Bootgen User Guide

UG1283 (v2018.2) September 28, 2018

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Revision History

The following table shows the revision history for this document.

Section	Revision Summary
09/24/2018 v2018.2	
Initial Xilinx Release	N/A

Introduction

Xilinx® FPGAs and system-on-chip (SoC) devices typically have multiple hardware and software binaries used to boot them to function as designed and expected. These binaries can include FPGA bitstreams, firmware images, bootloaders, operating systems, and user-chosen applications that can be loaded in both non-secure and secure methods.

Bootgen is a Xilinx tool that lets you *stitch* binary files together and generate device boot images. Bootgen defines multiple properties, attributes and parameters that are input while creating boot images for use in a Xilinx device.

The secure boot of Zynq® devices uses public and private key cryptographic algorithms. Bootgen provides assignment of specific destination memory addresses and alignment requirements for each partition. It also supports encryption and authentication, described in Using Encryption and Using Authentication. More advanced authentication flows and key management options are discussed in Using HSM Mode, where Bootgen can output intermediate hash files that can be signed offline using private keys to sign the authentication certificates included in the boot image. The program assembles a boot image by adding header blocks to a list of partitions. Optionally, each partition can be encrypted and authenticated with Bootgen. The output is a single file that can be directly programmed into the boot flash memory of the system. Various input files can be generated by the tool to support authentication and encryption as well. See BIF Syntax and Supported File Types for more information.

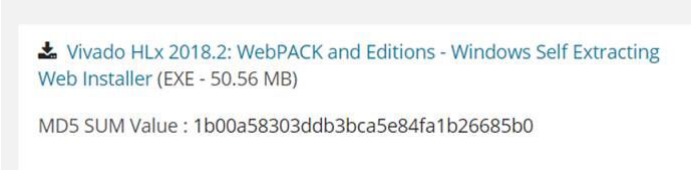
Bootgen comes with both a GUI interface and a command line option. The tool is integrated into the software development toolkit, SDK, for generating basic boot images using a GUI, but the majority of Bootgen options are command line-driven. Command line options can be scripted. The Bootgen tool is driven by a boot image format (BIF) file configuration file with a file extension of `*.bif`. Along with Zynq-7000 SoC SoC devices, Bootgen has the ability to encrypt and authenticate partitions for Xilinx 7 series FPGAs and later, as described in FPGA Support. In addition to the supported command and attributes that define the behavior of a Boot Image, there are utilities that help you work with Bootgen.

Installing Bootgen

Bootgen is the boot image creation tool for the Xilinx® Software Development Kit (SDK) and the Xilinx Software Command Line Tool (XSCT). You can use Bootgen in GUI mode for simple boot image creation, or in a command line mode for more complex boot images. The command line mode commands can be scripted too. You can Install Bootgen from SDK, from Vivado Design Suite Installer or standalone. SDK is available for use when you install the Vivado® Design Suite, or it is downloaded and installed individually. See the *Vivado Design Suite User Guide: Release Notes, Installation, and Licensing* (UG973) for all possible installation options.

To install Bootgen from Vivado, go to the Xilinx Download Site, and select the Vivado self-extracting installer as shown in the following figure:

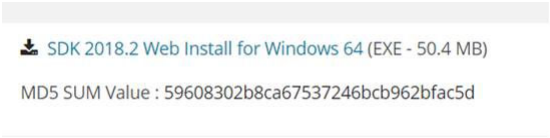
Figure 1: **Vivado Self-Extracting Installer**



During the Vivado installation, choose the option to install SDK as well. Bootgen is included along with SDK.

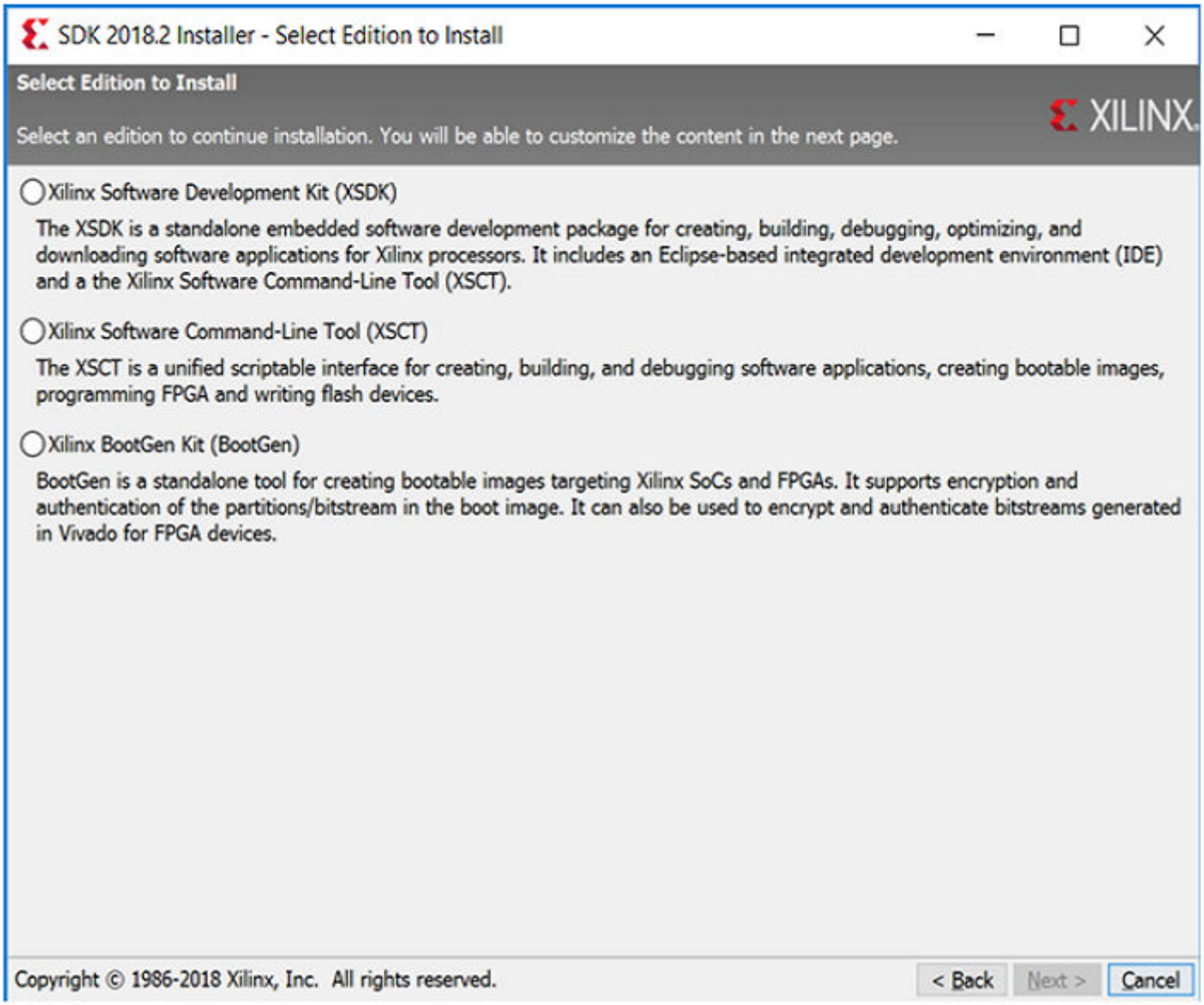
You can also install Bootgen from the SDK Installer. The following figure shows the SDK self-extracting installer found on the Xilinx Download site:

Figure 2: **SDK Installer**



The following figure shows the SDK Installer with options to download the XSCT or a standalone version of Bootgen:

Figure 3: **SDK Installer**



You can also select the **Download Full Image** option on the SDK Installer to get an offline installation. This offline installation is an important feature for customers using HSM mode. See more about this topic in Using HSM Mode.

After you install SDK with Bootgen, you can invoke and use the tool from the SDK GUI option that contains the most common actions for rapid development and experimentation, or from the XSCT.

The command line option provides many more options for implementing a boot image. See the Chapter 4: Using Bootgen Interfaces to see the GUI and command line options:

- From the SDK GUI: See Bootgen GUI Options.
- From the command line using the XSCT option. See the following: Using Bootgen Options on the Command Line.

For more information about SDK, see *SDK Online Help* (UG782).

Boot Time Security

Secure booting through latest authentication methods is supported to prevent unauthorized or modified code from being run on Xilinx® devices, and to make sure only authorized programs access the images for loading various encryption techniques.

For device-specific hardware security features, see the following documents:

- *Zynq-7000 SoC Technical Reference Manual* (UG585)
- *Zynq UltraScale+ Device Technical Reference Manual* (UG1085)

See Using Encryption and Using Authentication for more information about encrypting and authenticating content when using Bootgen.

The Bootgen hardware security monitor (HSM) mode increases key handling security because the BIF attributes use public rather than private RSA keys. The HSM is a secure key/signature generation device which generates private keys, encrypts partitions using the private key, and provides the public part of the RSA key to Bootgen. The private keys do not leave the HSM. The BIF for Bootgen HSM mode uses public keys and signatures generated by the HSM. See Using HSM Mode for more information.

Boot Image Layout

This chapter describes the format of the boot image for different architectures.

- For information about using Bootgen for Zynq®-7000 SoC devices, see Zynq-7000 Device Boot and Configuration.
- For information about using Bootgen for Zynq® UltraScale+™ MPSoC devices, see Zynq UltraScale + MPSoC Device Boot and Configuration.
- For information on how to use Bootgen for Xilinx FPGAs, see Chapter 6: FPGA Support.

Building a boot image involves the following steps:

1. Create a BIF file.
2. Run the Bootgen executable to create a binary file.

***Note*:** For the Quick Emulator (QEMU) you must convert the binary file to an image format corresponding to the boot device.

Each device requires files in a specific format to generate a boot image for that device. The following topics describe the required format of the Boot Header, Image Header, Partition Header, Initialization, and Authentication Certificate Header for each device.

Zynq-7000 Device Boot and Configuration

This section describes the boot and configuration sequence for Zynq®-7000 SoC devices.

See the *Zynq-7000 SoC Technical Reference Manual* (UG585) for more details on the available first stage boot loader (FSBL) structures.

BootROM on Zynq-7000

The BootROM is the first software to run in the application processing unit (APU). BootROM executes on the first Cortex™ processor, A9-0, while the second processor, Cortex, A9-1, executes the wait for event (WFE) instruction. The main tasks of the BootROM are to configure the system, copy the FSBL from the boot device to the on-chip memory (OCM), and then branch the code execution to the OCM.

Optionally, you can execute the FSBL directly from a Quad-SPI or NOR device in a non-secure environment. The master boot device holds one or more boot images. A boot image is made up of the boot header and the first stage boot loader (FSBL). Additionally, a boot image can have programmable logic (PL), a second stage boot loader (SSBL), and an embedded operating system and applications; however, these are not accessed by the BootROM. The BootROM execution flow is affected by the boot mode pin strap settings, the Boot Header, and what it discovers about the system. The BootROM can execute in a secure environment with encrypted FSBL, or a non-secure environment.

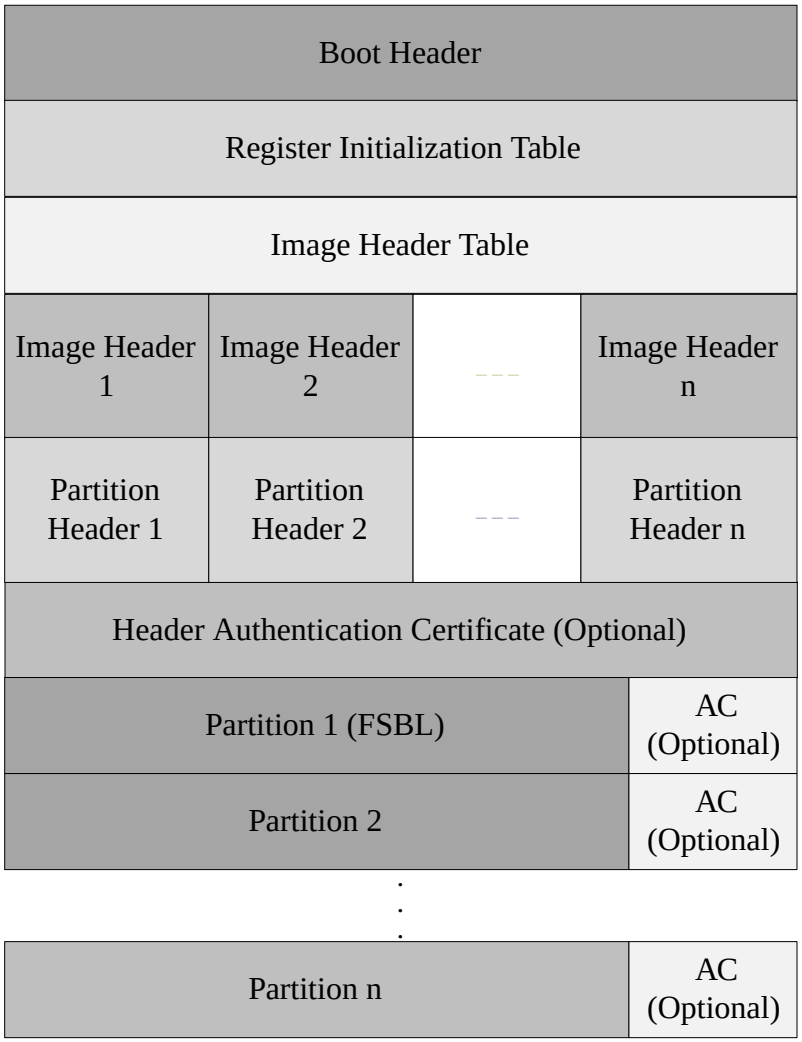
Supported boot modes are:

- JTAG mode is primarily used for development and debug.
- NAND, parallel NOR, Serial NOR (Quad-SPI), and Secure Digital (SD) flash memories are used for booting the device. The *Zynq SoC Technical Reference Manual* (UG585) provides the details of these boot modes. See Zynq-7000 Boot and Configuration AR#52538 for answers to common boot and configuration questions.

Zynq-7000 Device Boot Image Layout

The following is a diagram of the components that can be included in a Zynq®-7000 SoC device boot image.

Figure 4: **Boot Header**



Zynq-7000 SoC Device Boot Header

Bootgen attaches a boot header at the beginning of a boot image. The Boot Header table is a structure that contains information related to booting the primary bootloader, such as the FSBL. There is only one such structure in the entire boot image. This table is parsed by BootROM to get determine where FSBL is stored in flash and where it needs to be loaded in OCM. Some encryption and authentication related parameters are also stored in here. The additional Boot Header components are:

- Zynq-7000 SoC Device Register Initialization Table
- Zynq-7000 SoC Device Image Header Table
- Zynq-7000 SoC Device Partition Header

Additionally, the Boot Header contains a Zynq-7000 SoC Device Register Initialization Table.BootROM uses the Boot Header to find the location and length of FSBL and other details to initialize the system before handing off the control to FSBL.

The following table provides the address offsets, parameters, and descriptions for the Zynq®-7000 SoC Boot Header.

Table 1: **Zynq-7000 SoC Boot Header**

Address Offset	Parameter	Description
0x00-0x1F	Arm® Vector table	Filled with dummy vector table by Bootgen (Arm Op code `0xEAFFFFFE`, which is a branch-to-self infinite loop intended to catch uninitialized vectors.
0x20	Width Detection Word	This is required to identify the QSPI flash in single/dual stacked or dual parallel mode. `0xAA995566` in little endian format.
0x24	Header Signature	Contains 4 bytes 'X','N','L','X' in byte order, which is `0x584c4e58` in little endian format.
0x28	Key Source	Location of encryption key within the device: `0x3A5C3C5A`: Encryption key in BBRAM. `0xA5C3C5A3`: Encryption key in eFUSE. `0x00000000`: Not Encrypted.
0x2C	Header Version	`0x01010000`
0x30	Source Offset	Location of FSBL (bootloader) in this image file.
0x34	FSBL Image Length	Length of the FSBL, after decryption.
0x38	FSBL Load Address (RAM)	Destination RAM address to which to copy the FSBL.
0x3C	FSBL Execution address (RAM)	Entry vector for FSBL execution.
0x40	Total FSBL Length	Total size of FSBL after encryption, including authentication certificate (if any) and padding.
0x44	QSPI Configuration Word	Hard coded to `0x00000001`.
0x48	Boot Header Checksum	Sum of words from offset `0x20` to `0x44` inclusive. The words are assumed to be little endian.
0x4c-0x97	User Defined Fields	76 bytes
0x98	Image Header Table Offset	Pointer to Image Header Table (word offset).
0x9C	Partition Header Table Offset	Pointer to Partition Header Table (word offset).

Zynq-7000 SoC Device Register Initialization Table

The Register Initialization Table in Bootgen is a structure of 256 address-value pairs used to initialize PS registers for MIO multiplexer and flash clocks. For more information, see About Register Intialization Pairs and INT File Attributes.

Table 2: **Zynq-7000 SoC Device Register Initialization Table**

Address Offset	Parameter	Description
0xA0 to 0x89C	Register Initialization Pairs: <address>:<value>:	Address = 0xFFFFFFFF means skip that register and ignore the value. All the unused register fields must be set to Address=0xFFFFFFFF and value = 0x0.

Zynq-7000 SoC Device Image Header Table

Bootgen creates a boot image by extracting data from ELF files, bitstream, data files, and so forth. These files, from which the data is extracted, are referred to as images. Each image can have one or more partitions. The Image Header table is a structure, containing information which is common across all these images, and information like; the number of images, partitions present in the boot image, and the pointer to the other header tables. The following table provides the address offsets, parameters, and descriptions for the Zynq®-7000 SoC device.

Table 3: **Zynq-7000 SoC Device Image Header Table**

Address Offset	Parameter	Description
0x00	Version	0x01010000: Only fields available are 0x0, 0x4, 0x8, 0xC, and a padding 0x01020000:0x10 field is added.
0x04	Count of Image Headers	Total number of partitions in the image.
0x08	First Partition Header Offset	Pointer to first partition header. (word offset)
0x0C	First Image Header Offset	Pointer to first image header. (word offset)
0x10	Header Authentication Certificate Offset	Pointer to the authentication certificate header. (word offset)
0x14	Reserved	Defaults to 0xFFFFFFFF.

Zynq-7000 SoC Device Image Header

The Image Header is an array of structures containing information related to each image, such as an ELF file, bitstream, data files, and so forth. One image can have multiple partitions, for example an ELF can have multiple loadable sections, each of which forms a partition in the boot image. The table will also contain the information of number of partitions related to an image. The following table provides the address offsets, parameters, and descriptions for the Zynq®-7000 SoC device.

Table 4: **Zynq-7000 SoC Device Image Header**

Address Offset	Parameter	Description
0x00	Next Image Header.	Link to next Image Header. 0 if last Image Header (word offset).
0x04	Corresponding partition header.	Link to first associated Partition Header (word offset).
0x08	Reserved	Always 0.
0x0C	Partition Count Length	Number of partitions associated with this image.
0x10 to N	Image Name	Packed in big-endian order. To reconstruct the string, unpack 4 bytes at a time, reverse the order, and concatenate. For example, the string "FSBL10.ELF" is packed as 0x10: 'L','B','S','F', 0x14: 'E','.','0','1', 0x18: '\0','\0','F','L'. The packed image name is a multiple of 4 bytes.
N	String Terminator	0x00000000
N+4	Reserved	Defaults to 0xFFFFFFFF to 64 bytes boundary.

Zynq-7000 SoC Device Partition Header

The Partition Header is an array of structures containing information related to each partition. Each partition header table is parsed by the Boot Loader. The information such as the partition size, address in flash, load address in RAM, encrypted/signed, and so forth, are part of this table. There is one such structure for each partition including FSBL. The last structure in the table is marked by all NULL values (except the checksum.) The following table shows the offsets, names, and notes regarding the Zynq®-7000 SoC Partition Header.

***Note*:** An ELF file with three (3) loadable sections has one image header and three (3) partition header tables.

Table 5: **Zynq-7000 SoC Device Partition Header**

Offset	Name	Notes
0x00	Encrypted Partition length	Encrypted partition data length.
0x04	Unencrypted Partition length	Unencrypted data length.
0x08	Total partition word length (Includes Authentication Certificate.) See Zynq-7000 SoC Device Authentication Certificate	The total partition word length comprises the encrypted information length with padding, the expansion length, and the authentication length.
0x0C	Destination load address.	The RAM address into which this partition is to be loaded.
0x10	Destination execution address.	Entry point of this partition when executed.
0x14	Data word offset in Image	Position of the partition data relative to the start of the boot image

Table 5: **Zynq-7000 SoC Device Partition Header** *(cont'd)*

Offset	Name	Notes
0x18	Attribute Bits	See Zynq-7000 SoC Device Partition Attribute Bits
0x1C	Section Count	Number of sections in a single partition.
0x20	Checksum Word Offset	Location of the checksum word in the boot image.
0x24	Image Header Word Offset	Location of the Image Header in the boot image
0x28	Authentication Certification Word Offset	Location of the Authentication Certification in the boot image.
0x2C-0x38	Reserved	Reserved
0x3C	Header Checksum	Sum of the previous words in the Partition Header.

Zynq-7000 SoC Device Partition Attribute Bits

The following table describes the Partition Attribute bits of the partition header table for a Zynq®-7000 SoC device.

Table 6: **Zynq-7000 SoC Device Partition Attribute Bits**

Bit Field	Description	Notes
31:18	Data attributes	Not implemented
17:16	Partition owner	0: FSBL 1: UBOOT 2 and 3: reserved
15	RSA signature present	0: No RSA authentication certificate 1: RSA authentication certificate
14:12	Checksum type	0: None 1: MD5 2-7: reserved
11:8	Destination instance	Not implemented
7:4	Destination device	0: None 1: PS 2: PL 3: INT 4-15: Reserved
3:2	Head alignment	Not implemented
1:0	Tail alignment	Not implemented

Zynq-7000 SoC Device Authentication Certificate

The Authentication Certificate is a structure that contains all the information related to the authentication of a partition. This structure has the public keys, all the signatures that BootROM/FSBL needs to verify. There is an Authentication Header in each Authentication Certificate, which gives information like the key sizes, algorithm used for signing, and so forth. The Authentication Certificate is appended to the actual partition, for which authentication is enabled. If authentication is enabled for any of the partitions, the header tables also needs authentication. Header Table Authentication Certificate is appended at end of the header tables content.

The Zynq®-7000 SoC device uses an RSA-2048 authentication with a SHA-256 hashing algorithm, which means the primary and secondary key sizes are 2048-bit. Because SHA-256 is used as the secure hash algorithm, the FSBL, partition, and authentication certificates must be padded to a 512-bit boundary.

The format of the Authentication Certificate in a Zynq®-7000 SoC device is as shown in the following table.

Table 7: **Zynq-7000 SoC Device Authentication Certificate**

Authentication Certificate Bits	Description	
0x00	Authentication Header = 0x0101000. See Zynq-7000 SoC Device Authentication Certificate Header.	
0x04	Certificate size	
0x08	UDF (56 bytes)	
0x40	PPK	Mod (256 bytes)
0x140		Mod Ext (256 bytes)
0x240		Exponent
0x244		Pad (60 bytes)
0x280	SPK	Mod (256 bytes)
0x380		Mod Ext (256 bytes)
0x480		Exponent (4 bytes)
0x484		Pad (60 bytes)
0x4C0	SPK Signature = RSA-2048 (PSK, Padding || SHA-256(SPK))	
0x5C0	FSBL Partition Signature = RSA-2048 (SSK, SHA-256 (Boot Header || FSBL partition.	
0x5C0	Other Partition Signature = RSA-2048 (SSK, SHA-256 (Partition || Padding || Authentication Header || PPK || SPK || SPK Signature)	

Zynq-7000 SoC Device Authentication Certificate Header

The following table describes the Zynq®-7000 SoC Authentication Certificate Header.

