAD commands (B[23:20] = 1001, 1010, 1011). For these commands, which support a DAC address, the requested DAC register content will be returned, along with the selected DAC address. If all DACs are selected, readback will begin with DAC0 content and will progress through the remaining DAC channels. The LOAD_ALL and CODE_ALL_LOAD_ALL commands (B[23:16] = 11000001 and 11000010, respectively) behave identically to the LOAD command with all DACs selected.

Modified readback of the POWER register is supported for the POWER command (B[23:20] = 0100). The power status of each DAC is reported in locations B[7:0], with a 1 indicating the DAC is powered down and a zero indicating the DAC is operational (see Table 2).

Readback of all other registers is not directly supported. All requests to read unsupported registers reads back the device's current watchdog timer status (WD:0 = normal, 1 = timed out), reference setting (REF[2:0]), and $\overline{CLR}$ condition, along with the device revision (B[10:8] = 001) and part ID (B[7:0]) in the format as shown in Table 2.

### Interface Verification I²C Readback Operations

While the MAX5823/MAX5824/MAX5825 support standard I²C readback of selected registers, it is also capable of functioning in an interface verification mode. This mode is accessed any time a readback operation follows an executed write mode command. In this mode, the last executed three-byte command is read back in its entirety. This behavior allows verification of the interface.

Sample command sequences are shown in Figure 7. The first command transfer is given in write mode with R/$\overline{W}$ = 0 and must be run to completion to qualify for interface verification readback. There is now a STOP/

## Table 2. Standard I²C User Readback Data

| COMMAND BYTE (REQUEST) | | | | | | | | READBACK DATA HIGH BYTE | | | | | | | | READBACK DATA LOW BYTE | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
| 0 | 0 | 0 | 1 | X | X | X | X | WDOG Timeout Selection[11:4] | | | | | | | | Timeout Selection[3:0] | | | | WDM | WL[1:0] | | 0 |
| 0 | 1 | 0 | 0 | X | X | X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | PW7 | PW6 | PW5 | PW4 | PW3 | PW2 | PW1 | PW0 |
| 0 | 1 | 1 | 1 | DAC SELECTION | | | | RETURNn[11:4] | | | | | | | | RETURNn[3:0] | | | | ADDRESSn[3:0] | | | |
| 1 | 0 | 0 | 0 | DAC SELECTION | | | | CODEn[11:4] | | | | | | | | CODEn[3:0] | | | | ADDRESSn[3:0] | | | |
| 1 | 0 | 0 | 1 | DAC SELECTION | | | | DACn[11:4] | | | | | | | | DACn[3:0] | | | | ADDRESSn[3:0] | | | |
| 1 | 0 | 1 | 0 | DAC SELECTION | | | | DACn[11:4] | | | | | | | | DACn[3:0] | | | | ADDRESSn[3:0] | | | |
| 1 | 0 | 1 | 1 | DAC SELECTION | | | | DACn[11:4] | | | | | | | | DACn[3:0] | | | | ADDRESSn[3:0] | | | |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | CODE0[11:4] | | | | | | | | CODE0[3:0] | | | | ADDRESS0[3:0] | | | |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | DAC0[11:4] | | | | | | | | DAC0[3:0] | | | | ADDRESS0[3:0] | | | |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | DAC0[11:4] | | | | | | | | DAC0[3:0] | | | | ADDRESS0[3:0] | | | |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | RETURN0[11:4] | | | | | | | | RETURN0[03:0] | | | | ADDRESS0[3:0] | | | |
| All Other Commands (MAX5825) | | | | | | | | WD | REF[2:0] | | | $\overline{CLR}$ | REV_ID [2:0] (001) | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| All Other Commands (MAX5824) | | | | | | | | | | | | | | | | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| All Other Commands (MAX5823) | | | | | | | | | | | | | | | | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

## Table 3. Format DAC Data Bit Positions

| PART | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAX5823 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | X | X | X | X | X | X | X | X |
| MAX5824 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | X | X | X | X | X | X |
| MAX5825 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | X | X | X | X |

