SLAS373A-DECEMBER 2002-REVISED JULY 2003

# 16-BIT, LOW POWER, VOLTAGE OUTPUT, I<sup>2</sup>C INTERFACE DIGITAL-TO-ANALOG CONVERTER

#### **FEATURES**

- Micropower Operation: 160 μA @ 5 V
- Power-On Reset to Zero
- Single Supply: +2.7 V to +5.5 V
- 16-Bit Monotonic
- Settling Time: 10 μs to ±0.003% FSR
- I<sup>2</sup>C<sup>™</sup> Interface With High-Speed Mode
- Supports Data Receive and Transmit
- On-Chip Rail-to-Rail Output Buffer
- Double-Buffered Input Register
- Supports Synchronous Multichannel Update
- Offset Error: ±1 mV max at 25°C
- Full-Scale Error: ±3 mV max at 25°C
- Small 8 Lead MSOP Package

#### **APPLICATIONS**

- Process Control
- Data Acquisition Systems
- Closed-Loop Servo Control
- PC Peripherals
- Portable Instrumentation

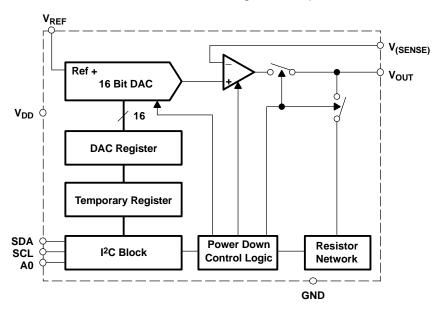
#### **DESCRIPTION**

The DAC8571 is a small low-power, 16-bit voltage output DAC with an  $\rm I^2C$  compatible two-wire serial interface. Its on-chip precision output amplifier allows rail-to-rail output swing and settles within 10 microseconds. The DAC8571 architecture is 16-bit monotonic, and factory trimming typically achieves  $\pm 4$  mV absolute accuracy at all codes. The DAC8571 requires an external reference voltage to set its output voltage range.

The low power consumption and small size of this part make it ideally suited to portable battery operated equipment. The power consumption is typically 800  $\mu$ W at V<sub>DD</sub> = 5 V reducing to 1  $\mu$ W in power-down mode.

The DAC8571 incorporates a 2-wire I<sup>2</sup>C interface. Standard, fast, and high-speed modes of I<sup>2</sup>C operation are all supported up to 3.4 MHz serial clock speeds. Multichannel synchronous data update and power-down operations are supported through the I<sup>2</sup>C bus. DAC8571 is also capable of transmitting the contents of its serial shift register, a key feature for I<sup>2</sup>C system verification.

The DAC8571 is available in an 8-lead MSOP package and is specified over -40°C to 105°C.



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

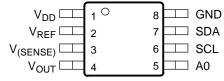
I<sup>2</sup>C is a trademark of Philips Corporation.





These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

## PIN CONFIGURATIONS



#### **PIN DESCRIPTION**

Pin	Name	Function
1	$V_{DD}$	Analog voltage supply input
2	V <sub>REF</sub>	Positive reference voltage input
3	V <sub>(SENSE)</sub>	Analog output sense
4	V <sub>OUT</sub>	Analog output voltage from DAC
5	A0	Device address select
6	SCL	Serial clock input
7	SDA	Serial data input/output
8	GND	Ground reference point for all circuitry on the part

#### **PACKAGE/ORDERING INFORMATION**

Product	Package	Package Designator	Specified Temperature Range	Package Marking	Ordering Number	Transport Media, Quantity
DAC8571	8-MSOP	DGK	-40°C to +105°C	D871	DAC8571IDGK DAC8571IDGKR	Tube, 80 Tape & Reel, 2500

## **ABSOLUTE MAXIMUM RATINGS**(1)

		UNITS	
V <sub>DD</sub> to GND		-0.3 V to +6 V	
Digital input voltage to GND	-0.3V to V <sub>DD</sub> + 0.3V		
V <sub>OUT</sub> to GND	-0.3V to +V <sub>DD</sub> + 0.3V		
Operating temperature range	-40°C to + 105°C		
Storage temperature range	-65°C to +150°C		
Junction temperature range (T <sub>J</sub> max)		+ 150°C	
$\Theta_{JA}$ Thermal impedance		260°C/W	
$\Theta_{JC}$ Thermal impedance		44°C/W	
Load townsystems coldering	Vapor phase (60s)	215°C	
Lead temperature, soldering	Infrared (15s)	220°C	

<sup>(1)</sup> Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. Exposure to absolute maximum conditions for extended periods may affect device reliability.



## **ELECTRICAL CHARACTERISTICS**

 $V_{DD}$  = +2.7 V to +5.5 V;  $R_L$  = 2 k $\Omega$  to GND;  $C_L$  = 200 pF to GND; low power mode; all specifications -40°C to 105°C (unless otherwise noted)

			DAC8571		
PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
STATIC PERFORMANCE (1)					
Resolution		16			Bits
Relative accuracy				±0.098	% of FSR
Differential nonlinearity	Monotonic by design		±0.25	±1	LSB
Offset error	Measured at code 485, 25°C		0.3	±1.0	mV
	Measured at code 485, -40°C105°C		1.0	±5.0	
Full-scale error	Measured at code 64714, 25°C		0.5	±3.0	mV
	Measured at code 64714, -40°C105°C		1.0	±5.0	
Gain error	Measured at code 64714, 25°C		1.0	±3.0	mV
	Measured at code 64714, -40°C105°C		2.0	±5.0	
Zero code error drift	All zeroes loaded to DAC register		-20		μV/°C
Gain temperature coefficient			-5		ppm of FSR/°C
Absolute accuracy	All codes from code 485 to code 64714, 25°C		±2.5		mV
	All codes from code 485 to code 64714, -40°C105°C		±3.5		
OUTPUT CHARACTERISTICS(2)					
Output voltage range		0		$V_{REF}$	V
Output voltage settling time (full	$R_L = 2 \text{ k}\Omega; C_L < 200 \text{ pF, fast settling}$		8	10	μs
scale)	$R_L = 2 \text{ k}\Omega$ ; $C_L = 500 \text{ pF}$ , fast settling		12		μs
	$R_L = 2 \text{ k}\Omega; C_L < 200 \text{ pF}, \text{ low power}$		13	15	μs
Slew rate	$R_L = 2 \text{ k}\Omega; C_L < 200 \text{ pF, fast settling}$		1		V/µs
	$R_L = 2 \text{ k}\Omega$ ; $C_L < 200 \text{ pF}$ , low power		0.5		
Capacitive load stability	R <sub>L</sub> = ∞		470		pF
	$R_L = 2 k\Omega$		1000		pF
Digital-to-analog glitch impulse			20		nV-s
Digital feedthrough			0.5		nV-s
DC output impedance			1		Ω
Short circuit current	V <sub>DD</sub> = +5 V		50		mA
	$V_{DD} = +3 \text{ V}$		20		mA
Power-up time	Coming out of power-down mode, V <sub>DD</sub> = +5 V		2.5		μs
	Coming out of power-down mode, V <sub>DD</sub> = +3 V		5		μs
PSRR			0.75		mV/V
REFERENCE INPUT					
V <sub>REFH</sub> input range		0		$V_{DD}$	V
Reference input impedance			140		kΩ
LOGIC INPUTS (2)					
Input current				±1	μΑ
V <sub>IN_L</sub> , Input low voltage	V <sub>DD</sub> = 2.7-5.5 V			0.3V <sub>DD</sub>	V
$V_{\text{IN\_H0}}$ , Input high voltage	V <sub>DD</sub> = 2.7-5.5 V	0.7V <sub>DD</sub>			V
Pin capacitance				3	pF
POWER REQUIREMENTS					
$V_{DD}$		2.7		5.5	V
I <sub>DD</sub> (normal operation)	DAC active, I <sub>ref</sub> included				

Linearity calculated using a reduced code range of 485 to 64714. Output unloaded. Assured by design and characterization, not production tested.

