SHA-1/HMAC BASED SECURITY AND AUTHENTICATION IC WITH SDQ INTERFACE

FEATURES

- **Provides Authentication of Battery Packs Through SHA-1 Engine Based HMAC**
- **160 Bytes OTP, 16 Bytes EEPROM**
- **Internal Time-Base Eliminates External Crystal Oscillator**
- **Low Power Operating Modes:**
  - **Active: < 50 μA**
  - **Sleep: 8 μA Typical**
- **Single-Wire SDQ Interface**
- **Powers Directly From the Communication Bus**
- **6 Lead SON Package**

APPLICATIONS

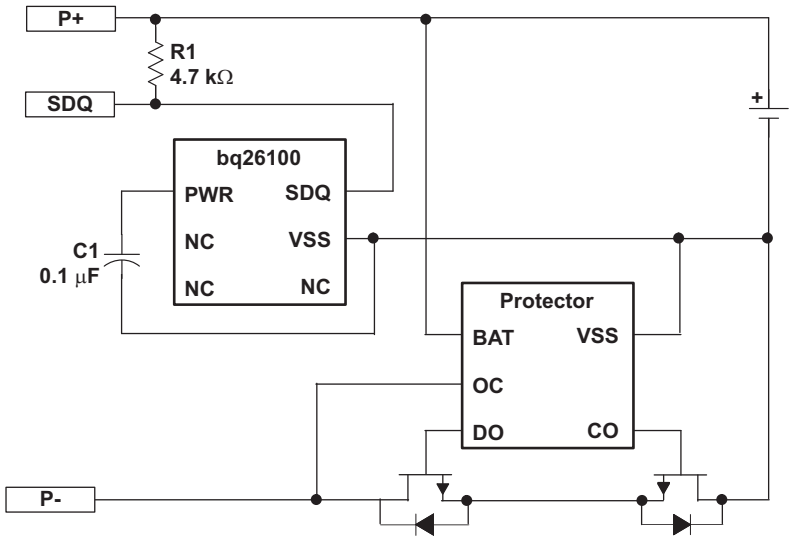
- **Cellular Phones**
- **PDA and Smart Phones**
- **MP3 Players**
- **Digital Cameras**
- **Internet Appliances**
- **Handheld Devices**

DESCRIPTION

The bq26100 provides a method to authenticate battery packs, ensuring that only packs manufactured by authorized sub-contractors are used in the end application. The security is achieved using the SHA-1 hash function inside the widely adopted HMAC construction. A unique 128-bit key is stored in each bq26100 device, allowing the host to authenticate each pack.

The bq26100 communicates to the system over a simple one-wire bi-directional serial interface. The 5-kbits/s SDQ bus interface reduces communications overhead in the external microcontroller. The bq26100 also derives power over the SDQ bus line via an external capacitor.

TYPICAL APPLICATION



ORDERING INFORMATION

T_A	PACKAGE	PART NUMBER
–40°C to 85°C	6-lead SON	bq26100DRP

ABSOLUTE MAXIMUM RATINGS(1)

		VALUE	UNIT
	Supply voltage (SDQ all with respect to VSS)	–0.3 to 7.7	V
	Output current (SDQ)	5	mA
T_A	Operating free-air temperature range	–40 to 85	°C
T_{stg}	Storage temperature range	–65 to 150	°C
T_J	Junction temperature range	–40 to 90	°C
	Lead temperature (Soldering, 10 sec)	300	°C

(1) 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 under *recommended operating conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

RECOMMENDED OPERATING CONDITIONS

over operating free-air temperature range (unless otherwise noted)

		MIN	MAX	UNIT
V_{sdq}	Pull-up voltage	2.5	5.0	V
T_J	Operating free-air temperature range	–40	85	°C

ELECTRICAL CHARACTERISTICS

all parameters over operating free-air temperature and supply voltage range (unless otherwise noted) (memory programming and authentication were tested with R1 = 4.7 kΩ, C1 = 0.1 µF over pull-up voltage range)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
	Power up communication delay	Power capacitor charge time		100		ms
I_{sleep}	Sleep current			8	11	µA
$I_{sdq(Vsdq)}$	V_{sdq} Current	$V_{sdq} \geq V_{sdq(min)}$			50	µA
	OTP Memory programming voltage		6.8	7	7.7	V
	OTP Memory programming time			100		µs/byte
	EEPROM Programming current (peak current)			83		µA
	EEPROM Peak current duration			100		µs
	EEPROM Programming time			50		ms
SDQ						
V_{IL}	Input low-level voltage				0.63	V
I_{OL}	Output low sink current	V_{OL} = 0.4 V			1	mA

STANDARD SERIAL COMMUNICATION (SDQ) TIMING

over recommended operating temperature and supply voltage range (unless otherwise noted) (See Figure 1)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{RSTL}	Reset time – low		480			µs
t_{RSTH}	Reset time – high		480			µs
t_{PDL}	Presence detect – low		60		240	µs
t_{PDH}	Presence detect – high		15		60	µs
t_{REC}	Recovery time		1			µs
t_{SLOT}	Host bit window		60		120	µs
t_{LOW1}	Host sends 1		1		13	µs

STANDARD SERIAL COMMUNICATION (SDQ) TIMING (continued)

over recommended operating temperature and supply voltage range (unless otherwise noted) (See Figure 1)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{LOW0}	Host sends 0		60		120	µs
t_{LOWR}	Host read bit start		1		13	µs
t_{SLOT}	bq26100 bit window		60		120	µs
t_{SU}	bq26100 data setup				1	µs
t_{RDV}	bq26100 data valid			exactly 15		µs
$t_{RELEASE}$	bq26100 data release		0	15	45	µs