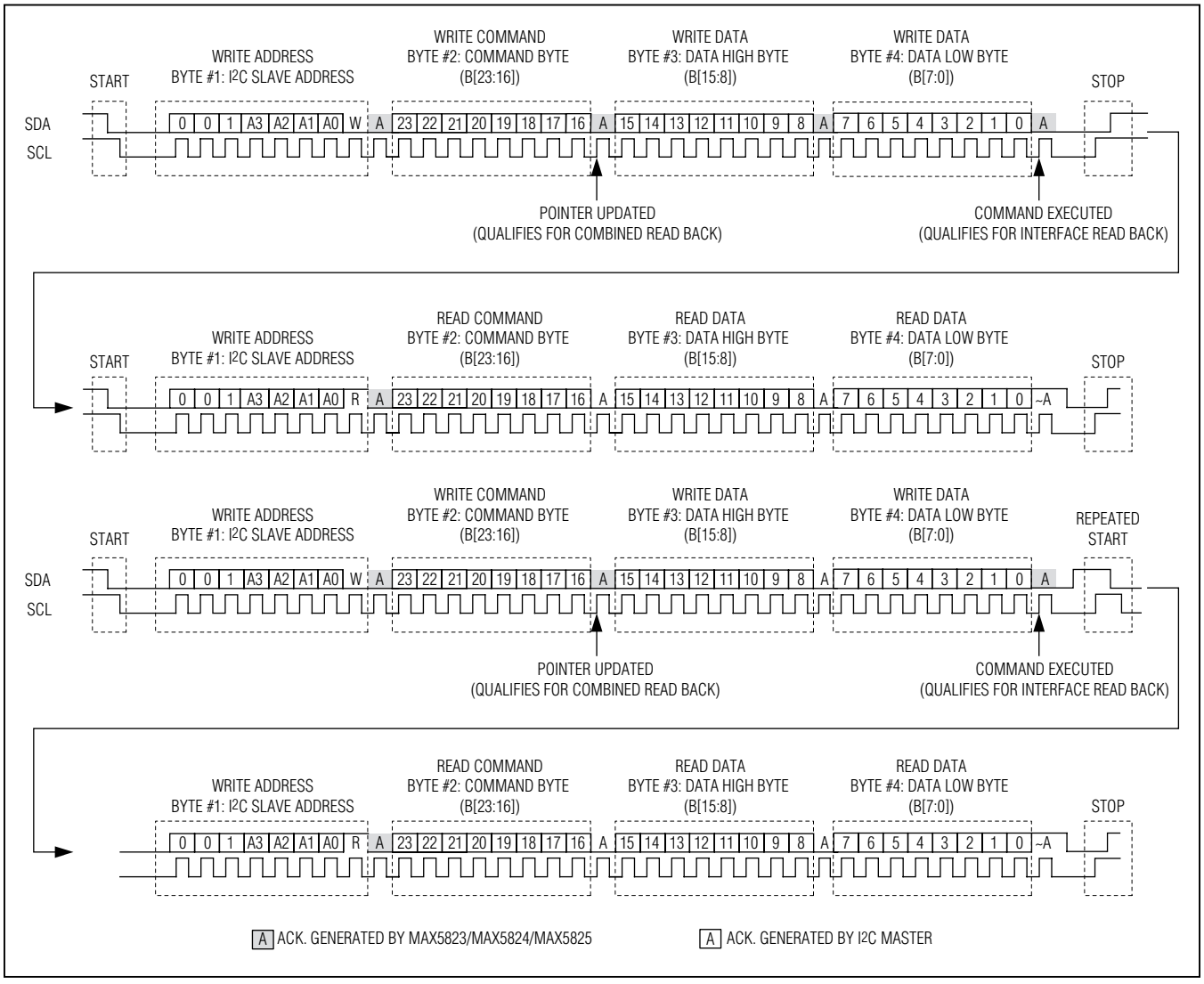



*Figure 7. Interface Verification I²C Register Read Sequences*

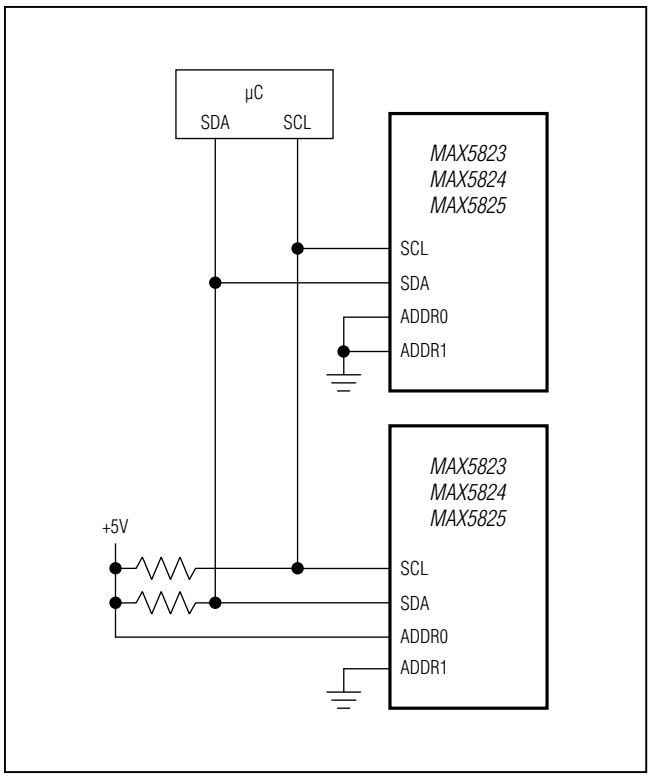



*Figure 8. Typical I²C Application Circuit*

START pair or Repeated START condition required, followed by the readback transfer with R/$\overline{W}$ = 1 to indicate a read and an acknowledge clock from the MAX5823/MAX5824/MAX5825. The master still has control of the SCL line but the MAX5823/MAX5824/MAX5825 take over the SDA line. The final three bytes in the frame contain the command and register data written in the first transfer presented for readback, followed by a STOP condition. If additional bytes beyond those required to readback the requested data are provided, the MAX5823/MAX5824/MAX5825 will continue to readback ones.

It is not necessary for the write and read mode transfers to occur immediately in sequence. I²C transfers involving other devices do not impact the MAX5823/MAX5824/MAX5825 readback mode. Toggling between readback modes is based on the length of the preceding write mode transfer. Combined format I²C readback operation is resumed if a write command greater than two bytes but less than four bytes is supplied. For commands written using multiple register write sequences, only the last command executed is read back. For each command written, the readback sequence can only be completed one time; partial and/or multiple attempts to readback executed in succession will not yield usable data.

## I²C Compatibility

The MAX5823/MAX5824/MAX5825 are fully compatible with existing I²C systems. SCL and SDA are high-impedance inputs; SDA has an open drain which pulls the data line low to transmit data or ACK pulses. Figure 8 shows a typical I²C application.

## I²C User-Command Register Map

This section lists the user-accessible commands and registers for the MAX5823/MAX5824/MAX5825.

Table 4 provides detailed information about the Command Registers.