<sup>(2)</sup> 



 $V_{DD}$  = +2.7 V to +5.5 V;  $R_L$  = 2 k $\Omega$  to GND;  $C_L$  = 200 pF to GND; low power mode; all specifications -40°C to 105°C (unless otherwise noted)

		DAC8571		
PARAMETER	CONDITIONS	MIN TYP	MAX	UNITS
V <sub>DD</sub> = +4.5 V to +5.5 V	$V_{IH} = V_{DD}$ , $V_{IL} = GND$ , fast settling	250	400	μΑ
	$V_{IH} = V_{DD}$ , $V_{IL} = GND$ , low power	160	225	
$V_{DD} = +2.7 \text{ V to } +3.6 \text{ V}$	$V_{IH} = V_{DD}$ , $V_{IL} = GND$ , fast settling	240	380	μΑ
	$V_{IH} = V_{DD}$ , $V_{IL} = GND$ , low power	140	200	
I <sub>DD</sub> (all power-down modes)	DAC active, I <sub>ref</sub> included			
$V_{DD} = +4.5 \text{ V to } +5.5 \text{ V}$	$V_{IH} = V_{DD}$ and $V_{IL} = GND$	0.2	1	μΑ
$V_{DD} = +2.7 \text{ V to } +3.6 \text{ V}$	$V_{IH} = V_{DD}$ and $V_{IL} = GND$	0.05	1	μΑ
POWER EFFICIENCY				
$I_{OUT}/I_{DD}$	$I_L = 2 \text{ mA}, V_{DD} = +5 \text{ V}$	93%		

### **TIMING CHARACTERISTICS**

 $V_{DD}$  = +2.7 V to +5.5 V;  $R_L$  = 2 k $\Omega$  to GND; all specifications -40°C to 105°C (unless otherwise noted)

SYMBOL	PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
		Standard mode			100	kHz
	SCI alack fraguency	Fast mode			400	kHz
t <sub>SCL</sub>	SCL clock frequency	High-speed mode, C <sub>B</sub> - 100pF max			3.4	MHz
		High-speed mode, C <sub>B</sub> - 400pF max			1.7	MHz
	Bus free time between a STOP and	Standard mode	4.7			μs
t <sub>BUF</sub>	START condition	Fast mode	1.3			μs
		Standard mode	4.0			\µs
t <sub>HO</sub> ; t <sub>STA</sub>	Hold time (repeated) START con- dition	Fast mode	600			ns
	dition	High-speed mode	160			ns
	LOW region of the CCL plants	Standard mode	4.7			μs
$t_{LOW}$	LOW period of the SCL clock	Fast mode	1.3			μs
		Standard mode	4.0			μs
	HIGH period of the SCL clock	Fast mode	600			ns
t <sub>HIGH</sub>		High-speed mode, C <sub>B</sub> - 100pF max	60			ns
		High-speed mode, C <sub>B</sub> - 400pF max	120			ns
		Standard mode	4.7			μs
$t_{SU}$ ; $t_{STA}$	Setup time for a repeated START condition	Fast mode	600			ns
	Condition	High-speed mode	160			ns
		Standard mode	250			ns
$t_{SU}$ ; $t_{DAT}$	Data setup time	Fast mode	100			ns
		High-speed mode	10			ns
		Standard mode	0		0.9	μs
	Data hold time	Fast mode	0		0.9	μs
t <sub>HD</sub> ; t <sub>DAT</sub>	Data noid time	High-speed mode, C <sub>B</sub> - 100pF max	0		70	ns
		High-speed mode, C <sub>B</sub> - 400pF max	0		150	ns
		Standard mode	20 + 0.1C <sub>B</sub>		1000	ns
	Disc time of CCL signal	Fast mode	20 + 0.1C <sub>B</sub>		300	ns
t <sub>RCL</sub>	Rise time of SCL signal	High-speed mode, C <sub>B</sub> - 100pF max	10		40	ns
		High-speed mode, C <sub>B</sub> - 400pF max	20		80	ns



## **TIMING CHARACTERISTICS (continued)**

 $V_{DD}$  = +2.7 V to +5.5 V;  $R_L$  = 2 k $\Omega$  to GND; all specifications -40°C to 105°C (unless otherwise noted)

SYMBOL	PARAMETER	TEST CONDITIONS	MIN	TYP MAX	UNITS
		Standard mode	20 + 0.1C <sub>B</sub>	1000	ns
	Rise time of SCL signal after a repeated START condition, and after an acknowledge BIT	Fast mode	20 + 0.1C <sub>B</sub>	300	ns
t <sub>RCL1</sub>		High-speed mode, C <sub>B</sub> - 100pF max	10	80	ns
		High-speed mode, C <sub>B</sub> - 400pF max	20	1600	ns
		Standard mode	20 + 0.1C <sub>B</sub>	300	ns
	Fall time of SCI pignal	Fast mode	20 + 0.1C <sub>B</sub>	300	ns
t <sub>FCL</sub>	Fall time of SCL signal	High-speed mode, C <sub>B</sub> - 100pF max	10	40	ns
		High-speed mode, C <sub>B</sub> - 400pF max	20	80	ns
		Standard mode	20 + 0.1C <sub>B</sub>	1000	ns
	Rise time of SDA signal	Fast mode	20 + 0.1C <sub>B</sub>	300	ns
t <sub>RCA</sub>		High-speed mode, C <sub>B</sub> - 100pF max	10	80	ns
		High-speed mode, C <sub>B</sub> - 400pF max	20	160	ns
		Standard mode	20 + 0.1C <sub>B</sub>	300	ns
	Fall times of CDA cinnel	Fast mode	20 + 0.1C <sub>B</sub>	300	ns
t <sub>FDA</sub>	Fall time of SDA signal	High-speed mode, C <sub>B</sub> - 100pF max	10	80	ns
		High-speed mode, C <sub>B</sub> - 400pF max	20	160	ns
		Standard mode	4.0		μs
t <sub>SU</sub> ; t <sub>STO</sub>	Setup time for STOP condition	Fast mode	600		ns
		High-speed mode	160		ns
C <sub>B</sub>	Capacitive load for SDA and SCL			400	pF
	Dulgo width of onits our proceed	Fast mode		50	ns
t <sub>SP</sub>	Pulse width of spike suppressed	High-speed mode		10	ns
	Noise margin at the HIGH level for	Standard mode			
$V_{NH}$	each connected device (including	Fast mode	$0.2V_{DO}$		V
	hysteresis)	High-speed mode			
	Noise margin at the LOW level for	Standard mode			
$V_{NL}$	each connected device (including	Fast mode	0.1V <sub>DO</sub>		V
ı	hysteresis)	High-speed mode			

### TYPICAL CHARACTERISTICS

At  $T_{\Delta} = +25^{\circ}C$ , unless otherwise noted.

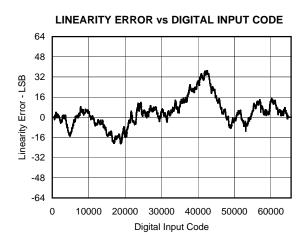


Figure 1.

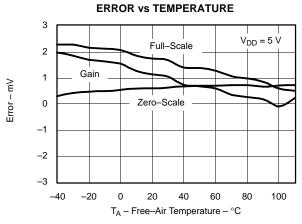


Figure 3.

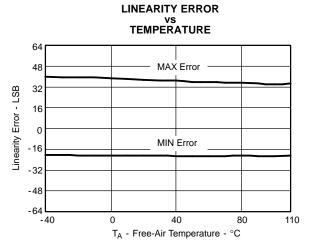


Figure 5.

## DIFFERENTIAL LINEARITY ERROR vs DIGITAL INPUT CODE

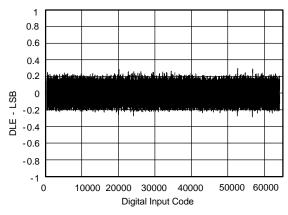


Figure 2.

#### **ERROR vs TEMPERATURE**

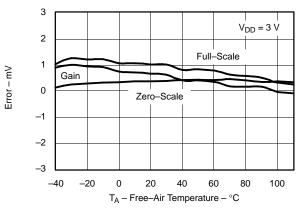


Figure 4.

#### DIFFERENTIAL LINEARITY ERROR VS TEMPERATURE

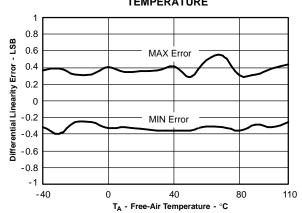
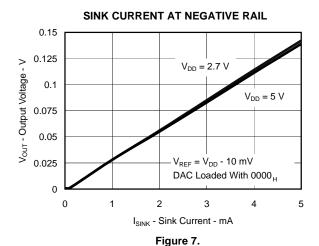


Figure 6.



At  $T_A = +25^{\circ}C$ , unless otherwise noted.