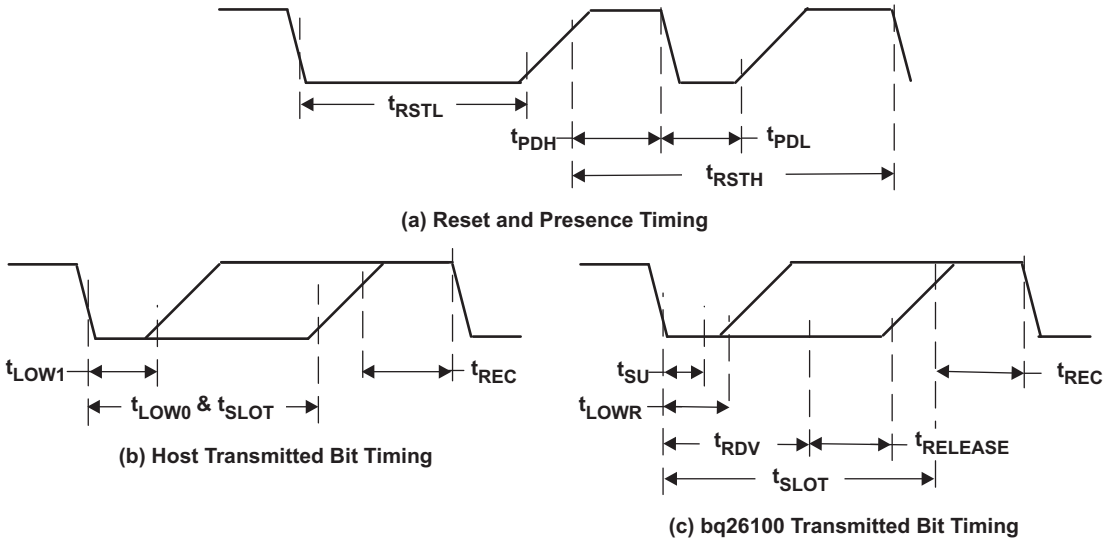


Figure 1. SDQ Timing Diagrams

The SDQ protocol requires a CRC calculation as part of the communication flow. The CRC, based on a polynomial of $x^8+x^5+x^4+1$, is computed to determine data integrity and its use varies in the protocol. The Memory Function flows show what data is shifted through the CRC and when the value is transmitted from the slave. Each data byte used in the CRC calculation is pushed through the CRC shift register from LSB to MSB. The byte wide CRC computation is:

```
for (i = 0; i < 8; i++)
{
    if (crc[0] ^ input[i])
        crc = (crc >> 1) ^ 0x8C;
    else
        crc = crc >> 1;
}
```

Where did the magic number 0x8C come from? CRC polynomials are defined such that the highest order simply shows the number of bits, so $x^8+x^5+x^4+1$ defines an 8-bit value with a binary value of 00110001 (bits 0, 4, and 5 are 1 and all others are 0). Since the SDQ CRC is computed by shifting in the LSB, the polynomial must be used in reverse bit order – binary 10001100 or hexadecimal 0x8C.

The CRC value is reset to 0 prior to the first byte being shifted through. The CRC is also reset when the CRC is shifted out as part of the SDQ protocol.

OTP PROGRAMMING SPECIFICATIONS

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{pon}	Program setup time		2			µs
t_{rise}	Pulse rise time		1		10	µs
t_{prog}	Pulse high time	Single byte programming	300			µs
		Key programming	3			µs
t_{fall}	Pulse fall time		1		10	µs

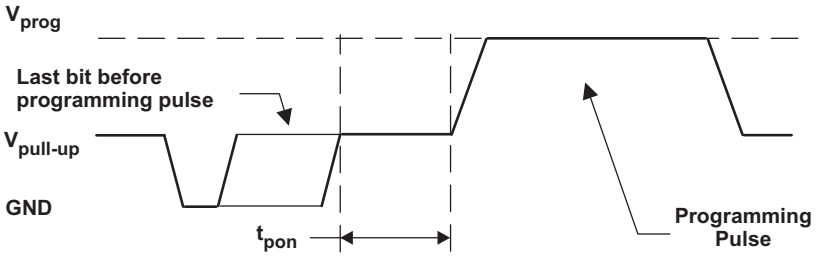


Figure 2. bq26100 Communication to OTP Programming Pulse Diagram

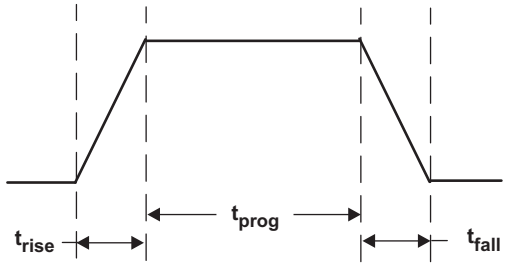
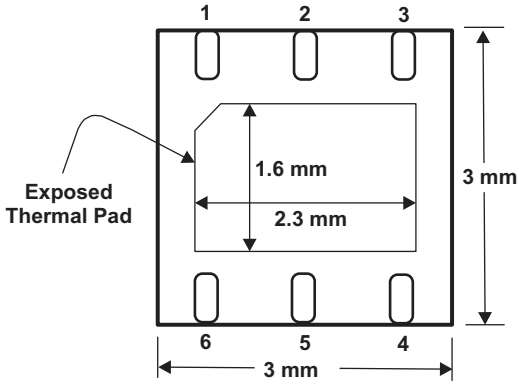


Figure 3. OTP Programming Pulse Detail

PIN ASSIGNMENT



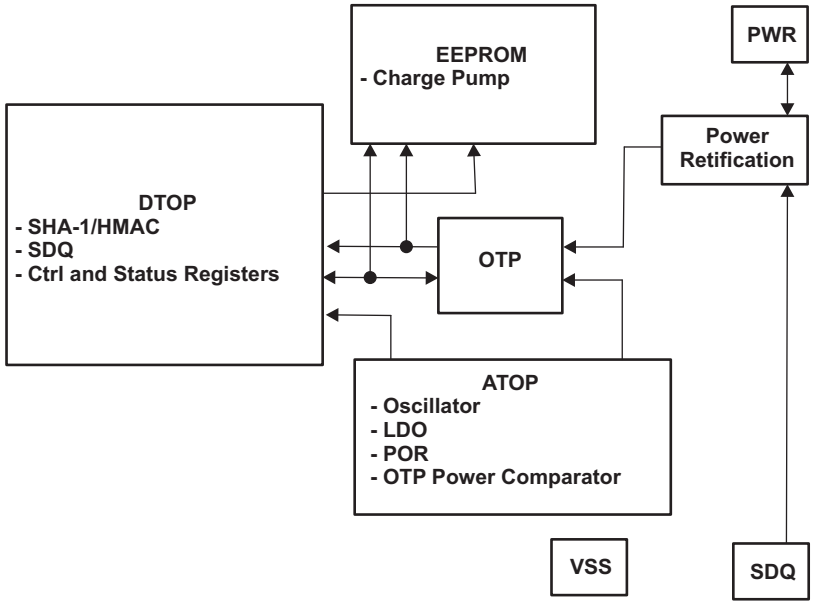
TERMINAL FUNCTIONS

TERMINAL		I/O	DESCRIPTION
NAME	NO.		
NC	2, 3, 4		No connect
PWR	1	I/O	Power capacitor connection

TERMINAL FUNCTIONS (continued)

TERMINAL		I/O	DESCRIPTION
NAME	NO.		
SDQ	6	I/O	Single wire SDQ interface to host
VSS	5	I	Ground

FUNCTIONAL BLOCK DIAGRAM



FUNCTIONAL DESCRIPTION

The bq26100 provides the same basic functionality as the bq2022 with added battery pack/accessory authentication functions. In addition to four 32-byte pages of general use One Time Programmable (OTP) non-volatile memory available on the bq2022, the bq26100 adds a fifth 32-byte page of OTP and a 16-byte page of EEPROM to be used at the host system designer's discretion. An external high voltage is required for programming the OTP, but not necessary for programming the EEPROM.

A modified form of the SHA-1/HMAC provides the authentication function of the bq26100. Both the host and the bq26100 share two 64-bit keys used in the authentication calculation. To authenticate a battery pack, the host writes a random 20-byte message to the bq26100 and sets the AUTH bit in the CTRL register. The bq26100 calculates the HMAC digest in less than 500 µs, replacing the random message sent by the host with the HMAC result. To complete the authentication process, the host computes the HMAC function with the same 20-byte random message originally written to the bq26100. The result is compared to the HMAC result computed by the bq26100. If the values match, the pack is authenticated.