## Table 4. I2C Commands Summary

| COMMAND | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CONFIGURATION AND SOFTWARE COMMANDS** | | | | | | | | | | | | | | | | | | | | | | | | | |
| WDOG | 0 | 0 | 0 | 1 | X | X | X` | X | TIMEOUT SELECTION[11:4] | | | | | | | | TIMEOUT SELECTION[3:0] | | | | WD_MASK | Safety Level 00: Low 01: Med 10: High 11: Max | | X | Updates watchdog settings and safety levels |
| REF | 0 | 0 | 1 | 0 | 0 | REF Power 0 = DAC 1 = ON | REF Mode 00 = EXT 01 = 2.5V 10 = 2.0V 11 = 4.1V | | X | X | X | | X | X | X | X | X | X | X | X | X | X | X | X | Sets the reference operating mode. REF Power (B18): 0 = Internal reference is only powered if at least one DAC is powered. 1 = Internal reference is always powered. |
| SW_GATE_CLR | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | Removes any existing GATE condition |
| SW_GATE_SET | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | Initiates a GATE condition |
| WD_REFRESH | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | Refreshes the watchdog timer |
| WD_RESET | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | Resets the watchdog timeout alarm status and refreshes the watchdog timer |
| SW_CLEAR | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | Executes a software clear (all CODE and DAC registers cleared to their default values) |
| SW_RESET | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | Executes a software reset (all CODE, DAC, and Control registers returned to their power-on reset values) |
| POWER | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | DAC 7 | DAC 6 | DAC 5 | DAC 4 | DAC 3 | DAC 2 | DAC 1 | DAC 0 | Power Mode 00 = Normal 01 = PD 1kΩ 10 = PD 100kΩ 11 = PD Hi-Z | | X | X | X | X | X | X | Sets the Power mode of the selected DACs (DACs selected with a 1 in the corresponding DACn bit are updated, DACs with a 0 in the corresponding DACn bit are not impacted) |
| CONFIG | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | DAC 7 | DAC 6 | DAC 5 | DAC 4 | DAC 3 | DAC 2 | DAC 1 | DAC 0 | WDOG Configuration 00: DIS 01: GATE 10: CLR 11: HOLD | | GATE_ENB | LDAC_ENB | CLEAR_ENB | X | X | X | Configures selected DAC watchdog, GATE, LOAD, and CLEAR operations. DACs selected with a 1 in the corresponding DACn bit are updated, DACs with a 0 in the corresponding DACn bit are not impacted) |

## Table 4. I²C Commands Summary (continued)

| COMMAND | B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEFAULT | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | DAC 7 | DAC 6 | DAC 5 | DAC 4 | DAC 3 | DAC 2 | DAC 1 | DAC 0 | Default Values: 000: M/$\overline{Z}$ 001: ZERO 010: MID 011: FULL 100: RETURN 101+: No Effect | | | | | | | | Sets the default code settings for selected DACs. Note: DACs in RETURN mode programmable RETURN codes. (DACs selected with a 1 in the corresponding DACn bit are updated, DACs with a 0 in the corresponding DACn bit are not impacted) |
| **DAC COMMANDS** | | | | | | | | | | | | | | | | | | | | | | | | | |
| RETURNn | 0 | 1 | 1 | 1 | DAC SELECTION | | | | RETURN REGISTER DATA[11:4] | | | | | | | | RETURN REGISTER DATA[3:0] | | | | X | X | X | X | Writes data to the selected RETURN register(s) |
| CODEn | 1 | 0 | 0 | 0 | DAC SELECTION | | | | CODE REGISTER DATA[11:4] | | | | | | | | CODE REGISTER DATA[3:0] | | | | X | X | X | X | Writes data to the selected CODE register(s) |
| LOADn | 1 | 0 | 0 | 1 | DAC SELECTION | | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | Transfers data from the selected CODE registers to the selected DAC register(s) |
| CODEn_ LOAD_ALL | 1 | 0 | 1 | 0 | DAC SELECTION | | | | CODE REGISTER DATA[11:4] | | | | | | | | CODE REGISTER DATA[3:0] | | | | X | X | X | X | Simultaneously writes data to the selected CODE register(s) while updating all DAC registers |
| CODEn_LOADn | 1 | 0 | 1 | 1 | DAC SELECTION | | | | CODE REGISTER DATA[11:4] | | | | | | | | CODE REGISTER DATA[3:0] | | | | X | X | X | X | Simultaneously writes data to the selected CODE register(s) while updating selected DAC register(s) |
| CODE_ALL | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | CODE REGISTER DATA[11:4] | | | | | | | | CODE REGISTER DATA[3:0] | | | | X | X | X | X | Writes data to all CODE registers |
| LOAD_ALL | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | Updates all DAC latches with current CODE register data |
| CODE_ALL LOAD_ALL | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | CODE REGISTER DATA[11:4] | | | | | | | | CODE REGISTER DATA[3:0] | | | | X | X | X | X | Simultaneously writes data to the all CODE registers while updating all DAC registers |
| RETURN_ALL | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | RETURN REGISTER DATA[11:4] | | | | | | | | RETURNREGISTER DATA[3:0] | | | | X | X | X | X | Writes data to all RETURN registers |
| **NO OPERATION COMMANDS** | | | | | | | | | | | | | | | | | | | | | | | | | |
| No Operation | 1 | 1 | 0 | 0 | 0 | 1 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | These commands will have no effect on the device, but will refresh the watchdog timer if safety level is set to Low |
| | 1 | 1 | 0 | 0 | 1 | 0 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| | 1 | 1 | 0 | 0 | 1 | 1 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| **Reserved Commands:** Any commands not specifically listed above are reserved for Maxim internal use only. | | | | | | | | | | | | | | | | | | | | | | | | | |

### RETURNn Command

The RETURNn command (B[23:20] = 0111) sets the programmable default RETURN value. This value is used for all future watchdog, clear, and gate operations when RET is selected for the DAC using the DEFAULT command. Issuing this command with DAC_ADDRESS set to all DACs will program the value for all RETURN registers and is equivalent to RETURN_ALL. **Note:** This command is inaccessible when a watchdog timeout has occurred if the watchdog timer is configured for safety level = high or max.

### CODEn Command

The CODEn command (B[23:20] = 1000) updates the CODE register contents for the selected DAC(s). Changes to the CODE register content based on this command will not affect DAC outputs directly unless the $\overline{LDAC}$ input is in a low state or the DAC latch has been configured as transparent using the CONFIG command. Issuing this command with DAC_ADDRESS set to all DACs will program the value for all CODE registers and is equivalent to CODE_ALL.

### LOADn Command

The LOADn command (B[23:20] = 1001) updates the DAC register content for the selected DAC(s) by uploading the current contents of the selected CODE register(s) into the selected DAC register(s). Channels for which CODE content has not been modified since the last LOAD or $\overline{LDAC}$ operation will not be updated to reduce digital crosstalk. Issuing this command with DAC_ADDRESS set to all DACs will update the contents of all DAC registers and is equivalent to LOAD_ALL.

### CODEn_LOADn Command

The CODEn_LOADn command (B[23:20] = 1011) updates the CODE register contents for the selected DAC(s) as well as the DAC register content of the selected DAC(s). Channels for which CODE content has not been modified since the last LOAD or $\overline{LDAC}$ operation will not be updated to reduce digital crosstalk. Issuing this command with DAC_ADDRESS set to all DACs is equivalent to the CODE_ALL_LOAD_ALL (B[23:16] = 1100_0010) command.