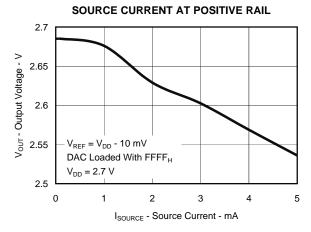


Figure 9.

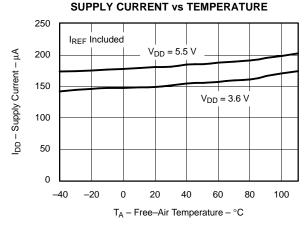


Figure 11.

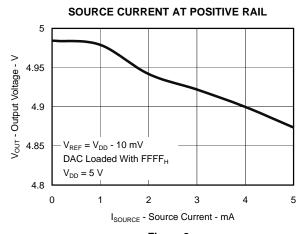


Figure 8.

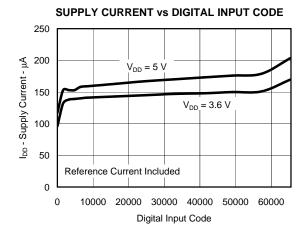


Figure 10.

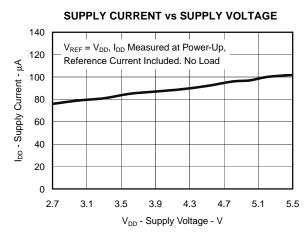


Figure 12.



At  $T_A = +25^{\circ}C$ , unless otherwise noted.

#### SUPPLY CURRENT vs LOGIC INPUT VOLTAGE

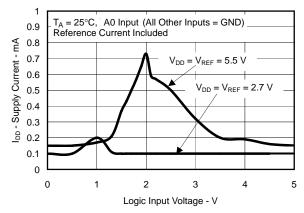


Figure 13.

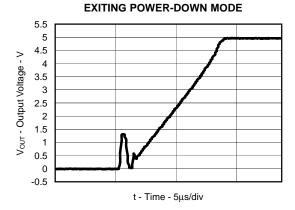


Figure 15.

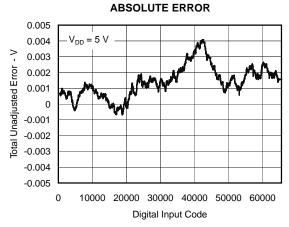


Figure 17.

#### HISTOGRAM OF CURRENT CONSUMPTION

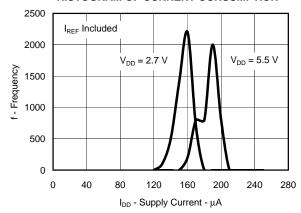


Figure 14.

#### **OUTPUT GLITCH (Mid-Scale)**

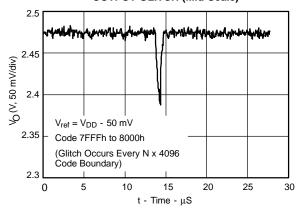
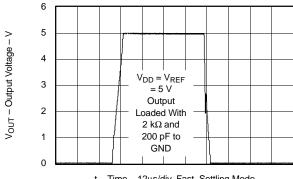


Figure 16.

#### **FULL-SCALE SETTLING TIME (Large Signal)**

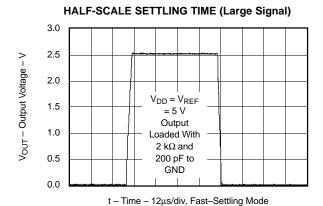


 $t-Time-12\mu s/\text{div},\,Fast\!-\!Settling\,Mode$ 

Figure 18.



At  $T_A = +25^{\circ}C$ , unless otherwise noted.





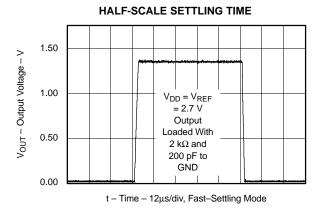


Figure 21.

#### TOTAL HARMONIC DISTORTION vs OUTPUT FREQUENCY

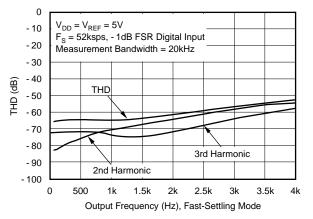


Figure 23.

#### **FULL-SCALE SETTLING TIME (Large Signal)**

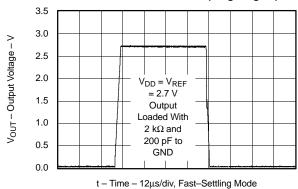


Figure 20.

#### SIGNAL-TO-NOISE RATIO vs OUTPUT FREQUENCY

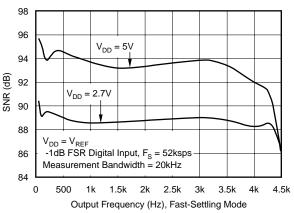


Figure 22.

#### TOTAL HARMONIC DISTORTION vs OUTPUT FREQUENCY

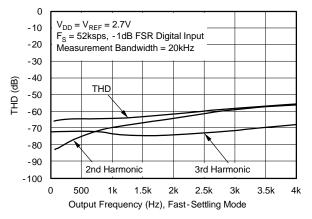


Figure 24.



At  $T_A = +25$ °C, unless otherwise noted.

## FULL-SCALE SETTLING TIME (Small-Signal-Positive Going Step)

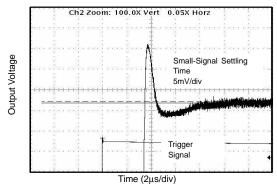


Figure 25.

## FULL-SCALE SETTLING TIME (Small-Signal-Negative Going Step)

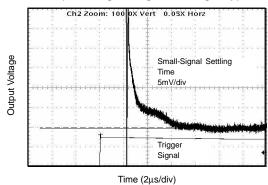


Figure 26.



#### THEORY OF OPERATION

#### D/A SECTION

The architecture of the DAC8571 consists of a string DAC followed by an output buffer amplifier. Figure 27 shows a block diagram of the DAC architecture.

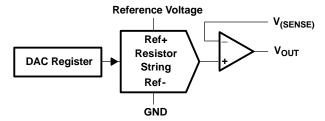


Figure 27. DAC8571 Architecture

The input coding to the DAC8571 is unsigned binary, which gives the ideal output voltage as:

$$V_{OUT} = V_{REF} \times \frac{D}{65536}$$

where D = decimal equivalent of the binary code that is loaded to the DAC register; it can range from 0 to 65535.

#### **RESISTOR STRING**

The resistor string section is shown in Figure 28. It is simply a divide-by-two resistor, followed by a string of resistors, each of value R. The code loaded into the DAC register determines at which node on the string the voltage is tapped off to be fed into the output amplifier by closing one of the switches connecting the string to the amplifier. Because it is a string of resistors, it is assured monotonic.

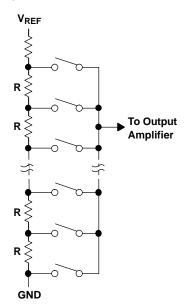


Figure 28. Resistor String.

#### **THEORY OF OPERATION (continued)**

#### **Output Amplifier**

The output buffer is a gain-of-2 noninverting amplifier capable of generating rail-to-rail voltages at its output, which gives an output range of 0 V to  $V_{DD}$ . It is capable of driving a load of 2 k $\Omega$  in parallel with 1000 pF to GND. The source and sink capabilities (fast settling) of the output amplifier can be seen in the typical curves. The slew rate is 1 V/µs with a full-scale settling time of 10 µs with the output loaded. The feedback and gain setting resistors of the amplifier are in the order of 50 k $\Omega$ . Their absolute value can be off significantly, but they are matched to within 0.1%.

The inverting input of the output amplifier is brought out to the VSENSE pin, through the feedback resistor. This allows for better accuracy in critical applications by tying the VSENSE point and the amplifier output together directly at the load. Other signal conditioning circuitry may also be connected between these points for specific applications including current sourcing.

### I<sup>2</sup>C Interface

The DAC8571 uses the I<sup>2</sup>C interface (see I<sup>2</sup>C-Bus Specification Version 2.1, January 2000, Philips Semiconductor) to receive and transmit digital data. I<sup>2</sup>C is a 2-wire serial interface that allows multiple devices on the same bus to communicate with each other. The serial bus consists of the serial data (SDA) and serial clock (SCL) lines. Connections to the SDA and SCL lines of the bus are made through open drain IO pins of each device on the bus. Since the devices that connect to the bus have open drain outputs, the bus should include pullup structures. When the bus is not active, both SCL and SDA lines are pulled high by these pullup devices.