The key is separated into two 64-bit spaces, allowing multiple parties to program separate portions of the key and providing an added level of security. Programming a key utilizes the SHA-1 algorithm to provide a mix from the values used to program the device to the actual key stored on the device. When put into key programming mode, the device combines the 160-bit message space with a pad as required to get the minimum 512-bit SHA-1 block, and run through the SHA-1 engine once. The 160-bit output is truncated to the lower 64 bits, scrambled internally, and then written to the appropriate non-volatile memory key space. The key can only be read and descrambled by the authentication engine, not by the communication engine, of the bq26100.

Communicating with the bq26100

The bq26100 communication protocol starts when the host pulls the bus low for reset time. All devices on the bus are to respond with a presence pulse, which is active low. The host can then transmit the ROM Function command, which is used to address the devices on the bus. The ROM functions include Match ID, Skip ID, Read ID, and Search ID.

Match ID	The host transmits the 64-bit ID of the 1-wire based device to communicate.
Skip ID	No ID is necessary for communication. Used only if one device is connected to the host.
Read ID	The 1-wire slave transmits its 64 bit address. This command is only useful if there is only one device connected to the host.
Search ID	Useful if there are multiple devices on the bus. This command initiates a communication with a single device, but it is more useful in allowing the host to determine the address of every device on the bus. The Match ID can then be used to communicate with a specific addressed device.

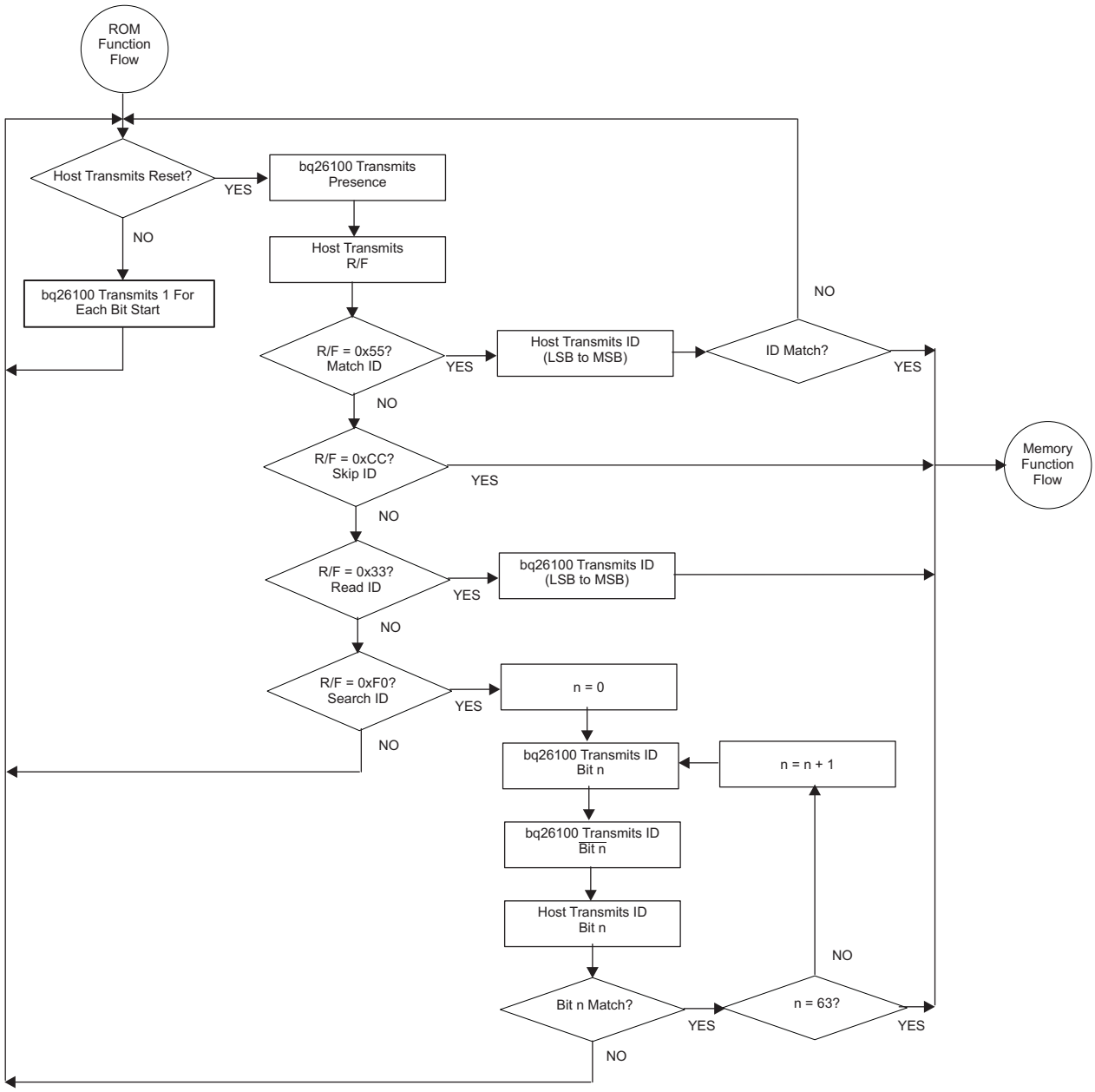


Figure 4. ROM Function Flow Chart

The 64-bit device ID is made up of an 8-bit family code, 48-bit random value, and a final 8-bit CRC.

ID MSB		ID LSB
CRC (8 bits)	Random Data (48 bits)	Family Code (8 bits, defaults to 0x09)

Contact Texas Instruments if specific data should be programmed into the ID.

After the ROM function command is issued and the bq26100 is selected, a Memory Function command can be issued. The Memory Function commands are Read Memory, Read EEPROM, Read Status, Read Page, Read Page 4, Read Digest, Read Control, Write Memory, Write Page 4, Write EEPROM, Write Status, Write Message, Write Control, and Profile.

Figure 5 shows the flow for the Memory Function selection. Figure 6 through Figure 12 illustrate the flow for each memory function.