### CODEn_LOAD_ALL Command

The CODEn_LOAD_ALL command (B[23:20] = 1010) updates the CODE register contents for the selected DAC(s) as well as the DAC register content of all DACs. Channels for which CODE content has not been modified since the last LOAD or $\overline{LDAC}$ operation will not be updated to reduce digital crosstalk. Issuing this command with DAC_ADDRESS set to all DACs will update the CODE and DAC register contents of all DACs and is equivalent to CODE_ALL_LOAD_ALL. Note this command by definition will modify at least one CODE register; to avoid this use the LOAD command with DAC_ADDRESS set to all DACs or the LOAD_ALL command.

## Table 5. DAC Selection

| B19 | B18 | B17 | B16 | DAC SELECTED |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | DAC0 |
| 0 | 0 | 0 | 1 | DAC1 |
| 0 | 0 | 1 | 0 | DAC2 |
| 0 | 0 | 1 | 1 | DAC3 |
| 0 | 1 | 0 | 0 | DAC4 |
| 0 | 1 | 0 | 1 | DAC5 |
| 0 | 1 | 1 | 0 | DAC6 |
| 0 | 1 | 1 | 1 | DAC7 |
| 1 | X | X | X | ALL DACs |

### CODE_ALL Command

The CODE_ALL command (B[23:16] = 1100_0000) updates the CODE register contents for all DACs.

### LOAD_ALL Command

The LOAD_ALL command (B[23:16] = 1100_0001) updates the DAC register content for all DACs by uploading the current contents of the CODE registers to the DAC registers.

### CODE_ALL_LOAD_ALL Command

The CODE_ALL_LOAD_ALL command (B[23:16] = 1100_0010) updates the CODE register contents for all DACs as well as the DAC register content of all DACs.

### RETURN_ALL Command

The RETURN_ALL command (B[23:16] = 1100_0011) updates the RETURN register contents for all DACs.

### NO_OP Commands Command

All unused commands in the space (B[23:16] = 1100_X1XX or 1100_1XXX) have no effect on the device, but will refresh the watchdog timer (if active) with the safety level set to low.

### WDOG Command

The WDOG command (B[23:20] = 0001) updates the watchdog timeout settings and safety levels for the device. Timeout thresholds are selected in 1ms increments (1ms to 4095ms are available). The WD_MASK bit can be used to mask the $\overline{IRQ}$ operation in response to the watchdog status, if WD_MASK = 1, watchdog alarms will not assert $\overline{IRQ}$. The watchdog alarm status (WD bit) can be polled using the available I²C status readback commands regardless of WD_MASK settings. A write to this register will not reset a previously triggered watchdog alarm (use the WD_RESET command for this purpose). The watchdog timer refresh and timeout behavior is defined by the programmable safety level below.

Available safety levels (WL[1:0]):

**Low (00):** Watchdog timer will refresh with the execution of any valid user mode command or no-op. Any successful slave address acknowledge qualifies to restart the watchdog timer (run to the ninth SCL edge), regardless of the command which follows. Issuing hardware $\overline{CLR}$ or $\overline{LDAC}$ falling edge will also refresh the watchdog timer. A triggered watchdog alarm does not prevent writes to any register. $\overline{LDAC}$ and $\overline{CLR}$ inputs still function after a watchdog timeout event.

**Medium (01):** A WD_REFRESH command must be executed in order to refresh the watchdog timer. Other commands as well as $\overline{LDAC}$ or $\overline{CLR}$ activity do not refresh the watchdog timer. A triggered watchdog alarm does not prevent writes to any register. $\overline{LDAC}$ and $\overline{CLR}$ inputs still function after a watchdog timeout event.

**High (10):** A WD_REFRESH command must be executed to refresh the watchdog timer. Other commands as well as $\overline{LDAC}$ or $\overline{CLR}$ activity do not refresh the watchdog timer. A triggered watchdog alarm prevents execution of all POWER, REF, CONFIG, DEFAULT, and RETURN commands. $\overline{LDAC}$ and $\overline{CLR}$ inputs still function after a watchdog timeout event.

**Max (11):** A WD_REFRESH command must be executed to refresh the watchdog timer. Other commands, as well as $\overline{LDAC}$ or $\overline{CLR}$ activity, do not refresh the watchdog timer. A triggered watchdog alarm prevents execution of all POWER, REF, CONFIG, DEFAULT, and RETURN commands. $\overline{LDAC}$ and $\overline{CLR}$ are gated and do not function after a watchdog timeout event.

## Table 6. WDOG Command Format

| B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 1 | X | X | X | X | C11 | C10 | C9 | C8 | C7 | C6 | C5 | C4 | C3 | C2 | C1 | C0 | WDM | WL1 | WL0 | X |
| WDOG Command | | | | Don't Care | | | | TIMEOUT SELECTION[11:4] | | | | | | | | TIMEOUT SELECTION[3:0] | | | | WD_MASK | WDOG Safety Level: 00: Low 01: Med 10: High 11: Max | | Don't Care |
| Default Value → | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X |
| Command Byte | | | | | | | | Data High Byte | | | | | | | | Data Low Byte | | | | | | | |

## Table 7. Watchdog Safety Level Protection

| WATCHDOG SAFETY LEVEL | ANY COMMAND REFRESHES WDT | $\overline{CLR}$/$\overline{LDAC}$ REFRESHES WDT | SW_RESET PLUS WD_RFRS REFRESHES WDT | ALL REGISTERS ACCESSIBLE AFTER WDT TIMEOUT* | $\overline{CLR}$/$\overline{LDAC}$ AFFECT DAC REGISTERS AFTER WDT TIMEOUT* |
|---|---|---|---|---|---|
| 00 (Low) | X | X | X | X | X |
| 01 (Med) | — | — | X | X | X |
| 10 (High) | — | — | X | — | X |
| 11 (Max) | — | — | X | — | — |

**Unless otherwise affected by Watchdog HOLD or $\overline{CLR}$ configurations as set by the CONFIG command. See the CONFIG register definition for details.*

### REF Command

The REF command (B[23:20] = 0010) updates the global reference setting used for all DAC channels. If an internal reference mode is selected, bit RF2 (B18) defines the reference power mode. If RF2 is set to zero (default), the reference will be powered down any time all DAC channels are powered down (i.e. the device is in STANDBY mode). If RF2 is set to one, the reference will remain powered even if all DAC channels are powered down, allowing continued operation of external circuitry (note in this mode the low current shutdown state is not available). This command is inaccessible when a watchdog timeout has occurred and the watchdog timer is configured with a safety level of high or max.