The DAC8571 supports the I<sup>2</sup>C serial bus and data transmission protocol, in all three defined modes: standard (100 Kbps), fast (400 kBps), and high speed (3.4 Mbps).

I<sup>2</sup>C specification states that the device that controls the message is called a *master*, and the devices that are controlled by the master are *slaves*. The master device generates the SCL signal. A master device also generates special timing conditions (start condition, repeated start condition, and stop condition) on the bus to indicate the start or stop of a data transfer. Device addressing is also done by the master. The master device on an I<sup>2</sup>C bus is usually a microcontroller or a digital signal processor (DSP). The DAC8571 on the other hand, operates as a slave device on the I<sup>2</sup>C bus. A slave device acknowledges master's commands and upon master's control, either receives or transmits data.

I<sup>2</sup>C specification states that a device that sends data onto the bus is defined as a transmitter, and a device receiving data from the bus is defined as a *receiver*. DAC8571 normally operates as a slave receiver. A master device *writes* to DAC8571, a slave receiver. However, if a master device inquires DAC8571 internal register data, DAC8571, operates as a slave transmitter. In this case, the master device *reads* from the DAC8571, a slave transmitter. According to I<sup>2</sup>C terminology, *read* and *write* are with respect to the master device.

Other than specific timing signals, I<sup>2</sup>C interface works with serial bytes. At the end of each byte, a 9<sup>th</sup> clock cycle is used to generate/detect an acknowledge signal. An acknowledge is when the SDA line is pulled low during the high period of 9<sup>th</sup> clock cycle. A *not-acknowledge* is when SDA line is left high during the high period of the 9<sup>th</sup> clock cycle.

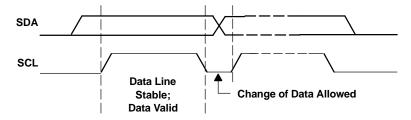


Figure 29. Valid Data



## **THEORY OF OPERATION (continued)**

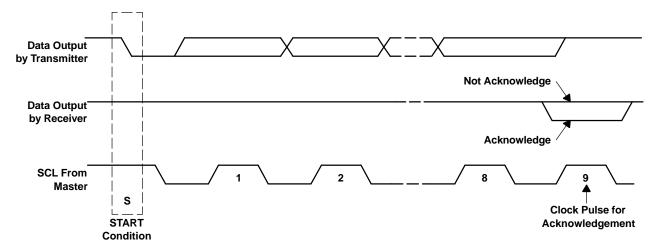


Figure 30. Acknowledge on the I<sup>2</sup>C Bus

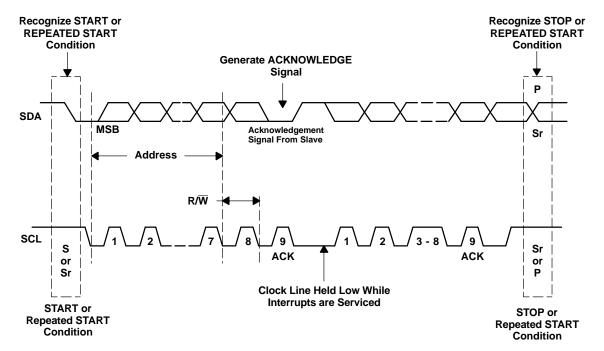


Figure 31. Bus Protocol



## Master Writing to a Slave Receiver (Standard/Fast Modes)

I<sup>2</sup>C protocol starts when the bus is idle, that is, when SDA and SCL lines are stable high. The master then pulls the SDA line low while SCL is still high indicating that serial data transfer has started. This is called a start condition, and can only be asserted by the master. After the start condition, the master generates the serial clock pulses and puts out an address byte, ADDRESS<7:0>. While generating the bit stream, the master ensures the timing for valid data. For each valid I2C bit, SDA line should remain stable during the entire high period of the SCL line. The address byte consists of 7 address bits (1001100, assuming A0=0) and a direction bit ( $R/\overline{W}=0$ ). After sending the address byte, the master generates a 9<sup>th</sup> SCL pulse and monitors the state of the SDA line during the high period of this 9<sup>th</sup> clock cycle. The SDA line being pulled low by a receiver during the high period of 9th clock cycle is called an acknowledge signal. If the master receives an acknowledge signal, it knows that a DAC8571 successfully matched the address the master sent. Upon the receipt of this acknowledge, the master knows that the communication link with a DAC8571 has been established and more data could be sent. The master continues by sending a control byte C<7:0>, which sets DAC8571's operation mode. After sending the control byte, the master expects an acknowledge signal. Upon receipt of the acknowledge, the master sends a most significant byte M<7:0> that represents the eight most significant bits of DAC8571's 16-bit digital-to-analog conversion data. Upon receipt of the M<7:0>, DAC8571 sends an acknowledge. After receiving the acknowledge, the master sends a least significant byte L<7:0> that represents the eight least significant bits of DAC8571's 16-bit conversion data. After receiving the L<7:0>, the DAC8571 sends an acknowledge. At the falling edge of the acknowledge signal following the L<0>, DAC8571 performs a digital to analog conversion. For further DAC updates, the master can keep repeating M<7:0> and L<7:0> sequences, expecting an acknowledge after each byte. After the required number of digital-to-analog conversions is complete, the master can break the communication link with DAC8571 by pulling the SDA line from low to high while SCL line is high. This is called a stop condition. A stop condition brings the bus back to idle (SDA and SCL both high). A stop condition indicates that communication with DAC8571 has ended. All devices on the bus including DAC8571 then await a new start condition followed by a matching address byte. DAC8571 stays at its current state upon receipt of a stop condition. Table 1 demonstrates the sequence of events that should occur while a master transmitter is writing to DAC8571.



## Table 1. Master Transmitter Writing to Slave Receiver (DAC8571)

Standard/Fast	Mode Wr	ite Seque	nce - Data	Input					
Transmitter	MSB	6	5	4	3	2	1	LSB	Comment
Master				Begin sequence					
Master	1	0	0	1	1	A0	0	R/W	Write addressing (LSB=0)
DAC8571									
Master	0	0	Load 1	Load 0	0	Brcsel	0	PD0	Control byte (PD0=0)
DAC8571				DAC8571	Acknowled	ges			
Master	D15	D14	D13	D12	D11	D10	D9	D8	Writing dataword, high byte
DAC8571				DAC8571	Acknowled	ges			
Master	D7	D6	D5	D4	D3	D2	D1	D0	Writing dataword, low byte
DAC8571									
Master				Done					

(1) High byte, low byte sequence can repeat.
 (2) Use repeated start to secure bus operation and loop back to the stage of write addressing for next Write

` '	Standard/Fast Mode Write Sequence-Power Down Input												
Transmitter	MSB	6	5	4	3	2	1	LSB	Comment				
Master				Begin sequence									
Master	1	0	0	1	1	A0	0	R/W	Write addressing (LSB=0)				
DAC8571		DAC8571 Acknowledges											
Master	0	0	Load 1	Load 0	0	Brcsel	0	PD0	Control byte (PD0=1)				
DAC8571				DAC8571 A	Acknowled	ges							
Master	PD1	PD2	PD3	0	0	0	0	0	Writing dataword, high byte				
DAC8571				DAC8571 A	Acknowled	ges							
Master	0	0	0	0	0	0	0	0	Writing dataword, low byte				
DAC8571		•		•									
Master			Ç		Done								

<sup>(1)</sup> High byte, low byte sequence can repeat.(2) Use repeated start to secure bus operation and loop back to the stage of write addressing for next Write.



