

**AC410**  
**Application Note**  
**Using AES System Services in SmartFusion2 and**  
**IGLOO2 Devices - Libero SoC v11.8**



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# 1 Revision History

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The revision history describes the changes that were implemented in the document. The changes are listed by revision, starting with the most current publication.

## 1.1 Revision 6.0

The following changes were made in revision 6.0 of this document.

- A footnote about SoftConsole was removed from the SmartFusion2 design requirements. For more information, see [Design Requirements](#), page 2.
- The procedure to run the design was updated. For more information, see [Running the Design](#), page 11.

## 1.2 Revision 5.0

The document was updated for Libero v11.7 software release (SAR 76152).

## 1.3 Revision 4.0

The document was updated for Libero v11.6 software release (SAR 71462).

## 1.4 Revision 3.0

The document was updated for Libero v11.5 software release (SAR 64229).

## 1.5 Revision 2.0

The following changes were made in revision 2.0 of this document.

- The document was updated for Libero version 11.4 (SAR 61019).
- Updates were made to maintain the style and consistency of the document.

## 1.6 Revision 1.0

Revision 1.0 was the first publication of this document.

## 2 Using AES System Services in SmartFusion2 and IGLOO2 Devices

AES is an encryption solution developed to achieve several rapidly-evolving security concerns that have arisen within the computer and embedded semiconductor industries. Selected devices of the SmartFusion<sup>®</sup>2 SoC FPGA and IGLOO<sup>®</sup>2 FPGA families allow the user to access the built-in AES engines and use AES encryption and decryption operation. These devices are marked as S (Data and Design Security) in the device part number. The AES engine in the SmartFusion2 and IGLOO2 devices is part of the Cryptographic Services block and resides in the system controller. The AES engine in the SmartFusion2 and IGLOO2 devices can accept 128-bit plain text input word and generates the corresponding 128-bit ciphertext output word using a supplied 128-/256-bit AES key. It also provides a reverse function by generating plaintext from the supplied ciphertext using the same AES key as used for encryption. The AES engine is accessible through the system services. The system services are system controller actions initiated by asynchronous events from the ARM Cortex-M3 processor in the SmartFusion2 device or a fabric master in the SmartFusion2 and IGLOO2 devices. The AES cryptographic services can be used for data security applications and can be disabled through factory or user security settings.

### 2.1 Design Requirements

The following tables list the design requirements of SmartFusion2 and IGLOO2 devices, respectively.

**Table 1 • Design Requirements for SmartFusion2 Devices**

Design Requirements	Description
<b>Hardware Requirements</b>	
SmartFusion2 Security Evaluation Kit (M2S-EVAL-KIT):	Rev D or later
– 12 V adapter (provided along with the kit)	
– FlashPro4 programmer (provided along with the kit)	
– M2S090TS-1FGG484	
Host PC or Laptop	Any 64-bit Windows operating system
<b>Software Requirements</b>	
Libero <sup>®</sup> System-on-Chip (SoC)	v11.8
SoftConsole	4.0

**Table 2 • Design Requirements for IGLOO2 Devices**

Design Requirements	Description
<b>Hardware Requirements</b>	
IGLOO2 Evaluation Kit:	Rev D or later
– 12 V wall-mounted power supply (provided along with the kit)	
– FlashPro4 programmer (provided along with the kit)	
– M2GL090TS-1FGG484	
Host PC or Laptop	Any 64-bit Windows Operating System
<b>Software Requirements</b>	
Libero SoC	v11.8

**Note:** The IGLOO2 design uses the M2GL090TS-1FGG484 device in the IGLOO2 Evaluation Kit. However, the official IGLOO2 Evaluation Kit uses M2GL010T-1FGG484 device. To run the application note design on an M2GL010T-1FGG484 device, refer to the KB5659 for migrating from M2GL090TS-1FGG484 to M2GL010T-1FGG484.

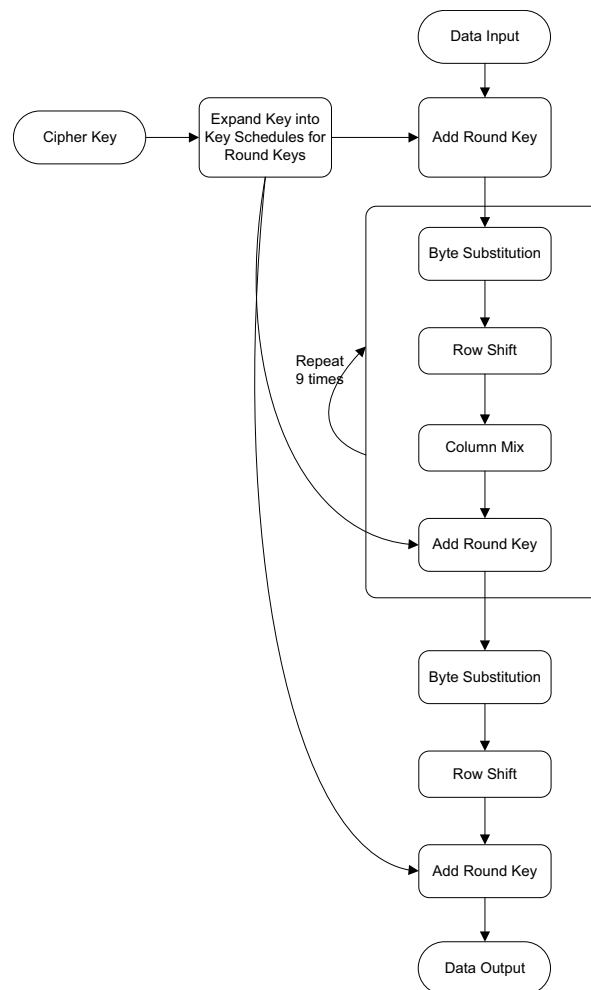
## 2.2 AES Engine

The AES engine uses the Rijndael algorithm with national institute of standards and technology (NIST) approved parameters as described in federal information processing standards (FIPS) publication (PUB) 197. The AES encryption algorithm receives 128-bit of plaintext data and 128-/192-/256-bit of a cipher key as input. After several rounds of computation, it produces 128-bit enciphered version of the original plaintext data as output. The key size used for an AES cipher determines the number of transformation rounds to convert the input into the final output, ciphertext. During the rounds of the algorithm, the data bits are subjected to byte substitution, data shift operations, data mixing operations, and additional operations (XOR) with an expanded version of the original 128-/192-/256-bit cipher key. The reverse happens during the decryption operation.

The SmartFusion2 and IGLOO2 AES engine can be operated in 128-bit key mode or 256-bit key mode and supports both encryption and decryption services.

The following figure shows the AES encryption algorithm with 128-bit key.

**Figure 1 • AES Encryption Algorithm (128-bit Cipher Key)**



The SmartFusion2 and IGLOO2 AES engine assumes that the input data is in complete 128-bit blocks and provides the complete 128-bit output blocks. Add any padding bits to the incomplete plaintext blocks before calling the AES encryption service and remove any padding bits after receiving the results of the



AES decryption service. The input and output data format of the AES services is little-endian type. The first byte of the first block is at the lowest address and there are no word alignment requirements. In other words, consecutive bytes of the plaintext, ciphertext, and keys from the first to last are stored in order in memory from the lowest to the highest bit address.

## 2.2.1 AES Mode of Operation

The mode of operation describes how to apply the ciphers single-block operation repeatedly to securely transform the data that is larger than a block. The built-in system services are designed to support the following cipher operating modes as recommended in NIST Special Publication 800-38A, recommendation for Block Cipher Modes of Operation:

### 2.2.1.1 Electronic Codebook

The electronic codebook (ECB) mode is a confidentiality mode that features, for a given key, the assignment of a fixed ciphertext block to each plaintext block, analogous to the assignment of code words in a codebook. It is the simplest encryption mode. The message is divided into blocks and each block is encrypted separately. Identical plaintext blocks are encrypted into identical ciphertext blocks; thus, it does not hide data patterns well.

### 2.2.1.2 Cipher-Block Chaining

The cipher block chaining (CBC) mode features the combination (chaining) of the plaintext blocks with the previous ciphertext blocks. To make each message unique, an initialization vector (IV) must be used in the first block. The IV need not to be secret, but it must be unpredictable.

### 2.2.1.3 Output Feedback

The output feedback (OFB) features the iteration of the forward cipher on an IV to generate a sequence of output blocks that are XORed with the plaintext to produce the ciphertext and vice-versa. The OFB mode requires a nonce IV, that is, the IV must be unique for each execution of the mode under the given key.