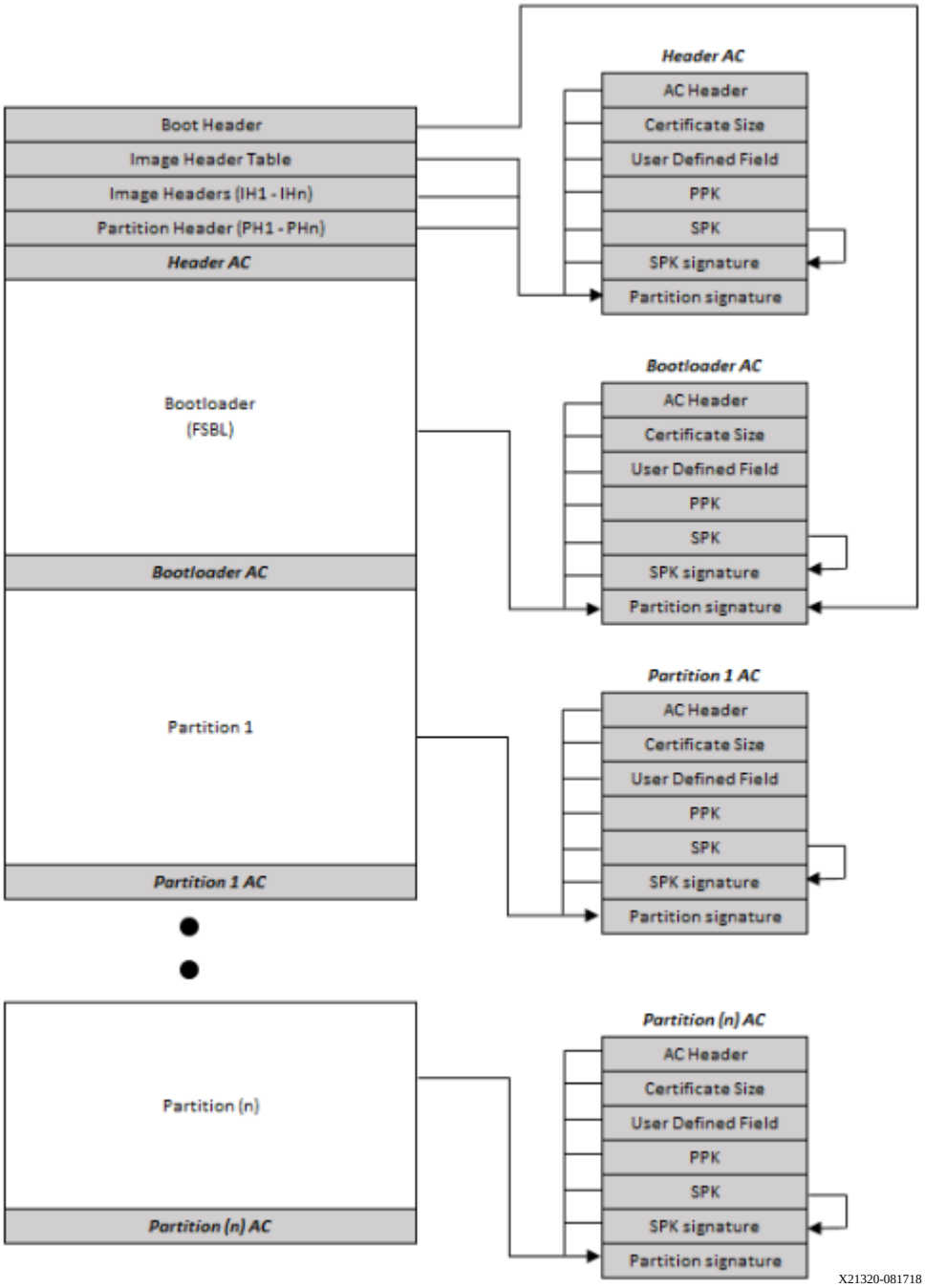
Table 8: **Zynq-7000 SoC Device Authentication Certificate Header**

Bit Offset	Field Name	Description
31:16	Reserved	0
15:14	Authentication Certificate Format	00: PKCS #1 v1.5
13:12	Authentication Certificate Version	00: Current AC
11	PPK Key Type	0: Hash Key
10:9	PPK Key Source	0: eFUSE
8	SPK Enable	1: SPK Enable
7:4	Public Strength	0:2048
3:2	Hash Algorithm	0: SHA256

Zynq-7000 SoC Device Boot Image Block Diagram

The following is a diagram of the components that can be included in a Zynq®-7000 SoC device boot image.

Figure 5: **Zynq-7000 SoC Device Boot Image Block Diagram**



Zynq UltraScale + MPSoC Device Boot and Configuration

Introduction

Zynq® UltraScale+™ MPSoC devices support the ability to boot from different devices such as a QSPI flash, an SD card, USB device firmware upgrade (DFU) host, and the NAND flash drive. This chapter details the booting process using different booting devices in both secure and non-secure modes. The boot-up process is managed and carried out by the platform management unit (PMU) and configuration security unit (CSU).

During initial boot, the following steps occur:

- The PMU is brought out of reset by the power on reset (POR).
- The PMU executes in ROM.
- The PMU initializes the SYSMON and, required PLL for the boot, clears the low power and full power domains and releases the CSU reset.

After the PMU releases the CSU, the CSU does the following:

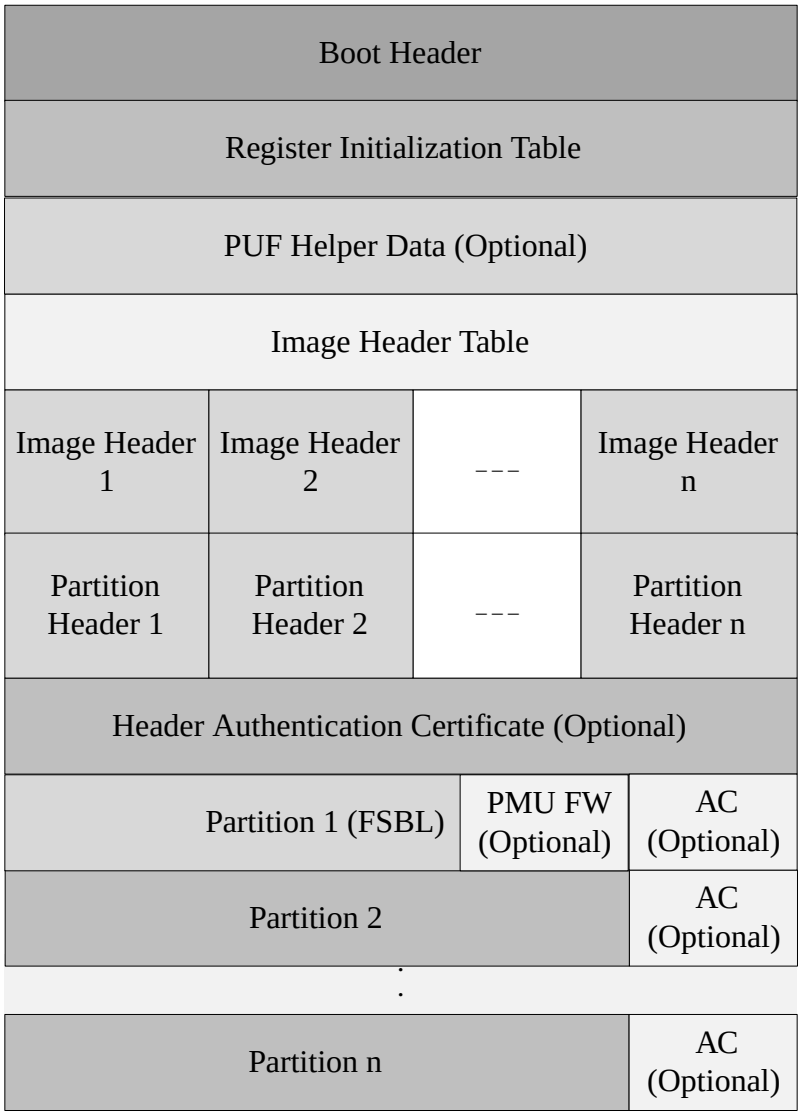
- Checks to determine if authentication is required by the FSBL or the user application.
- Performs an authentication check and proceeds only if the authentication check passes. Then checks the image for any encrypted partitions.
- If the CSU detects partitions that are encrypted, the CSU performs decryption and initializes OCM, determines boot mode settings, performs the FSBL load and an optional PMU firmware load.
- After execution of CSU ROM code, it hands off control to FSBL. FSBL uses PCAP interface to program the PL with bitstream.

FSBL then takes the responsibility of the system. The *Zynq UltraScale+ Device Technical Reference Manual* (UG1085) provides details on CSU and PMU. For specific information on CSU, see this link to the "Configuration Security Unit" section of the *Zynq UltraScale+ MPSoC: Software Developers Guide* (UG1137) .

Zynq UltraScale+ MPSoC Device Boot Image

The following figure shows the Zynq® UltraScale+™ MPSoC device boot image.

Figure 6: **Zynq UltraScale+ MPSoC Device Boot Image**



Zynq UltraScale+ MPSoC Device Boot Header

About the Boot Header

Bootgen attaches a boot header at the starting of any boot image. The Boot Header table is a structure that contains information related to booting of primary bootloader, such as the FSBL. There is only one such structure in entire boot image. This table is parsed by BootROM to get the information of where FSBL is stored in flash and where it needs to be loaded in OCM. Some encryption and authentication related parameters are also stored in here. The boot header components are:

- Zynq UltraScale+ MPSoC Device Boot Header, which also has the Zynq UltraScale+ MPSoC Device Boot Header Attribute Bits.
- Zynq UltraScale+ MPSoC Device Register Initialization Table
- Zynq UltraScale+ MPSoC Device PUF Helper Data
- Zynq UltraScale+ MPSoC Device Image Header Table
- Zynq UltraScale+ MPSoC Device Image Header
- Zynq UltraScale+ MPSoC Device Authentication Certificates

BootROM uses the Boot Header to find the location and length of FSBL and other details to initialize the system before handing off the control to FSBL. The following table provides the address offsets, parameters, and descriptions for the Zynq® UltraScale+™ MPSoC device.

Table 9: **Zynq UltraScale+ MPSoC Device Boot Header**

Address Offset	Parameter	Description
0x00-0x1F	Arm® vector table	XIP ELF vector table: 0xEAFFFFFE: for Cortex™ R5 and Cortex A53 (32-bit) 0x14000000: for Cortex A53 (64-bit)
0x20	Width Detection Word	This field is used for QSPI width detection. `0xAA995566` in little endian format.
0x24	Header Signature	Contains 4 bytes `'X','N','L','X'` in byte order, which is `0x584c4e58` in little endian format.
0x28	Key Source (FSBL-only)	`0x00000000` (Un-Encrypted) `0xA5C3C5A5` (Black key stored in eFUSE) `0xA5C3C5A7` (Obfuscated key stored in eFUSE) `0x3A5C3C5A` (Red key stored in BBRAM) `0xA5C3C5A3` (eFUSE RED key stored in eFUSE) `0xA35C7CA5` (Obfuscated key stored in Boot Header) `0xA3A5C3C5` (USER key stored in Boot Header) `0xA35C7C53` (Black key stored in Boot Header)
0x2C	FSBL Execution address (RAM)	
0x30	Source Offset	If no PMUFW, then it is the start offset of FSBL. If PMUFW, then start of PMUFW.FSBL execution address in OCM or XIP base address.
0x34	PMU Image Length	PMU FW original image length in bytes. (0-128KB). If size > 0, PMUFW is prefixed to FSBL. If size = 0, no PMUFW image.
0x38	Total PMU FW Length	FSBL execution address in OCM or XIP baseTotal PMUFW image length in bytes.(PMUFW length + encryption overhead)
0x3C	FSBL Image Length	Original FSBL image length in bytes. (0-250KB). If 0, XIP bootimage is assumed.

Table 9: **Zynq UltraScale+ MPSoC Device Boot Header** *(cont'd)*

Address Offset	Parameter	Description
0x40	Total FSBL Length	FSBL image length + Encryption overhead of FSBL image + Auth. Cert., + 64byte alignment + hash size (Integrity check).
0x44	FSBL Image Attributes	See Bit Attributes.
0x48	Boot Header Checksum	Sum of words from offset 0x20 to 0x44 inclusive. The words are assumed to be little endian.
0x4C-0x68	Obfuscated/Black Key Storage	Stores the Obfuscated key or Black key.
0x6C	Shutter Value	32-bit `PUF_SHUT` register value to configure PUF for shutter offset time and shutter open time.
0x70 -0x94	User-Defined Fields (UDF)	40 bytes.
0x98	Image Header Table Offset	Pointer to Image Header Table. (word offset)
0x9C	Partition Header Table Offset	Pointer to Partition Header. (word offset)
0xA0-0xA8	Secure Header IV	IV for secure header of bootloader partition.
0x0AC-0xB4	Obfuscated/Black Key IV	IV for Obfuscated or Black key.

Zynq UltraScale+ MPSoC Device Boot Header Attribute Bits

Table 10: **Zynq UltraScale+ MPSoC Device Boot Header Attribute Bits**

Field Name	Bit Offset	Width	Default	Description
Reserved	31:16	16	0x0	Reserved. Must be 0.
BHDR RSA	15:14	2	0x0	0x3: RSA Authentication of the boot image will be done, excluding verification of PPK hash and SPK ID. All Others others : RSA Authentication will be decided based on eFuse RSA bits.
SHA2 Select	13:12	2	0x0	0x3: SHA2 (deprecated) All others: SHA3
CPU Select	11:10	2	0x0	0x0: R5 Single 0x1: A53 Single 0x2: R5 Dual 0x3: Reserved

Table 10: **Zynq UltraScale+ MPSoC Device Boot Header Attribute Bits** *(cont'd)*

Field Name	Bit Offset	Width	Default	Description
Hashing Select	9:8	2	0x0	0x0, 0x1 : No Integrity check 0x3: SHA3 for BI integrity check
PUF-HD	7:6	2	0x0	0x3: PUF HD is part of boot header. All other: PUF HD is in eFuse
Reserved	5:0	6	0x0	Reserved for future use. Must be 0.

Zynq UltraScale+ MPSoC Device Register Initialization Table

The Register Initialization Table in Bootgen is a structure of 256 address-value pairs used to initialize PS registers for MIO multiplexer and flash clocks. For more information, see About Register Intialization Pairs and INT File Attributes.

Table 11: **Zynq UltraScale+ MPSoC Device Register Initialization Table**

Address Offset	Parameter	Description
`0xB8` to `0x8B4`	Register Initialization Pairs: `<address>:<value>:` (2048 bytes)	If the Address is set to `0xFFFFFFFF`, that register is skipped and the value is ignored. All unused register fields must be set to Address=`0xFFFFFFFF` and value =`0x0`.

Zynq UltraScale+ MPSoC Device PUF Helper Data

The PUF uses helper data to re-create the original KEK value over the complete guaranteed operating temperature and voltage range over the life of the part. The helper data consists of a `<syndrome_value>`, an `<aux_value>`, and a `<chash_value>`. The helper data can either be stored in eFUSEs or in the boot image. See puf_file for more information.Also, see this link to the section on "PUF Helper Data" in *Zynq UltraScale+ Device Technical Reference Manual* (UG1085).

Table 12: **Zynq UltraScale+ MPSoC Device PUF Helper Data**

Address Offset	Parameter	Description
0x8B8 to 0xEC0	PUF Helper Data (1544 bytes)	Valid only when Boot Header Offset 0x44 (bits 7:6) == 0x3. If the PUF HD is not inserted then Boot Header size = 2048 bytes. If the PUF Header Data is inserted, then the Boot Header size = 3584 bytes. PUF HD size = Total size = 1536 bytes of PUFHD + 4 bytes of CHASH + 2 bytes of AUX + 1 byte alignment = 1544 byte.

Zynq UltraScale+ MPSoC Device Image Header Table

Bootgen creates a boot image by extracting data from ELF files, bitstream, data files, and so forth. These files, from which the data is extracted, are referred to as images. Each image can have one or more partitions. The Image Header table is a structure, containing information which is common across all these images, and information like; the number of images, partitions present in the boot image, and the pointer to the other header tables.

Table 13: **Zynq UltraScale+ MPSoC Device Image Header Table**

Address Offset	Parameter	Description
0x00	Version	0x01010000 0x01020000 - 0x10 field is added
0x04	Count of Image Header	Indicates the number of image headers.
0x08	1st Partition Header Offset	Pointer to first partition header. (word offset)
0x0C	1st Image Header Offset Header	Pointer to first image header. (word offset)
0x10	Header Authentication Certificate	Pointer to header authentication certificate. (word offset)
0x14	Boot Device for FSBL	Options are: 0 - Same boot device 1 – QSPI-32 2 – QSPI-24 3 – NAND 4 – SD0 4 – SD1 5 – SDLS 6 – MMC 7 – USB 8 – ETHERNET 9 - PCIE 10 – SATA
0x18- 0x38	Padding	Reserved (0x0)
0x3C	Checksum	A sum of all the previous words in the image header.

Zynq UltraScale+ MPSoC Device Image Header

About Image Headers

The Image Header is an array of structures containing information related to each image, such as an `ELF` file, bitstream, data files, and so forth. One image can have multiple partitions, for example an `ELF` can have multiple loadable sections, each of which form a partition in the boot image. The table will also contain the information of number of partitions related to an image. The following table provides the address offsets, parameters, and descriptions for the Zynq® UltraScale+™ MPSoC device.

Table 14: **Zynq UltraScale+ MPSoC Device Image Header**

Address Offset	Parameter	Description
0x00	Next image header offset	Link to next Image Header. 0 if last Image Header. (word offset)
0x04	Corresponding partition header	Link to first associated Partition Header. (word offset)
0x08	Reserved	Always 0.
0x0C	Partition Count	Value of the actual partition count.
0x10 - N	Image Name	Packed in big-endian order. To reconstruct the string, unpack 4 bytes at a time, reverse the order, and concatenated. For example, the string "`FSBL10.ELF`" is packed as `0x10: 'L','B','S','F', 0x14: 'E','.','0','1', 0x18: '\0','\0','F','L'` The packed image name is a multiple of 4 bytes.
varies	String Terminator	`0x00000`
varies	Padding	Defaults to `0xFFFFFFF` to 64 bytes boundary.

Zynq UltraScale+ MPSoC Device Partition Header

About the Partition Header

The Partition Header is an array of structures containing information related to each partition. Each partition header table is parsed by the Boot Loader. The information such as the partition size, address in flash, load address in RAM, encrypted/signed, and so forth, are part of this table. There is one such structure for each partition including FSBL. The last structure in the table is marked by all `NULL` values (except the checksum.) The following table shows the offsets, names, and notes regarding the Zynq® UltraScale+™ MPSoC device.

Table 15: **Zynq UltraScale+ MPSoC Device Partition Header**

Offset	Name	Notes
0x0	Encrypted Partition Data Word Length	Encrypted partition data length.
0x04	Un-encrypted Data Word Length	Unencrypted data length.

Table 15: **Zynq UltraScale+ MPSoC Device Partition Header** *(cont'd)*

Offset	Name	Notes
0x08	Total Partition Word Length (Includes Authentication Certificate. See Authentication Certificate.	The total encrypted + padding + expansion +authentication length.
0x0C	Next Partition Header Offset	Location of next partition header (word offset).
0x10	Destination Execution Address	The executable address of this partition after loading.
0x14	Destination Execution Address `HI`	The executable address of this partition after loading.
0x18	Destination Load Address `LO`	The RAM address into which this partition is to be loaded.
0x1C	Destination Load Address `HI`	The RAM address into which this partition is to be loaded.
0x20	Actual Partition Word Offset	The position of the partition data relative to the start of the boot image. (word offset)
0x24	Attributes	The position of the partition data relative to the start of the boot image. (word offset) See Zynq UltraScale+ MPSoC Device Partition Attribute Bits
0x28	Section Count	The number of sections in a single partition.
0x2C	Checksum Word Offset	The location of the Authentication Certification in the boot image. (word offset)
0x30	Image Header Word Offset	The location of the Authentication Certification in the boot image. (word offset)
0x34	Partition Number/ID	Partition ID.
0x3C	Header Checksum	A sum of the previous words in the Partition Header.

Zynq UltraScale+ MPSoC Device Partition Attribute Bits

The following table describes the Partition Attribute bits on the partition header table for the Zynq® UltraScale+™ MPSoC device.

Bit Offset	Field Name	Description
31:24	Data Attributes	Not Implemented
23	Vector Location	Location of exception vector. 0: LOVEC (default) 1: HIVEC
22:20	Reserved	
19	Early Handoff	Handoff immediately after loading: 0: No Early Handoff 1: Early Handoff Enabled
18	Endianness	0: Little Endian 1: Big Endian

Bit Offset	Field Name	Description
17:16	Partition Owner	0: FSBL 1: U-Boot 2 and 3: Reserved
15	RSA Authentication Certificate present	0: No RSA Authentication Certificate 1: RSA Authentication Certificate
14:12	Checksum Type	0: None 1-2: Reserved 3: SHA3 4-7: Reserved
11:8	Destination CPU	0: None 1: A53-0 2: A53-1 3: A53-2 4: A53-3 5: R5-0 6: R5 -1 7 R5-lockstep 8: PMU 9-15: Reserved
7	Encryption Present	0: Not Encrypted 1: Encrypted
6:4	Destination Device	0: None 1: PS 2: PL 3-15: Reserved
3	A5X Exec State	0: AARCH64 (default) 1: AARCH32
2:1	Exception Level	0: EL0 1: EL1 2: EL2 3: EL3
0	Trustzone	0: Non-secure 1: Secure

Zynq UltraScale+ MPSoC Device Authentication Certificates

The Authentication Certificate is a structure that contains all the information related to the authentication of a partition. This structure has the public keys and the signatures that BootROM/FSBL needs to verify. There is an Authentication Header in each Authentication Certificate, which gives information like the key sizes, algorithm used for signing, and so forth. The Authentication Certificate is appended to the actual partition, for which authentication is enabled. If authentication is enabled for any of the partitions, the header tables also needs authentication. The Header Table Authentication Certificate is appended at end of the content to the header tables.

The Zynq® UltraScale+™ MPSoC device uses RSA-4096 authentication, which means the primary and secondary key sizes are 4096-bit. The following table provides the format of the Authentication Certificate for the Zynq UltraScale+ MPSoC device.