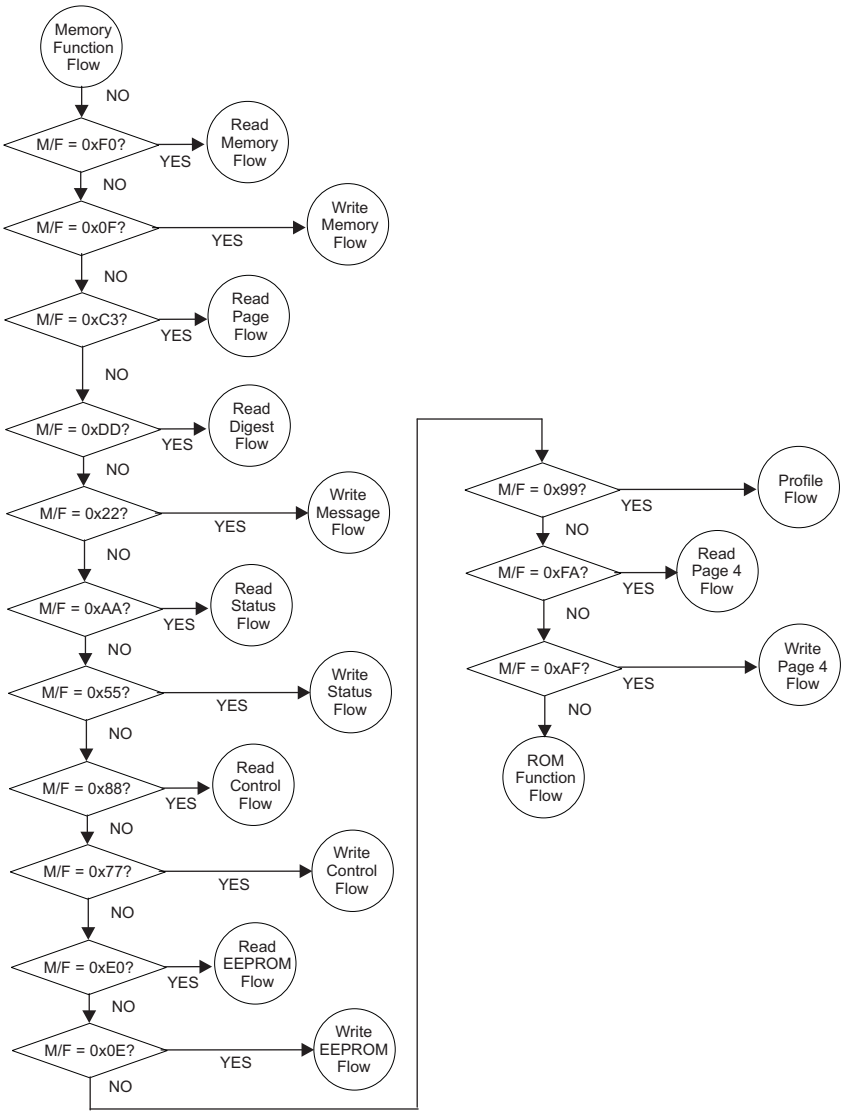


Figure 5. Memory Function Flow Chart

MEMORY DESCRIPTIONS

The bq26100 has a memory and command structure that is compatible with the bq2022, however additional memory and commands have been added. The bq26100 uses a combination of non-volatile One-Time-Programmable (OTP), non-volatile EEPROM, and volatile registers. The memory is split into the following sections:

Non-Volatile OTP Memory

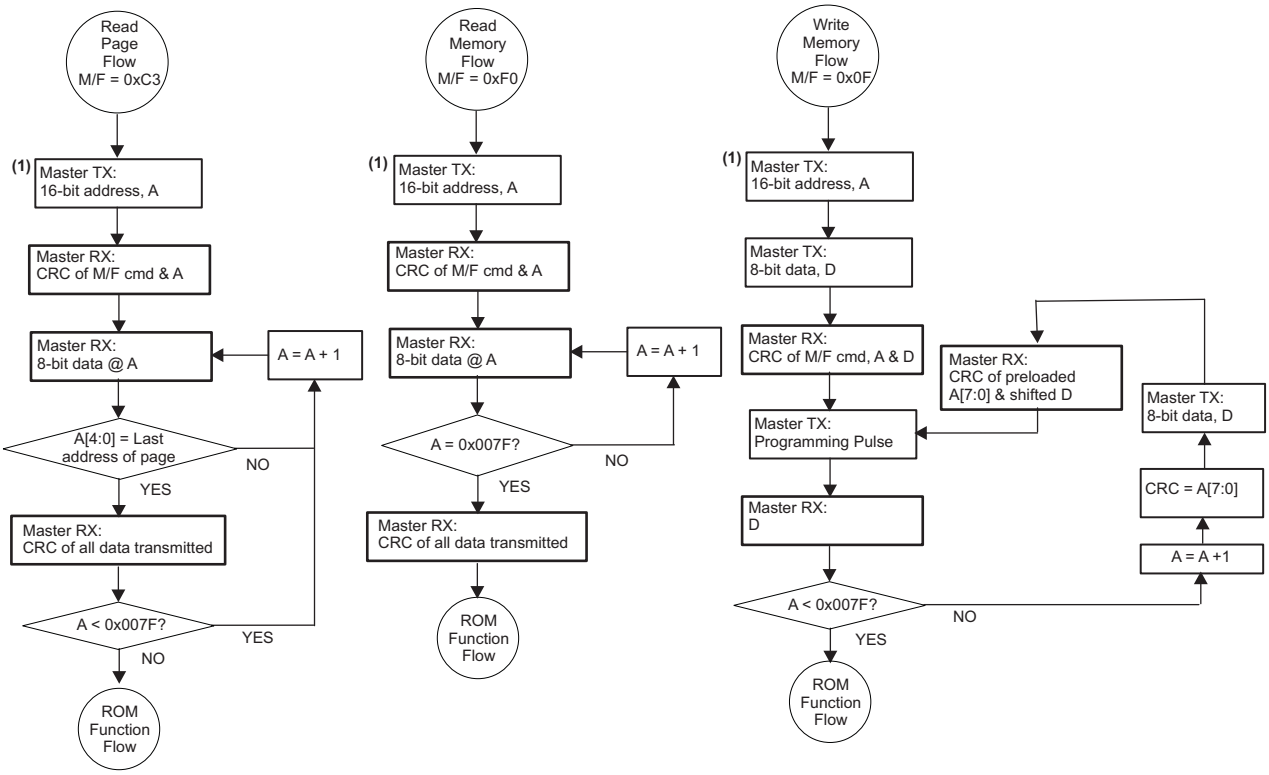
The One Time Programmable (OTP) memory is intended for factory programming. Programming the OTP requires putting a 7-V pulse on the communication pin after writing the data to the intended address.

General Use – Memory Function Commands 0xF0 (Read) and 0x0F (Write)

The general use space is erased to read 0x00. Data written to the general space is ORed with data already present at the address to be written. A bit can only be flipped from **0** to **1**.

Table 1. General Memory Space Addressing

ADDRESSES	FUNCTION
0x007F – 0x0060	Page 3 – 32 bytes general use
0x005F – 0x0040	Page 2 – 32 bytes general use
0x003F – 0x0020	Page 1 – 32 bytes general use
0x001F – 0x0000	Page 0 – 32 bytes general use



(1) 16-Bit address is sent with lower 8-bit address followed by higher 8-bit address with least significant bit first.