### 2.2.1.4 Counter

The counter (CTR) mode features the application of the forward cipher to a set of input blocks, called counters, to produce a sequence of output blocks that are XORed with the plaintext to produce the ciphertext and vice-versa. The sequence of counters must have the property that each block in the sequence is different from every other block, thus the IV should be a nonce and must be unique for each execution of the mode under the given key.

In the SmartFusion2 and IGLOO2 devices, the OPMODE parameter specifies the cipher operating mode, refer to [Table 3](#), page 7. The IV parameter used during the AES system service specifies the IV.

Refer to [Using AES Services in SmartFusion2 and IGLOO2 Devices](#), page 6 for more information.

## 2.3 SmartFusion2 and IGLOO2 Cryptographic Block

In the SmartFusion2 and IGLOO2 devices, the AES engine is part of this Cryptographic Services block that resides in System Controller.

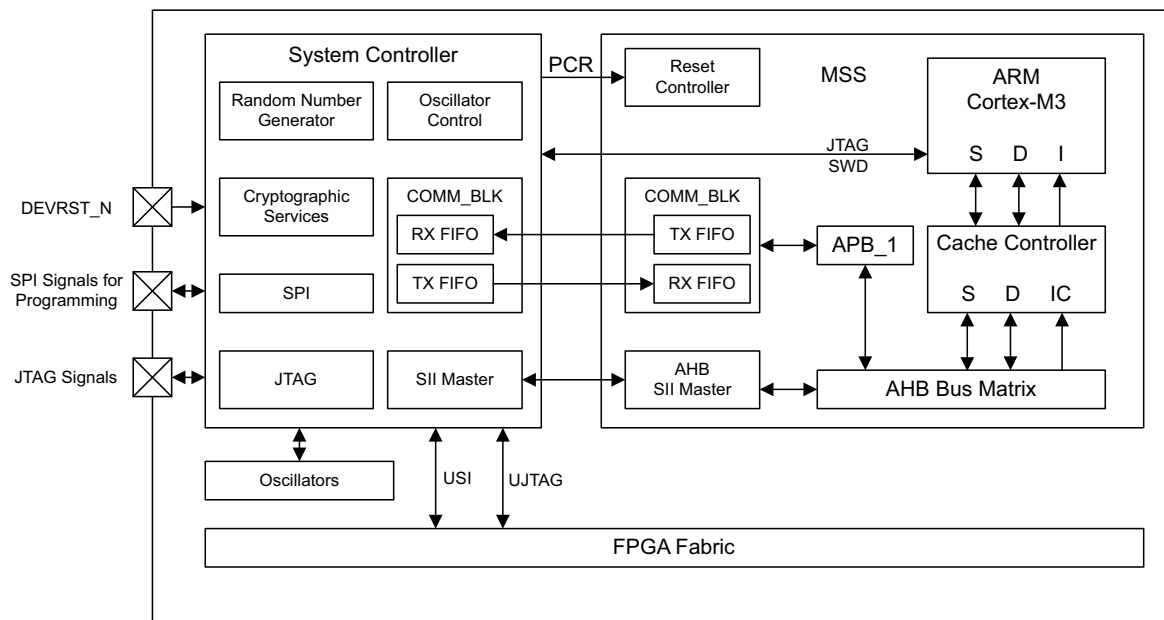
### 2.3.1 System Controller Block in SmartFusion2 Devices

The Cryptographic Services block can be accessed through the communication block (COMM\_BLK). There are two COMM\_BLK instances: one in the microcontroller subsystem (MSS) that the user interfaces with and the other that communicates with the first block that is located in the system controller. The COMM\_BLK consists an APB interface, eight byte transmit FIFO, and eight byte receive FIFO. The COMM\_BLK provides a bi-directional message passing facility between the MSS and the system controller. The AES system services are initiated using the COMM\_BLK in the MSS, which can be read or write by any master on the AMBA high performance bus (AHB) matrix; typically either the Cortex-M3 processor or a design in the FPGA fabric (also known as a fabric master). The system controller receives the command through the COMM\_BLK in the system controller. The system controller uses the SII master, an MSS bus master controlled by the system controller, to get the additional details and options of the AES command at an address provided in the original COMM\_BLK command, pointing where this structured data has been stored in the memory before invoking the command. The AES

output bytes returned by the system controller are written to a memory address specified in this data structure. On completion of the requested service, the system controller returns a status message through the COMM\_BLK.

The following figure shows the system controller block in the SmartFusion2 device, where the Cryptographic Services block resides.

**Figure 2 • System Controller Block in SmartFusion2 Devices**

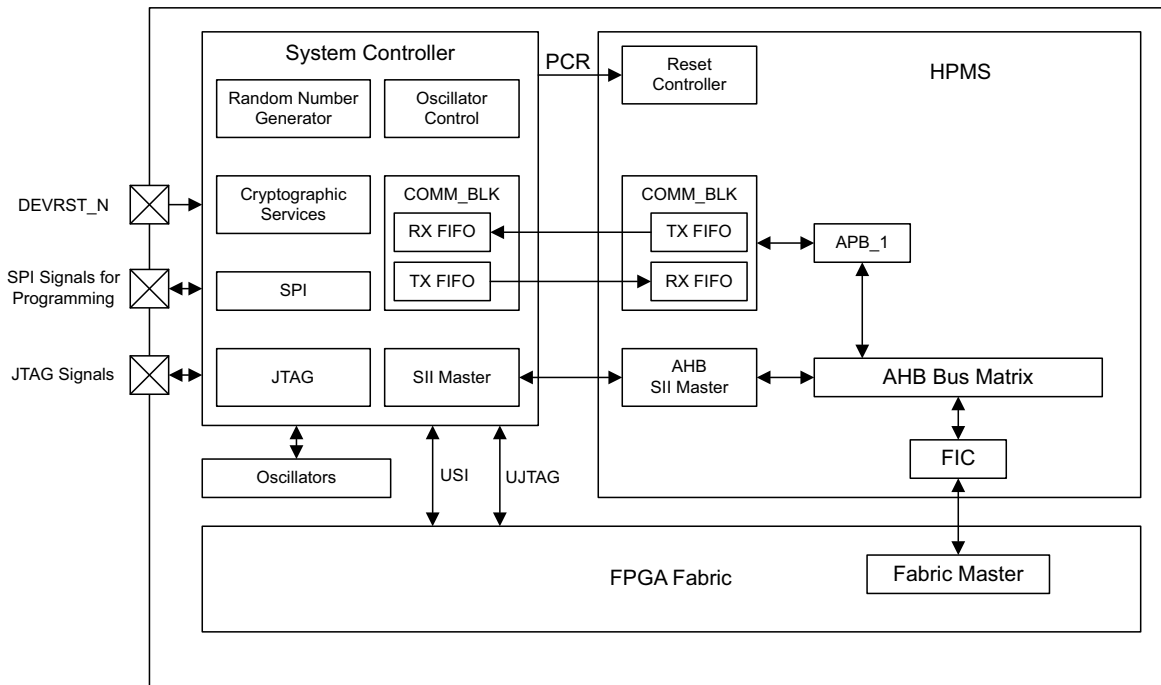


### 2.3.2 System Controller Block in IGLOO2

The architecture and uses of the AES engine are similar to the IGLOO2 device except the COMM\_BLK in the system controller communicated with COMM\_BLK in high performance memory subsystem (HPMS). It is required to use a fabric master to initiate the AES system services. Microsemi® provides the CoreSysService DirectCore IP that acts as fabric master to use the AES system services. The CoreSysServices soft IP communicates with the COMM\_BLK through one of the fabric interface controllers (FICs), sends the AES system service request, retrieves the ciphertext output, and sends to use the interface.

The following figure shows the system controller block in the IGLOO2 device.

**Figure 3 • System Controller Block in IGLOO2 Devices**



Refer to the [UG0450: SmartFusion2 SoC and IGLOO2 FPGA System Controller User Guide](#) for more details on System Controller.

Also, refer to the Communication Block chapter in the [UG0331: SmartFusion2 Microcontroller Subsystem User Guide](#), [UG0448: IGLOO2 FPGA High Performance Memory Subsystem User Guide](#) for more information on System Controller.

## 2.4 Using AES Services in SmartFusion2 and IGLOO2 Devices

In the SmartFusion2 device, the AES services can be accessed using the `mss_sys_services` driver in the firmware core configurator. In the IGLOO2 device, use a master in fabric to initiate the AES system services in the system controller through the COMM\_BLK. You can create any fabric master block following the steps explained below or use CoreSysServices soft IP for the AES services.

CoreSysServices provides a simple user interface in one side and an AHB-Lite master interface on the FIC side to use the system services through the COMM\_BLK. You can use the IGLOO2 approach in the SmartFusion2 device also.