Table 16: **Zynq UltraScale+ MPSoC Device Authentication Certificates**

Authentication Certificate		
0x00	Authentication Header = 0x0101000. See Zynq UltraScale+ MPSoC Authentication Certification Header.	
0x04	SPK ID	
0x08	UDF (56 bytes)	
0x40	PPK	Mod (512)
0x240		Mod Ext (512)
0x440		Exponent (4 bytes)
0x444		Pad (60 bytes)
0x480	SPK	Mod (512 bytes)
0x680		Mod Ext (512 bytes)
0x880		Exponent (4 bytes)
0x884		Pad (60 bytes)
0x8C0	SPK Signature = RSA-4096 (PSK, Padding || SHA-384 (SPK + Authentication Header + SPK-ID)	
0xAC0	Boot Header Signature = RSA-4096 (SSK, Padding || SHA-384 (Boot Header)	
0xCC0	Partition Signature = RSA-4096 (SSK, Padding || SHA-384 (Partition || Padding || Authentication Header || UDF || PPK || SPK || SPK Signature))	
0xCC0	FSBL Signature = RSA-4096 (SSK, Padding || SHA-384 (PMUFW || FSBL || Padding || Authentication Header || UDF || PPK || SPK || SPK Signature)	

Zynq UltraScale+ MPSoC Authentication Certification Header

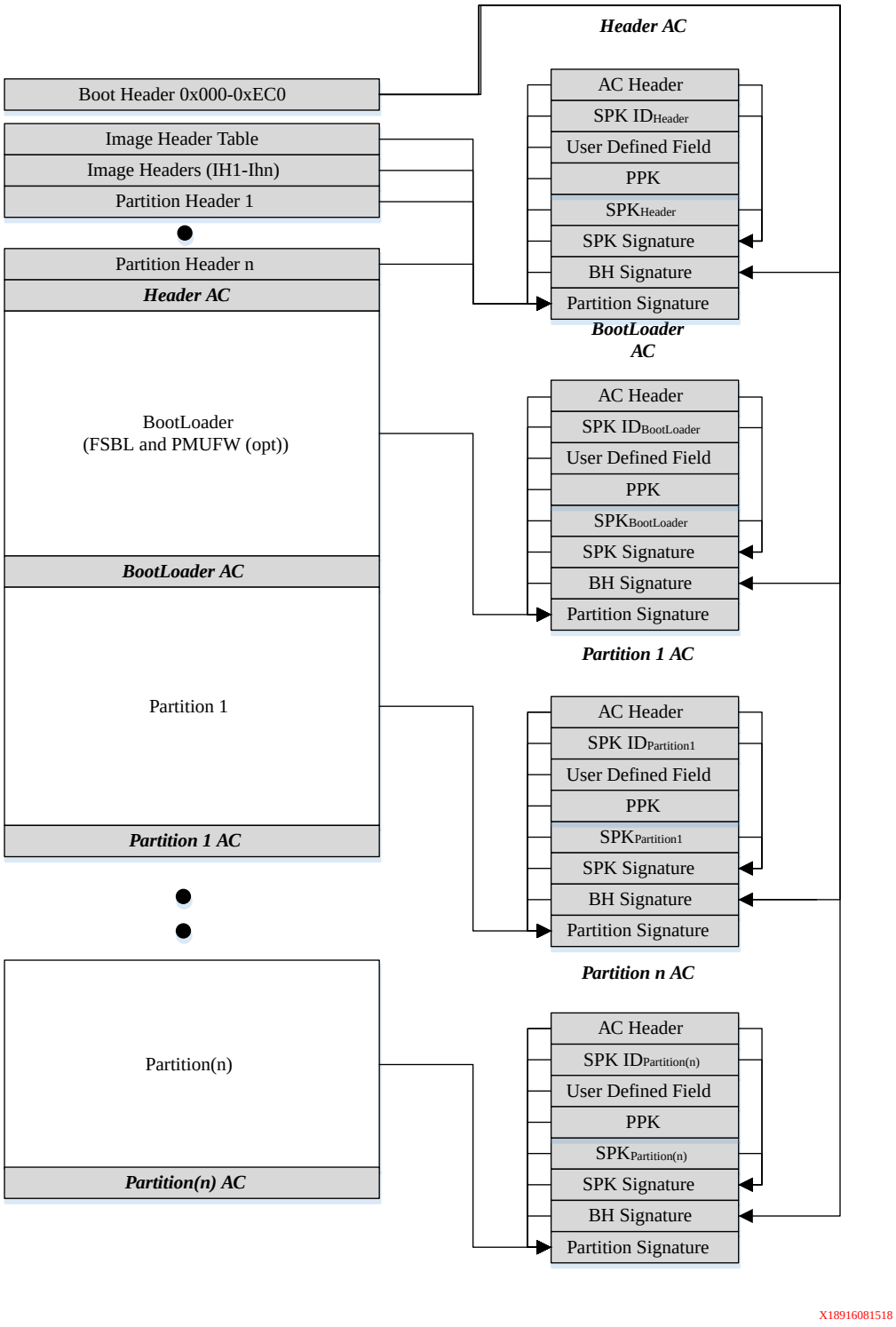
The following table describes the Authentication Header bit fields for the Zynq® UltraScale+™ MPSoC device.

Bit Field	Description	Notes
31:20	Reserved	0
19:18	SPK/User eFuse Select	01: SPK eFuse 10: User eFuse
17:16	PPK Key Select	0: PPK0 1: PPK1
15:14	Authentication Certificate Format	00: PKCS #1 v1.5
13:12	Authentication Certificate Version	00: Current AC
11	PPK Key Type	0: Hash Key
10:9	PPK Key Source	0: eFUSE
8	SPK Enable	1: SPK Enable
7:4	Public Strength	0 : 2048b 1 : 4096 2:3 : Reserved
3:2	Hash Algorithm	1: SHA3/384 2:3 Reserved
1:0	Public Algorithm	0: Reserved 1: RSA 2: ECC 3: Reserved

Zynq UltraScale+ MPSoC Device Boot Image Block Diagram

The following is a diagram of the components that can be included in a Zynq® UltraScale+™ MPSoC device boot image.

Figure 7: **Zynq UltraScale+ MPSoC Device Boot Image Block Diagram**



Creating Boot Images

Boot Image Format (BIF)

The Xilinx® boot image layout has multiple files, file types, and supporting headers to parse those files by boot loaders. Bootgen defines multiple attributes for generating the boot images and interprets and generates the boot images, based on what is passed in the files. Because there are multiple commands and attributes available, Bootgen defines a boot image format (BIF) to contain those inputs.A BIF comprises of the following:

- Configuration attributes to create secure/non-secure boot images
- An FSBL Image
- One or more Partition Images

Along with properties and attributes, Bootgen takes multiple commands to define the behavior while it is creating the boot images: For example; to create a boot image for a qualified FPGA device, a Zynq®-7000 SoC device, or a Zynq® UltraScale+™ MPSoC device, one needs to provide the appropriate arch command option to Bootgen. The Commands and Attributes chapter lists and describes the available options with which to direct Bootgen behavior.

The format of the boot image conforms to a hybrid of hardware and software requirements. The boot image Header is required by the BootROM loader which loads a single partition, typically the first stage boot loader (FSBL). The remainder of the boot image is loaded and processed by the FSBL. Bootgen generates a boot image by combining a list of partitions. These partitions can be:

- First Stage Boot Loader (FSBL)
- Secondary Stage Boot Loader (SSBL) like U-Boot
- Bitstream
- Linux
- Software applications to run on processors
- Data blobs

BIF Syntax and Supported File Types

The `BIF` file specifies each component of the boot image, in order of boot, and allows optional attributes to be applied to each image component. In some cases, an image component can be mapped to more than one partition if the image component is not contiguous in memory. BIF file syntax takes the following form:

```
<image_name>:
    {
        // common attributes
        [attribute1] <argument1>

        // partition attributes
        [attribute2, attribute3=<argument> <elf>
        [attribute2, attribute3=<argument>, attibute4=<argument] <bit>
        [attribute3] <elf>
        <bin>
    }
```

- The <image_name> and the {...} grouping brackets the files that are to be made into partitions in the ROM image.
- One or more data files are listed in the {...} brackets.
- Supported file types are: ELF, BIT, RBT, INT, or BIN files.
- Each partition data files can have an optional set of attributes preceding the data file name with the syntax `[attribute, attribute=<argument>]`.
- Attributes apply some quality to the data file.
- Multiple attributes can be listed separated with a "," as a separator. The order of multiple attributes is not important. Some attributes are one keyword, some are keyword equates.
- You can also add a filepath to the file name if the file is not in the current directory. How you list the files is free form; either all on one line (separated by any white space, and at least one space), or on separate lines.
- White space is ignored, and can be added for readability.
- You can use C-style block comments of `/*...*/`, or C++ line comments of `//`.

The following example is of a BIF with additional white space and new lines for improved readability:

```
<image_name>:
    {
        /* common attributes */
         [attribute1] <argument1>

        /* bootloader */
         [attribute2,
          attribute3,
          attribute4=<argument>
```

```
        ] <elf>

        /* pl bitstream */
        [
            attribute2,
            attribute3,
            attribute4=<argument>,
            attibute=<argument>
        ] <bit>

        /* another elf partition */
        [
            attribute3
        ] <elf>

        /* bin partition */
        <bin>
    }
```

Bootgen Support Files

The following table lists the Bootgen supported files.

Table 17: **Bootgen Supported Files**

Extension	Description	Notes
.bin	binary	Raw binary file
.bit/.rbt	bitstream	Strips the BIT file header
.dtb	binary	Raw binary file
image.gz	binary	Raw binary file
.elf	Executable Linked File (ELF)	Symbols and headers removed
.int	Register initialization file	
.nky	AES key	
.pk1/.pub/.pem	RSA key	
.sig	Signature files	Signature files generated by bootgen or HSM

Attributes and Descriptions

The following table lists the Bootgen attributes. Each attribute is linked to a longer description in the left column with a short description in the right column. The architecture name indicates what Xilinx® device uses that attribute:

- zynq = Zynq-7000 SoC device
- zynqmp = Zynq® UltraScale+™ MPSoC device

- fpga = any 7 series and above devices

Table 18: **Bootgen Attributes and Descriptions**

Option/Attribute	Description	Used By
aeskeyfile <aes_key_filepath>	The path to the AES keyfile. The keyfile contains the AES key used to encrypt the partitions. The contents of the key file needs to written to eFUSE or BBRAM. If the key file is not present in the path specified, a new key is generated by bootgen, which is used for encryption. For example: If encryption is selected for bitstream in the `BIF` file, the output is an encrypted bitstream.	All
alignment <byte>	Sets the byte alignment. The partition will be padded to be aligned to a multiple of this value. This attribute cannot be used with offset.	zynq, zynqmp

checksum <args>	This specifies the partition needs to be checksummed. Checksum algorithms are:
	`None`
	`md5`
		zynq, zynqmp

auth_params <options>	Extra options for authentication: `ppk_select`: 0=1, 1=2 of two PPKs supported. `spk_id`: 32-bit ID to differentiate SPKs. `spk_select`: To differentiate spk and user efuses. Default will be `spk-efuse`. `header_auth`: To authenticate headers when no partition is authenticated.	zynqmp
authentication <option>	Specifies the partition to be authenticated. Authentication for Zynq is done using RSA-2048. Authentication for ZynqMP is done using RSA-4096. The arguments are: `none`: Partition not encrypted. `rsa`: Partition encrypted using RSA algorithm.	All
bh_keyfile <filename>	256-bit obfuscated key or black key to be stored in the Boot Header. This is only valid when `[keysrc_encryption]=bh_gry_key` or `[keysrc_encryption]=bh_blk_key`.	zynqmp
bh_key_iv <filename>	Initialization vector used when decrypting the obfuscated key or a black key.	zynqmp
bhsignature <filename>	Imports Boot Header signature into authentication certificate. This can be used if you do not want to share the secret key PSK. You can create a signature and provide it to Bootgen. The file format is `bootheader.sha384.sig`	zynqmp
blocks <block sizes>	Specify block sizes for key-rolling feature in Encrytion. Each module is encrypted using its own unique key. The initial key is stored at the key source on the device, while keys for each successive blocks are encrypted (wrapped) in the previous module.	zynqmp

Table 18: **Bootgen Attributes and Descriptions** *(cont'd)*

Option/Attribute	Description	Used By

boot_device <options>	Specifies the secondary boot device. Indicates the device on which the partition is present. Options are:
	`qspi32`
	`qspi24`
	`nand`
	`sd0`
	`sd1`
	`sd-ls`
	`mmc`
	`usb`
	`ethernet`
	`pcie`
	`sata`
		zynqmp

bootimage <filename.bin>	Specifies that the listed input file is a boot image that was created by Bootgen.	zynq, zynqmp
bootloader <partition>	Specifies the partition is a bootloader (FSBL). This attribute is specified along with other partition BIF attributes.	zynq, zynqmp
bootvector <vector_values>	Specifies the vector table for execute in place (XIP).	zynqmp
checksum <arg>	Specifies that the partition needs to be checksummed. This option is not supported along with more secure features like authentication and encryption. Checksum algorithms are: `md5`: for Zynq®-7000 SoC devices. For Zynq® UltraScale+™ MPSoC, options are `none`: No checksum operation. `sha3`: sha3 checksum. zynq devices do not support checksum for boot loaders. For zynqmp does support checksum operation for bootloaders.	zynq, zynqmp

destination_cpu <device_core>	Specifies the core on which the partition needs to be executed. This option is not supported along with more secure features like authentication and encryption.
	`a53-0`
	`a53-1`
	`a53-2`
	`a53-3`
	`r5-0`
	`r5-1`
	`r5-lockstep`
	`pmu`
		zynqmp

destination_device <device_type>	This specifies if the partition is targeted for PS or PL. The options are: `ps`: the partition is targeted for PS (default). `pl`: the partition is targeted for PL, for bitstreams.	zynqmp

Table 18: **Bootgen Attributes and Descriptions** *(cont'd)*

Option/Attribute	Description	Used By
early_handoff	This flag ensures that the handoff to applications that are critical immediately after the partition is loaded; otherwise, all the partitions are loaded sequentially first, and then the handoff also happens in a sequential fashion.	zynqmp
encryption <partition_option>	Specifies the partition to be encrypted. Encryption algorithms are: zynq uses AES-CBC, and zynqmp uses AES-GCM. The partition options are: `none`: Partition not encrypted. `aes`: Partition encrypted using AES algorithm.	All

exception_level	Exception level for which the core should be configured.
	Options are:
	`el-0`
	`el-1`
	`el-2`
	`el-3`
		zynqmp

familykey	Specifies the family key.	zynqmp
fsbl_config	Specifies the sub-attributes used to configure the bootimage. Those sub-attributes are: `bh_auth_enable`: RSA authentication of the boot image is done excluding the verification of PPK hash and SPK ID. `auth_only`: boot image is only RSA signed. FSBL should not be decrypted. `opt_key`: Operational key is used for block-0 decryption. Secure Header has the opt key. `pufhd_bh`: PUF helper data is stored in Boot Header. (Default is `efuse`). PUF helper data file is passed to Bootgen using the option `[puf_file]`. `puf4kmode`; PUF is tuned to use in 4k bit configuration. (Default is 12k bit). `shutter = <value>`32 bit `PUF_SHUT` register value to configure PUF for shutter offset time and shutter open time.	zynqmp
headersignature<signature_file>	Imports the header signature into an Authentication Certificate. This can be used in case the user does not want to share the secret key, The user can create a signature and provide it to Bootgen.	zynq, zynqmp
hivec	Specifies the location of exception vector table as `hivec` (Hi-Vector). Default is taken as `lovec` (Low-Vector). This is applicable with A53 (32 bit) and R5 cores only. `hivec`: exception vector table at `0xFFFF0000` `lovec`: exception vector table at `0x00000000`.	zynqmp
init<filename>	Register initialization block at the end of the Bootloader, built by parsing the init (.int) file specification. A maximum of 256 address-value init pairs are allowed. The init files have a specific format.	zynq, zynqmp

Table 18: **Bootgen Attributes and Descriptions** *(cont'd)*

Option/Attribute	Description	Used By
keysrc_encryption	Specifies the Key source for encryption. The keys are: `efuse_gry_key`: Grey (Obfuscated) Key stored in eFUSE. See Gray/Obfuscated Keys `bh_gry_key`: Grey (Obfuscated) Key stored in boot header. `bh_blk_key`: Black Key stored in boot header. See Black/PUF Keys `efuse_blk_key` : Black Key stored in eFUSE. `kup_key`: User Key. `efuse_red_key`: Red key stored in eFUSE. See Rolling Keys `bbram_red_key`: Red key stored in BBRAM.	zynq, zynqmp
load <partition_address>	Sets the load address for the partition in memory.	zynq, zynqmp
offset <offset_address>	Sets the absolute offset of the partition in the boot image.	zynq, zynqmp
partition_owner<option> <partition>	Owner of the partition which is responsible to load the partition. Options are: fsbl: Partition is loaded by FSBL uboot: Partition is loaded by U-Boot.	zynq, zynqmp
pid <ID>	Specifies the Partition ID. PID can be a 32-bit value (0 to 0xFFFFFFFF).	zynqmp
pmufw_image <image_name>	PMU firmware image to be loaded by BootROM, before loading the FSBL.	zynqmp
ppkfile <key filename>	Primary Public Key (PPK). Used to authenticate partitions in the boot image. See Using Authentication for more information.	zynq, zynqmp
presign <sig_filename>	Partition signature (.sig) file.	All
pskfile <key filename>	Primary Secret Key (PSK). Used to authenticate partitions in the boot image. See the Using Authentication for more information.	zynq, zynqmp
puf_file <filename>	PUF helper data file. PUF is used with black key as encryption key source. PUF helper data is of 1544 bytes.1536 bytes of PUF HD + 4 bytes of HASH + 3 bytes of AUX + 1 byte alignment.	zynqmp
reserve	Reserves the memory, which is padded after the partition.	zynq, zynqmp
spkkfile<filename>	Keys used to authenticate partitions in the boot image. See Using Authenticationfor more information. SPK - Secondary Public Key	All

Table 18: **Bootgen Attributes and Descriptions** *(cont'd)*

Option/Attribute	Description	Used By
split	Splits the image into parts, based on the mode. Split options are: `slaveboot`: Supported for zynqmp only. Splits as follows: Boot Header + Bootloader Image and Partition Headers Rest of the partitions `normal`: Supported for both zynq and zynqmp. Splits as follows: Bootheader + Image Headers + Partition Headers + Bootloader Partiton1 Partition2 and so on Along with the split mode, output format can also be specified as `bin` or `mcs`. **Note:** The option split mode normal is same as the command line option split. This command line option is deprecated.	zynq, zynqmp
spk_select <SPK_ID>	Specify an SPK ID in user eFUSE.	zynqmp
spksignature <signature_file>	Imports the SPK signature into an Authentication Certificate. See Using AuthenticationThis can be used in case the user does not want to share the secret key PSK, The user can create a signature and provide it to Bootgen.	zynq zynqmp
sskfile <key filename>	Secondary Secret Key (SSK) key authenticates partitions in the Boot Image. The primary keys authenticate the secondary keys; the secondary keys authenticate the partitions.	All
startup	Sets the entry address for the partition, after it is loaded. This is ignored for partitions that do not execute.	zynq, zynqmp

trustzone <option>	The trustzone options are:
	
	`secure`
	`nonsecure`
		zynqmp

udf_bh <data_file>	Imports a file of data to be copied to the user defined field (UDF) of the Boot Header. The UDF is provided through a text file in the form of a hex string. Total number of bytes in UDF are: zynq = 76 bytes; zynqmp= 40 bytes.	zynq, zynqmp
udf_data<data_file>	Imports a file containing up to 56 bytes of data into user defined field (UDF) of the Authentication Certificate.	zynq, zynqmp
xip_mode	Indicates eXecute In Place (XIP) for FSBL to be executed directly from QSPI flash.	zynq, zynqmp

Chapter 4

Using Bootgen Interfaces

Bootgen has both a GUI and a command line option. The GUI option is available in the Xilinx® Software Development Kit (SDK) as a wizard. The functionality in this GUI is limited to the most standard functions when creating a boot image. The bootgen command line; however, is a full-featured set of commands that lets you create a complex boot image for your system.

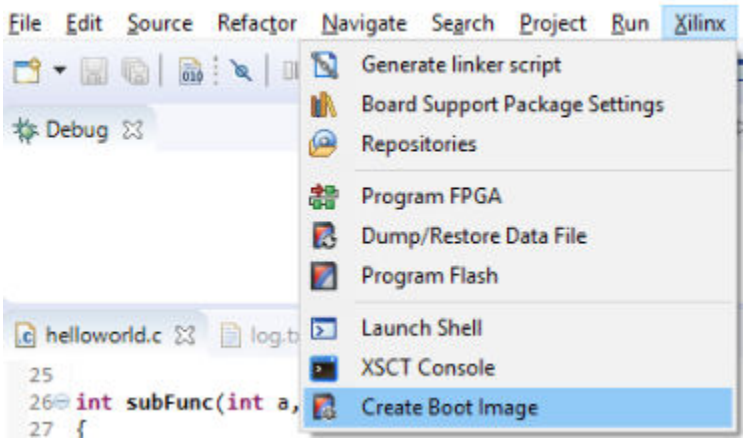
Bootgen GUI Options

The **Create Boot Image** wizard offers a limited number of Bootgen options to generate a boot image.

To create a boot image using the GUI, do the following:

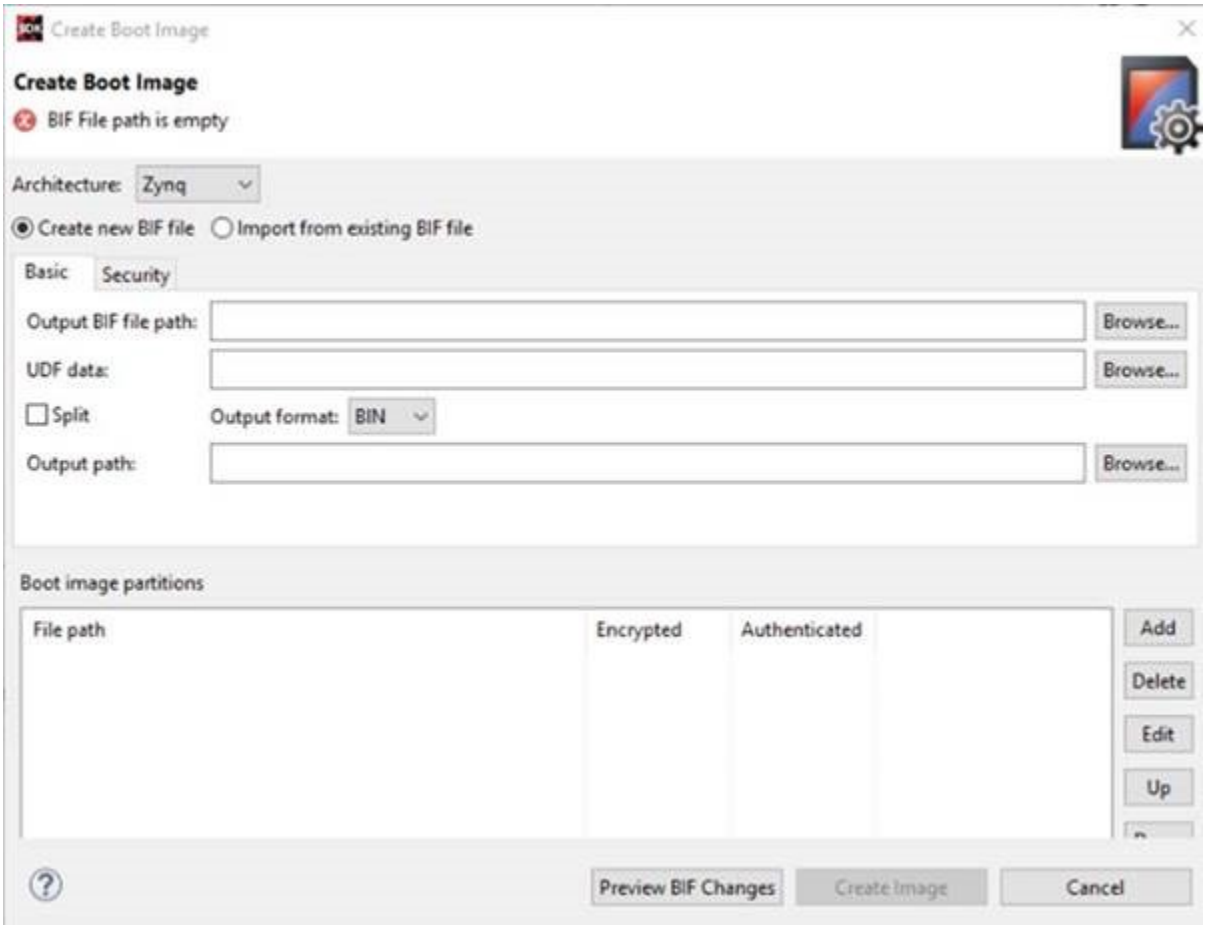
1. Select the application project in the **Project Navigator** or **C/C++ Projects** view and right-click **Create Boot Image**. Alternately, click **Xilinx Tools** → **Create boot image.**

Figure 8: **SCreate Bootgen Image Option**



The Create Boot Image dialog box opens, as shown in the following figure, with default values pre-selected from the context of the selected C project.