## Master Reading From a Slave Transmitter (Standard/Fast Modes)

I<sup>2</sup>C protocol starts when the bus is idle, that is, when SDA and SCL lines are stable high. The master then pulls the SDA line low while SCL is still high indicating that serial data transfer has started. This is called a start condition, and can only be asserted by the master. After the start condition, the master generates the serial clock pulses and puts out an address byte, ADDRESS<7:0>. While generating the bit stream, the master ensures the timing for valid data. For each valid I2C bit, SDA line should remain stable during the entire high period of the SCL line. The address byte consists of seven address bits (1001100, assuming A0=0) and a direction bit (R/W=1). After sending the address byte, the master generates a 9<sup>th</sup> SCL pulse and monitors the state of the SDA line during the high period of this 9<sup>th</sup> clock cycle (master leaves the SDA line high). The SDA line being pulled low by a receiver during the high period of 9th clock cycle is called an acknowledge signal. If the master receives an acknowledge signal, it knows that a DAC8571 successfully matched the address the master sent. Since the R/W bit in the address byte was set, master also knows that DAC8571 is ready to transmit data. Upon the receipt of this acknowledge, the master knows that the communication link with a DAC8571 has been established and more data could be received. The master continues by sending eight clock cycles during which DAC8571 transmits a most significant byte, M<7:0>. If the master detects all bits of the M<7:0> as valid data, it sends an acknowledge signal in the 9th cycle. DAC8571 detects this acknowledge signal and prepares to send more data. Upon the receipt of eight clock cycles from the master, DAC8571 transmits the least significant byte L<7:0>. If the master detects all bits of the L<7:0> as valid data, it sends an acknowledge signal to DAC8571 during the 9th clock cycle. DAC8571 detects this acknowledge signal and prepares to send more data. Upon the receipt of 8 more clock cycles from the master, DAC8571 transmits the control byte C<7:0>. During the 9<sup>th</sup> clock cycle, the master transmits a not-acknowledge signal to DAC8571 and terminates the sequence with a stop condition, by pulling the SDA line from low to high while clock is high. M<7:0> and L<7:0> data could be either DAC data or could be the data stored in the temporary register. Bits in the C<7:0> reveal this information. Table 2 demonstrates the sequence of events that should occur while a master receiver is reading from DAC8571.

Standard/Fast Mode Read Sequence-Data Transmit **Transmitter MSB** 2 1 **LSB** Comment 6 5 4 3 Master Start Begin sequence Master 1 0 0 Α0 0 R/W Read addressing  $(R/\overline{W} = 1)$ 1 DAC8571 DAC8571 Acknowledges DAC8571 D15 D14 D13 D12 D11 D10 D9 D8 High byte Master Master Acknowledges DAC8571 D7 D4 D6 D5 D2 D<sub>1</sub> D0 Low byte D3 Master Master Acknowledges DAC8571 C7 C6 C5 C2 C1 C0 C4 C3 Control byte Master Master Not Acknowledges Master signal end of read Master Stop or Repeated Start Done

Table 2. Master Receiver Reads From Slave Transmitter (DAC8571)

#### Master Writing to a Slave Receiver (High-Speed Mode)

All devices must start operation in standard/fast mode and switch to high-speed mode using a well defined protocol. This is required because high-speed mode requires the on chip filter settings of each I<sup>2</sup>C device (for SDA and SCL lines) to be switched to support 3.4 Mbps operation. A stop condition always ends the high speed mode and puts all devices back to standard/fast mode.

I<sup>2</sup>C protocol starts when the bus is idle, that is, when SDA and SCL lines are stable high. The master then pulls the SDA line low while SCL is still high indicating that serial data transfer has started. This is called a *start condition*, and can only be asserted by the master. After the start condition, the master device puts out the high-speed master code 0000 1xxx. No device is allowed to acknowledge the master code, but the devices are required to switch their internal settings to support 3.4 Mbps operation upon the receipt of this code. After the not-acknowledge signal, the master is allowed to operate at high speed. Now at much higher speed, the master generates a repeated start condition. After the start condition, master generates the serial clock pulses and puts out an address byte, ADDRESS<7:0>. While generating the bit stream, the master ensures the timing for valid data. For each valid I<sup>2</sup>C bit, SDA line should remain stable during the entire high period of the SCL line. The address byte consists of seven address bits and a direction bit (R/W=0). After sending the address byte, the



master generates a 9th SCL pulse and monitors the state of the SDA line during the high period of this 9th clock cycle (master leaves the SDA line high). The SDA line being pulled low by the receiver during the high period of 9<sup>th</sup> clock cycle is called an acknowledge signal. If the master receives an acknowledge signal, it knows that a DAC8571 successfully matched the address the master sent. Upon the receipt of this acknowledge, the master knows that the high-speed communication link with a DAC8571 has been established and more data could be sent. The master continues by sending a control byte, C<7:0>, which sets DAC8571 operation mode. After sending the control byte, master expects an acknowledge. Upon the receipt of an acknowledge, the master sends a most significant byte, M<7:0> that represents the eight most significant bits of DAC8571's 16-bit digital-to-analog conversion data. Upon the receipt of the M<7:0>, DAC8571 sends an acknowledge. After receiving the acknowledge, the master sends a least significant byte, L<7:0>, that represents the eight least significant bits of DAC8571's 16-bit conversion data. After receiving the L<7:0>, the DAC8571 sends an acknowledge. At the falling edge of the acknowledge signal following the L<0>, DAC8571 performs a digital to analog conversion, depending on the operational mode. For further DAC updates, the master can keep repeating M<7:0> and L<7:0> sequences, expecting an acknowledge after each byte. After the required number of digital to analog conversions is complete, the master can break the communication link with DAC8571 by pulling the SDA line from low to high while SCL line is high. This is called a stop condition. A stop condition brings the bus back to idle (SDA and SCL both high). A stop condition indicates that communication with a device (DAC8571) has ended. All devices on the bus including DAC8571 then await a new start condition followed by a matching address byte. DAC8571 stays at its current state upon the receipt of a stop condition. A stop condition during the high-speed mode also indicates the end of the high-speed mode. Table 3 demonstrates the sequence of events that should occur while a master transmitter is writing to DAC8571 in I<sup>2</sup>C high-speed mode.

Table 3. Master Transmitter Writes to Slave Receiver in High-Speed Mode

HS Mode Writ	te Sequer	nce-Data I	nput						
Transmitter	MSB	6	5	4	3	2	1	LSB	Comment
Master				Begin sequence <sup>(1)</sup>					
Master	0	0	0	0	1	Х	Х	Х	HS mode master code
NONE				No device may acknowledge HS master code					
Master				Repea	ted Start				
Master	1	0	0	1	1	A0	0	R/W	Write addressing (LSB = 0)
DAC8571				DAC8571 A	Acknowled	ges			
Master	0	0	Load 1	Load 0	0	Brcsel	0	PD0	Control byte (PD0=0)
DAC8571				DAC8571 A	Acknowled	ges			
Master	D15	D14	D13	D12	D11	D10	D9	D8	Writing dataword, high byte
DAC8571				DAC8571 A	Acknowled	ges			
Master	D7	D6	D5	D4	D3	D2	D1	D0	Writing dataword, low byte
DAC8571	DAC8571 Acknowledges								
Master					Done				

<sup>(1)</sup> High-byte, low-byte sequences can repeat

<sup>(2)</sup> Use repeated start to secure bus operation and loop back to the stage of write addressing for next Write.



## Master Receiver Reading From a Slave Transmitter (High-Speed Mode)

I<sup>2</sup>C protocol starts when the bus is idle, that is, when SDA and SCL lines are stable high. The master then pulls the SDA line low while SCL is still high indicating that serial data transfer has started. This is called a start condition, and can only be asserted by the master. After the start condition, the master device puts out the high-speed master code 0000 1xxx. No device is allowed to acknowledge the master code, but the devices are required to switch their internal settings to support 3.4 Mbps operation upon the receipt of this code. After the not-acknowledge signal, the master is allowed to operate at high speed. Now at much higher speed, the master generates a repeated start condition. After the start condition, the master generates the serial clock pulses and puts out an address byte, ADDRESS<7:0>. While generating the bit stream, the master ensures the timing for valid data. For each valid I<sup>2</sup>C bit, SDA line should remain stable during the entire high period of the SCL line. The address byte consists of seven address bits and a direction bit (R/ $\overline{W}$ =1). After sending the address byte, the master generates a 9<sup>th</sup> SCL pulse and monitors the state of the SDA line during the high period of this 9<sup>th</sup> clock cycle (master leaves the SDA line high). The SDA line being pulled low by the receiver during the high period of 9<sup>th</sup> clock cycle is called an acknowledge signal. If the master receives an acknowledge signal, it knows that a DAC8571 successfully matched the address the master sent. Since the R/W bit in the address byte was set, master also knows that DAC8571 is ready to transmit data. Upon the receipt of this acknowledge, the master knows that the communication link with a DAC8571 has been established and more data could be received. The master continues by sending eight clock cycles during which DAC8571 transmits an M<7:0>. If the master detects all bits of the M<7:0> as valid data, it sends an acknowledge signal in the 9<sup>th</sup> cycle. DAC8571 detects this acknowledge signal and prepares to send more data. Upon the receipt of eight more clock cycles from the master, DAC8571 transmits L<7:0>. If the master detects all bits of the L<7:0> as valid data, it sends an acknowledge signal to DAC8571 during the 9th clock cycle. DAC8571 detects this acknowledge signal and prepares to send more data. Upon the receipt of eight more clock cycles from the master, DAC8571 transmits the control byte, C<7:0>. In the 9th clock cycle the master transmits a not-acknowledge signal to DAC8571 and terminates the sequence with a stop condition, by pulling the SDA line from low to high while clock is high. M<7:0> and L<7:0> data could be either DAC data or could be the data stored in the temporary register. Bits in the C<7:0> reveal this information. A stop condition during the high-speed mode also indicates the end of the high-speed mode. Table 4 demonstrates the sequence of events that should occur while a master receiver is reading from DAC8571 in I<sup>2</sup>C high-speed mode.