Following are the two options to use the AES engine in the SmartFusion2 device:

- Using firmware core through the MSS
- Using CoreSysService or own state logic as fabric master

The following steps describe how to use the 128-bit AES encryption system service in the IGLOO2 device:

1. Set up the AES128DATAPTR descriptor in the user memory space, which contains the following 44 bytes as indicated in the following table.

**Table 3 • AES128DATAPTR Structure**

Offset	Length (Bytes)	Field	Description
0	16	KEY	Encryption key to be used
16	16	IV	IV (Ignored for ECB mode)
32	2	NBLOCKS	Number of 128-bit blocks to process (maximum 65535)
34	1	MODE	Cipher operating mode. – Bit 7: DECRYPT – Bit 6: RESERVED – Bit 1: OPMODE – Bit 0: OPMODE DECRYPT: If DECRYPT is 0 then the data at SRCADDRPTR field is treated as plaintext for encryption. If DECRYPT is 1 then the data at SRCADDRPTR field is treated as cipher text for decryption. OPMODE: Defines operating mode. – 00: ECB mode – 01: CBC mode – 10: OFB mode – 11: CTR mode
35	1	RESERVED	Reserved
36	4	DSTADDRPTR	Pointer to return data buffer
40	4	SRCADDRPTR	Pointer to data to encrypt/decrypt

2. Enable the COMBLK\_INTR interrupt from the COMM\_BLK block to fabric by enabling COMBLK\_INTR\_ENBL bit (29-bit) in INTERRUPT\_ENABLE0 register at address 0x40006000.
3. Setup the registers in the COMM\_BLK and send the command for 128-bit AES (0x03). The following table describes the AES command values.

**Table 4 • AES Command Value**

System Service Name	Command Value
128-bit AES Cryptographic Service	3
256-bit AES Cryptographic Service	6

The system controller receives the command through the COMM\_BLK in the system controller. The system controller reads the key and data from the address pointer and generates the AES ciphertext test. On completion, the service system controller returns a status message through the COMM\_BLK.

Wait for RCVOKAY bit to be set in the COMM\_BLK STATUS register.

- Read the Word Data register in the COMM\_BLK and check the command, status code, and AES128DATAPTR descriptor pointer, as indicated in the following table.

**Table 5 • 128-bit AES Service Response Parameters**

Offset	Length (Bytes)	Field	Description
0	1	CMD = 3	Command
1	1	STATUS	Command status
1	4	AES128DATAPTR	Pointer to AES128DATA descriptor

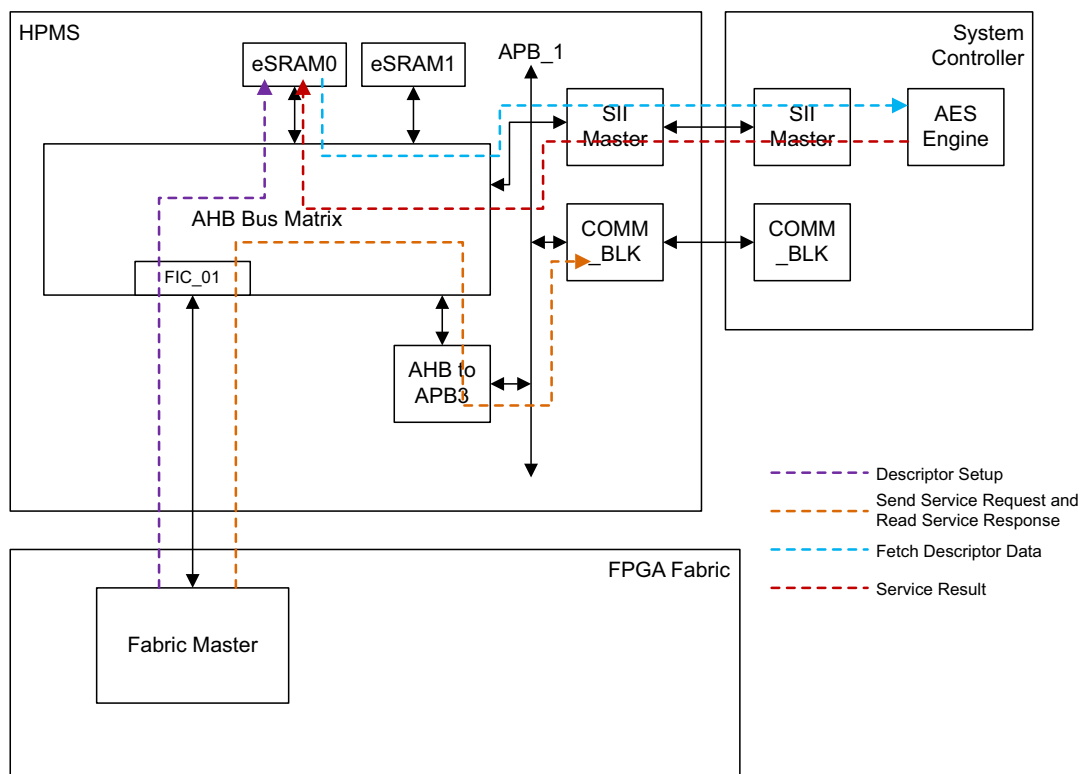
The following table lists the service response status codes.

**Table 6 • Service Response Status Codes**

Status	Description
0	Success
127	HRESP error occurred during the MSS transfer
253	Not licensed
254	Service disabled by factory security
255	Service disabled by user security

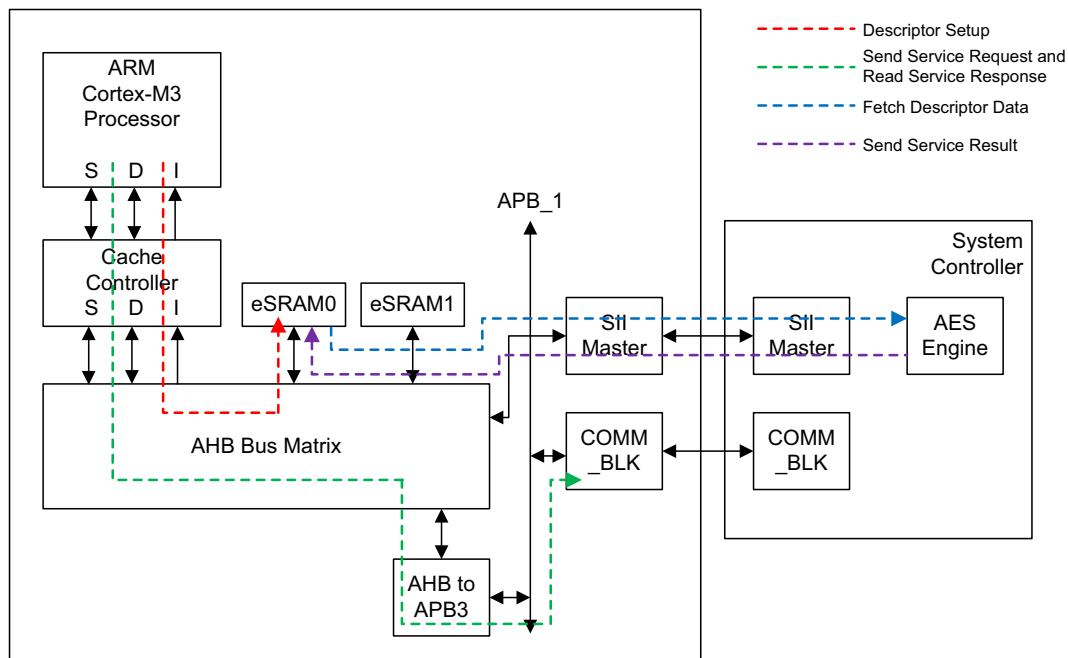
- Read the AES data from user memory space (at the return, data buffer address is specified in 1).  
The following figure shows the AES system service data flow diagram in the IGLOO2 device.

**Figure 4 • AES Service Flow Diagram for IGLOO2 Devices**



The steps for using the AES service in 256-bit key mode are similar to SmartFusion2. The following figure shows the system service data flow diagram while initiating the AES service from the Cortex-M3 processor.

**Figure 5 • AES Service Flow Diagram for SmartFusion2 Devices**



**Note:** You can use CoreSysServices IP in the SmartFusion2 or IGLOO2 devices and initiate the AES system service using its simple user interface. Send the AES service request with the required data/parameter to CoreSysServices IP. CoreSysServices IP performs the required steps to setup the descriptor, sends the command through the COM\_BLK to the AES service, and reads the data back from the eSRAM. Refer to the *CoreSysServices Handbook* for more information.