Figure 9: **Create boot image Dialog Box**



Note the following:

- When you run Create boot image the first time for an application, the dialog box is pre-populated with paths to the FSBL ELF file, and the bitstream for the selected hardware (if it exists in hardware project), and then the selected application ELF file.
- If a boot image was run previously for the application, and a BIF file exists, the dialog box is pre-populated with the values from the `/bif` folder.
- You can now create a boot image for Zynq®-7000 SoC or Zynq® UltraScale+™ MPSoC architectures.

IMPORTANT! *The data you enter for the boot image should be a maximum of 76 bytes with an offset of `0x4c` (for Zynq-7000 SoC) and 40 bytes and an offset of `0x70` (for Zynq UltraScale+ MPSoC). This is a hard limitation based on the Zynq architecture.*

2. Populate the Create boot image dialog box with the following information:
   a. From the **Architecture** drop-down, select the required architecture.
   b. Select either **Create a BIF file** or **Import an existing BIF file**.

c. From the Basic tab, specify the **Output BIF file path**.

d. If applicable, specify the **UDF data**: See udf_data for more information about this option.

e. Specify the **Output path**:

3. In the Boot image partitions, click the **Add** button to add additional partition images.
4. Create offset, alignment, and allocation values for partitions in the boot image, if applicable.

   The output file path is set to the `/bif` folder under the selected application project by default.
5. From the Security tab, you can specify the attributes to create a secure image. This security can be applied to individual partitions as required.

   a. To enable Authentication for a partition, check the **Use Authentication** option, then specify the PPK, SPK, PSK, and SSK values. See the Authentication topic for more information.

   b. To enable Encryption for a partition, select the Encryption tab, and check the **Use Encryption** option. See Using Encryption for more information.
6. Create or import a BIF file boot image one partition at a time, starting from the bootloader. The partitions list displays the summary of the partitions in the BIF file. It shows the file path, encryption settings, and authentication settings. Use this area to add, delete, modify, and reorder the partitions. You can also set values for enabling encryption, authentication, and checksum, and specifying some other partition related values like **Load**, **Alignment**, and **Offset**.

Using Bootgen on the Command Line

When you specify Bootgen options on the command line you have many more options than those provided in the GUI. In the standard install of theXilinx® SDK, the XSCT (Xilinx Software Command-Line Tool) is available for use as an interactive command line environment, or to use for creating scripting. In the XSCT, you can run bootgen commands. XSCT accesses the Bootgen executable, which is a separate tool. This bootgen executable can be installed stand-alone as described in Installing Bootgen. This is the same tool as is called from the XSCT, so any scripts developed here or in the XSCT will work in the other tool.

The *Xilinx Software Command-Line Tools (XSCT) Reference Guide* (UG1208) describes the tool. See the XSCT Use Cases chapter for an example of using Bootgen commands in XSCT.

Commands and Descriptions

The following table lists the Bootgen command options. Each option is linked to a longer description in the left column with a short description in the right column. The architecture name indicates what Xilinx® device uses that command:

- zynq = Zynq®-7000 SoC device
- zynqmp = Zynq® UltraScale+™ MPSoC device
- fpga = any 7 series and above devices

Table 19: **Bootgen Command and Descriptions**

Commands	Description and Options	Used by
arch <type>	Xilinx® device architecture: Options: zynq zynqmp fpga	All
bif_help	Prints out the BIF help summary.	All
dual_qspi_mode<configuration>	Generates two output files for dual QSPI configurations: parallel stacked <size>	zynq, zynqmp
efuseppkbits <PPK_filename>	Generates a PPK hash for eFUSE.	zynq, zynqmp
encrypt <options>	AES Key storage in device. Options are: bbram efuse	zynq, fpga
encryption_dump	Generates encryption log file, aes_log.txt.	zynqmp
fill <hex_byte>	Specifies the fill byte to use for padding.	zynq, zynqmp
generate_hashes	Output SHA2/SHA3 hash files with padding in PKCS#1v1.5 format.	zynq, zynqmp
generate_keys <key_type>	Generate the authentication keys. Options are: pem rsa obfuscatedkey	zynq, zynqmp
h, help	Prints out help summary.	All
image <filename(.bif)>	Provides a boot image format (.bif) file name.	All

Table 19: **Bootgen Command and Descriptions** *(cont'd)*

Commands	Description and Options	Used by
log<level_type>	Generates a log file at the current working directory with following message types: error warning info debug trace	All
nonbooting	Create an intermediate boot image.	zynq, zynqmp
o <filename>	Specifies the output file. The The format of the file is determined by the filename extension. Valid extensions are .bin .mcs	All
p <partname>	Specify the part name used in generating the encryption key.	All
padimageheader<option>	Pads the image headers to force alignment of following partitions. This feature is enabled (1) by default. Options are: 0 1	zynq, zynqmp
process_bitstream<option>	Specifies that the bitstream is processed and outputs as .bin or .mcs. For example, if encryption is selected for bitstream in BIF file, the output is an encrypted bitstream.	zynq, zynqmp
split <options>	Splits the boot image into partitions and outputs the files as .bin or .mcs.	zynq, zynqmp
spksignature <filename>	Generates an SPK signature file.	zynq, zynqmp

w <option>	Specifies whether to overwrite the output files:
	`on`
	`off`
	Note: The `-w` without an option is interpreted as `-w on`.
		All

zynqmpes1	Generates a boot image for ES1 (1.0). The default padding scheme is ES2 (2.0).	zynqmp

Boot Time Security

Xilinx® supports secure booting on all devices using latest authentication methods to prevent unathorized or modified code from being run on Xilinx devices. Xilinx supports various encryption techniques to make sure only authorized programs access the images. For hardware security features by device, see the following sections.

Secure and Non-Secure Modes in Zynq-7000 SoC Devices

For security reasons, CPU 0 is always the first device out of reset among all master modules within the PS. CPU 1 is held in an WFE state. While the BootROM is running, the JTAG is always disabled, regardless of the reset type, to ensure security. After the BootROM runs, JTAG is enabled if the boot mode is non-secure.

The BootROM code is also responsible for loading the FSBL/User code. When the BootROM releases control to stage 1, the user software assumes full control of the entire system. The only way to execute the BootROM again is by generating one of the system resets. The FSBL/User code size, encrypted and unencrypted, is limited to 192 KB. This limit does not apply with the non-secure execute-in-place option.

The PS boot source is selected using the `BOOT_MODE` strapping pins (indicated by a weak pull-up or pull-down resistor), which are sampled once during power-on reset (POR). The sampled values are stored in the `slcr.BOOT_MODE` register.

The BootROM supports encrypted/authenticated, and unencrypted images referred to as secure boot and non-secure boot, respectively. The BootROM supports execution of the stage 1 image directly from NOR or Quad-SPI when using the execute-in-place (xip_mode) option, but only for non-secure boot images. Execute-in-place is possible only for NOR and Quad-SPI boot modes.

- In secure boot, the CPU, running the BootROM code decrypts and authenticates the user PS image on the boot device, stores it in the OCM, and then branches to it.
- In non-secure boot, the CPU, running the BootROM code disables all secure boot features including the AES unit within the PL before branching to the user image in the OCM memory or the flash device (if execute-in-place (XIP) is used).

Any subsequent boot stages for either the PS or the PL are the responsibility of you, the developer, and are under your control. The BootROM code is not accessible to you. Following a stage 1 secure boot, you can proceed with either secure or non-secure subsequent boot stages. Following a non-secure first stage boot, only non-secure subsequent boot stages are possible.

Zynq UltraScale+ MPSoC Device Security

In a Zynq® UltraScale+™ MPSoC device, the secure boot is accomplished by using the hardware root of trust boot mechanism, which also provides a way to encrypt all of the boot or configuration files. This architecture provides the required confidentiality, integrity, and authentication to host the most secure of applications.

See this link in the *Zynq UltraScale+ Device Technical Reference Manual* (UG1085) for more information.

Using Encryption

Secure booting, which validates the images on devices before they are allowed to execute, has become a mandatory feature for most electronic devices being deployed in the field. For encryption, Xilinx supports an advanced encryption standard (AES) algorithm AES encryption.

AES provides symmetric key cryptography (one key definition for both encryption and decryption). The same steps are performed to complete both encryption and decryption in reverse order.

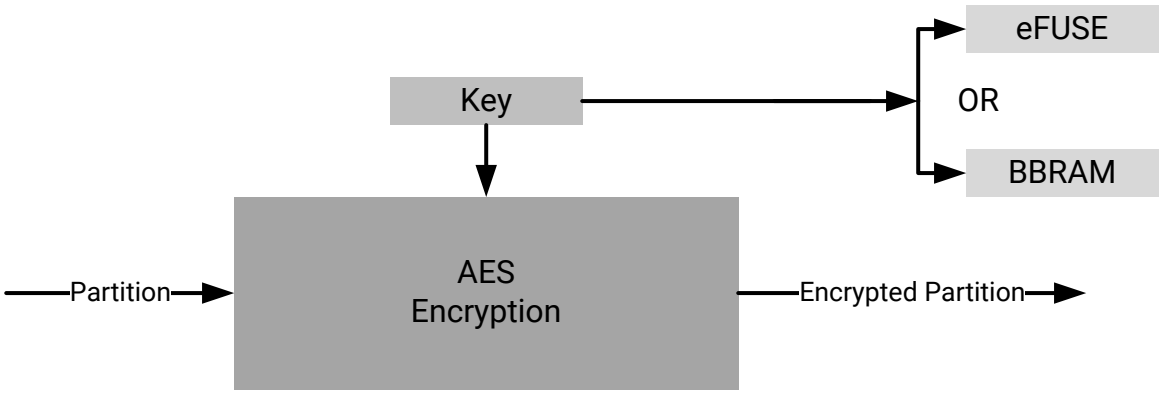
AES is an iterated symmetric block cipher, which means that it does the following:

- Works by repeating the same defined steps multiple times
- Uses a secret key encryption algorithm
- Operates on a fixed number of bytes

Encryption Process

Bootgen can encrypt the boot image partitions based on the user-provided encryption commands and attributes in the BIF file. AES is a symmetric key encryption technique; it uses the same key for encryption and decryption. The key used to encrypt a boot image should be available on the device for the decryption process while the device is booting with that boot image. Generally, the key is stored either in eFUSE or BBRAM, and the source of the key can be selected during boot image creation through BIF attributes, as shown in the following figure.

Figure 10: **Encryption Process Diagram**



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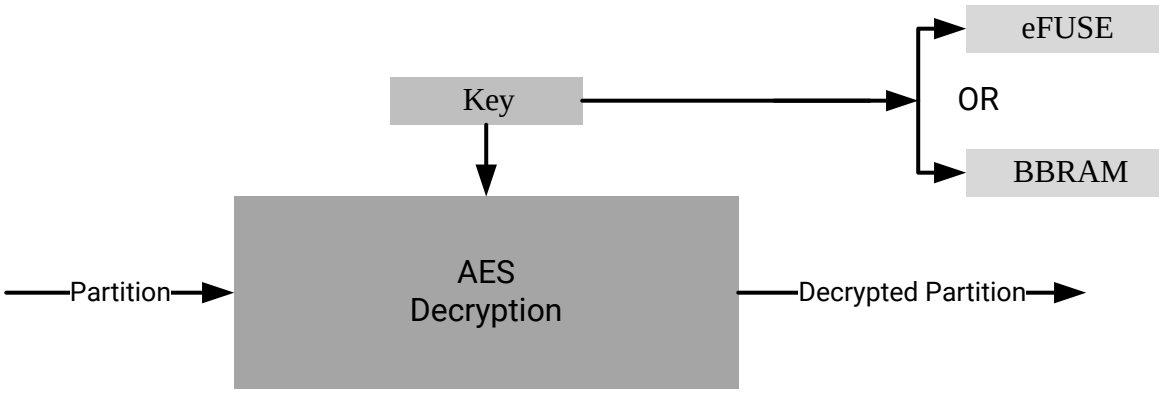
Decryption Process

For SoC devices, the BootROM and the FSBL decrypt partitions during the booting cycle. The BootROM reads FSBL from flash, decrypts, loads, and hands off the control. After FSBL start executing, it reads the remaining partitions, decrypts, and loads them. The AES key needed to decrypt the partitions can be retrieved from either EFUSE or BBRAM. The key source field of the Boot Header table in the boot image is read to know the source of the encryption key. Each encrypted partition is decrypted using a AES hardware engine.

Figure 11: **Decryption Process Diagram**



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Encrypting Zynq-7000 Device Partitions

Zynq®-7000 SoC devices use the embedded, Progammable Logic (PL), hash-based message authentication code (HMAC) and an advanced encryption standard (AES) module with a cipher block chaining (CBC) mode.

Example BIF File

To create a boot image with encrypted partitions, the AES key file is specified in the BIF using the aeskeyfile attribute. Specify an `encryption=aes` attribute for each image file listed in the `BIF` file to be encrypted. The example BIF file (`secure.bif`) is shown below:

```
image:
    {
        [aeskeyfile] secretkey.nky
        [keysrc_encryption] efuse
        [bootloader, encryption=aes] fsbl.elf
        [encryption=aes] uboot.elf
    }
```

From the command line, use the following command to generate a boot image with encrypted `fsbl.elf` and `uboot.elf`.

```
bootgen -arch zynq -image secure.bif -w -o BOOT.bin
```

Key Generation

Bootgen can generate AES-CBC keys. Bootgen uses the AES key file specified in the BIF for encrypting the partitions. If the key file is empty or non-existent, Bootgen generates the keys in the file specified in the BIF file. If the key file is not specified in the `BIF`, and encryption is requested for any of the partitions, then Bootgen generates a key file with the name of the BIF file with extension `.nky` in the same directory as of BIF. The following is a sample key file.

```
Device       xc7z020clg484;
Key 0        f878b838d8589818e868a828c8488808
Key StartCBC 5C9D95ECBFEC8A1F12A8EB312362C596
Key HMAC     000011112222333344445555666677777
```

Encrypting Zynq MPSoC Device Partitions

The Zynq® UltraScale+™ MPSoC device uses the AES-GCM core, which has a 32-bit, word-based data interface with support for a 256-bit key. The AES-GCM mode supports encryption and decryption, multiple key sources, and built-in message integrity check.

Operational Key

A good key management practice includes minimizing the use of secret or private keys. This can be accomplished using the operational key option enabled in Bootgen.

Bootgen creates an encrypted, secure header that contains the operational key (`opt_key`), which is user-specified, and the initialization vector (IV) needed for the first block of the configuration file when this feature is enabled. The result is that the AES key stored on the device, in either the BBRAM or eFUSEs, is used for only 384 bits, which significantly limits its exposure to side channel attacks. The attribute `opt_key` is used to specify operational key usage. See fsbl_config for more information about the `opt_key` value that is an argument to the `fsbl_config` attribute. The following is an example of using the `opt_key` attribute.

```
image:
    {
        [fsbl_config] opt_key
        [keysrc_encryption] bbram_red_key

        [
            bootloader,
            destination_cpu = a53-0,
            encryption      = aes,
            aeskeyfile      = aes_p1.nky
        ]    fsbl.elf

        [
            destination_cpu = a53-3,
            encryption      = aes,
            aeskeyfile      = aes_p2.nky,
        ]    hello.elf

    }
```

The operation key is given in the AES key (.nky) file with name `Key Opt` as shown in the following example.

Figure 12: **Operational Key**

```
Device      xczu9eg;
Key 0       9C42D9B74B633132F57C381D5CA4C7DF0829382CDBC455CDA08ECA62EB11D19D;
IV          42D3818AC135A365EDBD5316;
Key Opt     36AD8321ECA72E9F88E4F3A85ACD9ACDA27D1F50773E24B95067BA3BA75A3A62;
```

Bootgen generates the encryption key file. The operational key `opt_key` is then generated in the `.nky` file, if `opt_key` has been enabled in the BIF file, as shown in the previous example.

For another example of using the operational key, refer to Using the Op Key in a Development Environment to Protect the Device Key.

For more details about this feature, see the "Key Management" section of the "Security" chapter in the *Zynq UltraScale+ Device Technical Reference Manual* (UG1085).

Rolling Keys

The AES-GCM also supports the rolling keys feature, where the entire encrypted image is represented in terms of smaller AES encrypted blocks/modules. Each module is encrypted using its own unique key. The initial key is stored at the key source on the device, while keys for each successive module are encrypted (wrapped) in the previous module. The boot images with rolling keys can be generated using Bootgen. The BIF attribute blocks is used to specify the pattern to create multiple smaller blocks for encryption.

```
image:
    {
        [keysrc_encryption] bbram_red_key

        [
            bootloader,
            destination_cpu = a53-0,
            encryption      = aes,
            aeskeyfile      = aes_p1.nky,
            blocks          = 1024(2);2048;4096(2);8192(2);4096;2048;1024,
        ]    fsbl.elf

        [
            destination_cpu = a53-3,
            encryption      = aes,
            aeskeyfile      = aes_p2.nky,
            blocks          = 4096(1);1024,
        ]    hello.elf
    }
```

***Note*:**

- Number of keys in the key file should always be equal to the number of blocks to be encrypted.
    - If the number of keys are less than the number of blocks to be encrypted, Bootgen returns an error.
    - If the number of keys are more than the number of blocks to be encrypted, Bootgen ignores the extra keys.
- If you want to specify multiple Key/IV Pairs, you should specify `no. of blocks + 1` pairs
    - The extra Key/IV pair is to encrypt the secure header.

Gray/Obfuscated Keys

The user key is encrypted with the family key, which is embedded in the metal layers of the device. This family key is the same for all devices in the Zynq® UltraScale+™ MPSoC. The result is referred to as the *obfuscated key*. The obfuscated key can reside in either the Authenticated Boot Header or or in eFUSEs.

```
image:
    {
        [aeskeyfile] aes.nky
        [keysrc_encryption] bh_gry_key
        [bh_key_iv] bhiv.txt
        [
            bootloader,
            destination_cpu = a53-0,
            encryption      = aes,
            aeskeyfile      = aes_p1.nky
            fsbl.elf
        ]
        [
            destination_cpu = r5-0,
            encryption      = aes,
            aeskeyfile      = aes_p2.nky
            hello.elf
        [
    }
```

Bootgen does the following while creating an image:

1. Places the IV from `bhiv.txt` in the field BH IV in Boot Header.
2. Places the IV 0 from `aes.nky` in the field "Secure Header IV" in Boot Header.
3. Encrypts the partition, with Key0 and IV0 from `aes.nky`.

Another example of using the gray/family key is found in Chapter 7: Use Cases and Examples.

For more details about this feature, refer to the *Zynq UltraScale+ Device Technical Reference Manual* (UG1085).

Key Generation

Bootgen has the capability of generating AES-GCM keys. It uses the NIST-approved Counter Mode KDF, with CMAC as the pseudo random function. Bootgen takes seed as input in case the user wants to derive multiple keys from seed due to key rolling. If a seed is specified, the keys are derived using the seed. If seeds are not specified, keys are derived based on Key0. If an empty key file is specified, Bootgen generates a seed with time based randomization (not KDF), which in turn is the input for KDF to generate other the Key/IV pairs.

Note:

- If one encryption file is specified and others are generated, Bootgen can make sure to use the same Key0/IV0 pair for the generated keys as in the encryption file for first partition.
- If an encryption file is generated for the first partition and other encryption file with Key0/IV0 is specified for a later partition, then Bootgen exits and returns the error that an incorrect Key0/IV0 pair was used.

Key Generation

A sample key file is shown below.

```
Device      xczu9eg;
Key 0       AD00C023E238AC9039EA984D49AA8C819456A98C124AE890ACEF002100128932;
IV 0        11198912D243EF0AFEAC8970;
Key 1       C023E238AC903111DEF0AABB98C1CCDDEEFF021001289011198C1E238AC34012;
IV 1        111DEF0AABBCCDDEEFF00112;
Key 2       11456A9B8764DE111444C023E238A98C1CCC9031177112E01289011198CFF010;
IV 2        9C64778CBAF48D6DDE13749B;
Key Opt     229C993D1310DD27B6713749B6D07FCF8D3DCA01EC9C64778CBAF457D613508F;
```

Obfuscated Key Generation

Bootgen can generate the Obfuscated key by encrypting the red key with the family key and a user-provided IV. The family key is delivered by the Xilinx® Security Group. For more information, see familykey.To generate an obfuscated key, Bootgen takes the following inputs from the BIF file.

```
obf_key:
    {
        [aeskeyfile] aes.nky
        [familykey] familyKey.cfg
        [bh_key_iv] bhiv.txt
    }
```

The command to generate the Obfuscated key is:

```
bootgen -arch zynqmp -image all.bif -generate_keys obfuscatedkey
```

Black/PUF Keys

The black key storage solution uses a cryptographically strong key encryption key (KEK), which is generated from a PUF, to encrypt the user key. The resulting black key can then be stored either in the eFUSE or as a part of the authenticated boot header.

```
image:
    {
        [fsbl_config] pufhd_bh
        [aeskeyfile] aes.nky
        [keysrc_encryption] efuse_blk_key
```

```
        [puf_file] pufdata.txt
        [bh_key_iv]black_iv.txt
        [bh_keyfile]black_key.txt
        [fsbl_config] puf4kmode, shutter=0x0100005E,
        pufhd_bh
        [keysrc_encryption]bh_blk_key
    }
        [
            bootloader,
            destination_cpu = a53-0,
            encryption      = aes,
            aeskeyfile      = aes_p1.nky
        ]    fsbl.elf

        [
            destination_cpu = r5-0,
            encryption      = aes,
            aeskeyfile      = aes_p2.nky
        ]    hello.elf
    }
```

For another example of using the black key, see Chapter 7: Use Cases and Examples.

Multiple Encryption Key Files

Earlier versions of Bootgen supported creating the boot image by encrypting multiple partitions with a single encryption key. The same key is used over and over again for every partition. This is a security weakness and not recommended. Each key should be used only once in the flow.

Bootgen supports separate encryption keys for each partition. In case of multiple key files, ensure that each encryption key file uses the same Key0 (device key), IV0, and Operational Key. Bootgen does not allow creating boot images if these are different in each encryption key file.

The user can now specify multiple encryption key files, one for each of partition in the image. The partitions are encrypted using the key that is specified for the partition.

***Note*:** You can have unique key files for each of the partition created due to multiple loadable sections by having key file names appended with `".1", ".2"..."n"` so on in the same directory of the key file meant for that partition.

```
all:
    {
        [keysrc_encryption] bbram_red_key
        // FSBL (Partition-0)
        [
            bootloader,
            destination_cpu = a53-0,
            encryption = aes,
            aeskeyfile = key_p0.nky,
            fsbla53.elf
        [

        // application (Partition-1)
        [
            destination_cpu = a53-0,
            encryption = aes,
```

```
            aeskeyfile = key_p1.nky,
            hello.elf
        ]

    }
```

- The partition `fsbla53.elf` is encrypted using the keys from `key_p0.nky` file.
- Assuming `hello.elf` has three partitions because it has three loadable sections, then partition `hello.elf.0` is encrypted using keys from the `test2.nky` file.
- Partition `hello.elf.1` is then encrypted using keys from `test2.1.nky`.
- Partition `hello.elf.2` is encrypted using keys from `test2.2.nky`.

Using Authentication

AES encryption is a self-authenticating algorithm with a symmetric key, meaning that the key to encrypt is the same as the one to decrypt. This key must be protected as it is secret (hence storage to internal key space). There is an alternative form of authentication in the form of RSA (Rivest-Shamir-Adleman). RSA is an asymmetric algorithm, meaning that the key to verify is not the same key used to sign. A pair of keys are needed for authentication.