### SW_GATE_CLR Command

The SW_GATE_CLR command (B[23:0] = 0011_0000_1001_0110_0011_0000) will remove any existing GATE condition initiated by a previous SW_GATE_SET comand.

### SW_GATE_SET Command

The SW_GATE_SET command (B[23:0] = 0011_0001_1001_0110_0011_0000) will initiate a GATE condition. Any DACs configured with GTB = 0 (see the *CONFIG Command* section) will have their outputs held at the selected DEFAULT value until the GATE condition is later removed by a subsequent SW_GATE_CLR command. While in gate mode, the CODE and DAC registers continue to function normally and are not reset (unless reset by a watchdog timeout).

### WD_REFRESH Command

The WD_REFRESH command (B[23:0] = 0011_0010_1001_0110_0011_0000) will refresh the watchdog timer. This is the only command which will refresh the watchdog timer if the device is configured with a safety level of medium, high, or max. Use this command to prevent the watchdog timer from timing out.

### WD_RESET Command

A WD_RESET command (B[23:0] = 0011_0011_1001_0110_0011_0000) will reset the watchdog interrupt (timeout) status and refresh the watchdog timer. Use this command to reset the $\overline{IRQ}$ timeout condition after the watchdog timer has timed out. Any DACs impacted by an existing timeout condition will return to normal operation.

### SW_CLEAR Command

A software clear command (B[23:0] = 0011_0100_001_0110_0011_0000) will clear the contents of the CODE and DAC registers to the DEFAULT state for all channels configured with CLB = 0 (see CONFIG command).

### SW_RESET Command

A software reset command (B[23:0] = 0011_0101_1001_0110_0011_0000) will reset all CODE, DAC, and configuration registers to their defaults (including POWER, DEFAULT, CONFIG, WDOG, and REF registers), simulating a power-on reset.

## Table 8. REF Command Format

| B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 0 | 0 | RF2 | RF1 | RF0 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| REF Command | | | | Reserved | 0 = DAC Controlled<br>1 = Always ON | REF Mode:<br>00: EXT<br>01: 2.5V<br>10: 2.0V<br>11: 4.0V | | Don't Care | | | | | | | | Don't Care | | | | | | | |
| Default Value → | | | | | 0 | 0 | 0 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Command Byte | | | | | | | | Data High Byte | | | | | | | | Data Low Byte | | | | | | | |

### POWER Command

The POWER command (B[23:20] = 0100) updates the power mode settings of the selected DACs. DACs that are not selected do not update their power settings in response to the command. The new power setting is determined by bits PD[1:0] (B[7:6]) while the affected DAC(s) are selected using B[15:8]). If all DACs are powered down and the RF2 bit is not set, the device enters a STANDBY mode (all analog circuitry is disabled). This command is inaccessible when a watchdog timeout has occurred and the watchdog timer is configured with a safety level of high or max.

Available power modes (PD[1:0]):

Normal (00): DAC channel is active (default),

PD 1kΩ (01): Power down with 1kΩ termination to GND,

PD 100kΩ (10): Power down with 100kΩ termination to GND,

PD Hi-Z (11): Power down with high-impedance output.

## Table 9. POWER Command Format

| B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | PD1 | PD0 | X | X | X | X | X | X |
| POWER Command | | | | Reserved | | | | Multiple DAC Selection | | | | | | | | Power Mode: 00 = Normal 01 = 1kΩ 10 = 100kΩ 11 = Hi-Z | | Don't Care | | | | | |
| Default Value → | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | X | X | X | X | X | X |
| Command Byte | | | | | | | | Data High Byte | | | | | | | | Data Low Byte | | | | | | | |

### CONFIG Command

The CONFIG command (B[23:16] = 0101) updates the watchdog, gate, load, and clear mode settings of the selected DACs. DACs which are not selected do not update their settings in response to the command. The new mode settings to be written are determined by bits B[7:3] while the affected DAC(s) are selected by B[15:8]. This command is inaccessible when a watchdog timeout has occurred and the watchdog timer is configured with a safety level of high or max.

**Watchdog Configuration:**

WDOG Config settings are written by WC[1:0] (B[7:6]):

DISABLE (WC = 00): Watchdog timeout does not affect the operation of the selected DAC.

GATE (WC = 01): DAC code is gated to DEFAULT value in response to watchdog timeouts. Unless otherwise prohibited by the watchdog safety level, $\overline{LDAC}$, $\overline{CLR}$, and write operations to the CODE and DAC registers are accepted but will not be reflected on the DAC output until the watchdog timeout status is reset.

$\overline{CLR}$ (WC = 10): CODE and DAC register contents are cleared to DEFAULT value in response to watchdog time-outs. All writes to CODE and DAC registers are ignored and $\overline{LDAC}$ or $\overline{CLR}$ input activity has no effect until the watchdog timeout status is reset, regardless of watchdog safety level.

HOLD (WC = 11): DAC code is held at its previously programmed value in response to watchdog time-out. All writes to DAC and CODE registers are ignored and $\overline{LDAC}$ or $\overline{CLR}$ input activity has no effect until the watchdog timeout status is reset, regardless of watchdog safety level.

**Note:** For the watchdog to timeout and have an impact, the function must first be enabled and configured using the WDOG command.

**Gate Configuration:**

The DAC GATE setting is written by GTB (B5); GATE operation is as follows:

GTB = 0: Enables software gating function (default), DAC outputs are gated to their DEFAULT settings as long as the device remains in GATE mode (set by SW_GATE_SET and removed by SW_GATE_CLR).