## 2.5 Design Description

This application note includes two design examples for using the AES system service:

- AES\_Services\_SF2 design example: Demonstrates 128-bit and 256-bit AES encryption and decryption in the SmartFusion2 device using the Microsemi system driver firmware code.
- AES\_Services\_IGL2 design example: Demonstrates 128-bit AES encryption and decryption in the IGLOO2 device using the Microsemi CoreSysServices IP core.

The SmartFusion2 device design is implemented on the SmartFusion2 Security Evaluation Kit (M2S-EVAL-KIT) using the M2S090TS-1FGG484 device. The IGLOO2 device design is implemented on the IGLOO2 Evaluation Kit board using the M2GL090TS-1FGG484 device.

## 2.6 Design Example - Using AES Services in SmartFusion2 Devices

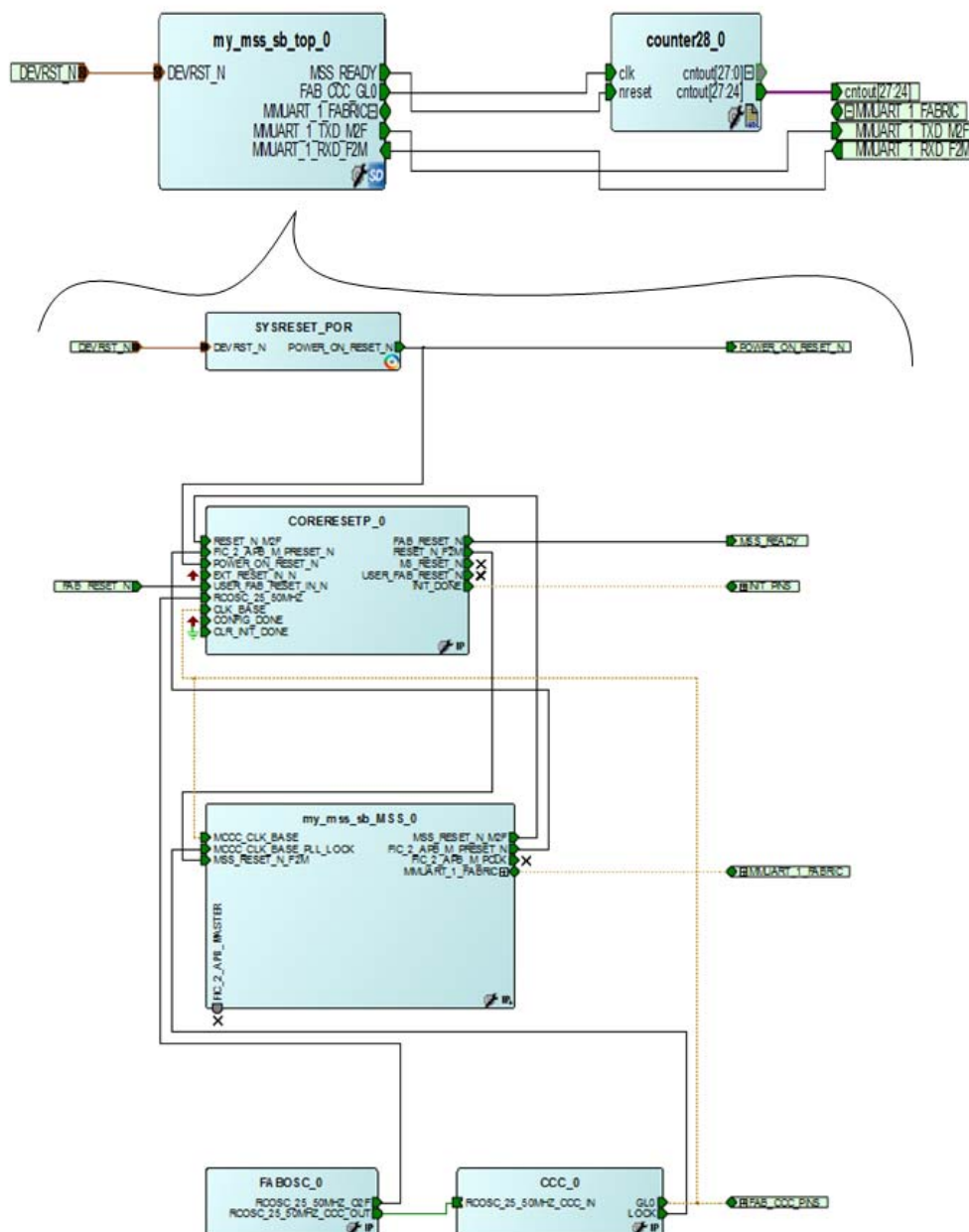
The design example consists the RC oscillator, a fabric CCC, and MSS. The fabric PLL is used to provide the base clock for the MSS. The system services are run using various C routine in the MSS, as shown in the sub-sections. In addition, a universal asynchronous receiver/transmitter (UART1) in the MSS is used to display the operation of the AES system service.

### 2.6.1 Hardware Implementation

The RC oscillator is used to generate a 50 MHz input clock and the fabric PLL is used to generate a 100 MHz clock from the RC oscillator. The 100 MHz clock is used as the base clock for the MSS. The MMUART\_1 signals are routed through the FPGA fabric for communicating with the serial terminal program. The counter block is used to show that the device is up and running.

The following figure shows a block diagram of the design example.

**Figure 6 • SmartFusion2 AES System Service Design Example**



## 2.6.2 Software Implementation

The software design example performs the following operations:

1. Initialize the System Controller Enable
2. Initialize MMUART\_1
3. Perform various cryptography services:
  - Encrypt with 128-bit AES cryptography service
  - Decrypt with 128-bit AES cryptography service
  - Encrypt with 256-bit AES cryptography service
  - Decrypt with 256-bit AES cryptography service

### 2.6.2.1 aes128\_encryption ();

The aes128\_encryption() function provides access to the SmartFusion2 AES-128 encryption cryptography service. It allows you to perform AES encryption and choose the mode of operation: ECB, CBC, OFB, or CTR mode. It allows you to specify the number of 128-bit blocks of plaintext to be processed by the AES-128 system service. It also adds the padding bits to the incomplete blocks before calling the AES system service.

### 2.6.2.2 aes128\_decryption ();

The aes128\_decryption() function provides access to the SmartFusion2 AES-128 decryption cryptography service. It allows you to perform AES decryption and choose the mode of operation: ECB, CBC, OFB, or CTR mode. It allows you to specify the number of 128-bit blocks of ciphertext to be processed by the AES-128 system service. It also adds the padding bits to the incomplete blocks before calling the AES system service.

### 2.6.2.3 aes256\_encryption ();

This function is similar to aes128\_encryption() and provides access to the SmartFusion2 AES-256 encryption cryptography service function using the 256-bit key.

### 2.6.2.4 aes256\_decryption ();

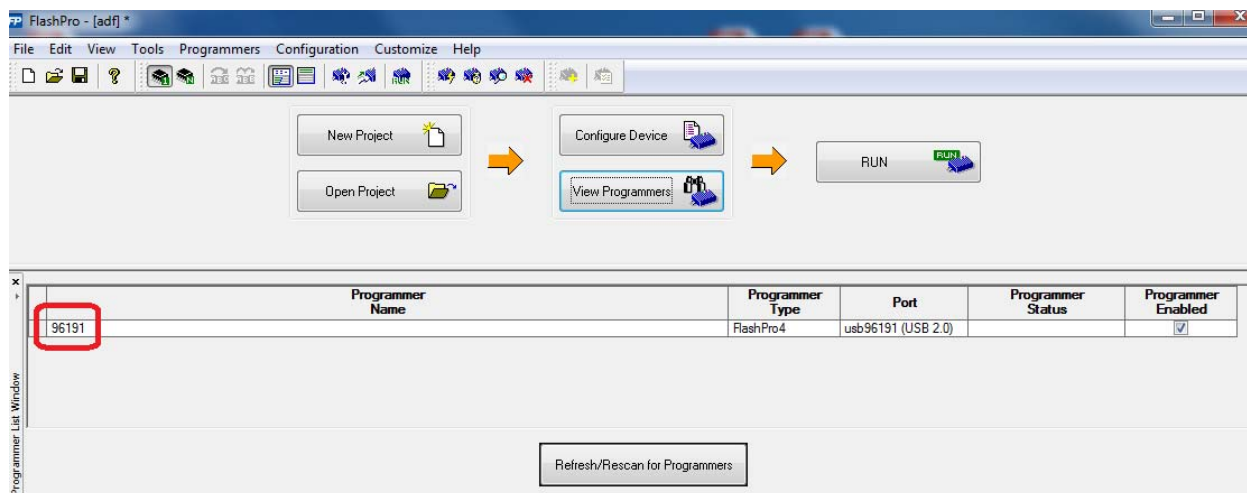
This function is similar to aes128\_decryption() and provides access to the SmartFusion2 AES-256 decryption cryptography service function using the 256-bit key.