- Signing is done using Secret Key/ Private Key
- Verification is done using a Public Key

This public key does not need to be protected, and does not need special secure storage. This form of authentication can be used with encryption to provide both authenticity and confidentiality. RSA can be used with either encrypted or unencrypted partitions.

RSA not only has the advantage of using a public key, it also has the advantage of authenticating prior to decryption. The hash of the RSA Public key must be stored in the eFUSE. Xilinx® SoC devices support authenticating the partition data before it is sent to the AES decryption engine. This method can be used to help prevent attacks on the decryption engine itself by ensuring that the partition data is authentic before performing any decryption.

In Xilinx SoCs, two pairs of public and secret keys are used - primary and secondary. The function of the primary public/secret key pair is to authenticate the secondary public/secret key pair. The function of the secondary key is to sign/verify partitions.

The first letter of the acronyms used to describe the keys is either P for primary or S for secondary. The second letter of the acronym used to describe the keys is either P for public or S for secret. There are four possible keys:

- PPK = Primary Public Key
- PSK = Primary Secret Key

- SPK = Secondary Public Key
- SSK = Secondary Secret Key

Bootgen can create a authentication certificate in two ways:

- Supply the PSK and SSK. The SPK signature is calculated on-the-fly using these two inputs.
- Supply the PPK and SSK and the SPK signature as inputs. This is used in cases where the PSK is not known.

The primary key is hashed and stored in the eFUSE. This hash is compared against the hash of the primary key stored in the boot image by the FSBL. This hash can be written to the PS eFUSE memory using standalone driver provided along with SDK.

The following is an example BIF file:

```
image:
    {
        [aeskeyfile]secretkey.nky
        [pskfile]primarykey.pem
        [sskfile]secondarykey.pem
        [bootloader,authentication=rsa] fsbl.elf
        [authentication=rsa]uboot.elf
    }
```

For device-specific Authentication information, see the following:

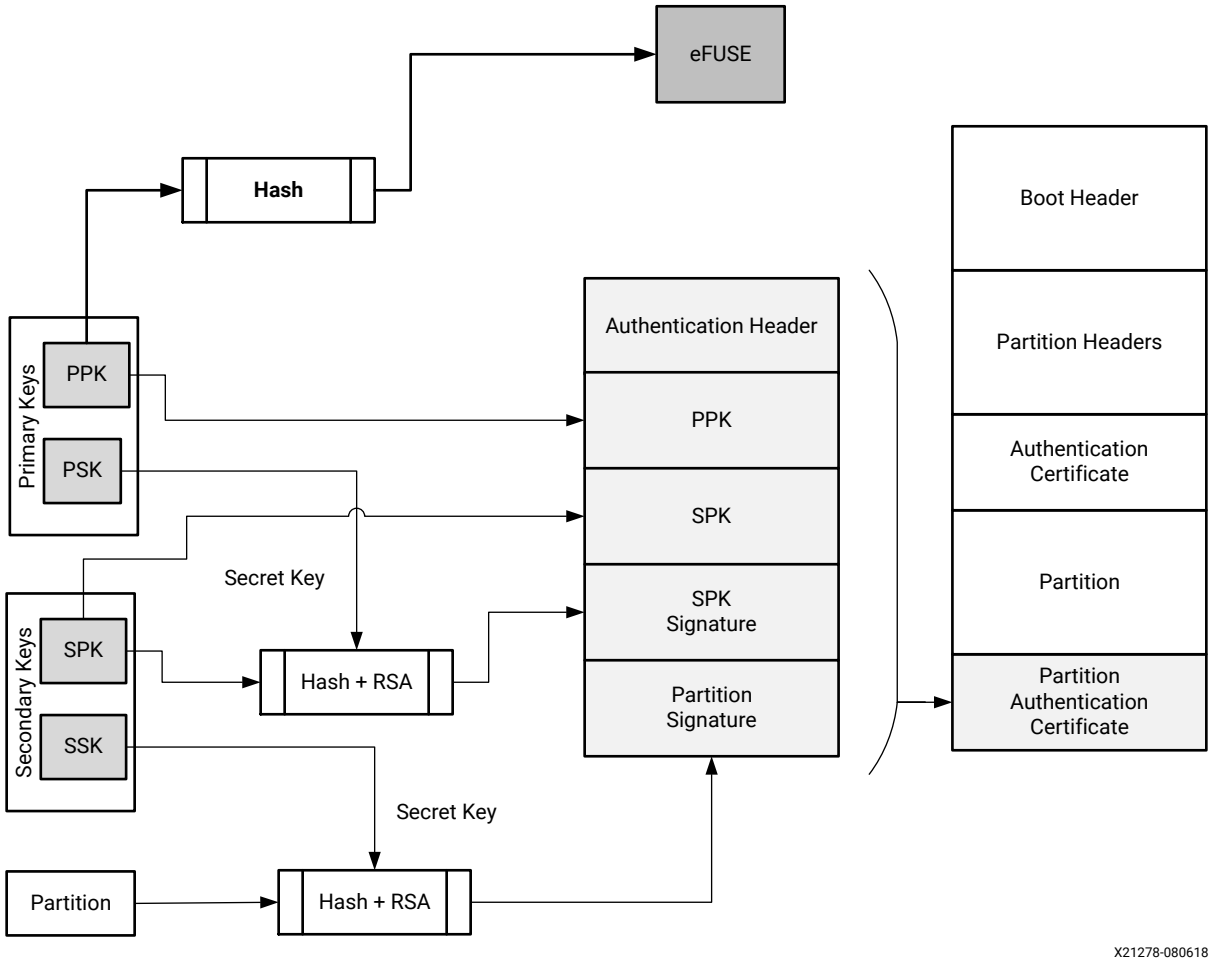
- Zynq-7000 Authentication Certificates
- Zynq UltraScale+ MPSoC Authentication Certificates

Signing

The following figure shows RSA signing of partitions. From a secure facility, Bootgen signs partitions using the Secret key. The signing process is described in the following steps:

1. PPK and SPK are stored in the Authentication Certificate (AC).
2. SPK is signed using PSK to get SPK signature; also stored as part of the AC.
3. Partition is signed using SSK to get Partition signature, populated in the AC.
4. The AC is appended to each partition that is opted for authentication.
5. PPK is hashed and stored in eFUSE.

Figure 13: **RSA Partition Signature**



The following table shows the options for Authentication.

Table 20: **Supported File Formats for Authentication Keys**

Key	Name	Description	Supported File Format
PPK	Primary Public Key	This key is used to authenticate a partition. It should always be specified when authenticating a partition.	*.txt *.pem *.pub *.pk1
PSK	Primary Secret Key	This key is used to authenticate a partition. It should always be specified when authenticating a partition.	*.txt *.pem *.pk1
SPK	Secondary Public Key	This key, when specified, is used to authenticate a partition.	*.txt *.pem *.pub *.pk1

Table 20: **Supported File Formats for Authentication Keys** *(cont'd)*

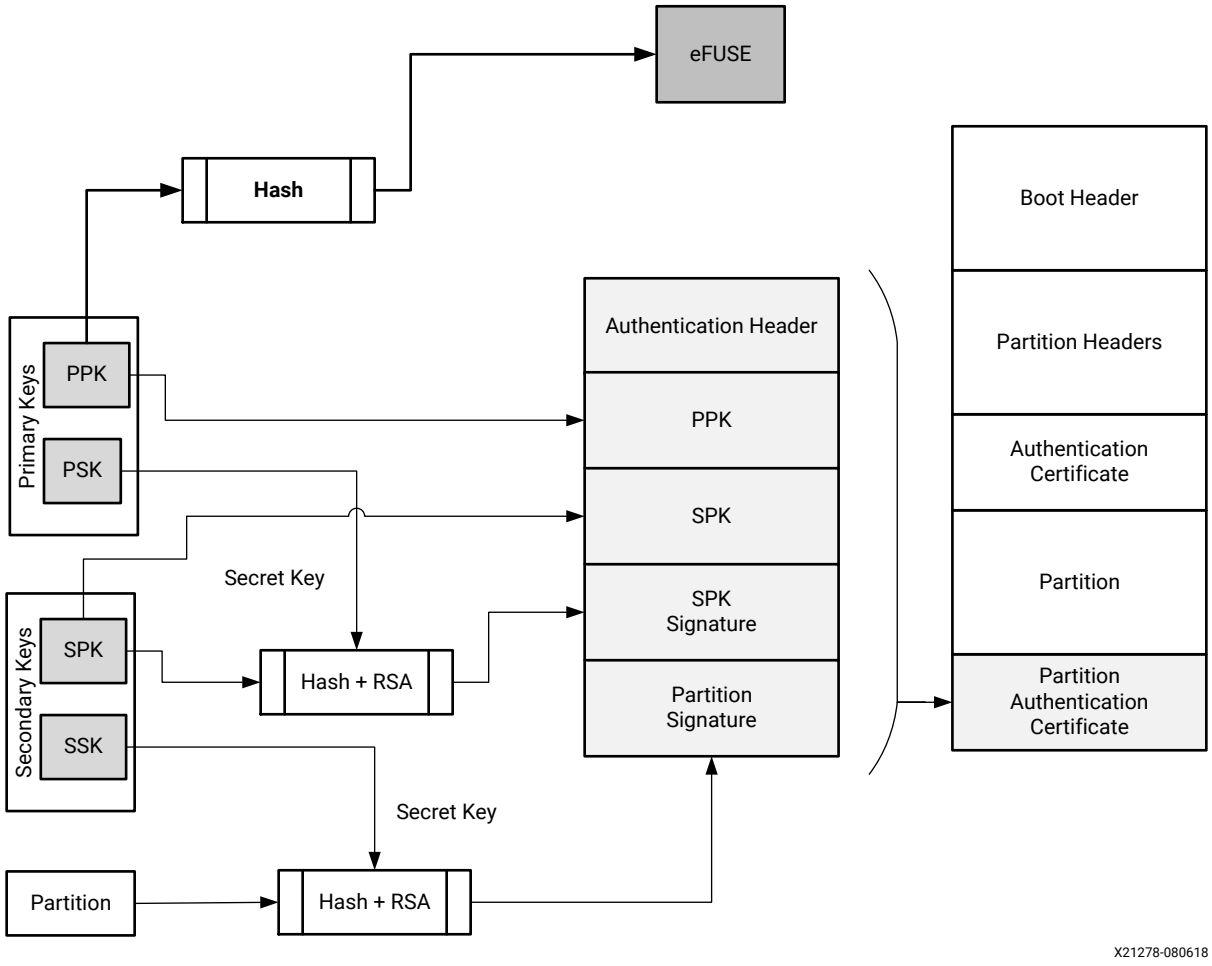
Key	Name	Description	Supported File Format
SSK	Secondary Secret Key	This key, when specified, is used to authenticate a partition.	*.txt *.pem *.pk1

Verifying

In the device, the BootROM verifies the FSBL, and either the FSBL or U-Boot verifies the subsequent partitions using the Public key.

1. Verify PPK - This step establishes the authenticity of primary key, which is used to authenticate secondary key.
    a. PPK is read from AC in boot image
    b. Generate PPK hash
    c. Hashed PPK is compared with the PPK hash retrieved from eFUSE
    d. If same, then primary key is trusted, else secure boot fail
2. Verify secondary keys: This step establishes the authenticity of secondary key, which is used to authenticate the partitions.
    a. SPK is read from AC in boot image
    b. Generate SPK hashed
    c. Get the SPK hash, by verifying the SPK signature stored in AC, using PSK
    d. Compare hashes from step (b) and step (c)
    e. If same, then secondary key is trusted, else secure boot fail.
3. Verify partitions - This step establishes the authenticity of partition which is being booted.
    a. Partition is read from the boot image.
    b. Generate hash of the partition.
    c. Get the partition hash, by verifying the Partition signature stored in AC, using SSK.
    d. Compare the hashes from step (b) and step (c)
    e. If same, then partition is trusted, else secure boot fail

Figure 14: **Verification Flow Diagram**



Bootgen can create a authentication certificate in two ways:

- Supply the PSK and SSK. The SPK signature is calculated on-the-fly using these two inputs.
- Supply the PPK and SSK and the SPK signature as inputs. This is used in cases where the PSK is not known.

Zynq UltraScale+ MPSoC Authentication Support

The Zynq® UltraScale+™ MPSoC device uses RSA-4096 authentication, which means the primary and secondary key sizes are 4096-bit.

NIST SHA-3 Support

***Note*:** For SHA-3 Authentication, always use Keccak SHA-3 to calculate hash on boot header, PPK hash and boot image. NIST-SHA3 is used for all other partitions which are not loaded by ROM.

The generated signature uses the Keccak-SHA3 or NIST-SHA3 based on following table:

Table 21: **Authentication Signatures**

Which Authentication Certificate (AC)?	Signature	SHA Algorithm and SPK eFUSE	Secret Key used for Signature Generation
Header AC (loader by FSBL/FW)	SPK Signature	If SPKID eFUSEs, then Keecak; If User eFUSE, then NIST	PSK
	BH Signature	Always Keecak	SSK_{header}
	Header Signature	Always Nist	SSK_{header}
BootLoader AC (loaded by ROM)	SPK Signature	Always Keecak; Always SPKID eFUSE for SPK	PSK
	BH Signature	Always Keecak	$SSK_{Bootloader}$
	Header Signature	Always Keecak	$SSK_{Bootloader}$
Partition AC (loaded by FSBL FW)	SPK Signature	If SPKID eFUSEs then Keecak; If User eFUSE then NIST	PSK
	BH Signature	Always Keecak	$SSK_{Partition}$
	Header Signature	Always NIST	$SSK_{Partition}$

Examples

Example 1: BIF file for authenticating the partition with single set of key files:

```
image:
    {
        [fsbl_config] bh_auth_enable
        [auth_params] ppk_select=0; spk_id=0x00000000
        [pskfile] primary_4096.pem
        [sskfile] secondary_4096.pem
        [pmufw_image] pmufw.elf
        [bootloader, authentication=rsa, destination_cpu=a53-0] fsbl.elf
        [authenication=rsa, destination_cpu=r5-0] hello.elf
    }
```

Example 2: BIF file for authenticating the partitions with separate secondary key for each partition:

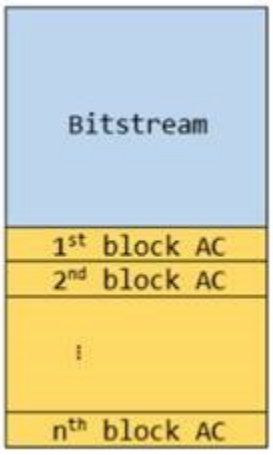
```
image:
    {
        [auth_params] ppk_select=1;
        [pskfile] primary_4096.pem
        [sskfile] secondary_4096.pem
        // FSBL (Partition-0)
        [bootloader,
        destination_cpu = a53-0,
        authentication = rsa,
        spk_id = 0x01,
        sskfile = secondary_p1.pem
        fsbla53.elf
    ]
        // ATF (Partition-1)
    [
        destination_cpu = a53-0,
        authentication = rsa,
```

```
        exception_level = el-3,
        trustzone = secure,
        spk_id = 0x04,
        sskfile = secondary_p2.pem
        bl31.elf
    ]
        // UBOOT (Partition-2)
    [
        destination_cpu = a53-0,
        authentication = rsa,
        exception_level = el-2,spk_id = 0x08,
        sskfile = secondary_p3.pemu-boot.elf
    [
    }
```

Bitstream Authentication Using External Memory

The authentication of a bitstream is different from other partitions. The FSBL can be wholly contained within the OCM, and therefore authenticated and decrypted inside of the device. For the bitstream, the size of the file is so large that it cannot be wholly contained inside the device and external memory must be used. The use of external memory creates a challenge to maintain security because an adversary may have access to this external memory. When bitstream is requested for authentication, Bootgen divides the whole bitstream into 8MB blocks and has an authentication certificate for each block. If a bitstream is not in multiples of 8MB, the last block contains the remaining bitstream data. When authentication and encryption are both enabled, encryption is first done on the bitstream, then Bootgen divides the encrypted data into blocks and places an authentication certificate for each block.

Figure 15: **Bitstream Authentication Using External Memory**



User eFUSE Support with Enhanced RSA Key Revocation

Enhanced RSA Key Revocation Support

The RSA key provides the ability to revoke the secondary keys of one partition without revoking the secondary keys for all partitions.

***Note*:** The primary key should be the same across all partitions.

This is achieved by using `USER_FUSE0` to `USER_FUSE7` eFUSEs with the BIF parameter spk_select.

***Note*:** You can revoke up to 256 keys, if all are not required for their usage.

The following BIF file sample shows enhanced user fuse revocation: Image header and FSBL uses different SSKs for authentication (`ssk1.pem` and `ssk2.pem` respectively) with the following BIF input.

```
the_ROM_image:
    {
        [auth_params]ppk_select = 0
        [pskfile]psk.pem
        [sskfile]ssk1.pem
        [bootloader,
         authentication = rsa,
         spk_select = spk-efuse,
         spk_id = 0x8,
         sskfile = ssk2.pem
        zynqmp_fsbl.elf
        ]
        [
         destination_cpu = a53-0,
        authentication = rsa,
        spk_select = user-efuse,
        spk_id = 0x200,
        sskfile = ssk3.pem
        application.elf
        ]
        [
        destination_cpu = a53-0,
        authentication = rsa,
        spk_select = spk-efuse,
        spk_id = 0x400,
        sskfile = ssk4.pem
        application2.elf
        ]
    }
```

- `spk_select = spk-efuse` indicates that `spk_id` eFUSE will be used for that partition.
- `spk_select = user-efuse` indicates that user eFUSE will be used for that partition.

Partitions loaded by CSU ROM will always use `spk_efuse`.

***Note*:** The `spk_id` eFUSE specifies which key is valid. Hence, the ROM checks the entire field of `spk_id` eFUSE against the SPK ID to make sure its a bit for bit match.

The user eFUSE specifies which key ID is NOT valid (has been revoked). Therefore, the firmware (non-ROM) checks to see if a given user eFUSE that represents the SPK ID has been programmed.

Key Generation

Bootgen has the capability of generating RSA keys. Alternatively, you can create keys using external tools such as OpenSSL. Bootgen creates the keys in the paths specified in the BIF file.

The figure shows the sample RSA private key file.

Figure 16: **Sample RSA Private Key File**

```
-----BEGIN RSA PRIVATE KEY-----
MIIJKAIBAAKCAgEA4ppimme6TvPT5+JB2CgXQLU9AyStbnEr2lEJu+ZpR9HZ5Plq
6KbOcFuV6q3EKvI5PJsMS0yHpVr/11/uTPxyUT6Im5goMyaskz0PS3xTWuYoSDba
YD50ZlPi5xBrswWvys6YcIbLTbk2+o86o0Rr/sdQtLR0pbsLfuBFoKMEsKl9N12k
E1l6DMlTjh9KSpZOzmj7yew2Rm857QqQp8su1Vi4qdtIr58+MoQxeETeHcN+zuq4
drlUsUqX3msVb9z0rRwYrBVtSksWr5d+xj+cAUpiPjeMGRXg00L6gEGGPTjnqQtG
YFCoCFcBL4JknHF/yMyV7f6wh2xtkKbme+Kuovcz/pQVKEGELkQ9kjweBf5c8Vmk
b13NvkrAUOXYLM+py0uY/PGjtz6B5W964LOcrT+TRROi4FGotYzk2XmJtODO5dYH
Lw58IOT3zAYwaC/98bUDGYP6kJ9+YqprerLmZU55Ew30PPodjHYihLmBj1pvmu4g
oZ9tXJPch/uRk/tv3e53P2JhWKwdb72FUi8hEgSkCWWAFfJwCVFWATettzGlhtz+
Ww3eBAQi9fFbgr6YERwxOOLopaRQiZPaC/8XG8u0bTE3MdvsJK/IIOAqVnTl7Dfs
QKzTZap8+Iwx/vuaWAiLd0qYCDKKKmlGGz5bQhEgRnk0I/lpOKIlPRL8wH0CAwEA
AQKCAgA3qhscuOxgZq8gYEkycy67G4pgUks0PSK7n3qXqNM17FvtToO/oPJHUYgz
PPpaXmRHCgNsH+GWchM08gDU8pKWeJkQN8FwR0jPZolyTpkfVDiC/M6KI+1uEZ9E
iZkbQgNb+4Ig6kvYzO2/gR2za6Rn0shli3q4F4mMYkVYX5NQXmI/Doa2ph1ANdQX
roIObnvvYoSvppHynXIKU7UTMutPRlsdhpuFYMXjnOuWErzJbPOimrAzofU3FA7Y
eU+ryghk2ekJpL3TKTzqZ3mh85A8FOyrQfPtWZ1/6A0nInF6apclxHpGQKn2WoEV
DZ/vekYcqn0OGKl+qtkDVqx5tEaXlXG1c0PBWg5aofkpNZ0K0wOG6iCueNvATcJ9
RoMq7c7zZOYh4SzWgSjP3a8neGcnhG0T6BGYCGjPXRW2Y6ri/71rDcOBVSc3zS8p
IVKABpl3PIgZlhMnxdC60RPh8dhXRR0TUa3+1SyGx37Ad9260UeHHJIpz28DkzTg
CY7RU5SDSh6wDuDbhelu4nzZDGWeKq9zeAzXGZhIn0zcxpWvG54uHTHNnqBEFJ2S
ZSJ8sq4aYiZCiW/PrqKgg8wBygKcEtr3/LcAm4r3pl9mHk1555QQNdpk+ba+3GLp
bEy0889KwCyPKfWY5pl6VNgLycxe/TofMDCHQARAZwLRnN1sQQKCAQEA80nn83su
OYN9Oc22owfm/MHGJ6mFi5LpRtGy1WbcAbDsZs7rjQ4IZ46JQlMpiQl0IpNbVub7
sW0FUX7sVo0XZMSl+EpsZDq021+7hY6+MGALtPpg9n2Jz9lfCyVXfNqv5SiMv6Te
6/jur69KiwhztYFi7JK4GGUdcCWyAwMTdgm3pQDDH99Vp436klvk4lMyjeQaIpO/
FzkiklfYN84j9jvtagoMk0fzaickiOGSs4ciOdS3DEgGC9xlhDkIs9UFPk1Pfw+7
qYnsT7XIwoTCBrvQlllKp5fLZUhSRsIQV82u44IPfcU3xWgeyInSGx0RfSV5RWOv
v9sJPVsFlXE5EQKCAQEA7nFNK5gbPKA0nxKTeM1ZMHp99/YqRxpj5irmXmrF54cn
sZPpG/dvbJBXILAd9hsSYjW8FNY5ehJhL9IQzEVavFr8SAvu2FyI9MN0d9wUvpJG
55JxX9K090uSzaXZVimV/5xumbnynwx2ZwgxslSAYoNy+8soviZlXQxZzeUaohaM
VVuLlHdRzE0afrcFsnfugIDl72MbI4t2cKTfTek/iYAvF9bkO76upkPmWu4V7yFT
of9QFkq8qBRthEpvaKNTObpU5TrzsxUH3rYXVnAZgpEXEJdeVVFYzSLf4SC45mxe
GPp37pYetPBKVrUesuEvQ70IeoiCGRXFgC9TPmYwrQKCAQEA5D1CoPbAD+7ejVsD
a4FfX2K+7rin86A4v1q9hlzAK8n6jhyzeRpgIh7jgFiaj9hRnppVx3pdSD+6DJGh
UTV+a+fcuMnBVGqK/3+ZYhvfK2z/rqJyUuzFXDxWYROANz7GY5seKDCZfhGEg0dV
DIg6XV5sGvsuQJyj+HE0xoSdPlCxe9fyNrWEGvQkzxgX64gX1mvXZPbs//F3EIne
68O1kyz3d1LEJ2wJ3V2pdc0BnvE4175K1/f9zCTgDtKe6m7/Q0quOMreyJf/HWyy
UmLP0BdlAogfdIkApR0rKvym7milGQUMWXaq8sTSlFpPxWYI4TpFwiZaXAg2a9w3
qdKVsQKCAQBH8noloFT/mxulsBY9ikDSRvPBoU6qe8UPC3zNmowyy25nv8jD/opp
iLgxjdLMkuieJ7ajluwq8GbQ5iLZcEfrs8yR9L/SG0HcESoQjKDZzAuHDoIVNuAS
CoS2dse4nv26zjn1Os2BvmHvvuI3/BVtJFrKrUeS8MT/KZ3jabD6nbEkhGX+m25c
JhvLhnA6pMOblMlMzWu/8vH/FVCoEqxwUfRjzhy6BlRuqOhWIacOq9Cvff1tcImy
cc+F7mvld/rB3X6GWJ52N+9S/UDXfSXFZwA9ql7lgYE5DL/fD1+bb7GI+fK8VCHZ
2POlbCtiMF5xoxVu28fdx9r7TcxhdLZVAoIBADmGYfxvgEqhALqdWZQmtRRNisWQ
y0/RfED7dNtN8o5vjBCbrOV/tQ3Ddbb7a0kwo1NFr1xR7KIki98SkKN0EiCrpRfc
+ccs6kASTZcPH/nGG91brOAm9FOG2q5cX6kDK1hqHe+1UYm/34a+2wN0/CwAh7MH
gECABtqx9QCD/DJI+n5ocrYk5RsQJrtnwoP4L8X24dRiMiRMIsS4V9uyyRLQTWV/
k3TOjRgL5eRKbcVwV7c8kmaGDWfM/eVL1QW+wEa0wY+TdSUhlYvgsG5yijkhCAEe
/+Az0w5Zu1vnLbj5eXKiULWIS1OsDCBfJepuINHoUpBwsGzFb7ZXtpK2X1M=
-----END RSA PRIVATE KEY-----
```

BIF Example

A sample BIF file, `generate_pem.bif`:

```
generate_pem:
    {
        [pskfile] psk0.pem
        [sskfile] ssk0.pem
    }
```

Command

The command to generate keys is, as follows:

```
bootgen -generate_keys pem -arch zynqmp -image generate_pem.bif
```

PPK Hash for eFUSE

Bootgen generates the PPK hash for storing in eFUSE for PPK to be trusted. This step is required only for RSA Authentication with eFUSE mode, and can be skipped for RSA Boot Header Authentication for the Zynq® UltraScale+™ MPSoC device. The value from `efuseppksha.txt` can be programmed to eFUSE for RSA authentication with the eFUSE mode.