GTB = 1: Disable software gating function, DAC outputs are not impacted by GATE mode.

**Load Configuration:**

The LDAC_ENB setting is written by LDB (B4); LDAC_ENB operation is as follows:

LDB = 0: DAC latch is operational, enabling $\overline{LDAC}$ and LOAD functions (default).

LDB = 1: DAC latch is transparent, the CODE register content controls the DAC output directly.

**Clear Configuration:**

CLEAR_ENB setting is written by CLB (B3); CLEAR_ENB operation is as follows:

CLB = 0: Clear input and command functions impact the DAC (default), clearing CODE and DAC registers to their DEFAULT value.

CLB = 1: Clear input and command functions have no effect on the DAC.

## Table 10. CONFIG Command Format

| B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | WC1 | WC0 | GTB | LDB | CLB | X | X | X |
| CONFIG Command | | | | Reserved | | | | Multiple DAC Selection | | | | | | | | WDOG Config: 00: DISABLE 01: GATE 10: $\overline{CLR}$ 11: HOLD | | GATE_ENB | LDAC_ENB | CLEAR_ENB | Don't Care | | |
| Default Value → | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | X | X | X |
| Command Byte | | | | | | | | Data High Byte | | | | | | | | Data Low Byte | | | | | | | |

### DEFAULT Command

The DEFAULT command (B[23:20] = 0110) selects the default value for selected DACs. DACs which are not selected do not update their default settings in response to the command. These default values are used for all future watchdog, clear, and gate operations. The new default setting is determined by bits DF[2:0] (B[7:5]) while the affected DAC(s) are selected using B[15:8]. This command is inaccessible when a watchdog timeout has occurred and the watchdog timer is configured with a safety level of high or max. Note the selected default values do not apply to resets initiated by SW_RESET commands or supply cycling, both of which return all DACs to the values determined by the M/$\overline{Z}$ input and reset this register to M/$\overline{Z}$ mode.

Available default values (DF[2:0]):

M/$\overline{Z}$ (000): DAC channel defaults to value as selected by the M/$\overline{Z}$ input (default).

ZERO (001): DAC channel defaults to zero scale.

MID (010): DAC channel defaults to midscale.

FULL (011): DAC channel defaults to full scale.

RETURN (100): DAC channel defaults to the value programmed by the RETURN command.

No Effect (101, 110, 111): DAC channel default behavior is unchanged.

## Table 11. DEFAULT Command Format

| B23 | B22 | B21 | B20 | B19 | B18 | B17 | B16 | B15 | B14 | B13 | B12 | B11 | B10 | B9 | B8 | B7 | B6 | B5 | B4 | B3 | B2 | B1 | B0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | DF2 | DF1 | DF0 | X | X | X | X | X |
| DEFAULT Command | | | | Reserved | | | | Multiple DAC Selection | | | | | | | | Default Values:<br>000: M/$\overline{Z}$<br>001: ZERO<br>010: MID<br>011: FULL<br>100: RETURN<br>101+: No Effect | | | Don't Care | | | | |
| Default Value → | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | X | X | X | X | X |
| Command Byte | | | | | | | | Data High Byte | | | | | | | | Data Low Byte | | | | | | | |

## Applications Information

### Power-On Reset (POR)

When power is applied to $V_{DD}$ and $V_{DDIO}$, the DAC output is set to zero scale. To optimize DAC linearity, wait until the supplies have settled and the internal setup and calibration sequence completes (200µs, typ).

### Power Supplies and Bypassing Considerations

Bypass $V_{DD}$ and $V_{DDIO}$ with high-quality ceramic capacitors to a low-impedance ground as close as possible to the device. Minimize lead lengths to reduce lead inductance. Connect the GND to the analog ground plane.

### Layout Considerations

Digital and AC transient signals on GND can create noise at the output. Connect GND to form the star ground for the DAC system. Refer remote DAC loads to this system ground for the best possible performance. Use proper grounding techniques, such as a multilayer board with a low-inductance ground plane, or star connect all ground return paths back to the MAX5823/MAX5824/MAX5825 GND. Carefully layout the traces between channels to reduce AC cross-coupling. Do not use wire-wrapped boards and sockets. Use shielding to maximize noise immunity. Do not run analog and digital signals parallel to one another, especially clock signals. Avoid routing digital lines underneath the MAX5823/MAX5824/MAX5825 package.

## Definitions

### Integral Nonlinearity (INL)

INL is the deviation of the measured transfer function from a straight line drawn between two codes once offset and gain errors have been nullified.

### Differential Nonlinearity (DNL)

DNL is the difference between an actual step height and the ideal value of 1 LSB. If the magnitude of the DNL ≤ 1 LSB, the DAC guarantees no missing codes and is monotonic. If the magnitude of the DNL ≥ 1 LSB, the DAC output may still be monotonic.

### Offset Error

Offset error indicates how well the actual transfer function matches the ideal transfer function. The offset error is calculated from two measurements near zero code and near maximum code.

### Gain Error

Gain error is the difference between the ideal and the actual full-scale output voltage on the transfer curve, after nullifying the offset error. This error alters the slope of the transfer function and corresponds to the same percentage error in each step.

### Zero-Scale Error

Zero-scale error is the difference between the DAC output voltage when set to code zero and ground. This includes offset and other die level nonidealities.

### Full-Scale Error

Full-scale error is the difference between the DAC output voltage when set to full scale and the reference voltage. This includes offset, gain error, and other die level nonidealities.

### Settling Time

The settling time is the amount of time required from the start of a transition, until the DAC output settles to the new output value within the converter's specified accuracy.