## 2.6.3 Running the Design

The following steps describe how to run the design example on the SmartFusion2 Security Evaluation Kit (M2S-EVAL-KIT) using the M2S090TS-1FGG484 device:

1. Connect the power supply to the SmartFusion2 Security Evaluation Kit (M2S-EVAL-KIT) board.
2. Plug the FlashPro4 ribbon cable into JTAG Programming Header on the SmartFusion2 Security Evaluation Kit (M2S-EVAL-KIT) board.
3. Program the SmartFusion2 Security Evaluation Kit (M2S-EVAL-KIT) board with the provided STAPL file (refer to [Design and Programming Files](#), page 21) using FlashPro4.
4. Make a note of the five-digit FlashPro 4 programmer number. To find the programmer number, open the FlashPro software while the FlashPro 4 programmer is plugged into your PC.

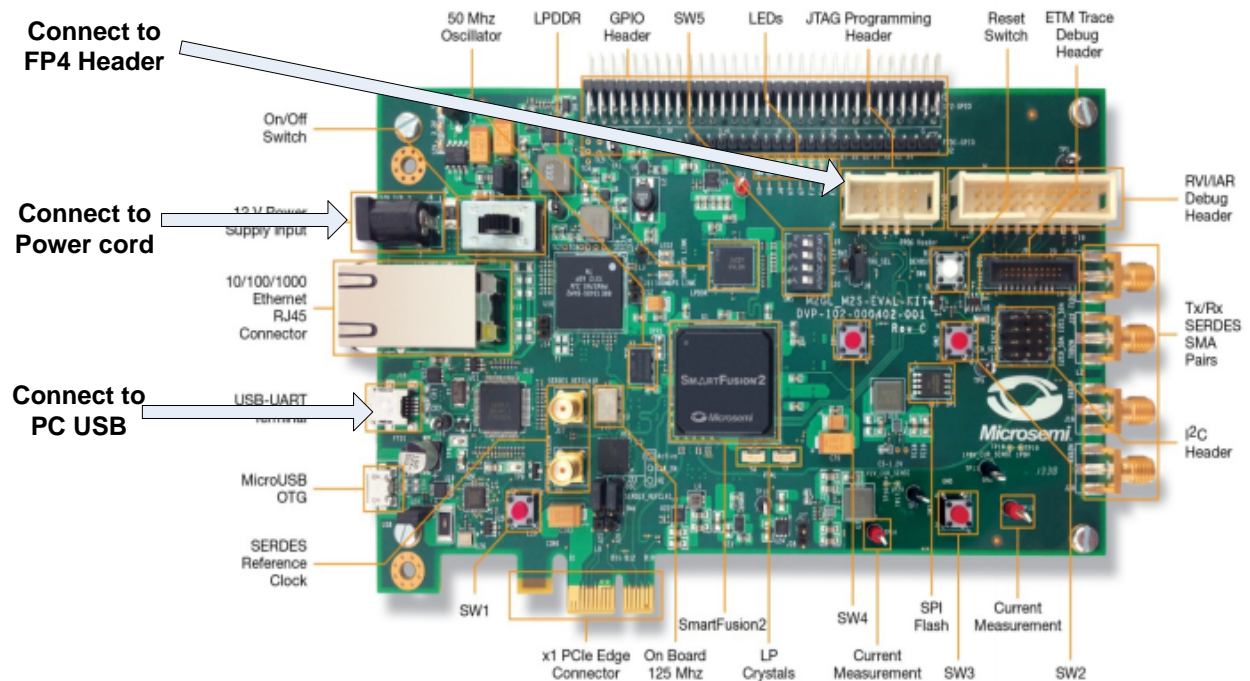
**Figure 7 • FlashPro Programmer Number**





- Connect the host PC to the J24 connector using the USB min-B cable.

**Figure 8 • SmartFusion2 Security Evaluation Kit (M2S-EVAL-KIT) Board**



- Invoke the SoftConsole project, click **Debug Configurations** from the Run menu, and then click the Debugger tab.
- Change the *usb* number in the following config option to match the number of your FlashPro 4 programmer (recorded during step 3):  

```
--command microsemi_flashpro_port usb96191
```
- Click **Apply** and launch the debugger.
- Start a HyperTerminal session with 57600 baud rate, 8 data bits, 1 stop bit, no parity, and no flow control. Use other serial terminal emulation programs such as PuTTY or Tera Term if HyperTerminal is not available. Refer to the [Configuring Serial Terminal Emulation Programs Tutorial](#) for configuring HyperTerminal, Tera Term, or PuTTY.
- Run the debugger in the SoftConsole tool. The HyperTerminal window shows various options to run the AES encryption and decryption. Follow the instruction on the screen to run the example.

The following figures show the HyperTerminal.

**Figure 9 • AES System Service Design Example in ECB Mode Using HyperTerminal**

```

File Edit Setup Control Window Help
***** SmartFusion2 Cryptography System Services Example *****
***** This example project demonstrates the use of the SmartFusion2 cryptography
System Services. The following system service are demonstrated:
- AES-128 encryption and decryption.
- AES-256 encryption and decryption.
Please refer to the README.txt for input and output data format.
-----
Select the Cryptographic operation to perform:
Press Key '1' to perform AES-128 encryption
Press Key '2' to perform AES-128 decryption
Press Key '3' to perform AES-256 encryption
Press Key '4' to perform AES-256 decryption
-----
Enter the 128 bit key to be used for AES (as hex Bytes, LS Byte first):
0x01 0x02 0x03 0x04 0x05 0x06 0x07 0x08
0x09 0x01 0x02 0x03 0x04 0x05 0x06 0x07
-----
Enter the 128 bit initialization vector(IV) to be used for AES
(as hex Bytes, LS Byte first):
0x03 0x03 0x03 0x03 0x03 0x03 0x03 0x03
0x03 0x03 0x03 0x03 0x03 0x03 0x03 0x03
-----
Select AES modes:
- ECB: Electronic CodeBook Mode.      Press key 'A'
- CBC: Cipher Block Chaining Mode.     Press key 'B'
- OFB: Output Feedback Mode.          Press key 'C'
- CTR: Counter Mode.                  Press key 'D'
Selected Encryption Mode : Electronic CodeBook Mode
-----
Enter the 16 bytes of input data to encrypt (as hex Bytes, LS Byte first):
0x02 0x02 0x02 0x02 0x02 0x02 0x02 0x02
0x02 0x02 0x02 0x02 0x02 0x02 0x02 0x02
-----
Encrypted data:
0xc5 0x93 0x37 0x8e 0x11 0xf8 0x0d 0x7d
0xcd 0x83 0x42 0x87 0xaa 0xe 0x15 0xe6
-----
Press any key to continue.
-----
Select the Cryptographic operation to perform:
Press Key '1' to perform AES-128 encryption
Press Key '2' to perform AES-128 decryption
Press Key '3' to perform AES-256 encryption
Press Key '4' to perform AES-256 decryption
-----
Enter the 128 bit key to be used for AES (as hex Bytes, LS Byte first):
0x01 0x02 0x03 0x04 0x05 0x06 0x07 0x08
0x09 0x01 0x02 0x03 0x04 0x05 0x06 0x07
-----
Enter the 128 bit initialization vector(IV) to be used for AES
(as hex Bytes, LS Byte first):
0x03 0x03 0x03 0x03 0x03 0x03 0x03 0x03
0x03 0x03 0x03 0x03 0x03 0x03 0x03 0x03
-----
Select AES modes:
- ECB: Electronic CodeBook Mode.      Press key 'A'
- CBC: Cipher Block Chaining Mode.     Press key 'B'
- OFB: Output Feedback Mode.          Press key 'C'
- CTR: Counter Mode.                  Press key 'D'
Selected Decryption Mode : Cipher Block Chaining Mode
-----
Enter the 16 bytes of input data to decrypt (as hex Bytes, LS Byte first):
0x02 0x02 0x02 0x02 0x02 0x02 0x02 0x02
0x02 0x02 0x02 0x02 0x02 0x02 0x02 0x02
-----
Decrypted data:
0xc5 0xc6 0x77 0x52 0x62 0x0c 0x6d 0x50
0xe2 0xe0 0x34 0x2c 0xa0 0x78 0x5e 0x29
-----
Press any key to continue.