For more information about BBRAM and eFUSE programming, see *Programming BBRAM and eFUSEs* (XAPP1319).

BIF File Example

The following is a sample BIF file, `generate_hash_ppk.bif`.

```
generate_hash_ppk:
    {
       [pskfile] psk0.pem
       [sskfile] ssk0.pem
       [bootloader, destination_cpu=a53-0, authentication=rsa] fsbl_a53.elf
    }
```

Command

The command to generate PPK hash for eFUSE programming is:

```
bootgen -image generate_hash_ppk.bif -arch zynqmp -w -o /
test.bin -efuseppkbits efuseppksha.txt
```

Using HSM Mode

In current cryptography, all the algorithms are public, so it becomes critical to protect the private/secret key. The hardware security module (HSM) is a dedicated crypto-processing device that is specifically designed for the protection of the crypto key lifecycle, and increases key handling security, because only public keys are passed to the Bootgen and not the private/secure keys. A *Standard* mode is alao available; this mode does not require passing keys.

In some organizations, an Infosec staff is responsible for the production release of a secure embedded product. The Infosec staff might use a HSM for digital signatures and a separate secure server for encryption. The HSM and secure server typically reside in a secure area. The HSM is a secure key/signature generation device which generates private keys, encrypts partitions using the private key, and provides the public part of the RSA key to Bootgen. The private keys reside in the HSM only.

Bootgen in HSM mode uses only RSA public keys and the signatures that were created by the HSM to generate the boot image. The HSM accepts hash values of partitions generated by Bootgen and returns a signature block, based on the hash and the secret RSA key.

In contrast to the HSM mode, Bootgen in its Standard mode uses AES encryption keys and the RSA Secret keys provided through the BIF file, to encrypt and authenticate the partitions in the image, respectively. The output is a single boot image, which is encrypted and authenticated. For authentication, the user has to provide both sets of public and private/secret keys. The private/secret keys are used by the Bootgen to sign the partitions and create signatures. These signatures along with the public keys are embedded into the final boot image.

For more information about the HSM mode for FPGAs, see the HSM Mode for FPGAs.

Using Advanced Key Management Options

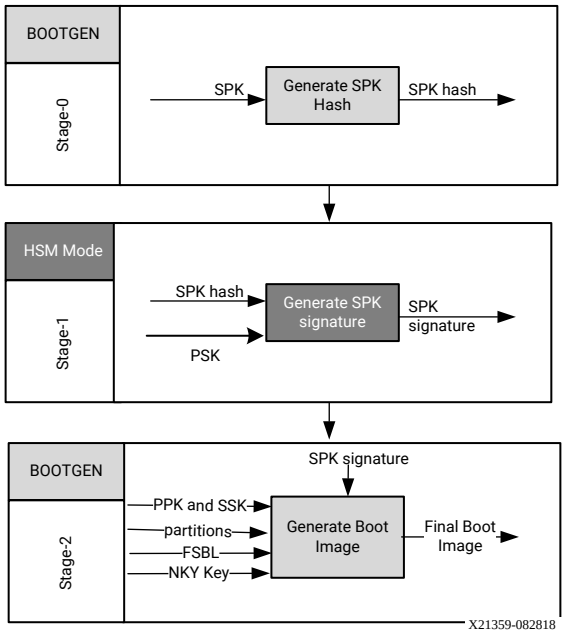
The public keys associated with the private keys are `ppkZynq.pem` and `spk.pem`. The HSM accepts hash values of partitions generated by Bootgen and returns a signature block, based on the hash and the secret key.

Creating a Boot Image Using HSM Mode: PSK is not Shared

The following figure shows a Stage 0 to Stage 2 Boot stack for a Zynq® device that uses the HSM mode. It reduces the number of steps by distributing the SSK.

This figure uses the Zynq® UltraScale+™ MPSoC device to illustrate the stages.

Figure 17: **Generic 3-stage boot image**



Boot Process

To create a boot image using HSM mode, it is similar to a boot image created using a Standard flow with following BIF file.

```
all:
    {
        [aeskeyfile]my_efuse.nky
        [pskfile]primary.pem
        [sskfile]secondary.pem
        [bootloader,encryption=aes,authentication=rsa]zynq_fsbl_0.elf
        [authentication=rsa]system.bit
    }
```

Stage 0: Create a boot image using HSM Mode

Trusted individual creates the SPK signature using the Primary Secret Key. The SPK Signature is on the Authentication Certificate Header, SPK, and SPKID. Generate a hash for SPK. The following is the snippet from the BIF file.

```
stage )
    {
        [auth_params] ppk_select=1;spk_id=0x12345678
        [pskfile]keys/primary0.pem
        [spkfile]keys/secondary.pub
    }
```

The following is the Bootgen command:

```
bootgen.exe -image stage0.bif -generate_hashes
```

The output of this command is: `secondary.pub`.

Stage 1: Distribute the SPK Signature

Trusted individual distributes the SPK Signature to the development teams.

```
openssl rsautl -raw -sign -inkey keys/primary0.pem -in
secondary.pub.sha384 >
secondary.pub.sha384.sig
```

The output of this command is: `secondary.pub.sha384.sig`

Stage 2: Encrypt using AES in FSBL

The development teams use Bootgen to create as many boot images as needed. The development teams use:

- The SPK Signature from the Trusted Individual.
- The Secondary Secret Key (SSK), SPK, and SPKID

Encrypt using AES. The following is the snippet from the BIF file.

```
Stage2:
    {
        [aeskeyfile]my_efuse.nk [auth_params]
ppk_select=1;spk_id=0x12345678
        [ppkfile]keys/primary.pub
        [sskfile]keys/secondary0.pem
        [spksignature]secondary.pub.sha384.sig
        [bootloader,destination_cpu=a53-0, encryption=aes,
authentication=rsa] fsbl.elf
        [destination_cpu=a53-0, encryption=aes, authentication=rsa]
hello_a53_0_64.elf
    }
```

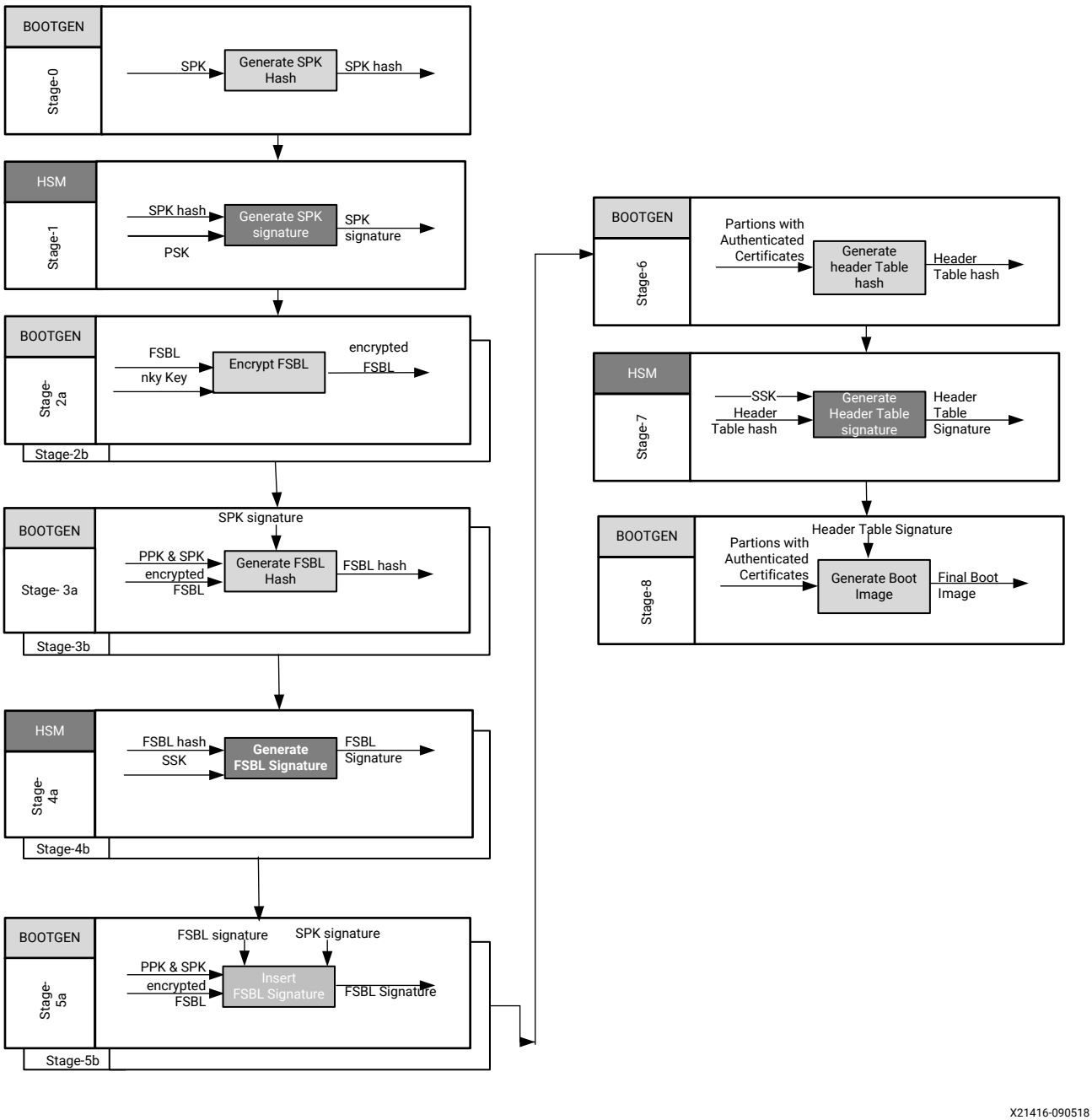
The Bootgen command is:

```
bootgen -image stage2.bif -o final.bin
```

Creating a Zynq-7000 SoC Device Boot Image using HSM Mode

The following figure provides a diagram of an HSM mode boot image for a Zynq®-7000 SoC device. The steps to create this boot image are immediately after the diagram.

Figure 18: **Stage 0 to 8 Boot Process**



X21416-090518

To create a boot image using HSM mode for a Zynq®-7000 SoC device, it would be similar to a boot image created using a standard flow with the following BIF file. These examples, where needed, use the OpenSSL program to generate hash files.

```
all:
    {
        [aeskeyfile]my_efuse.nky [pskfile]primary.pem
[sskfile]secondary.pem
        [bootloader,encryption=aes,authentication=rsa] zynq_fsbl_0.elf
        [authentication=rsa]system.bit
    }
```

Stage 0: Generate a hash for SPK

The following is the snippet from the BIF file. The following is the snippet from the BIF file.

```
stage0:
        {
      [ppkfile]primary.pub
      [spkfile]secondary.pub
    }
```

The following is the Bootgen command:

```
bootgen.exe -image stage0.bif -w on -generate_hashes
```

Stage 1: Sign the SPK Hash

Encrypt the partitions.

```
xil_rsa_sign.exe -gensig -sk primary.pem /
-data secondary.pub.sha256 /
-out secondary.pub.sha256.sig
```

The output of this command is: `secondary.pub.sha256.sig`

Stage 2: Encrypt using AES

Encrypt using the following snippet in the BIF file.

```
Stage 2:
    {
        [aeskeyfile]my_efuse.nky
        [bootloader,encryption=aes]zynq_fsbl_0.elf
    }
```

The bootgen command is:

```
bootgen -image stage2a.bif -w -o fsbl_e.bin -encrypt efuse
```

The output is the following encrypted file: `fsbl_e.bin`.

Stage 3: Generate Partition Hashes

Stage 3a: Generate the boot header hash using the following BIF file:

```
stage3a:
    {
        [ppkfile] primary.pub
        [spkfile] secondary.pub
        [spksignature]secondary.pub.sha256.sig
        [bootimage,authentication=rsa]fsbl_e.bin
    }
```

The Bootgen command is:

```
bootgen.exe -image stage3a.bif -w -o -generate_hashes
```

The output is the following hash file: `zynq_fsbl_0.elf.0.sha256`

Stage 3b: Generate the boot header hash using the following BIF file:

```
stage3b:
    {
        [ppkfile] primary.pub
        [spkfile] secondary.pub
        [spksignature]secondary.pub.sha256.sig
        [bootimage,authentication=rsa]system.bit
    }
```

The Bootgen command is:

```
bootgen.exe -image stage3b.bif -w -o -generate_hashes
```

The output is the following hash file: `system.bit.0.sha256`.

Stage 4: Sign the Hashes

Stage 4a: Sign the FSBL partition hash using the following BIF file:

```
xil_rsa_sign.exe -gensig -sk secondary.pem -data system.bit.0.sha256 -
out system.bit.0.sha256.sig
```

The output is the following hash file: `system.bit.0.sha256.sig`

Stage 4b: Sign the bitstream hash using the following BIF file:

```
xil_rsa_sign.exe -gensig -sk secondary.pem -data system.bit.0.sha256 -
out system.bit.0.sha256.sig
```

The output is the following signature file: `system.bit.0.sha256.sig`.

Stage 5: Insert Partition Signatures into Authentication Certificates

Stage 5a: Insert the FSBL hash with the following BIF file:

```
stage5a:
    {
        [ppkfile]primary.pub
        [spkfile]secondary.pub
        [spksignature]secondary.pub.sha256.sig
        [bootimage,authentication=rsa,presign=zynq_fsbl_0.elf.0.sha256.sig]
        fsbl_e.bin
    }
```

The Bootgen command is:

```
bootgen.exe -image stage5a.bif -w -o fsbl_e_ac.bin -efuseppkbits
efuseppkbits.txt -nonbooting
```

The authenticated output files are: `fsbl_e_ac.bin` and `efuseppkbits.txt`.

Stage 5b: Insert the bitstream hash the following BIF file:

```
stage5b:
    {
        [ppkfile]primary.pub
        [spkfile]secondary.pub
        [spksignature]secondary.pub.sha256.sig
        [bootimage,authentication=rsa,presign=zynq_fsbl_0.elf.0.sha256.sig]
        system.bit
    }
```

The Bootgen command is:

```
bootgen.exe -image stage5b.bif -o system_e_ac.bin -nonbooting
```

The authenticated output file is `system_e_ac.bin`.

Stage 6: Generate Header Table Hash

The BIF file and the Bootgen command look like the following:

```
bootgen.exe -image stage6.bif -generate_hashes
```

The output hash file is: `ImageHeaderTable.sha256`.

Stage 7: Generate Header Table Signature

Generate the header table signature using the following comand:

```
xil_rsa_sign.exe -gensig -sk secondary.pem -data
ImageHeaderTable.sha256 -out ImageHeaderTable.sha256.sig
```

The output hash file is: `ImageHeaderTable.sha256.sig`.

Stage 8: Combine Partitions, Insert Header Table Signature

Enter the following in a BIF file:

```
stage8:
    {
        [headersignature]ImageHeaderTable.sha256.sig
        [bootimage]fsbl_e_ac.bin
        [bootimage]system_e_ac.bin
    }
```

The Bootgen command is:

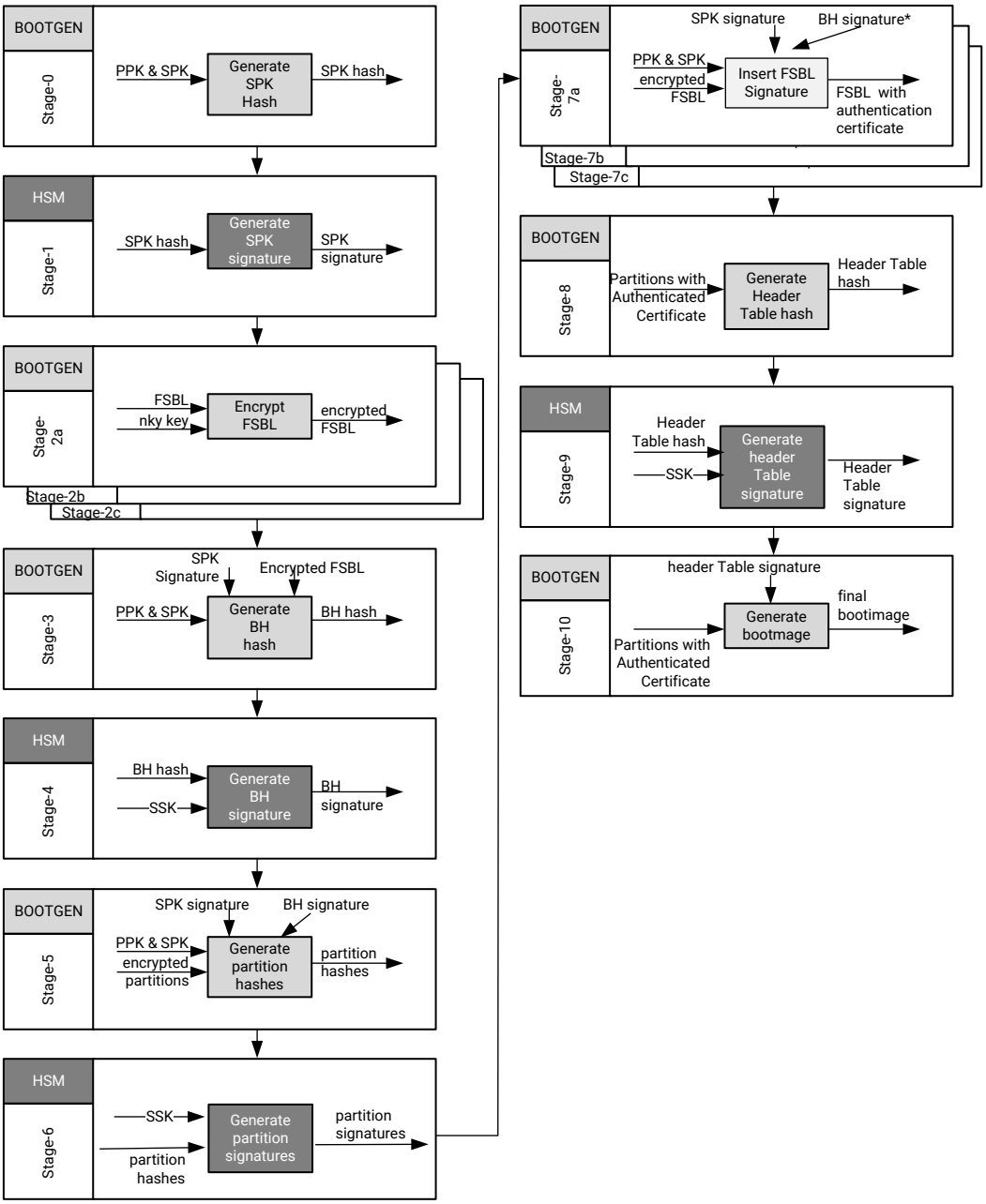
```
bootgen.exe -image stage8.bif -w -o final.bin
```

The output file is the final boot image: `final.bin`.

Creating a Zynq UltraScale+ MPSoC Device Boot Image using HSM Mode

The following figure provides a diagram of an HSM mode boot image.

Figure 19: **0 to 10 Stage Boot Process**



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To create a boot image using HSM mode for a Zynq® UltraScale+™ MPSoC device, it would be similar to a boot image created using a standard flow with the following BIF file. These examples, where needed, use the OpenSSL program to generate hash files.

```
all:
    {
        [aeskeyfile]my_efuse.nky
        [fsbl_config] bh_auth_enable
        [keysrc_encryption] bbram_red_key
        [pskfile] primary0.pem
        [sskfile] secondary0.pem

[bootloader,destination_cpu=a53-0,encryption=aes,authentication=rsa]fsbl.el
f
        [destination_device=pl,encryption=aes,authentication=rsa]
system.bit

[destination_cpu=a53-0,authentication=rsa,exception_level=el-3,trustzone=se
cure]bl31.elf
        [destination_cpu=a53-0,authentication=rsa,exception_level=el-2]u-
boot.elf
    }
```

Stage 0: Generate a hash for SPK

The following is the snippet from the BIF file.

```
stage0:
    {
      [ppkfile]primary.pub
      [spkfile]secondary.pub
    }
```

The following is the Bootgen command:

```
bootgen -arch zynqmp -image stage0.bif -generate_hashes -w on -log error
```

Stage 1: Sign the SPK Hash (encrypt the partitions)

The following is a code snippet using OpenSSL to generate the SPK hash:

```
openssl rsautl -raw -sign -inkey primary0.pem -in secondary.pub.sha384 >
secondary.pub.sha384.sig
```

The output of this command is `secondary.pub.sha256.sig`.

Stage 2: Encrypt Using AES

Stage 2a: Encrypt the FSBL using the following snippet in the BIF file.

```
Stage 2a:
    {
        [aeskeyfile]my_efuse.nky
        [keysrc_encryption] bbram_red_key
        [bootloader,destination_cpu=a53-0,encryption=aes]fsbl.elf
    }
```

The bootgen command is:

```
bootgen -arch zynqmp -image stage2a.bif -o fsbl_e.bin -w on -log error
```

Generate the following BIF file entry:

```
stage2b:
    {
        [aeskeyfile]my_efuse.nky
        [encryption=aes,destination_device=pl,pid=1]system.bit
    }
```

Stage 2b: Encrypt the bitstream.