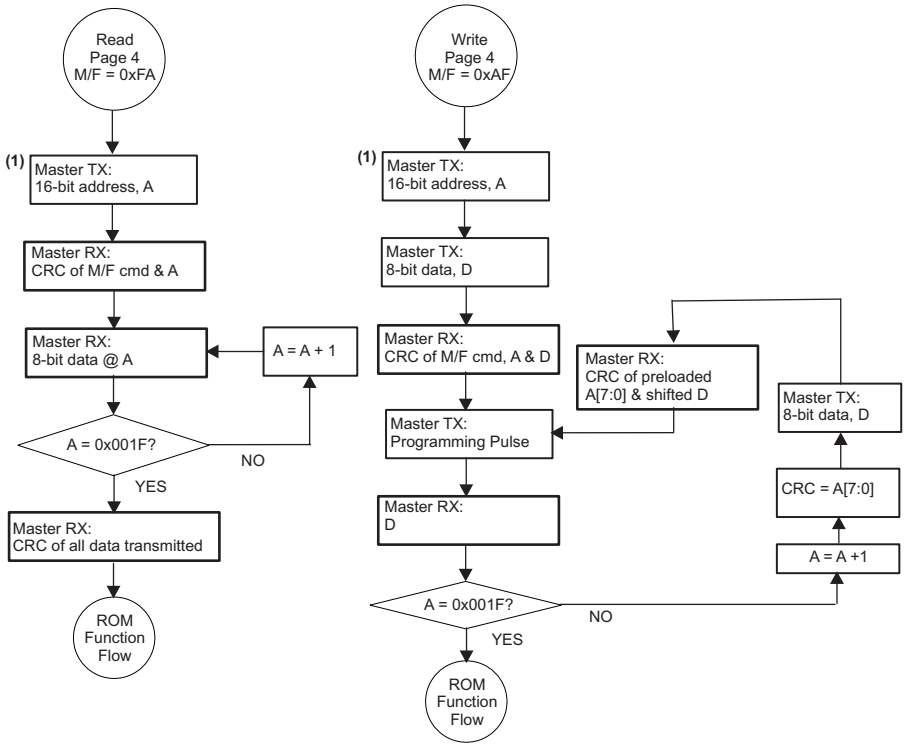
Figure 6. General Memory OTP Write/Read Flows

General Use — Memory Function Commands 0xFA (Read) and 0xAF (Write)

The general use space is erased to read 0x00. Data written to the general space is ORed with data already present at the address to be written. A bit can only be flipped from **0** to **1**.

Table 2. General Memory Space Addressing

ADDRESSES	FUNCTION
0x001F – 0x0000	Page 4 – 32 bytes general use



(1) 16-Bit address is sent with lower 8-bit address followed by higher 8-bit address with least significant bit first.

Figure 7. General Memory OTP Write/Read Flows

Status – Memory Function Commands 0xAA (Read) and 0x55 (Write)

Unlike the general use pages, the status bytes read 0xFF when not programmed and a bit is programmed from **1** to **0**. A zero represents the active state.

Address 0x0007 Reserved

Programmed at the factory to read 0x00

Address 0x0006 Key Index

The host can determine which one of multiple keys was programmed into the bq26100 by reading the key index value.

Address 0x0005 – 0x0001 Page Redirection

A pointer for alternative page information, these bytes can be used if information in the original page has been invalidated. The host can read these locations and direct reads and/or writes to the page pointed to by the value in the register. For example, if the data in page 2 is corrupted by an incorrectly written data value, and the corrected data is in page 1, the value written to address 0x0003 would be 0xFE (1's complement value of 0x01). Upon reading address 0x0003, the host would receive 0xFE and would take the 1's complement to determine that page 1 contains redirected data.

Table 3. Page Redirection

ADDRESS	PAGE REDIRECTED
0x0005	Page 4
0x0004	Page 3
0x0003	Page 2
0x0002	Page 1
0x0001	Page 0

There is no hardware mapping of the page redirection bytes. The host is responsible for sending the correct address for a redirected page.

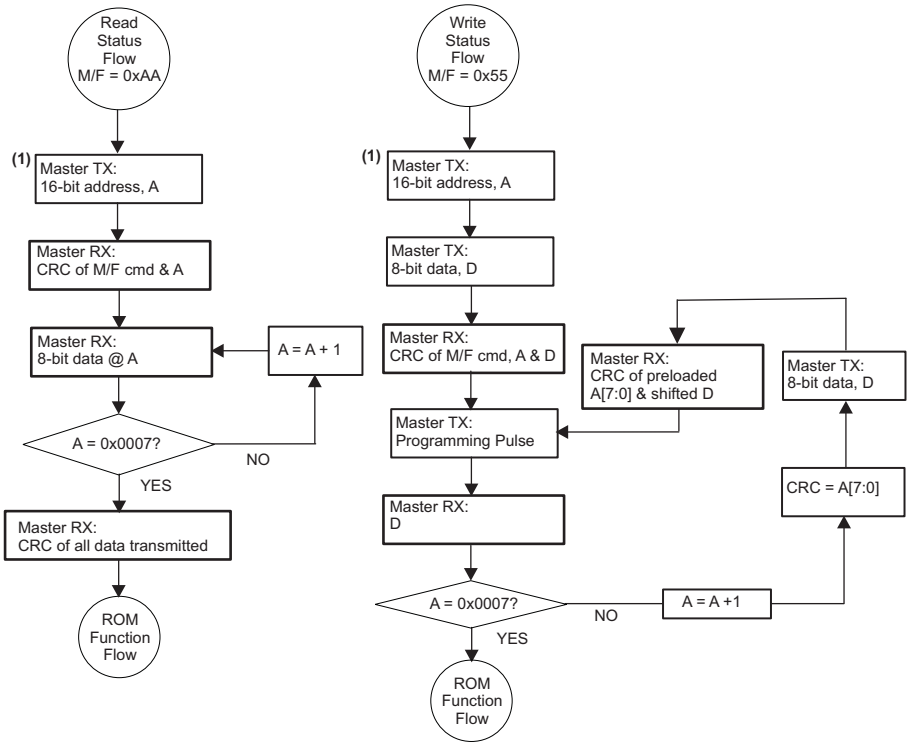
Address 0x0000 PAGE LOCK

	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
FUNCTION	LOCKK1	LOCKK0	RSVD	PAGE 4	PAGE 3	PAGE 2	PAGE 1	PAGE 0

LOCKK1 Programming this bit to **0** locks the upper 64 bits of the device key, preventing additional writes. This bit can only be written once.

LOCKK0 Programming this bit to **0** locks the lower 64 bits of the device key, preventing additional writes. This bit can only be written once.

PAGEx Programming this bit to **0** locks page designated by x, preventing additional writes. This bit can only be programmed once.



(1) 16-Bit address is sent with lower 8-bit address followed by higher 8-bit address with least significant bit first.