Table 4. Master Receiver Reads Data From Slave Transmitter in High-Speed Mode

HS Mode Rea	d Sequen	ce-Data Ti	ransmit						
Transmitter	MSB	6	5	4	3	2	1	LSB	Comment
Master			Begin sequence						
Master	0	0	0	0	1	Х	Х	Х	HS Mode master code
NONE				No device may acknowledge HS master code					
Master				Repea	ted Start				
Master	1	0	0	1	1	A0	0	R/W	Read addressing (R/W=1)
DAC8571				DAC8571 A	cknowledg	es			
DAC8571	D15	D14	D13	D12	D11	D10	D9	D8	High byte
Master				Master Ac	knowledge	S			
DAC8571	D7	D6	D5	D4	D3	D2	D1	D0	Low byte
Master				Master Ac	knowledge	S			
DAC8571	C7	C6	C5	C4	C3	C2	C1	C0	Control byte
Master			Master signal end of read						
Master				Stop or Rep	eated Start	t <sup>(1)</sup>			Done

<sup>(1)</sup> Use repeated start to secure bus operation and loop back to the stage of write addressing for next Write.



## **DAC8571 Update Sequence**

DAC8571 requires a start condition, a valid I<sup>2</sup>C address, a control byte, an MS byte and an LS byte for an update. The control byte sets the operational mode of the DAC8571. After the receipt of the control byte, DAC8571 expects an MS byte and an LS byte. After the receipt of each byte, DAC8571 acknowledges by pulling the SDA line low. At the falling edge of the acknowledge signal that follows the LS byte, DAC8571 performs an update.

After the first update, further data can be sent as MS byte and LS byte sequences and DAC8571 keeps updating at the falling edge of the acknowledge signal that follows each LS byte. The bits of the last control byte determine the type of update being performed. Thus, for the first update, DAC8571 requires a start condition, a valid I<sup>2</sup>C address, a control byte, an MS byte and an LS byte. For all consecutive updates, DAC8571 needs an MS byte and an LS byte.

Using the I<sup>2</sup>C high-speed mode, the clock running a 3.4 MHz, each 16-bit DAC update can be done within 18-clock cycles (MS byte, acknowledge bit, LS byte, acknowledge bit), at 188.88 KSPS. Using the fast mode, clock running at 400 kHz, maximum DAC update rate is limited to 22.22 KSPS.

#### **DAC8571 Address Byte**

MSB										
1	0	0	1	1	A0	0	R/W			

The address byte is the first byte received following a START condition from the master device. The first five bits (MSBs) of the slave address are factory preset to 10011. The next bit of the address byte is the device select bit A0, followed by a fixed 0 and the read/write direction bit  $R/\overline{W}$ . In order for DAC8571 to respond, the 7-bit address should be 10011A00, where the state of the A0 bit matches the state of the A0 pin. A maximum of two DAC8571 devices with the same preset code can therefore be connected on the same bus at one time. The A0 Address inputs can be permanently connected to VDD or digital ground, or can be actively driven by TTL or CMOS logic levels. The device address is set by the state of these pins upon power up of the DAC8571. The last bit of the address byte ( $R/\overline{W}$ ) defines the direction of the data flow. When set to a 1, a read operation is selected (master device reads from DAC8571); when set to a 0, a write operation is selected (master device writes to DAC8571). Following the START condition, the DAC8571 monitors the SDA bus, checking the device address being transmitted. Upon receiving the 10011A00 code, and the R/W bit, the DAC8571 outputs an acknowledge signal on the SDA line.

Broadcast addressing is also supported by DAC8571. Broadcast addressing can be used for synchronously updating or powering down multiple DAC8571 devices on the same bus. DAC8571 is designed to work with other members of DAC857x, DAC757x families to support multichannel synchronous update. When broadcast addressing is used, DAC8571 responds regardless of the state of the A0 pin. Broadcast address is only valid for write operation and cannot be used for read operation. Broadcast address is as follows.

MSB							LSB
1	0	0	1	0	0	0	0

#### **Control Byte**

After transmitting an acknowledge pulse following a valid address, DAC8571 expects a control byte C<7:0>. Control byte functionality is shown in Table 5.

The first two MSBs C<7> and C<6> of the control byte must be zeroes for DAC8571 to update. If these two bits are not assigned to zero, DAC8571 ignores all update commands, but still generates an acknowledge signal.

C<5> and C<4> are used for setting the update mode. Some of these modes are designed to support multichannel synchronous operation between multiple devices.

- C<5>=0, C<4>=0: Store I<sup>2</sup>C data. The contents of MS byte and LS byte data (or power-down information) are stored into the temporary register. This mode does not change the DAC output.
- C<5>=0, C<4>=1: Update DAC with I<sup>2</sup>C data. Most common mode. The contents of MS byte and LS byte data (or power-down information) are stored into the temporary data register and into the DAC register. This mode changes the DAC output with the contents of I<sup>2</sup>C MS byte and LS byte data.



- C<5>=1, C<4>=0: Update with previously stored data. The contents of MS byte and LS byte data (or power-down information) are ignored. The DAC is updated with the contents of the data previously stored in the temporary register. This mode changes the DAC output.
- C<5>=1, C<4>=1: Broadcast update, If C<2>=0, DAC is updated with the contents of its temporary register. If C<2>=1, DAC is updated with I<sup>2</sup>C MS byte and LS byte data. C<7> and C<6> do not have to be zeroes in order for DAC8571 to update. This mode is intended to help DAC8571 work with other DAC857x and DAC757x devices for multichannel synchronous update applications.

C<3> should always be zero.

C<2> is utilized only when C<5>=C<4>=1. Otherwise, C<2> must be assigned to zero.

C<1> should always be zero.

C<0> should be zero during normal DAC operation. C<0>=1 is a power-down flag. If C<0>=1, M<7>, M<6>, and M<5> indicate a powerdown operation as shown in Table 6.

C<7>	C<6>	C<5>	C<4>	C<3>	C<2>	C<1>	C<0>	M<7>	M<6>	M<5>			
		Load1	Load0		Brcsel		PD0	MSB	MSB-1	MSB-2LSB	DAC8571 FUNCTION		
0	0	0	0	0	0	0	0	Data		a	Write temporary register with data		
0	0	0	0	0	0	0	1	See Table 6			Write temporary register with power down command		
0	0	0	1	0	0	0	0	Data		a	Write temporary register and load DAC with data		
0	0	0	1	0	0	0	1	See Table 6		ble 6	Power down DAC		
0	0	1	0	0	0	0	0		х		Update DAC with temporary register data or power down		
Broadc	ast Com	mands	•										
х	х	1	1	х	0	х	х		х		х		Load all DACs, all devices with tem- porary register data
х	х	1	1	Х	1	Х	0	Data		a	Load all DACs, all devices with data		
х	х	1	1	Х	1	Х	1	See Table 6		See Table 6			Power down all DACs, all devices

**Table 5. Control Byte Functionality** 

#### **Most Significant Byte**

Most Significant Byte M<7:0> consists of 8 most significant bits of D/A conversion data. When C<0>=1. M<7>, M<6>, M<5> indicate a powerdown operation as shown in Table 6.

#### **Least Significant Byte**

Least Significant Byte L<7:0> consists of the 8 least significant bits of D/A conversion data. DAC8571 updates at the falling edge of the acknowledge signal that follows the L<0> bit.

#### **Data Transmit and Read-Back**

I<sup>2</sup>C bus can be noisy and data integrity and can be a problem in a system of many I<sup>2</sup>C devices. To enable I<sup>2</sup>C system verification, DAC8571 provides read back capability for the user. During read back operation, the contents of the control byte, MS byte and the LS byte can be sent back to the master device using the I<sup>2</sup>C bus. This read-back function is also useful if a device on the I<sup>2</sup>C bus inquires DAC8571 data.