The Bootgen command is:

```
bootgen -arch zynqmp -image stage2b.bif -o system_e.bin -w on -log error
```

Stage 3: Generate Boot Header Hash

Generate the boot header hash using the following BIF file:

```
stage3:
    {
     [fsbl_config] bh_auth_enable
     [ppkfile] primary.pub
     [spkfile] secondary.pub
     [spksignature]secondary.pub.sha384.sig
     [bootimage,authentication=rsa]fsbl_e.bin
    }
```

The Bootgen command is:

```
bootgen -arch zynqmp -image stage3.bif -generate_hashes -w on -log error
```

Stage 4: Sign Boot Header Hash

Generate the boot header hash with the following OpenSSL command:

```
openssl rsautl -raw -sign -inkey secondary0.pem -in bootheader.sha384 >
bootheader.sha384.sig
```

Stage 5: Get Partition Hashes

Get partition hashes using the following command in a BIF file:

```
stage5:
    {
        [ppkfile]primary.pub
        [spkfile]secondary.pub
        [spksignature]secondary.pub.sha384.sig
        [bhsignature]bootheader.sha384.sig
[bootimage,authentication=rsa]fsbl_e.bin
        [bootimage,authentication=rsa]system_e.bin

[destination_cpu=a53-0,authentication=rsa,exception_level=el-3,trustzone=se
cure]bl31.elf
        [destination_cpu=a53-0,authentication=rsa,exception_level=el-2]u-
boot.elf
    }
```

The Bootgen command is:

```
bootgen -arch zynqmp -image stage5.bif -generate_hashes -w on -log error
```

Multiple hashes will be generated for a bitstream partition. For more details, see Bitstream Authentication Using External Memory.

The Boot Header hash is also generated from in this stage 5; which is different from the one generated in stage3, because the parameter `bh_auth_enable` is not used in stage5. This can be added in stage5 if needed, but does not have a significant impact because the Boot Header hash generated using stage3 is signed in stage4 and this signature will only be used in the HSM mode flow.

Stage 6: Sign Partition Hashes

Create the following files using OpenSSL:

```
openssl rsautl -raw -sign -inkey secondary0.pem -in fsbl.elf.0.sha384 >
fsbl.elf.0.sha384.sig
openssl rsautl -raw -sign -inkey secondary0.pem -in system.bit.0.sha384 >
system.bit.0.sha384.sig
openssl rsautl -raw -sign -inkey secondary0.pem -in system.bit.1.sha384 >
system.bit.1.sha384.sig
openssl rsautl -raw -sign -inkey secondary0.pem -in system.bit.2.sha384 >
system.bit.2.sha384.sig
```

```
openssl rsautl -raw -sign -inkey secondary0.pem -in system.bit.3.sha384 >
system.bit.3.sha384.sig
openssl rsautl -raw -sign -inkey secondary0.pem -in u-boot.elf.0.sha384 >
u-boot.elf.0.sha384.sig
openssl rsautl -raw -sign -inkey secondary0.pem -in bl31.elf.0.sha384 >
bl31.elf.0.sha384.sig
openssl rsautl -raw -sign -inkey secondary0.pem -in bl31.elf.1.sha384 >
bl31.elf.1.sha384.sig
```

Stage 7: Insert Partition Signatures into Authentication Certificate

Stage 7a: Insert the FSBL signature by adding this code to a BIF file:

```
Stage7a:
    {
     [fsbl_config] bh_auth_enable
     [ppkfile] primary.pub
     [spkfile] secondary.pub
     [spksignature]secondary.pub.sha384.sig
     [bhsignature]bootheader.sha384.sig
     [bootimage,authentication=rsa,presign=fsbl.elf.0.sha384.sig]fsbl_e.bin
    }
```

The Bootgen command is as follows:

```
bootgen -arch zynqmp -image stage7a.bif -o fsbl_e_ac.bin -efuseppkbits
efuseppkbits.txt -nonbooting -w on -log error
```

Stage 7b: Insert the bitstream signature by adding the following to the BIF file:

```
stage7b:
    {
     [ppkfile]primary.pub
     [spkfile]secondary.pub
     [spksignature]secondary.pub.sha384.sig
     [bhsignature]bootheader.sha384.sig

[bootimage,authentication=rsa,presign=system.bit.0.sha384.sig]system_e.bin
    }
```

The Bootgen command is:

```
bootgen -arch zynqmp -image stage7b.bif -o system_e_ac.bin -nonbooting -w
on -log error
```

Stage 7c: Insert the U-Boot signature by adding the following to the BIF file:

```
stage7c:
    {
     [ppkfile] primary.pub
     [spkfile] secondary.pub
     [spksignature]secondary.pub.sha384.sig
```

```
      [bhsignature]bootheader.sha384.sig

[destination_cpu=a53-0,authentication=rsa,exception_level=el-2,presign=u-
boot.elf.0.sha384.sig]u-boot.elf
     }
```

The Bootgen command is:

```
bootgen -arch zynqmp -image stage7c.bif -o u-boot_ac.bin -nonbooting -w on
-log error
```

Stage 7d: Insert the ATF signature by entering the following into a BIF file:

```
stage7d:
     {
      [ppkfile] primary.pub
      [spkfile] secondary.pub
      [spksignature]secondary.pub.sha384.sig
      [bhsignature]bootheader.sha384.sig

[destination_cpu=a53-0,authentication=rsa,exception_level=el-3,trustzone=se
cure,presign=bl31.elf.0.sha384.sig]bl31.elf
     }
```

The Bootgen command is:

```
bootgen -arch zynqmp -image stage7d.bif -o bl31_ac.bin -nonbooting -w on -
log error
```

Stage 8: Combine Partitions, Get Header Table Hash

Enter the following in a BIF file:

```
stage8:
     {
      [bootimage]fsbl_e_ac.bin
      [bootimage]system_e_ac.bin
      [bootimage]bl31_ac.bin
      [bootimage]u-boot_ac.bin
     }
```

The Bootgen command is:

```
bootgen -arch zynqmp -image stage8.bif -generate_hashes -o stage8.bin -w
on -log error
```

Stage 9: Sign Header Table Hash

Generate the following files using OpenSSL:

```
openssl rsautl -raw -sign -inkey secondary0.pem -in
ImageHeaderTable.sha384 > ImageHeaderTable.sha384.sig
```

Stage 10: Combine Partitions, Insert Header Table Signature

Enter the following in a BIF file:

```
stage10:
    {
     [headersignature]ImageHeaderTable.sha384.sig
     [bootimage]fsbl_e_ac.bin
     [bootimage]system_e_ac.bin
     [bootimage]bl31_ac.bin
     [bootimage]u-boot_ac.bin
    }
```

The Bootgen command is:

```
bootgen -arch zynqmp -image stage10.bif -o final.bin -w on -log error
```

FPGA Support

As described in the Chapter 5: Boot Time Security, FPGA-only devices also need to maintain security while deploying them in the field. Xilinx® tools provide embedded IP modules to achieve the Encryption and Authentication, is part of programming logic. Bootgen extends the secure image creation (Encrypted and/or Authenticated) support for FPGA family devices from 7 series and beyond. This chapter details some of the examples of how Bootgen can be used to encrypt and authenticate a bitstream. Bootgen support for FPGAs is available in the standalone Bootgen install.

Note: Only bitstreams from 7 series devices and beyond are supported.

Encryption and Authentication

Xilinx® FPGAs use the embedded, PL-based, hash-based message authentication code (HMAC) and an advanced encryption standard (AES) module with a cipher block chaining (CBC) mode.

Encryption Example

To create an encrypted bitstream, the AES key file is specified in the BIF using the attribute `aeskeyfile`. The attribute `encryption=aes` should be specified against the bitstream listed in the `BIF` file that needs to be encrypted.

```
bootgen -arch fpga -image secure.bif -w -o securetop.bit
```

The BIF file looks like the following:

```
all.bif
the_ROM_image:
    {
        [aeskeyfile] encrypt.nky
        [encryption=aes] top.bit
    }
```

Authentication Example

A Bootgen command to authenticate an FPGA bitstream is as follows:

```
bootgen -arch fpga -image all.bif -o rsa.bit -w on -log error
```

The BIF file is as follows:

```
all.bif
the_ROM_image:
    {
        [sskfile] rsaPrivKeyInfo.pem
        [authentication=rsa] plain.bit
    }
```

Family or Obfuscated Key

To support obfuscated key encryption, you must register with Xilinx support and request the family key file for the target device family. The path to where this file is stored must be passed as a bif option before attempting obfuscated encryption. Contact secure.solutions@xilinx.com to obtain the Family Key.

```
image:
    {
        [aeskeyfile] key_file.nky
        [familykey] familyKey.cfg
        [encryption=aes] top.bit
    }
```

A sample Family Key is shown in the following image.

Figure 20: **Family Key Sample**

```
Device xcku115;
EncryptKeySelect BBRAM;
KeyObfuscate 94da9014cb2203f502f81d14fa2471f4a8902b16d9d408c9c66db214c1640db7, 0;
StartIvObfuscate c485144e397a92081ad20c867a005272, 0;
Key0 dcd2e72ad1b281ecca5e0790b65b94090ec1c8fc010eb01e56717345df4c7010, 0;
StartIV0 3fe826e5495db1bdaf0c2ca2e8640911, 0;
KeyObfuscate 967a6d1ecccefddd1990241007de18f41d69ca7231852c0061fb6c78e204c5f3, 1;
StartIvObfuscate 7ab9a7ca88474d7f95ed1b548523451b, 1;
Key0 af84947a9cc256c090d5ae1c53ed3fd33bb553d7039e445829ba4cffbe56ffe3, 1;
StartIV0 a50026e212363e1d71fa6f4fb540ce42, 1;
```

HSM Mode

For production, FPGAs use the HSM mode, and can also be used in Standard mode.

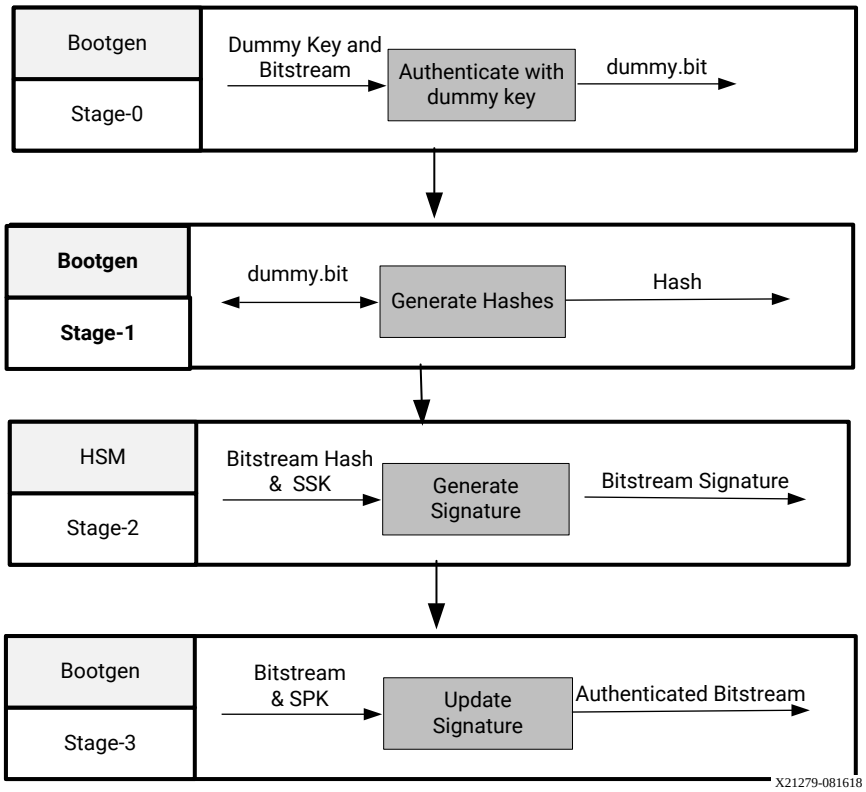
Standard Mode

Standard mode generates a bitstream which has the authentication signature embedded. In this mode, the secret keys are supposed to be available to the user for generating the authenticated bitstream. Run Bootgen as follows:

```
bootgen -arch fpga -image all.bif -o rsa_ref.bit -w on -log error
```

The following steps listed below describe how to generate an authenticated bitstream in HSM mode, where the secret keys are maintained by secure team and not available with the user. The following figure shows the HSM mode flow:

Figure 21: **HSM Mode Flow**



Stage 0: Authenticate with dummy key

This is a one time task for a given bit stream. For stage 0, Bootgen generates the `stage0.bif`file.

```
the_ROM_image:
    {
        [sskfile] dummykey.pem
        [authentication=rsa] plain.bit
    }
```

***Note*:** The authenticated bitstream has a header, an actual bitstream, a signature and a footer. This `dummy.bit` is created to get a bitstream in the format of authenticated bitstream, with a dummy signature. Now, when the dummy bit file is given to Bootgen, it calculates the signature and inserts at the offset to give an authenticated bitstream.

Stage 1: Generate hashes

```
bootgen -arch fpga
          -image stage1.bif -generate_hashes -log error
```

`Stage1.bif` is as follows:

```
the_ROM_image:
    {
        [authentication=rsa] dummy.bit
    }
```

Stage 2: Sign the Hash HSM, here OpenSSL is used for Demonstration

```
openssl rsautl -sign
  -inkey rsaPrivKeyInfo.pem -in dummy.sha384 > dummy.sha384.sig
```

Stage 3: Update the RSA certificate with Actual Signature

The `Stage3.bif` is as follows:

```
bootgen -arch fpga -image stage3.bif -w -o rsa_rel.bit -log error
```

```
the_ROM_image:
    {
         [spkfile] rsaPubKeyInfo.pem
         [authentication=rsa, presign=dummy.sha384.sig]
                dummy.bit
    }
```

***Note*:** The public key digest, which must be burnt into eFUSEs, can be found in the generated `rsaPubKeyInfo.pem.nky` file in Stage3 of HSM mode.

Use Cases and Examples

The following are typical use cases and examples for Bootgen. Some use cases are more complex and require explicit instruction. These typical use cases and examples have more definition when you reference the Attributes and Descriptions.

Simple Application Boot on Different Cores

The following example shows how to create a boot image with applications running on different cores. The `pmu_fw.elf` is loaded by BootROM. The `fsbl_a53.elf` is the bootloader and loaded on to A53-0 core. The `app_a53.elf` is executed by A53-1 core, and `app_r5.elf` by r5-0 core.

```
the_ROM_image:
    {
         [pmufw_image] pmu_fw.elf
         [bootloader, destination_cpu=a53-0] fsbl_a53.elf
         [destination_cpu=a53-1] app_a53.elf
         [destination_cpu=r5-0] app_r5.elf
    }
```

PMUFW Load by BootROM

This example shows how to create a boot image with `pmu_fw.elf` loaded by BootROM.

```
the_ROM_image:
    {
        [pmufw_image] pmu_fw.elf
        [bootloader, destination_cpu=a53-0] fsbl_a53.elf
        [destination_cpu=r5-0] app_r5.elf
    }
```

PMUFW Load by FSBL

This example shows how to create a boot image with `pmu_fw.elf` loaded by FSBL.

```
{
    [bootloader, destination_cpu=a53-0] fsbl_a53.elf
    [destination_cpu=pmu] pmu_fw.elf
    [destination_cpu=r5-0] app_r5.elf
}
```

Note: Bootgen uses the options provided to `[bootloader]` for `[pmufw_image]` as well. The `[pmufw_image]` does not take any extra parameters.

Booting Linux

This example shows how to boot Linux on a Zynq® UltraScale+™ MPSoC device (`arch=zynqmp`).

- The `fsbl_a53.elf` is the bootloader and runs on a53-0.
- The `pmu_fw.elf` is loaded by FSBL.
- The`bl31.elf` is the Arm® Trusted Firmware (ATF), which runs at el-3.
- The U-Boot program, `uboot`, runs at el-2 on a53-0.
- The Linux image, `image.ub`, is placed at offset `0x1E40000` and loaded at `0x10000000`.

```
the_ROM_image:
    {
        [bootloader, destination_cpu = a53-0]fsbl_a53.elf
        [destination_cpu=pmu]pmu_fw.elf
        [destination_cpu=a53-0, exception_level=el-3, trustzone]bl31.elf
        [destination_cpu=a53-0, exception_level=el-2] u-boot.elf
        [offset=0x1E40000, load=0X10000000, destination_cpu=a53-0]image.ub
    }
```

Encryption Flow: BBRAM Red Key

This example shows how to create a boot image with the encryption enabled for FSBL and the application with the Red key stored in BBRAM:

```
the_ROM_image:
    {
        [aeskeyfile] bbram.nky
        [keysrc_encryption] bbram_red_key
        [bootloader, encryption=aes, destination_cpu=a53-0]ZynqMP_Fsbl.elf
        [destination_cpu=a53-0, encryption=aes]App_A53_0.elf
    }
```

Encryption Flow: Red Key Stored in eFUSE

This example shows how to create a boot image with encryption enabled for FSBL and application with the RED key stored in EFUSE.

```
the_ROM_image:
    {
        [aeskeyfile] efuse.nky
        [keysrc_encryption] efuse_red_key
        [bootloader, encryption=aes, destination_cpu=a53-0]
ZynqMP_Fsbl.elf
        [destination_cpu = a53-0, encryption=aes] App_A53_0.elf
    }
```

Encryption Flow: Black Key Stored in EFUSE

This example shows how to create a boot image with the encryption enabled for FSBL and an application with the `efuse_blk_key` stored in eFUSE. Authentication is also enabled for FSBL.

```
the_ROM_image:
    {
        [pskfile] PSK.pem
        [sskfile] SSK.pem
        [fsbl_config] shutter=0x0100005E
        [auth_params] ppk_select=0 spk_id=0x0aB
        [aeskeyfile] red.nky
        [bh_key_iv] black_key_iv.txt
        [keysrc_encryption] efuse_blk_key
    }
```

***Note*:** Boot image authentication is compulsory for using black key encryption.

Encryption Flow: Black Key Stored in Boot Header

This example shows how to create a boot image with encryption enabled for FSBL and the application with the `bh_blk_key` stored in the Boot Header. Authentication is also enabled for FSBL.

```
the_ROM_image:
    {
        [pskfile] PSK.pem
        [sskfile] SSK.pem
        [fsbl_config] shutter=0x0100005E
        [auth_params] ppk_select=0
        [aeskeyfile] red.nky
        [bh_keyfile] blackkey.txt
        [bh_key_iv] black_key_iv.txt
        [puf_file]helperdata4k.txt
        [keysrc_encryption] bh_blk_key
        [bootloader, encryption=aes,authentication=rsa,
destination_cpu=a53-0]ZynqMP_Fsbl.elf
        [destination_cpu = a53-0, encryption=aes] App_A53_0.elf
    }
```

***Note*:** Boot image Authentication is required when using black key Encryption.

Encryption Flow: Gray Key Stored in eFUSE

This example shows how to create a boot image with encryption enabled for FSBL and the application with the `efuse_gry_key` stored in eFUSE.

```
the_ROM_image:
    {
        [aeskeyfile] red.nky
        [keysrc_encryption] efuse_gry_key
        [bh_key_iv] bh_key_iv.txt
        [bootloader, encryption=aes, destination_cpu=a53-0]
ZynqMP_Fsbl.elf
        [destination_cpu=a53-0, encryption=aes] App_A53_0.elf
    }
```

Encryption Flow: Gray Key stored in Boot Header

This example shows how to create a boot image with encryption enabled for FSBL and the application with the `bh_gry_key` stored in the Boot Header.

```
{
    [aeskeyfile] red.nky
    [keysrc_encryption] bh_gry_key
    [bh_keyfile] bhkey.txt
    [bh_key_iv] bh_key_iv.txt
    [bootloader, encryption=aes, destination_cpu=a53-0]ZynqMP_Fsbl.elf
    [destination_cpu=a53-0, encryption=aes] App_A53_0.elf
}
```

Operational Key

This example shows how to create a boot image with encryption enabled for FSBL and the application with the gray key stored in the Boot Header. This example shows how to create a boot image with encryption enabled for FSBL and application with the red key stored in eFUSE.

```
{
    aeskeyfile] red.nky
    [fsbl_config] opt_key
    [keysrc_encryption] efuse_red_key
    [bootloader, encryption=aes, destination_cpu=a53-0]ZynqMP_Fsbl.elf
    [destination_cpu=a53-0, encryption=aes]App_A53_0.elf
}
```

Using Op Key to Protect the Device Key in a Development Environment

Authentication Flow

This example shows how to create a boot image with authentication enabled for FSBL and application with Boot Header authentication enabled to bypass the PPK hash verification:

```
the_ROM_image:
    {
        [fsbl_config] bh_auth_enable
        [auth_params] ppk_select=0; spk_id=0x00000000
        [pskfile] PSK.pem
        [sskfile] SSK.pem
        [bootloader, authentication=rsa, destination_cpu=a53-0]
ZynqMP_Fsbl.elf
        [destination_cpu=a53-0, encryption=aes] App_A53_0.elf
    }
```

BIF File with SHA-3 eFUSE RSA Authentication and PPK0

This example shows how to create a boot image with authentication enabled for FSBL and the application with boot header authentication enabled to bypass the PPK hash verification:

```
the_ROM_image:
    {
        [auth_params] ppk_select=0; spk_id=0x00000000
        [pskfile] PSK.pem
        [sskfile] SSK.pem
        [bootloader, authentication=rsa, destination_cpu=a53-0]
ZynqMP_Fsbl.elf
        [destination_cpu=a53-0, authentication=aes] App_A53_0.elf
    }
```

XIP

This example shows how to create a boot image that executes in place for a zynqmp (Zynq® UltraScale+™ MPSoCdevice:

```
the_ROM_image:
    {
        [bootloader, destination_cpu=a53-0, xip_mode] mpsoc_qspi_xip.elf
    }
```

See xip_mode for more information about the command.

BIF Attribute Reference

aeskeyfile

Syntax

```
[aeskeyfile] <key filename>
```

Description

The path to the AES keyfile. The keyfile contains the AES key used to encrypt the partitions. The contents of the key file needs to written to eFUSE or BBRAM. If the key file is not present in the path specified, a new key is generated by Bootgen, which is used for encryption

***Note*:** For Zynq® UltraScale+™ MPSoC only: Multiple key files can be specified in the BIF file. Key0, IV0 and Key Opt should be the same across all nky files that will be used. For cases where multiple partitions are generated for an ELF file, each partition can be encrypted using keys from a unique key file.

The partition `fsbl.elf` is encrypted with keys in `test1.nky`. All `hello.elf` partitions are encrypted using keys in `test2.nky`. User can have unique key files for each hello partition by having key files named `test2.1.nky` and `test2.2.nky` in the same path as `test2.nky`.

- `hello.elf.0` uses `test2.nky`
- `hello.elf.1` uses `test2.1.nky`
- `hello.elf.2` uses `test2.2.nky`

If any of the key files (`test2.1.nky` or `test2.2.nky`) is not present, the key file specified in `BIF` (`test2.nky`) is used.

Arguments

Specified file name.

Return Value

None

Example

Bootgen creates three partitions for `hello.elf`:

```
hello.elf.0, hello.elf.1 & hello.elf.2
Sample BIF - test_multiple.bif
 all:
     {
        [aeskeyfile] test1.nky
        [bootloader, encryption=aes] fsbl.elf
        [aeskeyfile] test2.nky
        [encryption=aes] hello.elf
     }
```

alignment

Syntax

```
[alignment= <value>] <partition>
```

Sets the byte alignment. The partition will be padded to be aligned to a multiple of this value. This attribute cannot be used with offset.

Arguments

Number of bytes to be aligned.