Figure 8. Status OTP Write/Read Flows

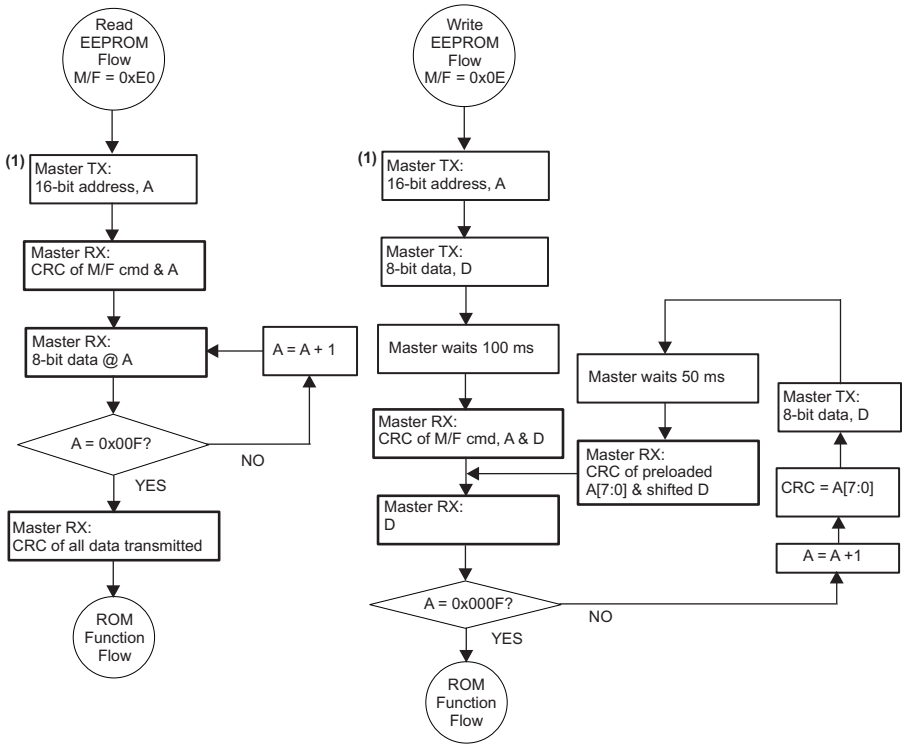
Non-Volatile EEPROM Memory

The EEPROM memory is intended for in-field programming. Programming the EEPROM is no different than writing to RAM or registers, but the timing between the write and read back is different. A bit can be written to **1** or cleared to **0** multiple times and the value is retained when power to the device is removed.

General Use – Memory Function Commands 0xE0 (Read) and 0x0E (Write)

Table 4. General Memory Space Addressing

ADDRESSES	FUNCTION
0x000F – 0x0000	16 Bytes general use



(1) 16-Bit address is sent with lower 8-bit address followed by higher 8-bit address with least significant bit first.

Figure 9. EEPROM Write/Read Flows

Volatile Register Memory

The register memory is intended for in-field programming.

Message and Digest Registers – Memory Function Command 0xDD (Read) and 0x22 (Write)

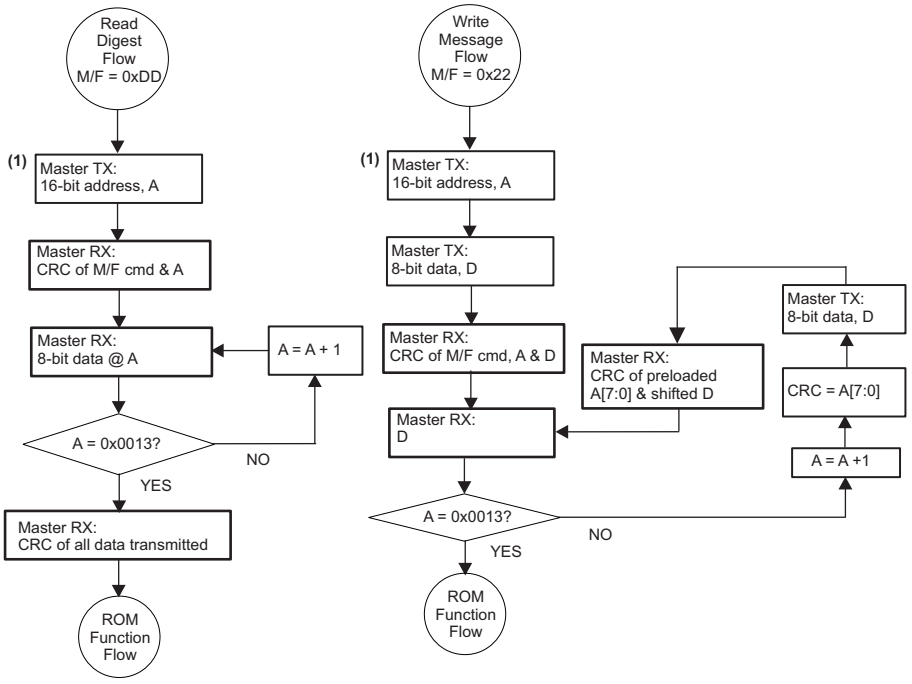
The message is a 160-bit input to the HMAC calculation, and the digest is the 160-bit output of the HMAC calculation. The message and digest share the same memory space, meaning that the message cannot be read back once the digest has been computed. The MSB of the message should be written to address 0x0013, and the LSB written to address 0x0000. The digest overwrites the message in the following manner.

Table 5. Message/Digest Space Addressing

ADDRESS	MESSAGE VALUE	DIGEST VALUE
0x0013 – 0x0010	M[159:128]	A[31:0]
0x000F – 0x000C	M[127:96]	B[31:0]
0x000B – 0x0008	M[95:64]	C[31:0]
0x0007 – 0x0004	M[63:32]	D[31:0]
0x0003 – 0x0000	M[31:0]	E[31:0]

NOTE:

See the SHA-1 and HMAC descriptions for more information on the meaning of the variables in the above table.



(1) 16-Bit address is sent with lower 8-bit address followed by higher 8-bit address with least significant bit first.

Figure 10. Message/Digest Write/Read Flows

Control and Version Registers – Memory Function Command 0x88 (Read) and 0x77 (Write)

The control register starts authentication, clears the message/digest values, and flags when the authentication process has completed. The version register is used to determine the silicon revision.

Table 6. General Memory Space Addressing

ADDRESSES	FUNCTION
0x0001	Silicon Revision Number
0x0000	Control Register

The bits of the Control register are as follows:

	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
NAME	PROGK1	PROGK0	RSVD	CLEAR	RSVD	POR	DONE	AUTH
POR STATUS	0	0	0	0	0	1	0	0

PROGK1 If LOCKK1 is **1** (see Status Register), writing this bit to **1** enables the programming of Device Key 1. Further information about the programming of the keys is found in the SHA-1 section.

PROGK0 If the LOCKK0 bit is **1** (see Status Register), writing this bit to **1** enables the programming of Device Key 0. Further information about the programming of the keys is found in the SHA-1 section.

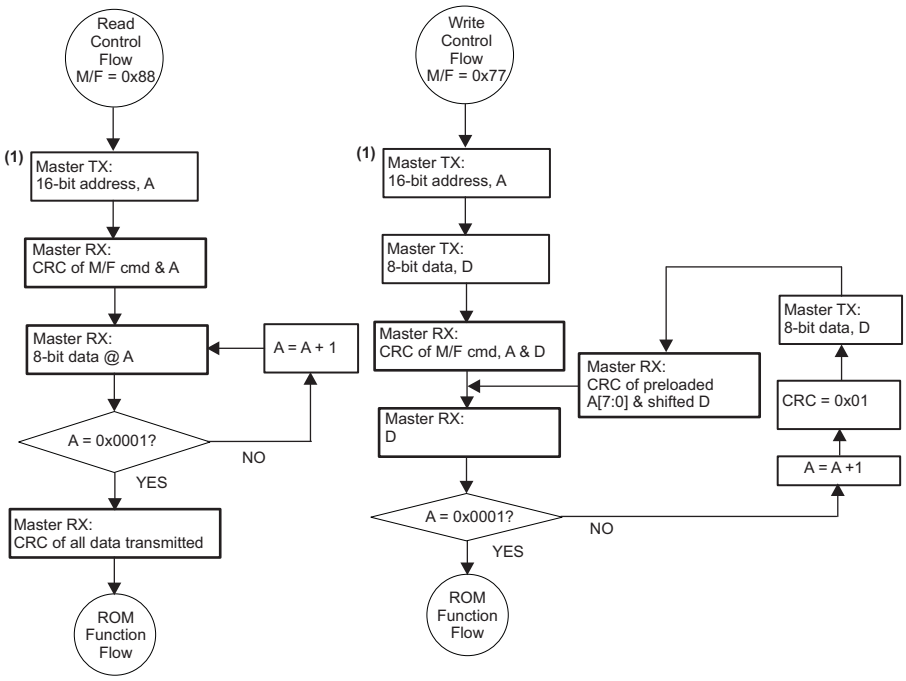
RSVD These bits are reserved for future use. They should always be written to **0**.