```

Figure 10 • AES System Service Design Example in CBC Mode Using HyperTerminal

```

-----
Select the Cryptographic operation to perform:
  Press Key '1' to perform AES-128 encryption
  Press Key '2' to perform AES-128 decryption
  Press Key '3' to perform AES-256 encryption
  Press Key '4' to perform AES-256 decryption
-----

Enter the 128 bit key to be used for AES (as hex Bytes, LS Byte first):
0x01 0x02 0x03 0x04 0x05 0x06 0x07 0x08
0x09 0x01 0x02 0x03 0x04 0x05 0x06 0x07
-----

Enter the 128 bit initialization vector(IV) to be used for AES
(as hex Bytes, LS Byte first):
0x03 0x03 0x03 0x03 0x03 0x03 0x03 0x03
0x03 0x03 0x03 0x03 0x03 0x03 0x03 0x03
-----

Select AES modes:
- ECB: Electronic CodeBook Mode.      Press key 'A'
- CBC: Cipher Block Chaining Mode.     Press key 'B'
- OFB: Output Feedback Mode.          Press key 'C'
- CTR: Counter Mode.                 Press key 'D'
Selected Decryption Mode : Cipher Block Chaining Mode
-----

Enter the 16 bytes of input data to decrypt (as hex Bytes, LS Byte first):
0x02 0x02 0x02 0x02 0x02 0x02 0x02 0x02
0x02 0x02 0x02 0x02 0x02 0x02 0x02 0x02
-----

Decrypted data:
0xc5 0xc6 0x77 0x52 0x62 0x0c 0x6d 0x50
0xe2 0xe0 0x34 0x2c 0xa0 0x98 0x5e 0x29
-----

Press any key to continue.
-----

Select the Cryptographic operation to perform:
  Press Key '1' to perform AES-128 encryption
  Press Key '2' to perform AES-128 decryption
  Press Key '3' to perform AES-256 encryption
  Press Key '4' to perform AES-256 decryption
-----

Enter the 256 bit key to be used for AES (as hex Bytes, LS Byte first):
0x12 0x12 0x12 0x12 0x23 0x23 0x23 0x23
0x34 0x34 0x34 0x34 0x45 0x45 0x45 0x45
0x56 0x56 0x56 0x56 0x67 0x67 0x67 0x67
0x78 0x78 0x78 0x78 0x89 0x89 0x89 0x89
-----

Enter the 128 bit initialization vector(IV) to be used for AES
(as hex Bytes, LS Byte first):
0x00 0x01 0x02 0x03 0x04 0x05 0x06 0x07
0x09 0x09 0x10 0x11 0x12 0x12 0x12 0x12
-----

Select AES modes:
- ECB: Electronic CodeBook Mode.      Press key 'A'
- CBC: Cipher Block Chaining Mode.     Press key 'B'
- OFB: Output Feedback Mode.          Press key 'C'
- CTR: Counter Mode.                 Press key 'D'
Selected Encryption Mode : Output Feedback Mode
-----

Enter the 16 bytes of input data to encrypt (as hex Bytes, LS Byte first):
0x12 0x23 0x34 0x45 0x67 0x78 0x89 0x0a
0x0b 0x0c 0x0d 0x0e 0x0f 0x10 0x02 0x03
-----

Encrypted data:
0xf5 0x14 0xae 0x69 0x27 0x21 0x72 0x5a
0xe9 0x87 0xa6 0x27 0x86 0xfc 0xd3 0xe9
-----

Press any key to continue.

```

Figure 11 • AES System Service Design Example in OFB Mode Using HyperTerminal

```

-----
Enter the 256 bit key to be used for AES (as hex Bytes, LS Byte first):
0x12 0x12 0x12 0x12 0x23 0x23 0x23 0x23
0x34 0x34 0x34 0x34 0x45 0x45 0x45 0x45
0x56 0x56 0x56 0x56 0x67 0x67 0x67 0x67
0x78 0x78 0x78 0x78 0x89 0x89 0x89 0x98
-----
Enter the 128 bit initialization vector(IV) to be used for AES
(as hex Bytes, LS Byte first):
0x00 0x01 0x02 0x03 0x04 0x05 0x06 0x07
0x09 0x09 0x10 0x11 0x12 0x12 0x12 0x12
-----
Select AES modes:
- ECB: Electronic CodeBook Mode.      Press key 'A'
- CBC: Cipher Block Chaining Mode.     Press key 'B'
- OFB: Output Feedback Mode.          Press key 'C'
- CTR: Counter Mode.                 Press key 'D'
Selected Encryption Mode : Output Feedback Mode
-----
Enter the 16 bytes of input data to encrypt (as hex Bytes, LS Byte first):
0x12 0x23 0x34 0x45 0x67 0x78 0x89 0x0a
0x0b 0x0c 0x0d 0x0e 0x0f 0x10 0x02 0x03
-----
Encrypted data:
0xf5 0x14 0xae 0x69 0x27 0x21 0x72 0x5a
0xe9 0x87 0xa6 0x27 0x86 0xfc 0xd3 0xe9
-----
Press any key to continue.
-----
Select the Cryptographic operation to perform:
Press Key '1' to perform AES-128 encryption
Press Key '2' to perform AES-128 decryption
Press Key '3' to perform AES-256 encryption
Press Key '4' to perform AES-256 decryption
-----
Enter the 256 bit key to be used for AES (as hex Bytes, LS Byte first):
0x11 0x11 0x11 0x11 0x11 0x11 0x11 0x11
0x11 0x11 0x11 0x11 0x11 0x11 0x11 0x11
0x11 0x11 0x11 0x11 0x11 0x11 0x11 0x11
0x11 0x11 0x11 0x11 0x11 0x11 0x11 0x11
-----
Enter the 128 bit initialization vector(IV) to be used for AES
(as hex Bytes, LS Byte first):
0x12 0x12 0x12 0x12 0x12 0x12 0x12 0x12
0x12 0x12 0x12 0x12 0x12 0x12 0x12 0x12
-----
Select AES modes:
- ECB: Electronic CodeBook Mode.      Press key 'A'
- CBC: Cipher Block Chaining Mode.     Press key 'B'
- OFB: Output Feedback Mode.          Press key 'C'
- CTR: Counter Mode.                 Press key 'D'
Selected Decryption Mode : Counter Mode
-----
Enter the 16 bytes of input data to decrypt (as hex Bytes, LS Byte first):
0x11 0x11 0x11 0x11 0x22 0x22 0x22 0x22
0x33 0x33 0x33 0x33 0x44 0x44 0x44 0x44
-----
Decrypted data:
0x29 0xd1 0xfc 0xa3 0x3e 0xc0 0x54 0xb1
0x2e 0xd6 0x1a 0x4f 0x27 0x43 0x18 0x3b
-----
Press any key to continue.

```

**Note:** The ASCII-Hex notation is used for input by the program so the data is more easily readable.

The data goes from the first byte to the last byte of the multi-byte message, IV, key, and so on entered or displayed from left to right (and then top to bottom, if multi-line) as shown by the terminal emulator. Each byte is represented by two ASCII characters selected by value from the ordered sixteen character set 0-9 and a-f with the leftmost ASCII character representing the first four bits of the byte (that is, bits 7:4) encoded into a hexadecimal digit having its first binary bit (bit 7) interpreted as the most significant bit, and then the resulting hexadecimal digit encoded into an 8-bit ASCII character; the rightmost ASCII character representing the following four bits (bits 3:0) are encoded with the last binary bit of the byte (bit 0) being interpreted as the least significant of the second hexadecimal digit. The AES output is the Hex data displayed in endian order.

## 2.7 Design Example - Using AES Services in IGLOO2 Devices

The design consists the IGLOO2 HPMS, the on-chip 50 MHz RC oscillator, a Fabric CCC, the CoreSysServices IP block, the CoreRESET IP block, a CoreABC IP block, a CoreUART\_apb IP block, a fabric state machine to control the CoreSysServices bock, and an APB data block to reformat the AES output so it can be displayed by a terminal emulator.