### Digital Feedthrough

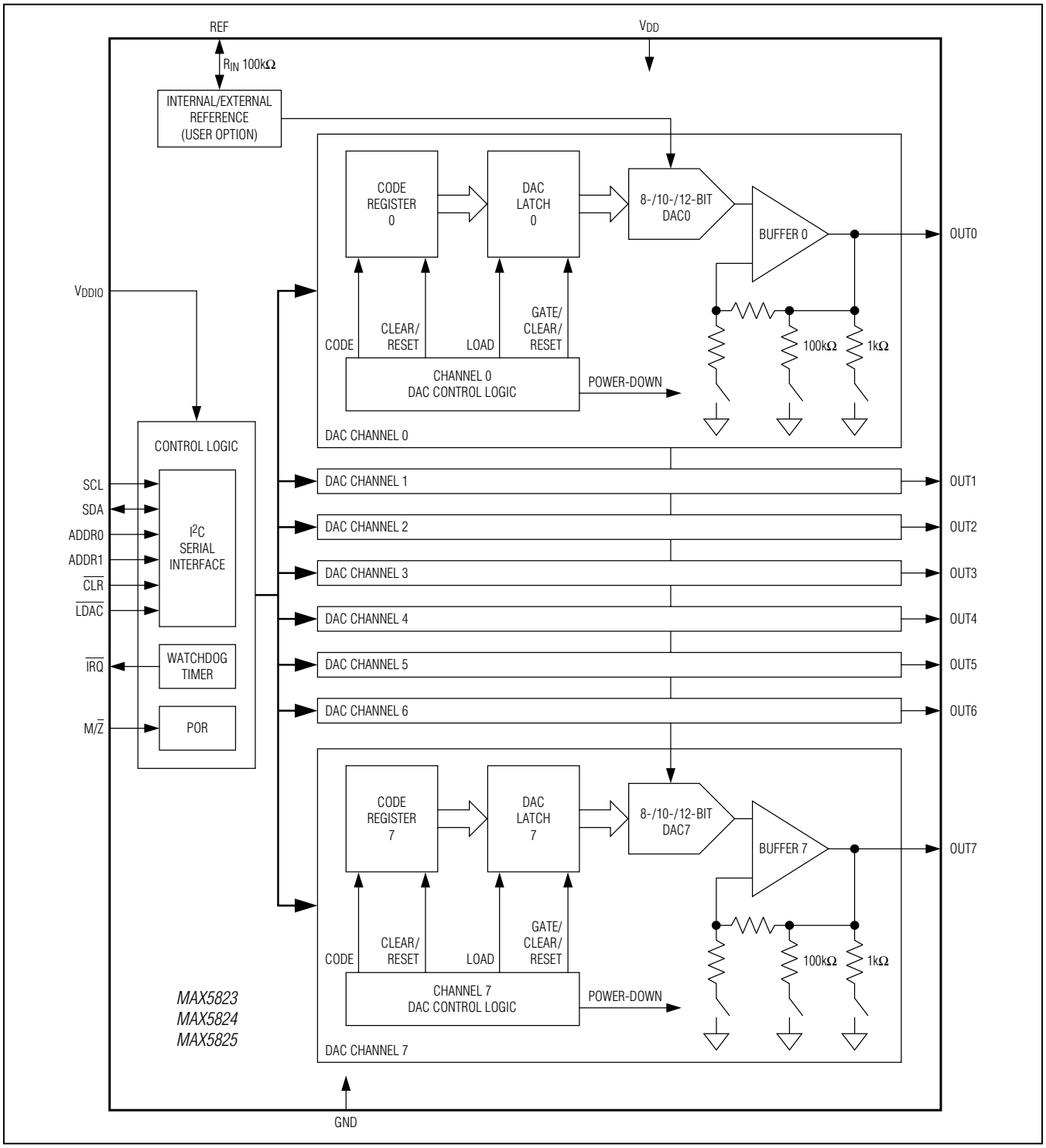
Digital feedthrough is the amount of noise that appears on the DAC output when the DAC digital control lines are toggled.

### Digital-to-Analog Glitch Impulse

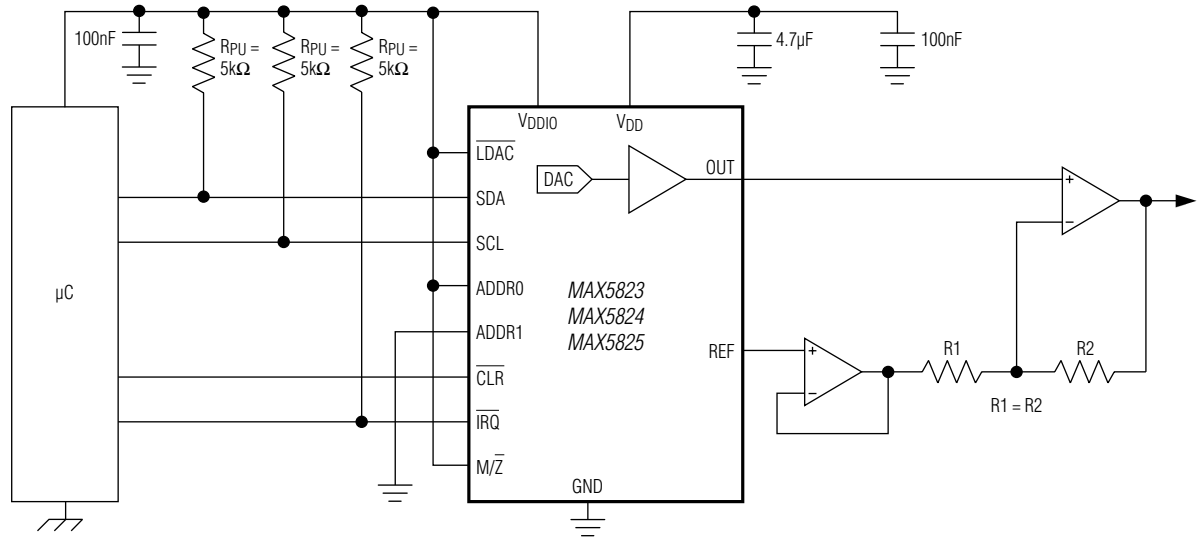
A major carry transition occurs at the midscale point where the MSB changes from low to high and all other bits change from high to low, or where the MSB changes from high to low and all other bits change from low to high. The duration of the magnitude of the switching glitch during a major carry transition is referred to as the digital-to-analog glitch impulse. Although all bits change, larger steps may lead to larger glitch energy.

The digital-to-analog power-up glitch is the duration of the magnitude of the switching glitch that occurs as the device exits power-down mode.