CLEAR Writing this bit to **1** clears the message/digest registers. This can be done before the message is written to ensure that all data values are known or after the digest is read to clear the HMAC calculation output. The bq26100 resets the bit back to 0.

POR This bit is set when the device comes out of a POR condition. The bit can be written to **0** to clear the flag. Writing the bit to **1** has no effect on device operation.

DONE This bit is set when the device completes the HMAC calculation. The host should poll for this bit to determine when the digest is available for reading. This bit is automatically cleared when the AUTH bit is written to **1**. This bit is also cleared at POR.

AUTH This bit is set to initiate the HMAC calculation. This bit is automatically cleared when the DONE bit is written to **1**.



(1) 16-Bit address is sent with lower 8-bit address followed by higher 8-bit address with least significant bit first.

Figure 11. Control Register Write/Read Flows

Profile Command

Pack manufacturers can use the profile command to determine how the device should be programmed.

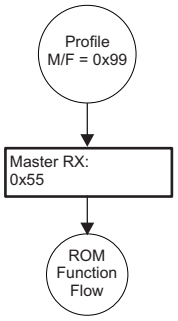


Figure 12. Profile Command Flow

SLEEP MODE DESCRIPTION

The bq26100 enters sleep mode when the SDQ enters a stop state or when SDQ encounters an invalid ID.

SHA-1 DESCRIPTION

The SHA-1 is known as a one-way hash function, meaning there is no known mathematical method of computing the input given only the output. The specification of the SHA-1, as defined by FIPS 180-2, states that the input consists of 512 bit blocks with a total input length less than 2^{64} bits. Inputs which do not conform to integer multiples of 512 bit blocks are padded before any block is input to the hash function. The SHA-1 algorithm outputs 160 bits, commonly referred to as the digest.

The full SHA-1 specification and algorithm can be found at http://csrc.nist.gov/publications/fips under FIPS 180. (As of April 23, 2004 the latest revision is FIPS 180-2).

The bq26100 generates an SHA-1 input block of 288 bits (total input = 160 bit message + 128 bit key). To complete the 512 bit block size requirement of the SHA-1, the bq26100 pads the key and message with a 1, followed by 159 0's, followed by the 64 bit value for 288 (000…00100100000), which conforms to the pad requirements specified by FIPS 180-2:

HMAC DESCRIPTION

The SHA-1 engine is used to calculate a modified HMAC value. Using a public message and a secret key, the HMAC output is considered to be a secure *fingerprint* that authenticates the device used to generate the HMAC.

To compute the HMAC let *H* designate the SHA-1 hash function, *M* designate the message transmitted to the bq26100, and K_D designate the unique 128 bit device key of the bq26100. HMAC(M) is defined as:

$H[K_D \,||\, H(K_D \,||\, M)]$, where || symbolizes an append operation

The message, *M*, is appended to the device key, K_D, and padded to become the input to the SHA-1 hash. The output of this first calculation is then appended to the device key, K_D, padded again, and cycled through the SHA-1 hash a second time. The output is the HMAC digest value.

KEY PROGRAMMING DESCRIPTION

The 128-bit key used in the HMAC calculation is built from two 64-bit key spaces on the bq26100. Each key can be programmed independently, allowing multiple parties to program part of the full 128-bit key without the knowledge necessary to reproduce the full 128-bit key. To further protect the 128-bit key, the value written to each 64-bit non-volatile key space is the output of a SHA-1 calculation on a 160-bit input. Figure 13 provides a flow for the programming of the 128-bit device key. Once KEYx has been programmed, the LOCKKx bit should be programmed to 0 in the status register, preventing another value from overwriting that key space.

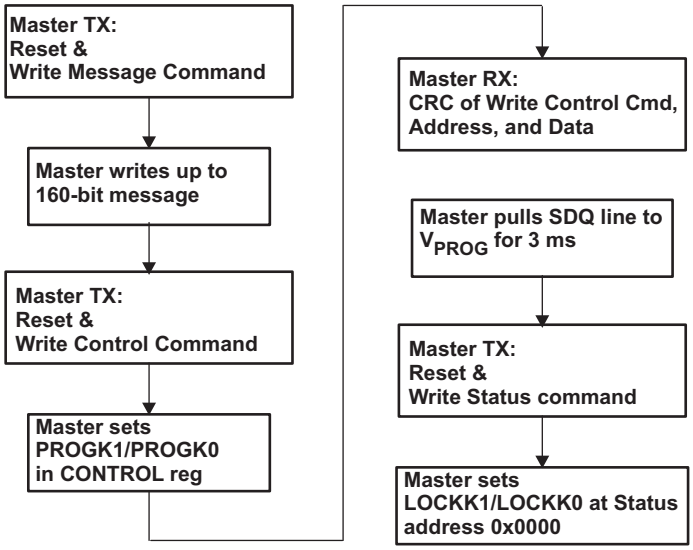


Figure 13. Key Programming Flow

This flow is run twice, for KEY0 and KEY1. An external power source is required on the PWR pin during key programming. Figure 14 shows a typical connection for the external power source.

Since there is no key pre-appended to the message, the key message is padded with a 1, followed by 287 0's, followed by the 64-bit value for 160 (00..01010000):