For read-back operation, the master device sends the  $I^2C$  address and sets the  $R/\overline{W}$  bit. DAC8571 acknowledges. Then, upon the receipt of clock pulses from the master, DAC8571 sends the MS byte. If the master acknowledges, DAC8571 sends the LS byte. If the master acknowledges, DAC8571 sends the control byte. This sequence is interrupted by the master sending a not acknowledge signal.

Depending on the contents of the control byte transmitted by the DAC8571, the MS byte and LS byte information (transmitted by the DAC8571) is interpreted as follows:

C<5>	C<4>	C<2>	
0	0	0	MS and LS bytes represent temporary register data



C<5>	C<4>	C<2>	
0	1	0	MS and LS bytes represent temporary and DAC register data
1	0	0	MS and LS bytes represent I <sup>2</sup> C data that is discarded
1	1	0	MS and LS bytes represent I <sup>2</sup> C data that is discarded
1	1	1	MS and LS bytes represent temporary and DAC register data

## EXAMPLES (A0 TIED TO GND, VDD = 5 V)

	(- 1- 1- 1- 1- 1- 1- 1- 1- 1- 1- 1- 1- 1-	,		• /					
EXAMPLE 1	: Write 1/4 scale to D	AC8571							
	ADDRESS <70>		C<70>		M<70>		L<70>		
START	1001 1000	ACK	0001 0000	ACK	0100 0000	ACK	0000 0000	ACK	STOP
Previous out	put voltage is valid							Vout = 1	.25 V
EXAMPLE 2	2: Switch DAC8571 to	fast settli	ng mode						
	ADDRESS <70>		C<70>		M<70>		L<70>		
START	1001 1000	ACK	0001 0001	ACK	0010 0000	ACK	0000 0000	ACK	STOP
Previous out	put voltage is valid							Vout = 0	V
EXAMPLE 3	3: Switch DAC8571 ba	ack to low	power mode	•					
	ADDRESS <70>		C<70>		M<70>		L<70>		
START	1001 1000	ACK	0001 0001	ACK	0000 0000	ACK	0000 0000	ACK	STOP
Previous out	tput voltage is valid							Vout = 0	V
EXAMPLE 4	: Power-down DAC8	571 with H	i-Z output						
	ADDRESS <70>		C<70>		M<70>		L<70>		
START	1001 1000	ACK	0001 0001	ACK	1100 0000	ACK	0000 0000	ACK	STOP
Previous out	tput voltage is valid							Vout = F	li-Z
EXAMPLE 5	: Power-down DAC8	571 with 11	K output imp	edance to gro	ound				
	ADDRESS <70>		C<70>		M<70>		L<70>		
START	1001 1000	ACK	0001 0001	ACK	0100 0000	ACK	0000 0000	ACK	STOP
Previous out	tput voltage is valid							Vout = 0	V
EXAMPLE 6	3: Power-down DAC8	571 with 10	00K output ii	mpedance to	ground				
	ADDRESS <70>		C<70>		M<70>		L<70>		
START	1001 1000	ACK	0001 0001	ACK	1000 0000	ACK	0000 0000	ACK	STOP
Previous out	tput voltage is valid							Vout = 0	V
EXAMPLE 7	: Store full scale data	a in tempo	rary register	•					
	ADDRESS <70>		C<70>		M<70>		L<70>		
START	1001 1000	ACK	0000 0000	ACK	1111 1111	ACK	1111 1111	ACK	STOP
Previous out	tput voltage is valid								
EXAMPLE 8	3: Update DAC8571 w	ith the dat	a previously	stored in the	temporary regis	ster			
	ADDRESS <70>		C<70	>	M<70>		L<70>		
START	1001 1000	ACK	0010 000	00 ACK	XXXX XXXX	ACK	XXXX XXXX	ACK	STOP
Previous out	tput voltage is valid							New Vout	valid
EXAMPLE 9	: Broadcast a power		mand to all I	DAC8571s on	the I <sup>2</sup> C bus				
	ADDRESS <70>		C<7(	0>	M<70>		L<70>		
START	1001 0000	ACK	0011 01	101 ACK	1100 0000	ACK	0000 0000	ACK	STOP
	tput voltage is valid							out = Hi-Z	
EXAMPLE 1 registers	0: Broadcast update.	. All DAC8	571s on the	I <sup>2</sup> C bus updat	e synchronousl	y with the c	ontents of thei	r tempora	ry
	ADDRESS <70>		C<70	>	M<70>		L<70>		
START	1001 0000	ACK	0011 00	00 ACK	xxxx xxxx	ACK	xxxx xxxx	ACK	STOP
Previous out	put voltage is valid		,	•	•	•		New Vout	valid



EXAMPLE	11: Read back DAC85	71 internal da	ıta. V denotes	valid logic	<b>).</b>				
	ADDRESS<70>		M<70>	MASTER	L<70>	MASTER	C<70>	MASTER	
START	1001 1001	ACK	VVVV VVVV	ACK	VVVV VVVV	ACK	VVVV VVVV	NOT ACK	STOP
EXAMPLE	12: Ramp generation	in high speed	mode (up to	code 7 is s	hown)				
	HS Master Code			ADDRESS		C<70>			
START	0000 1000	NOT ACK	REPEATED START		1001 1000	ACK	0001 0000		ACK
Previous V	out voltage valid								
MSB<70:	<70> LSB<70>			MSB<70>		LSB<70>			
0000 0000	ACK	0000 0000	ACK		0000 0000	ACK	0000 0001		ACK
Previous V	out voltage valid		Vout = 0 V	Vout = 0 V					6 μV
MSB<70:	>	LSB<70>			MSB<70>		LSB<70>		
0000 0000	ACK	0000 0010	ACI	<	0000 0000	ACK	0000 0011		ACK
Vout = 76	μV			Vout = 2 ×76 μV					: 3 ×76 μV
MSB<70	>	LSB<70>			MSB<70>		LSB<70>		
0000 0000	ACK	0000 0100	ACI	<	0000 0000	ACK	0000 0101		ACK
Vout = $3 \times 7$	76 μV				Vout = 4 ×76 µ	١V		Vout =	: 5 ×76 μV
MSB<70	>	LSB<70>			MSB<70>		LSB<70>		
0000 0000	ACK	0000 0110	ACI	<	0000 0000	ACK	0000 0111		ACK
Vout = $5 \times 7$	76 μV			Vout = 6 ×76 μV					

#### **Power-On Reset**

The DAC8571 contains a power-on-reset circuit that controls the output voltage during power-up. On power-up, the DAC register is filled with zeros and the output voltage is 0V; it remains there until a valid write sequence is made to the DAC. This is useful in applications where it is important to know the state of the output of the DAC while it is in the process of powering up. No input is brought high before the power is applied.

#### **Power-Down Modes**

The DAC8571 contains five separate power settings. These modes are programmable when C<0>=1. When C<0>=1, M<7>, M<6>, and M<5> bits represent power setting control bits, and M<4...0> and L<7...0> are assigned to zeroes. Power setting of DAC8571 is updated at the falling edge of the acknowledge signal that follows the least significant byte. To set the power consumption of the device, following  $I^2C$  sequence is used.

Start_condition ->	
Valid_address	(1001 1000) -> ack
C<7:0>	(0001 0001) -> ack
M<7:0>	( vvv0 0000) -> ack
L<7:0>	(0000 0000) -> ack
Stop_condition	

## Table 6. Power Settings for the DAC8571 (C<0>=1)

M<7>	M<6>	M<5>	Operating Mode
0	0	0	Low power mode, default
0	0	1	Fast settling mode
0	1	X	PWD. 1kΩ to GND
1	0	Х	PWD. 100 $k\Omega$ to GND
1	1	Х	PWD. Output Hi-Z



After power-up, the device works in low power mode with its normal power consumption of 170  $\mu$ A at 5 V. At fast settling mode, device consumes 250  $\mu$ A nominally, but settles in 10  $\mu$ s. For the three power-down modes, the supply current falls to 200 nA at 5 V (50 nA at 3 V). Not only does the supply current fall but the output stage is also internally switched from the output of the amplifier to a resistor network of known values. This has the advantage that the output impedance of the device is known while in power-down mode. There are three different options: The output is connected internally to GND through a 1-k $\Omega$  resistor, a 100-k $\Omega$  resistor or it is left open-circuit (high impedance). The output stage is illustrated in Figure 32.