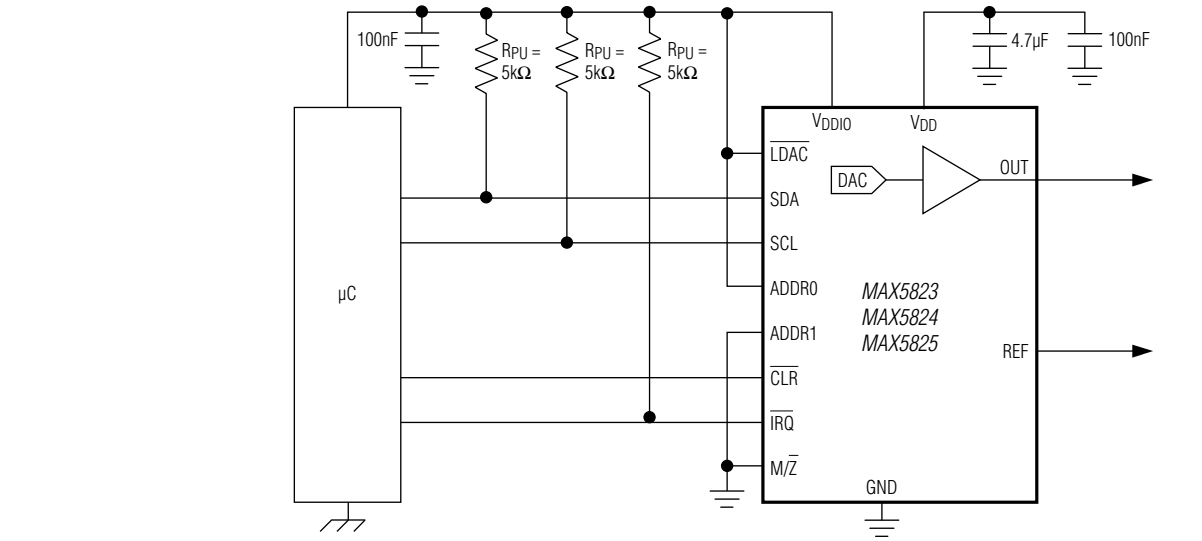
## Detailed Functional Diagram



## Typical Operating Circuits




**NOTE:** BIPOLAR OPERATING CIRCUIT, ONE CHANNEL SHOWN




**NOTE:** UNIPOLAR OPERATING CIRCUIT, ONE CHANNEL SHOWN

## Ordering Information

| PART | TEMPERATURE RANGE | PIN-PACKAGE | RESOLUTION (BIT) |
|---|---|---|---|
| **MAX5823**AUP+ | -40°C to +125°C | 20 TSSOP | 8 |
| MAX5823AWP+T | -40°C to +125°C | 20 WLP | 8 |
| **MAX5824**AUP+ | -40°C to +125°C | 20 TSSOP | 10 |
| **MAX5825**AAUP+ | -40°C to +125°C | 20 TSSOP | 12 |
| MAX5825AWP+T | -40°C to +125°C | 20 WLP | 12 |
| MAX5825BAUP+ | -40°C to +125°C | 20 TSSOP | 12 |

***Note:*** *All devices are specified over the -40°C to +125°C temperature range.*
*+Denotes a lead(Pb)–free/RoHS-compliant package.*
*T = Tape and reel.*

## Chip Information

PROCESS: BiCMOS

## Package Information

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

| PACKAGE TYPE | PACKAGE CODE | OUTLINE NO. | LAND PATTERN NO. |
|---|---|---|---|
| 20 TSSOP | U20+1 | **21-0066** | **90-0116** |
| 20 WLP | W202C2+1 | **21-0059** | Refer to **Application Note 1891** |

## Revision History

| REVISION NUMBER | REVISION DATE | DESCRIPTION | PAGES CHANGED |
|---|---|---|---|
| 0 | 2/12 | Initial release | — |
| 1 | 11/12 | Revised the *Electrical Characteristics, Ordering Information, Typical Operating Characteristics, Pin Configuration, Pin Description, CODEn_LOADn Command,* and *Offset Error* sections. Added the Zero-Scale Error and Full-Scale Error sections. | 1, 3, 5, 7, 9–12, 14, 15, 25, 28–31, 34 |
| 2 | 2/13 | Released the MAX5823/MAX5824/MAX5825B. Updated the *Electrical Characteristics* global and Note 3. | 2–7, 35 |
| 3 | 8/19 | Updated *Ordering Information* table | 34 |

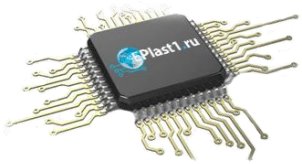
Компания «ЭлектроПласт» предлагает заключение долгосрочных отношений при поставках импортных электронных компонентов на взаимовыгодных условиях!

Наши преимущества:

- Оперативные поставки широкого спектра электронных компонентов отечественного и импортного производства напрямую от производителей и с крупнейших мировых складов;
- Поставка более 17-ти миллионов наименований электронных компонентов;
- Поставка сложных, дефицитных, либо снятых с производства позиций;
- Оперативные сроки поставки под заказ (от 5 рабочих дней);
- Экспресс доставка в любую точку России;
- Техническая поддержка проекта, помощь в подборе аналогов, поставка прототипов;
- Система менеджмента качества сертифицирована по Международному стандарту ISO 9001;
- Лицензия ФСБ на осуществление работ с использованием сведений, составляющих государственную тайну;
- Поставка специализированных компонентов (Xilinx, Altera, Analog Devices, Intersil, Interpoint, Microsemi, Aeroflex, Peregrine, Syfer, Eurofarad, Texas Instrument, Miteq, Cobham, E2V, MA-COM, Hittite, Mini-Circuits,General Dynamics и др.);

Помимо этого, одним из направлений компании «ЭлектроПласт» является направление «Источники питания». Мы предлагаем Вам помощь Конструкторского отдела:

- Подбор оптимального решения, техническое обоснование при выборе компонента;
- Подбор аналогов;
- Консультации по применению компонента;
- Поставка образцов и прототипов;
- Техническая поддержка проекта;
- Защита от снятия компонента с производства.




**Как с нами связаться**

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