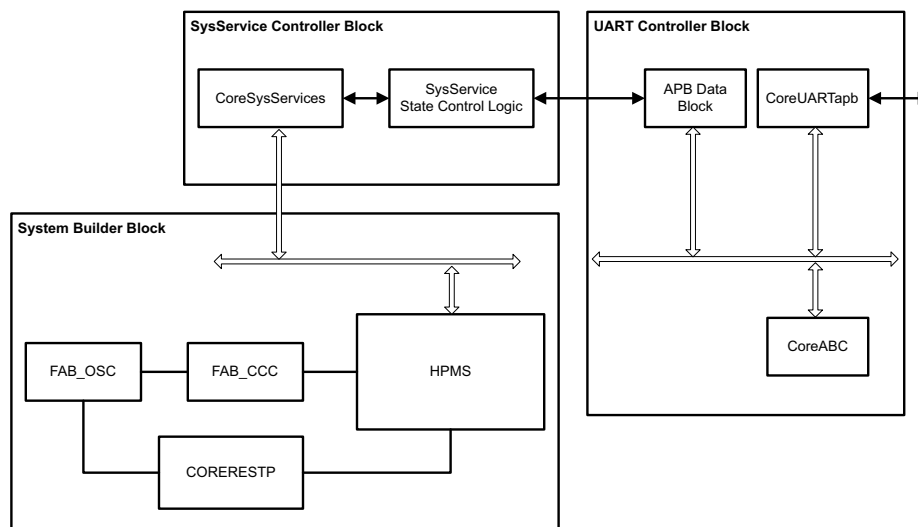
## 2.7.1 Hardware Implementation

The 50 MHz RC oscillator is used as the main clock. It is used with a CCC to provide the 100 MHz reference clock to the HPMS. The 100 MHz clock is also used as a main clock for the fabric blocks. The HPMS is configured to use the CoreResetP block to generate reset signals for all the blocks. The CoreSysServices IP is configured to use the AES system services. It sends a command to the system controller through COMM block in the HPMS. The fabric Syservice state control logic initiates the AES system service and captures the AES data from CoreSysService. The fabric Syservice state block sends the plaintext AES data that (in the example design) is basically a big-endian binary counter that increments the AES plaintext after every AES encryption operation. The incremented value is used as the input for the next encryption operation. The fabric Syservice state block uses the most recent ciphertext AES data that is calculated as input for the decryption operation. The UART controller block is mainly used to display the AES output to HyperTerminal; it is not required for the AES operation. The APB data block captures the AES data values and converts the binary data to ASCII Hexa data to display in human readable format on the HyperTerminal.

The CoreABC program controls initiating fabric state machine and displaying the data through the CoreUARTapb interface.

The following figure shows the block diagram of the design example.

**Figure 12 • IGLOO2 AES System Service Design Example**



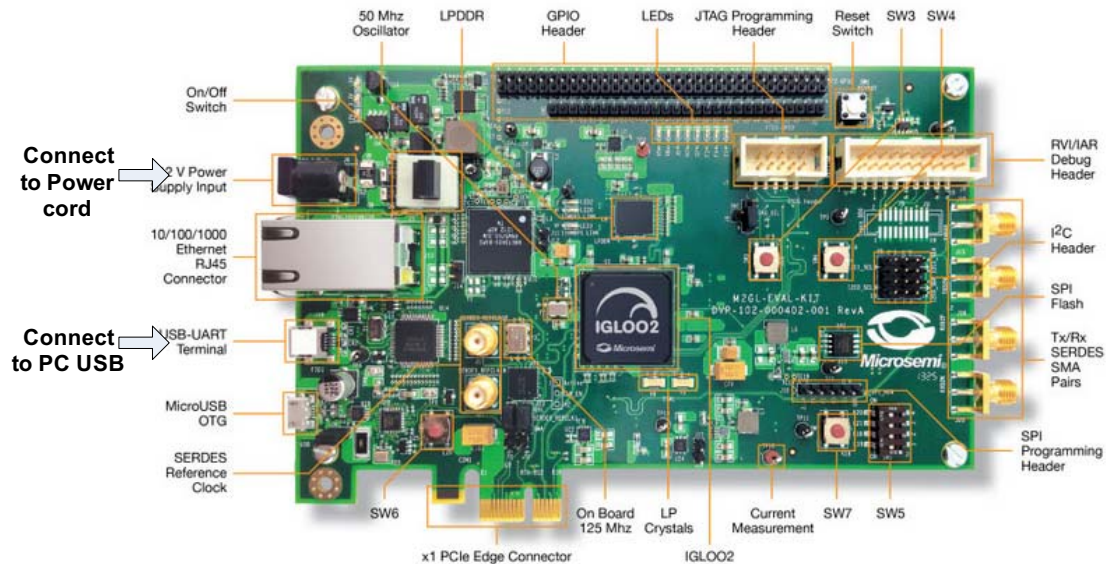
## 2.7.2 Running the Design

The following steps describes how to run the design example on the IGLOO2 Evaluation Kit board using the M2GL090TS-1FGG484 device:

1. Connect the power supply to the IGLOO2 Evaluation Kit board.
2. Plug the FlashPro4 ribbon cable into connector J5 (JTAG Programming Header) on the IGLOO2 Evaluation Kit board.
3. Connect the mini USB cable between the FlashPro4 and the USB port of the PC.
4. Connect the host PC to the J18 connector using the USB min-B cable. Ensure that the USB to UART bridge drivers are automatically detected (can be verified in the Device Manager).
5. If USB to UART bridge drivers are not installed, download and install the drivers from [www.microsemi.com/soc/documents/CDM\\_2.08.24\\_WHQL\\_Certified.zip](http://www.microsemi.com/soc/documents/CDM_2.08.24_WHQL_Certified.zip).
6. Start a HyperTerminal session with 57600 baud rate, 8 data bits, 1 stop bit, no parity, and no flow control. Use other serial terminal emulation programs such as PuTTY or Tera Term if HyperTerminal is not available. Refer to [Configuring Serial Terminal Emulation Programs Tutorial](#) for configuring HyperTerminal, Tera Term, or PuTTY.

- Program the IGLOO2 Evaluation Kit board with the provided STAPL file (refer to [Design and Programming Files](#), page 21) using FlashPro4.

**Figure 13 • IGLOO2 Evaluation Kit Board**



After programming, HyperTerminal displays a message to run the AES system services, as shown in the following figure.

**Note:** Depending on the terminal program used, the board may need to be power cycled after programming.

**Figure 14 • HyperTerminal Showing CoreSystemService Design Output**

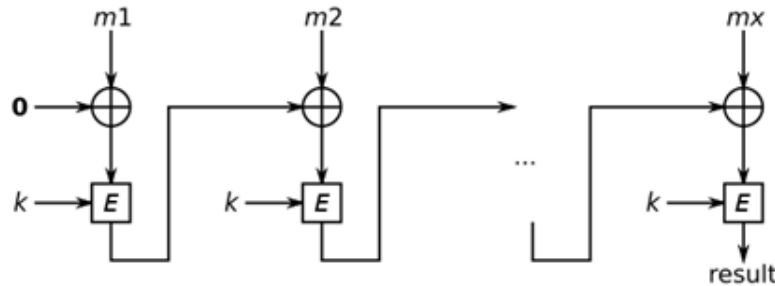
```
File Edit Setup Control Window Help
Enter your choice
1.Start aes encryption
2.Start aes decryption
1
aes value
C8BE1814
BA085B45
46E52106
0333DD0E
Enter your choice
1.Start aes encryption
2.Start aes decryption
2
aes value
00000000
00000000
00000000
00000000
Enter your choice
1.Start aes encryption
2.Start aes decryption
1
aes value
39A94C2
005E231D
EB176A82
E30D3E5
Enter your choice
1.Start aes encryption
2.Start aes decryption
2
aes value
00000000
00000000
00000000
00000001
Enter your choice
1.Start aes encryption
2.Start aes decryption
```

## 2.8 CBC-MAC Example

In cryptography, CBC-MAC is a technique for constructing a message authentication code from a block cipher. It uses the AES encryption in CBC mode. The IV used in first block is zero. Then a chain of blocks is created as each block depends on the proper encryption of the previous block.

The following figure shows the computation technique for CBC-MAC of a message.

**Figure 15 • CBC-MAC Computation Diagram**



This application note shows the design example to generate CBC-MAC in the SmartFusion2 and IGLOO2 devices.

**Note:** The CBC-MAC design example uses message size that is exact multiple of 128 bits, and it must not be used in a production environment without careful review by a qualified cryptographer.

## 2.9 Design Example - CBC-MAC

This section describes the CBC-MAC application design example. The CBC-MAC design is implemented in both the SmartFusion2 and IGLOO2 devices.

- **CBC\_MAC\_SF2** design example: Demonstrates using CBC-MAC in the SmartFusion2 device. It uses firmware code to generate CBC-MAC.
- **CBC\_MAC\_IGL2** design example: Demonstrates using CBC-MAC in the IGLOO2 device. It uses CoreSysServices IP to generate CBC-MAC.

### 2.9.1 Design Example - Using CBC-MAC in SmartFusion2 Devices

This design example is similar to AES\_Services\_SF2 design example. It uses same hardware implementation and uses UART1 in the MSS to display the CBC-MAC operation.