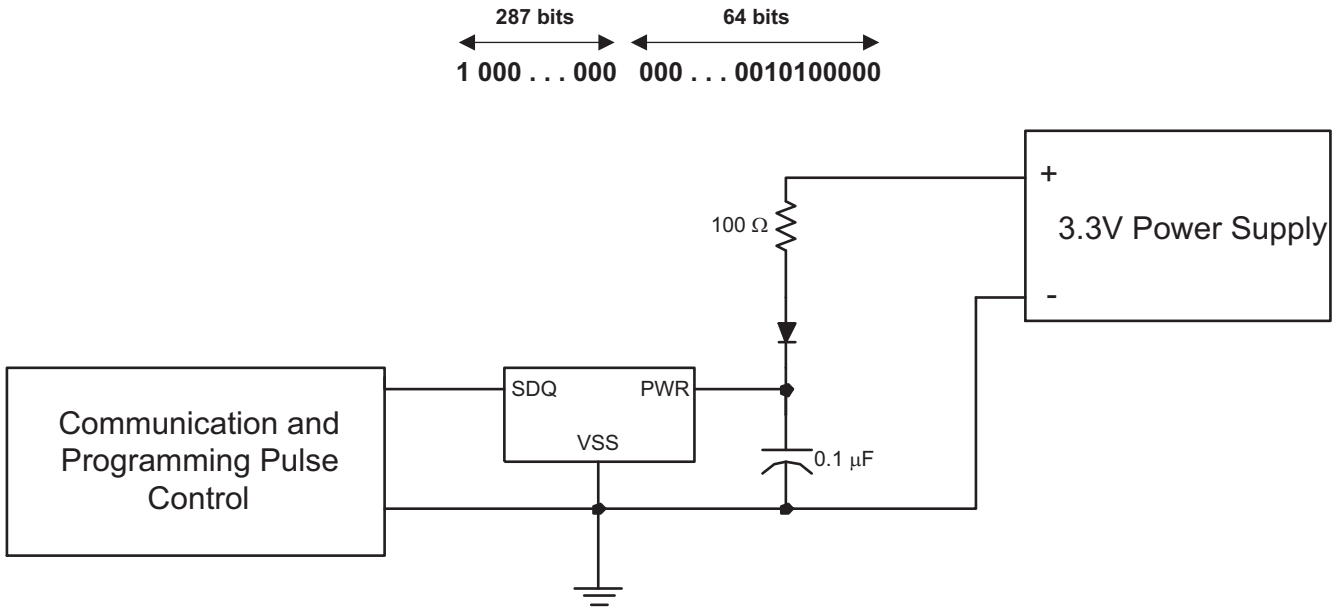


Figure 14. External Power Source Connection

PACKAGING INFORMATION

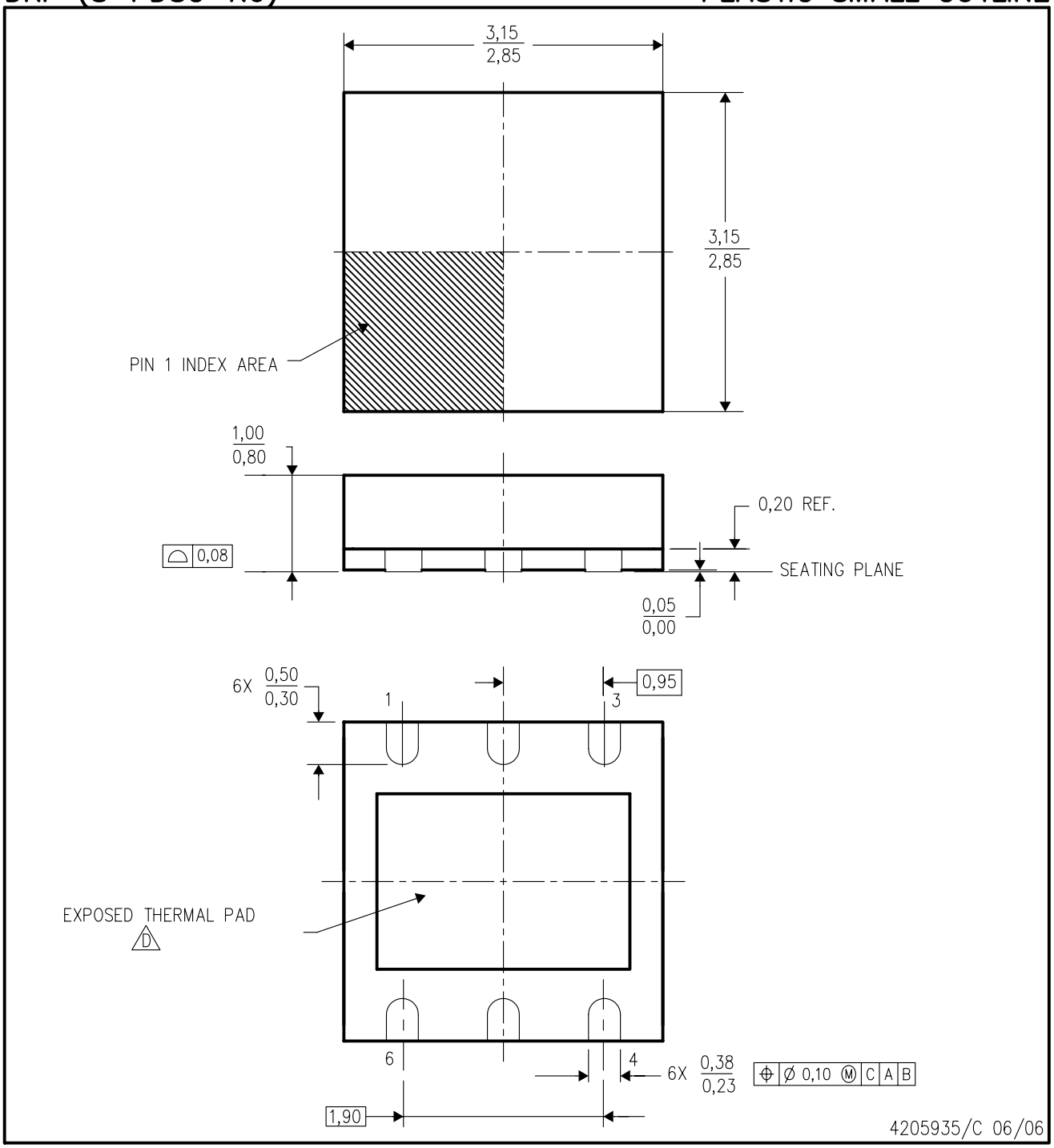
Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
BQ26100DRPR	ACTIVE	SON	DRP	6	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
BQ26100DRPRG4	ACTIVE	SON	DRP	6	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR

(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.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
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.

DRP (S–PDSO–N6) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. Small Outline No–Lead (SON) package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance. See the Product Data Sheet for details regarding the exposed thermal pad dimensions.

THERMAL PAD MECHANICAL DATA

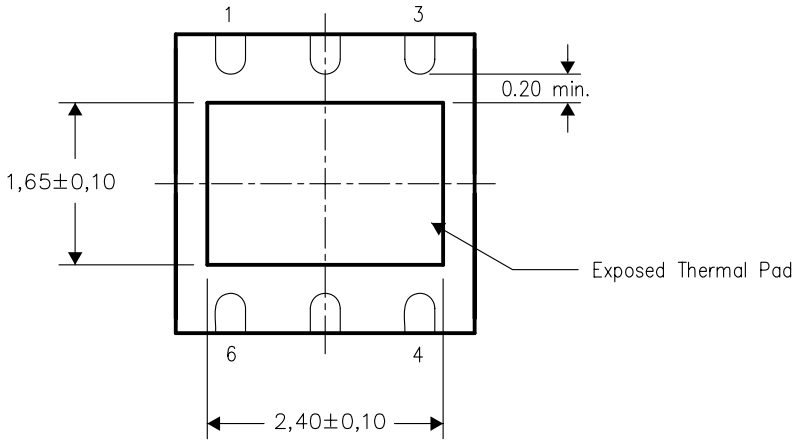
DRP (S–PDSO–N6)

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to a ground or power plane (whichever is applicable), or alternatively, a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No–Lead (QFN) package and its advantages, refer to Application Report, Quad Flatpack No–Lead Logic Packages, Texas Instruments Literature No. SCBA017. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.



Bottom View

NOTE: All linear dimensions are in millimeters

Exposed Thermal Pad Dimensions

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Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265