A power on reset starts the DAC8571 in the low power mode. Low power mode and fast-settling mode settings stay unchanged during DAC8571 data updates, unless they are specifically overwritten as explained in Table 6. On the other hand, each new data sequence requiring a DAC update brings the DAC8571 out of the three power-down conditions.

DAC8571 power settings can be stored in the temporary register, just like data (use C<7:0> = 0000 0001). This allows simultaneous powerdown capability for multichannel applications.

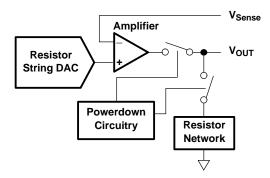


Figure 32. Output Stage During Power-Down

All linear circuitry is shut down when the power-down mode is activated. However, the contents of the DAC register are unaffected when in power-down. The time to exit power-down is typically 2.5  $\mu$ s for  $V_{DD} = 5$  V and 5  $\mu$ s for  $V_{DD} = 3$  V. (See the Typical Characteristics section for additional information.)

#### **CURRENT CONSUMPTION**

In the low power mode, the DAC8571 typically consumes 170  $\mu$ A at  $V_{DD}=5$  V and 150  $\mu$ A at  $V_{DD}=3$  V including reference current consumption. Fast settling mode adds 80  $\mu$ A of current consumption, but ensures 10- $\mu$ s settling. Additional current consumption can occur at the digital inputs if VIH<<VDD. For most efficient power operation, CMOS logic levels are recommended at the digital inputs to the DAC. In power-down mode, typical current consumption is 200 nA.

#### DRIVING RESISTIVE AND CAPACITIVE LOADS

The DAC8571 output stage is capable of driving loads of up to 1000 pF while remaining stable. Within the offset and gain error margins, the DAC8571 can operate rail-to-rail when driving a capacitive load. Resistive loads of 2 k $\Omega$  can be driven by the DAC8571 while achieving a very good load regulation. Load regulation error increases when the DAC output voltage is close to supply rails. When the outputs of the DAC are driven to the positive rail under resistive loading, the PMOS transistor of each Class-AB output stage can enter into the linear region. When this occurs, the added IR voltage drop deteriorates the linearity performance of the DAC. This only occurs within approximately the top 20 mV of the DAC's digital input-to-voltage output transfer characteristic. The reference voltage applied to the DAC8571 may be reduced below the supply voltage applied to VDD in order to eliminate this condition if good linearity is a requirement at full scale (under resistive loading conditions).

#### **AC PERFORMANCE**

DAC8571 can achieve typical ac performance of 96-dB signal-to-noise ratio (SNR) and 65-dB total harmonic distortion (THD), making the DAC8571 a solid choice for applications requiring low SNR at output frequencies at or below 4 kHz.

#### **OUTPUT VOLTAGE STABILITY**

The DAC8571 exhibits excellent temperature stability of 5 ppm/ $^{\circ}$ C typical output voltage drift over the specified temperature range of the device. This enables the output voltage of each channel to stay within a  $\pm 25~\mu$ V window for a  $\pm 1^{\circ}$ C ambient temperature change. Good power supply rejection ratio (PSRR) performance reduces supply noise present on V<sub>DD</sub> from appearing at the outputs to well below 10  $\mu$ V. Combined with good dc noise performance and true 16-bit differential linearity, the DAC8571 becomes a perfect choice for closed-loop control applications.

#### SETTLING TIME AND OUTPUT GLITCH PERFORMANCE

Settling time to within the 16-bit accurate range of the DAC8571 is achievable within 10  $\mu$ s for a full-scale code change at the input. Worst case settling times between consecutive code changes is typically less than 2  $\mu$ s, therefore, the update rate is limited by the I<sup>2</sup>C interface for digital input signals changing code-to-code. For full-scale output swings, the output stage of each DAC8571 channel typically exhibits less than 100-mV overshoot and undershoot when driving a 200-pF capacitive load. Code-to-code change glitches are extremely low (~10 $\mu$ V) given that the code-to-code transition does not cross an Nx4096 code boundary. Due to internal segmentation of the DAC8571, code-to-code glitches occur at each crossing of an Nx4096 code boundary. These glitches can approach 100 mVs for N = 15, but settle out within ~2  $\mu$ s.

#### **USING REF02 AS A POWER SUPPLY FOR DAC8571**

Due to the extremely low supply current required by the DAC8571, a possible configuration is to use a REF02 5-V precision voltage reference to supply the required voltage to the DAC8571's supply input as well as the reference input, as shown in Figure 33. This is especially useful if the power supply is quite noisy or if the system supply voltages are at some value other than 5 V. The REF02 outputs a steady supply voltage for the DAC8571. If the REF02 is used, the current it needs to supply to the DAC8571 is 160- $\mu$ A typical and 225- $\mu$ A max for V<sub>DD</sub> = 5 V. When a DAC output is loaded, the REF02 also needs to supply the current to the load. The total typical current required (with a 5- $\mu$ A load on a given DAC output) is:

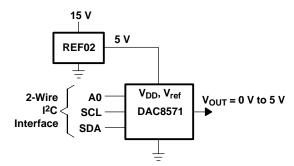


Figure 33. REF02 as a Power Supply

$$160 \,\mu A + \frac{5 \,V}{5 \,k\Omega} = 1.16 \,mA$$

The load regulation of the REF02 is typically 0.005%/mA, which results in an error of 290  $\mu$ V for a 1.16-mA current drawn. This corresponds to a 3.82 LSB error for a 0-V to 5-V output range.

#### **LAYOUT**

A precision analog component requires careful layout, adequate bypassing, and clean, well-regulated power supplies.

The power applied to  $V_{DD}$  and  $V_{REF}$  should be well regulated and low noise. Switching power supplies and dc/dc converters often has high-frequency glitches or spikes riding on the output voltage. In addition, digital components can create similar high-frequency spikes as their internal logic switches states. This noise easily couples into the DAC output voltage through various paths between the power connections and analog output.



As with the GND connection,  $V_{DD}$  is connected to a +5-V power supply plane or trace that is separate from the connection for digital logic until they are connected at the power entry point. In addition, the 1- $\mu$ F to 10- $\mu$ F, and 0.1- $\mu$ F bypass capacitors are strongly recommended. In some situations, additional bypassing may be required, such as a 100- $\mu$ F electrolytic capacitor or even a Pi filter made up of inductors and capacitors—all designed to essentially lowpass filter the 5-V supply, removing the high frequency noise.





10-Jan-2011

#### **PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/ Ball Finish	MSL Peak Temp <sup>(3)</sup>	Samples (Requires Login)
DAC8571IDGK	ACTIVE	MSOP	DGK	8	80	Green (RoHS & no Sb/Br)	CU NIPDAUAGI	evel-2-260C-1 YEAR	Contact TI Distributor or Sales Office
DAC8571IDGKG4	ACTIVE	MSOP	DGK	8	80	Green (RoHS & no Sb/Br)	CU NIPDAUAGI	evel-2-260C-1 YEAR	Contact TI Distributor or Sales Office
DAC8571IDGKR	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAUAGI	evel-2-260C-1 YEAR	Request Free Samples
DAC8571IDGKRG4	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAUAGI	evel-2-260C-1 YEAR	Request Free Samples

(1) The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

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Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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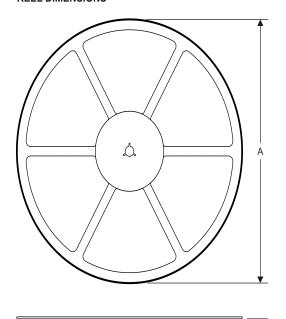
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## PACKAGE MATERIALS INFORMATION

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## TAPE AND REEL INFORMATION

#### **REEL DIMENSIONS**



#### **TAPE DIMENSIONS**



A0	Dimension designed to accommodate the component width
В0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

#### TAPE AND REEL INFORMATION

### \*All dimensions are nominal

Device	Package Type	Package Drawing		SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
DAC8571IDGKR	MSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1

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#### \*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
DAC8571IDGKR	MSOP	DGK	8	2500	346.0	346.0	29.0

## DGK (S-PDSO-G8)

## PLASTIC SMALL-OUTLINE PACKAGE



NOTES:

- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
- Body width does not include interlead flash. Interlead flash shall not exceed 0.50 per side.
- E. Falls within JEDEC MO-187 variation AA, except interlead flash.



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