#### 2.9.1.1 Software Implementation

The software design example performs the following operations:

1. Initializes the system controller enable
2. Initializes MMUART\_1
3. Performs CBC-MAC

##### 2.9.1.1.1 `cbc_mac ();`

The **cbc\_mac ()** function allows to run CBC-MAC in the SmartFusion2 AES-128 device. It allows you to enter messages with variable length, perform CBC-MAC operation, and display the result.

#### 2.9.1.2 Running the Design

This section describes how to run the CBC-MAC design example in the SmartFusion2 Security Evaluation Kit (M2S-EVAL-KIT) using the M2S090TS-1FGG484 device. Use AES\_Services\_SF2 design example steps to program the device and open HyperTerminal. Then, invoke the CBC-MAC SoftConsole project, and follow the same steps in the AES\_Services\_SF2 design example, including modifying the debugger settings to run the debugger.

The following figure shows how to run the demo design.

**Figure 16 • HyperTerminal showing CBC-MAC Design in a SmartFusion2 Device**

```

File Edit Setup Control Window Help
*****
***** SmartFusion2 Cryptography System Services Example *****
*****
This example project demonstrates using CBC_MAC SmartFusion2

-----
Select the Cryptographic operation to perform:
Press Key '1' to perform CBC_MAC

-----

Enter the 128 bit key to be used for AES (as hex Bytes, LS Byte first):
0x01 0x02 0x03 0x04 0x05 0x06 0x07 0x08
0x09 0x01 0x02 0x03 0x04 0x05 0x06 0x07
Enter the number of messages for CBC-MAC :
5
-----
Enter Messages

-----

Enter the 16 bytes of input data to encrypt (as hex Bytes, LS Byte first):
0x11 0x11 0x11 0x11 0x11 0x11 0x11 0x11
0x11 0x11 0x11 0x11 0x11 0x11 0x11 0x12

-----

Enter the 16 bytes of input data to encrypt (as hex Bytes, LS Byte first):
0x12 0x12 0x12 0x12 0x12 0x12 0x12 0x12
0x12 0x12 0x12 0x12 0x12 0x12 0x12 0x13

-----

Enter the 16 bytes of input data to encrypt (as hex Bytes, LS Byte first):
0x13 0x13 0x13 0x13 0x13 0x13 0x13 0x13
0x13 0x13 0x13 0x13 0x13 0x13 0x13 0x14

-----

Enter the 16 bytes of input data to encrypt (as hex Bytes, LS Byte first):
0x14 0x14 0x14 0x14 0x14 0x14 0x14 0x14
0x14 0x11 0x14 0x14 0x14 0x14 0x14 0x15

-----

Enter the 16 bytes of input data to encrypt (as hex Bytes, LS Byte first):
0x15 0x15 0x15 0x15 0x15 0x15 0x15 0x15
0x15 0x15 0x15 0x15 0x15 0x15 0x15 0x16

-----

Encrypted data output:
0x7d 0xfa 0xd3 0x8d 0xd6 0x2e 0xc6 0xcf
0x35 0x4f 0x72 0x6b 0x50 0x37 0xe9 0x50

-----

Encrypted data output:
0x72 0xa8 0xd7 0x6b 0xaa 0xc8 0x33 0x8d
0xd2 0xc7 0xd7 0x2b 0x81 0xa8 0x64 0xfa

-----

Encrypted data output:
0xa3 0x5a 0x63 0xfe 0xba 0xc4 0xd7 0xe9
0x33 0x5e 0x7a 0x52 0xb0 0x89 0x50 0x7a

-----

Encrypted data output:
0x37 0xf0 0xa7 0xbe 0x35 0x4f 0x6f 0x7a
0xb7 0xcc 0xbc 0x53 0xba 0xb8 0x40 0x61

-----

Encrypted data output:
0x0a 0x80 0xd1 0x25 0xfe 0xdc 0x52 0x5a
0xe1 0x91 0x55 0x1d 0x43 0xbc 0x01 0x8a

-----
CBC-MAC data:
0x0a 0x80 0xd1 0x25 0xfe 0xdc 0x52 0x5a
0xe1 0x91 0x55 0x1d 0x43 0xbc 0x01 0x8a
-----
Press any key to continue.

```



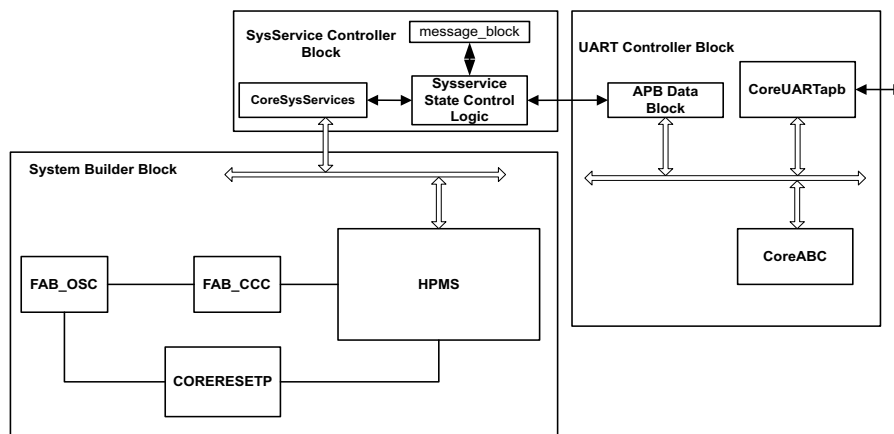
## 2.9.2 Design Example - Using CBC-MAC in IGLOO2 Devices

This design example is similar to the AES\_Services\_IGL2 design example. The fabric system service state control logic configures CoreSysService to generate AES CBC mode. It also sends the appropriate IV during each AES services. The design example uses a message block that sends the messages for AES operation. The message block uses four messages in the current implementation. One of the messages is tied to DIP switch in the IGLOO2 Evaluation Kit. You can change the DIP switch and change the message.

**Note:** You can modify the message block, content, and size. However, you need to change the counter in SysService state control logic to match the message length. The other blocks are similar to the AES\_Services\_IGL2 design example.

The following figure shows the block diagram of CBC-MAC design.

**Figure 17 • IGLOO2 CBC-MAC Design Example**



### 2.9.2.1 Running the Design

This section describes running the CBC-MAC design example in the IGLOO2 Evaluation Kit using the M2GL090TS-1FGG484 device. Use AES\_Services\_IGL2 design example steps to program the device and open HyperTerminal.

The following figure shows running the demo design.

**Figure 18 • CBC-MAC of a Message**

```

COM42:57600baud - Tera Term VT
File Edit Setup Control Window Help
Enter your choice
1.Start cb-mac encryption
1
cbc-mac value
B41835D5
21757DEF
CB2A4C4D
7CF70FEB
Enter your choice
1.Start cb-mac encryption

```

## 2.10 Design and Programming Files

Download the SmartFusion2 and IGLOO2 AES design files from the Microsemi Corporation website:  
[http://soc.microsemi.com/download/rsc/?f=m2s\\_m2gl\\_ac410\\_aes\\_services\\_liberov11p8\\_df](http://soc.microsemi.com/download/rsc/?f=m2s_m2gl_ac410_aes_services_liberov11p8_df)

Download the SmartFusion2 and IGLOO2 CBC-MAC design files from the Microsemi Corporation website:

[http://soc.microsemi.com/download/rsc/?f=m2s\\_m2gl\\_ac410\\_cbc\\_mac\\_liberov11p8\\_df](http://soc.microsemi.com/download/rsc/?f=m2s_m2gl_ac410_cbc_mac_liberov11p8_df)

The SmartFusion2 design file consists a Libero Verilog project, SoftConsole software project, and programming files (.stp) for the SmartFusion2 Security Evaluation Kit (M2S-EVAL-KIT). The IGLOO2 design file consists a Libero Verilog project and programming files (.stp) for the IGLOO2 Evaluation Kit. Refer to the `Readme.txt` file included in the design file folder for the directory structure and description.

## 2.11 Conclusion

The SmartFusion2 and IGLOO2 family of FPGAs are the most secure programmable logic devices ever made. In selected SmartFusion2 and IGLOO2 devices, the AES engine can perform encryption or decryption on 128-bit blocks of user data using either 128-bit or 256-bit keys as defined in NIST FIPS 197. Several common modes are provided to encrypt or decrypt arbitrarily sized blocks of data, including ECB, CBC, OFB, and CTR modes as defined in NIST SP800-38a. The AES system services, along with the other cryptographic services offered, allow you to use the SmartFusion2 and IGLOO2 devices in various secure applications.