Example

```
Sample BIF - test.bif
all:
    {
        [bootloader]fsbl.elf
        [alignment=64] u-boot.elf
    }
```

auth_params

- **Syntax:**

```
[auth_params] ppk_select=<0|1>; spk_id <32-bit spk id>;/
 spk_select=<spk-efuse/user-efuse>; auth_header
```

Description

Authentication parameters specify additional configuration such as which PPK, SPK to use for authentication of the partitions in the boot image. Arguments for this bif parameter are:

- `ppk_select`: Selects which PPK to use: 0 or 1.
- `spk_id`: Specifies which SPK can be used or revoked. See User eFUSE Support with Enhanced RSA Key Revocation.
- `spk_select` : To differentiate spk and user efuses. Options are (default) `spk-efuse` and `user_efuse`.
- `header_auth` : To authenticate headers when no partition is authenticated.

***Note*:**

1. `ppk_select` is unique for each image.
2. Each partition can have its own `spk_select` and `spk_id`.
3. `spk-efuse id` is unique across the image, but `user-efuse id` can vary between partitions.
4. `spk_select/spk_id` outside the partition scope will be used for headers and any other partition that does not have these specifications as partition attributes.

Example

```
Sample BIF 1 - test.bif
all:
    {
        [auth_params]ppk_select=0;spk_id=0x12345678
        [pskfile] primary.pem
        [sskfile]secondary.pem
        [bootloader, authentication=rsa]fsbl.elf
    }

Sample BIF 2 - test.bif
all:
    {
        [auth_params] ppk_select=0;spk_select=user-efuse;spk_id=0x22
          [pskfile]     primary.pem
          [sskfile]     secondary.pem
          [bootloader, authentication = rsa]
fsbl.elf
    }

Sample BIF 3 - test.bif
all:
    {
          [auth_params] ppk_select=1; spk_select= user-efuse; spk_id=0x22;
header_auth
          [pskfile]     primary.pem
          [sskfile]     secondary.pem
          [destination_cpu=a53-0] test.elf
    }
```

```
Sample BIF 4 - test.bif
all:
    {
          [auth_params]  ppk_select=1;spk_select=user-efuse;spk_id=0x22
          [pskfile]      primary.pem
          [sskfile]      secondary0.pem

     /* FSBL - Partition-0) */
      [
        bootloader,
        destination_cpu    = a53-0,
        authentication     = rsa,
        spk_id             = 0x12345678,
        spk_select         = spk-efuse,
        sskfile            = secondary1.pem
      ]fsbla53.elf

     /* Partition-1 */
      [
        destination_cpu     = a53-1,
        authentication      = rsa,
        spk_id              = 0x24,
        spk_select          = user-efuse,
        sskfile             = secondary2.pem
       ]hello.elf
    }
```

authentication

Syntax

```
[authentication=<option>] <partition>
```

Description

This specifies the partition to be authenticated.

Arguments

- `none`: Partition not authenticated
- `rsa`: Partition authenticated using RSA algorithm.

Example

```
Sample BIF - test.bif
all:
    {
        [ppkfile] ppk.txt
        [spkfile] spk.txt
        [bootloader,authentication=rsa] fsbl.elf
        [authentication=rsa] hello.elf
    }
```

bh_keyfile

Syntax

```
[bh_keyfile] <key file path>
```

Description

256-bit obfuscated key or black key to be stored in boot header. This is only valid when the encryption key source is either grey key or black key.

Arguments

Path to the obfuscated key or black key, based on which source is selected.

Example

```
Sample BIF - test.bif
all:
    {
        [aeskeyfile] encr.nky
        [keysrc_encryption] bh_gry_key
        [bh_keyfile] obfuscated_key.txt
        [bh_key_iv] obfuscated_iv.txt
        [bootloader, encryption=aes, destination_cpu=a53-0]fsbl.elf
    }
```

bh_key_iv

Syntax

```
[bh_key_iv] <iv file path>
```

Description

Initialization vector used when decrypting the obfuscated key or black key.

Arguments

Path to file.

Example

```
Sample BIF - test.bif
all:
    {
        [aeskeyfile] encr.nky
        [keysrc_encryption] bh_gry_key
        [bh_keyfile] obfuscated_key.txt
        [bh_key_iv] obfuscated_iv.txt
        [bootloader, encryption=aes, destination_cpu=a53-0]fsbl.elf
    }
```

bhsignature

Syntax

```
[bhsignature] <signature-file>
```

Description

Imports Boot Header signature into authentication certificate. This can be used if you do not want to share the secret key PSK. You can create a signature and provide it to Bootgen.

Example

```
all:
    {
        [ppkfile] ppk.txt
        [spkfile] spk.txt
        [spksignature] spk.txt.sha384.sig
        [bhsignature] bootheader.sha384.sig
        [bootloader,authentication=rsa] fsbl.elf
    }
```

blocks

Syntax

```
[blocks = <size><num>;<size><num>;...;<size><*>] <partition>
```

Description

Specify block sizes for key-rolling feature in encrytion. Each module is encrypted using its own unique key. The initial key is stored at the key source on the device, while keys for each successive module are encrypted (wrapped) in the previous module.

Arguments

The <size> mentioned is taken in Bytes. If the size is specified as X(*), then all the remaining blocks will be of the size 'X'.

Example

```
Sample BIF - test.bif
all:
    {
        [aeskeyfile] encr.nky
        [keysrc_encryption] bbram_red_key
        [bootloader,encryption=aes,
        destination_cpu=a53-0,blocks=4096(2);1024;2048(2);4096(*)]
        fsbl.elf
    }
```

***Note*:** In the above example, the first two blocks are of 4096 bytes, the second block is of 1024 bytes, and the next two blocks are of 2048 bytes. The rest of the blocks are of 4096 bytes.

boot_device

Syntax

```
[boot_device] <options>
```

Description

Specifies the secondary boot device. Indicates the device on which the partition is present.

Arguments

Options are:

- qspi32
- qspi24
- nand
- sd0
- sd1
- sd-ls
- mmc
- usb
- ethernet
- pcie
- sata

Example

```
all:
    {
        [boot_device]sd0
        [bootloader,destination_cpu=a53-0]fsbl.elf
    {
```

bootimage

Syntax

```
[bootimage] <image created by bootgen>
```

Description

This specifies that the following file specification is a bootimage that was created by Bootgen, being reused as input.

Arguments

Specified file name.

Example

```
Sample BIF - test.bif
all:
    {
        [bootimage]fsbl.bin
        [bootimage]system.bin
    }
```

In the above example, the `fsbl.bin` and `system.bin` are images generated using Bootgen.

Example fsbl.bin generation

```
image:
    {
        [aeskeyfile] encr_key.nky
        [pskfile] primary.pem
        [sskfile] secondary.pem
        [bootloader, authentication=rsa, encryption=aes] fsbl.elf
     }
Command: bootgen -image fsbl.bif -o fsbl.bin -encrypt efuse
```

Example system.bin generation

```
image:
    {
        [pskfile] primary.pem
        [sskfile] secondary.pem
        [authentication=rsa] system.bit
    }
Command: bootgen -image system.bif -o system.bin
```

bootloader

Syntax

```
[bootloader] <partition>
```

Description

Identifies an ELF file as the FSBL.

- Only ELF files can have this attribute.
- Only one file can be designated as the bootloader.
- The program header of this ELF file must have only one LOAD section with filesz >0 , and this section must be executable (x flag must be set).

Arguments

Specified file name.

Example

```
Sample BIF - test.bif
all:
    {
        [bootloader] fsbl.elf
        hello.elf
    }
```

bootvectors

Syntax

```
[bootvectors] <values>
```

Description

This attribute specifies the vector table for eXecute in Place (XIP).

Example

```
all:
    {

[bootvectors]0x14000000,0x14000000,0x14000000,0x14000000,0x14000000,0x14000
000,0x14000000,0x14000000
        [bootloader,destination_cpu=a53-0]fsbl.elf
    }
```

checksum

Syntax

```
[checksum = <options>] <partition>
```

Description

This specifies the partition needs to be checksummed. This is not supported along with more secure features like authentication and encryption.

Arguments

- `none`: No checksum operation.
- `MD5`: MD5 checksum operation for Zynq®-7000 SoC devices. In these devices, checksum operations are not supported for bootloaders.
- `SHA3`: Checksum operation for Zynq® UltraScale+™ MPSoC devices.

destination_cpu

Syntax

```
[destination_cpu <options>] <partition>
```

Description

Specifies which core will execute the partition. The following example specifies that FSBL will be executed on A53-0 core and application on R5-0 core.

***Note*:**

- FSBL can only run on either A53-0 or R5-0.
- PMU loaded by FSBL: `[destination_cpu=pmu] pmu.elf` In this flow, BootROM loads FSBL first, and then FSBL loads the PMU firmware.
- PMU loaded by BootROM: `[pmufw_image] pmu.elf`. In this flow, BootROM loads PMU first and then the FSBL so PMU does the power management tasks, before the FSBL comes up.

Arguments

- a53-0
- a53-1
- a53-2
- a53-3
- r5-0
- r5-1

- r5-lockstep
- pmu

Example

```
Sample BIF - test.bif
all:
    {
        [bootloader,destination_cpu=a53-0]fsbl.elf
        [destination_cpu=r5-0] app.elf
    }
```

destination_device

Syntax

```
[destination_device <options>] <partition>
```

Description

Specifies whether the partition is targeted for PS or PL.

Arguments

- `ps`: The partition is targeted for PS (default).
- `pl`: The partition is targeted for PL, for bitstreams.

Example

```
 Sample BIF - test.bif
all:
    {
        [bootloader,destination_cpu=a53-0]fsbl.elf
        [destination_device=pl]system.bit
        [destination_cpu=r5-1]app.elf
    }
```

early_handoff

Syntax

```
[early_handoff] <partition>
```

Description

This flag ensures that the handoff to applications that are critical immediately after the partition is loaded; otherwise, all the partitions are loaded sequentially and handoff also happens in a sequential fashion.

***Note*:** In the following scenario, the FSBL loads app1, then app2, and immediately hands off the control to app2 before app1.

Example

```
Sample BIF - test.bif
all:
    {
        [bootloader, destination_cpu=a53_0]fsbl.el
        [destination_cpu=r5-0]app1.elf
        [destination_cpu=r5-1,early_handoff]app2.elf
    }
```

encryption

Syntax

```
[encryption = <options>] <partition>
```

Description

This specifies the partition needs to be encrypted. Encryption Algorithms are:

Arguments

- `none`: Partition not encrypted.
- `aes`: Partition encrypted using AES algorithm.

Example

```
Sample BIF - test.bif
all:
    {
        [aeskeyfile]test.nky
        [bootloader,encryption=aes] fsbl.elf
        hello.elf
    }
```

exception_level

Syntax

```
[exception_level=<options>] <partition>
```

Description

Exception level for which the core should be configured.

Arguments

- el-0
- el-1
- el-2
- el-3

Example

```
Sample BIF - test.bif
all:
    {
        [bootloader, destination_cpu=a53-0]fsbl.elf
        [destination_cpu=a53-0, exception_level=el-3] bl31.elf
        [destination_cpu=a53-0, exception_level=el-2] u-boot.elf
    }
```

familykey

Syntax

```
[familykey] <key file path>
```

Description

Specify Family Key. To obtain family key, contact a Xilinx® representative at secure.solutions@xilinx.com.

Arguments

Path to file.

Example

```
Sample BIF - test.bif
all:
    {
        [aeskeyfile] encr.nky
        [bh_key_iv] bh_iv.txt
        [familykey] familykey.cfg
    }
```

fsbl_config

Syntax

```
[fsbl_config <options>] <partition>
```

Description

This option specifies the parameters used to configure the boot image. FSBL, which should run on A53 in 64-bit mode in Boot Header authentication mode.

Arguments

- `bh_auth_enable`: Boot Header Authentication Enable: RSA authentication of the bootimage will be done excluding the verification of PPK hash and SPK ID.
- `auth_only`: Boot image is only RSA signed. FSBL should not be decrypted.

- `opt_key`: Optional key is used for block-0 decryption. Secure Header has the opt key.
- `pufhd_bh`: PUF helper data is stored in Boot Header. (Default is `efuse`)/ PUF helper data file is passed to bootgen using the option `[puf_file]`.
- `puf4kmode`: PUF is tuned to use in 4k bit configuration. (Default is 12k bit).
- `shutter = <value>` 32 bit`PUF_SHUT` register value to configure PUF for shutter offset time and shutter open time.

Example

```
all:
    {
        [fsbl_config] bh_auth_enable,
        [pskfile] primary.pem
        [sskfile]secondary.pem
        [bootloader,destination_cpu=a53-0,authentication=rsa] fsbl.elf
    }
```

headersignature

Syntax

```
[headersignature] <signature file>
```

Description

Imports the Header signature into the Authentication Certificate. This can be used in case the user does not want to share the secret key, The user can create a signature and provide it to Bootgen.

Arguments

`<signature_file`

Example

```
Sample BIF - test.bif
all:
    {
        [ppkfile] ppk.txt
        [spkfile] spk.txt
        [headersignature] headers.sha256.sig
        [spksignature] spk.txt.sha256.sig
        [bootloader, authentication=rsa] fsbl.elf
    {
```

hivec

Syntax

```
[hivec] <partition>
```

Description

To specify the location of Exception Vector Table as `hivec`. Default is taken as `lovec`. This is applicable with a53 (32 bit) and r5 cores only.

- `hivec`: exception vector table at 0xFFFF0000.
- `lovec`: exception vector table at 0x00000000.

Arguments

None

Example

A sample BIF file is shown below :

```
all:
   {
        [bootloader, destination_cpu=a53_0]fsbl.elf
        [destination_cpu=r5-0,hivec]app1.elf
   }
```

init

Syntax

```
[init] <filename>
```

Description

Register initialization block at the end of the bootloader, built by parsing the .int file specification. Maximum of 256 address-value init pairs are allowed. The int files have a specific format.

Example

A sample BIF file is shown below:

```
Sample BIF - test.bif
all:
    {
        [init] test.int
    }
```

keysrc_encryption

Syntax

```
[keysrc_encryption] <options> <partition>
```

Description

This specifies the Key source for encryption.

Arguments

- `bbram_red_key`: RED key stored in BBRAM
- `efuse_red_key`: RED key stored in efuse
- `efuse_gry_key`: Grey (Obfuscated) Key stored in eFUSE.
- `bh_gry_key` : Grey (Obfuscated) Key stored in boot header.
- `bh_blk_key`: Black Key stored in boot header.
- `efuse_blk_key` : Black Key stored in eFUSE.
- `kup_key`: User Key.

Example

```
all:
    {
        [aeskeyfile]encr.nky
        [keysrc_encryption]efuse_gry_key
        [bootloader,encryption=aes,destination_cpu=a53-0]fsbl.elf
    }
```

FSBL is encrypted using the key `encr.nky`, which is stored in the efuse for decryption purpose.

load

Syntax

```
[load=<value>] <partition>
```

Description

Sets the load address for the partition in memory.

Example

```
all:
   {
        [bootloader] fsbl.elf
        u-boot.elf
        [load=0x3000000, offset=0x500000] uImage.bin
        [load=0x2A00000, offset=0xa00000] devicetree.dtb
        [load=0x2000000, offset=0xc00000] uramdisk.image.gz
   }
```

offset

Syntax

```
[offset=<value>] <partition>
```

Description

Sets the absolute offset of the partition in the boot image.

Arguments

Specified value and partition.

Example

```
all:
   {
        [bootloader] fsbl.elf u-boot.elf
        [load=0x3000000, offset=0x500000]uImage.bin
        [load=0x2A00000, offset=0xa00000] devicetree.dtb
        [load=0x2000000, offset=0xc00000] uramdisk.image.gz
   }
```

partition_owner

Syntax

```
[partition_owner = <options>] <partition>
```

Description

Owner of the partition which is responsible to load the partition.

Arguments

File Name

Example

```
Sample BIF - test.bif
all:
    {
        [bootloader]fsbl.elf
        [partition_owner=uboot] hello.elf
    }
```

pid

Syntax

```
 [pid = <id_no>] <partition>
```

Description

This specifies the partition id.

Example

```
Sample BIF - test.bif
all:
    {
        [aeskeyfile] test.nky
        [encryption=aes,pid=1] hello.elf
    }
```

pmufw_image

Syntax

```
[pmufw_image] <PMU ELF file>
```

Description

PMU Firmware image to be loaded by BootROM, before loading the FSBL. The options for the `pmufw_image` are inline with the bootloader partition. Bootgen does not consider any extra attributes given along with the `pmufw_image` option.

Arguments

Filename

Example

```
the_ROM_image:
    {
        [pmufw_image] pmu_fw.elf
        [bootloader, destination_cpu=a53-0] fsbl_a53.elf
        [destination_cpu=a53-1] app_a53.elf
        [destination_cpu=r5-0] app_r5.elf
    }
```

ppkfile

Syntax

```
[ppkfile] <key
filename>
```

Description

The Primary Public Key (PPK) key is used to authenticate partitions in the boot image.

See Using Authentication

Arguments

Specified file name.

***Note*:** The secret key file contains the public key component of the key. You need not specify the public key (PPK) when the secret key (PSK) is mentioned.

Example

```
all:
    {
        [ppkfile] primarykey.pub
        [pskfile] primarykey.pem
        [spkfile] secondarykey.pem
        [sskfile] secondarykey.pem
        [bootloader, authentication=rsa] fsbl.elf
        [authentication=rsa] hello.elf
    }
```

presign

Syntax

```
[presign = <signature_file>] <partition>
```

Description

Imports partition signature into partition authentication certificate. Use this if you do not want to share the secret key (SSK). You can create a signature and provide it to Bootgen.

- `<signature_file>`: Specifies the signature file.
- `<partition>` :Lists the partition to which to apply to the signature_file.

Example

```
Sample BIF - test.bif
all:
    {
        [ppkfile] ppk.txt
        [spkfile] spk.txt
        [headsignature] headers.sha256.sig
        [spksignature] spk.txt.sha256.sig
        [bootloader, authentication=rsa, presign=fsbl.sig]fsbl.elf
    }
```

pskfile

Syntax

```
[pskfile] <key filename>
```

Description

This Primary Secret Key (PSK) is used to authenticate partitions in the boot image. For more information, see Using Authentication

Arguments

Specified file name.

***Note*:** The secret key file contains the public key component of the key. You need not specify the public key (PPK) when the secret key (PSK) is mentioned.

Example

```
//Sample BIF - test.bif
all:
    {
        [pskfile]primarykey.pem
        [sskfile]secondarykey.pem
        [bootloader,authentication=rsa]fsbl.elf
        [authentication=rsa] hello.elf
    }
```

puf_file

Syntax

```
[puf_file] <puf data file>
```

Description

PUF helper data file.

- PUF is used with black key as encryption key source.
- PUF helper data is of 1544 bytes.

- 1536 bytes of PUF HD + 4 bytes of CHASH + 3 bytes of AUX + 1 byte alignment.

See Black/PUF Keys for more information.

Example

```
all:
    {
        [fsbl_config]pufhd_bh
        [puf_file] pufhelperdata.txt
        [bh_keyfile] black_key.txt
        [bh_key_iv] bhkeyiv.txt
        [bootloader,destination_cpu=a53-0,encryption=aes]
        fsbl.elf
    }
```

reserve

Syntax

```
[reserve=<value>] <partition>
```

Description

Reserves the memory and padded after the partition. The value specified for reserving the memory is in bytes.

Arguments

Specified partition

Example

```
all:
    {
        [bootloader]fsbl.elf
        [reserve=0x1000]test.bin
    }
```

split

Syntax

```
[split] mode = <mode-options>, fmt=<format>
```

Description

Splits the image into parts based on mode. Slaveboot mode splits as follows:

- Boot Header + Bootloader
- Image and Partition Headers
- Rest of the partitions

Normal mode splits as follows:

- Bootheader + Image Headers + Partition Headers + Bootloader
- Partiton1
- Partition2 and so on

Slaveboot is supported only for ZynqMP, normal is supported for both Zynq and ZynqMP. Along with the split mode, output format can also be specified as `bin` or `mcs`.

Options

The available options for argument mode are:

- slaveboot
- normal
- bin
- mcs

Example

```
all:
{
     [split]mode=slaveboot,fmt=bin
     [bootloader,destination_cpu=a53-0]fsbl.elf
     [destination_device=pl]system.bit
     [destination_cpu=r5-1]app.elf
}
```

***Note*:** The option split mode normal is same as the command line option split. This command line option is schedule to be deprecated.

spkfile

Syntax

```
[spkfile] <key filename>
```

Description

The Secondary Public Key (SPK) is used to authenticate partitions in the boot image. For more information, see Using Authentication.

Arguments

Specified file name.

Example

```
all:
    {
        [pskfile] primarykey.pem
        [spkfile] secondarykey.pem
        [sskfile] secondarykey.pem
        [bootloader, authentication=rsa] fsbl.elf
        [authentication=rsa] hello.elf
    }
```

***Note*:** The secret key file contains the public key component of the key. You need not specify public key (SPK) when the secret key (SSK) is mentioned.

spksignature

Code Example

```
[spksignature] <Signature file>
```

Description

Imports SPK signature into the Authentication Certificate. This can be when the user does not want to share the secret key PSK, the user can create a signature and provide it to Bootgen.

Arguments

Specified file name.

Example

```
Sample BIF - test.bif
all:
    {
        [ppkfile] ppk.txt
        [spkfile] spk.txt
        [headersignature]headers.sha256.sig
        [spksignature] spk.txt.sha256.sig
        [bootloader, authentication=rsa] fsbl.elf
    {
```

spk_select

Syntax

```
[spk_select = <options>]
or
[auth_params] spk_select = <options>
```

Description

Options are:

- `spk-efuse`: Indicates that `spk_id` eFUSE is used for that partition.
- `user-efuse`: Indicates that user eFUSE is used for that partition.

Partitions loaded by CSU ROM will always use `spk_efuse`.

***Note*:** The `spk_id` eFUSE specifies which key is valid. Hence, the ROM checks the entire field of `spk_id` eFUSE against the SPK ID to make sure its a bit for bit match.

The user eFUSE specifies which key ID is NOT valid (has been revoked). Hence, the firmware (non-ROM) checks to see if a given user eFUSE that represents the SPK ID has been programmed. `spk_select = user-efuse` indicates that user eFUSE will be used for that partition.

Example

```
the_ROM_image:
    {
        [auth_params]ppk_select = 0
        [pskfile]psk.pem
        [sskfile]ssk1.pem
        [bootloader, authentication = rsa, spk_select = spk-efuse, spk_id
= 0x12345678,sskfile = ssk2.pem]zynqmp_fsbl.elf
        [destination_cpu =a53-0,authentication = rsa,spk_select = user-
efuse,spk_id = 200,sskfile = ssk3.pem]
        application1.elf
        [destination_cpu =a53-0, authentication = rsa,spk_select = spk-
efuse,spk_id =0x12345678,sskfile = ssk4.pem]
        application2.elf
    }
```

sskfile

Syntax

```
[sskfile] <key filename>
```

Description

The SSK - Secondary Secret Key key is used to authenticate partitions in the boot image. For more information, see Using Authentication

Arguments

Specified file name.

Example

```
//Sample BIF - test.bif
all:
    {
        [pskfile] primarykey.pem
        [sskfile] secondarykey.pem
        [bootloader, authentication=rsa]fsbl.elf
        [authentication=rsa] hello.elf
    }
```

***Note*:** The secret key file contains the public key component of the key. You need not specify the public key (PPK) when the secret key (PSK) is mentioned.

startup

Syntax

```
[startup=<address_value>] <pattiion>
```

Description

This option sets the entry address for the partition, after it is loaded. This is ignored for partitions that do not execute.

Example

```
Sample BIF - test.bif
all:
    {
        [bootloader] fsbl.elf
        [startup=0x1000000] app.elf
    }
```

trustzone

Syntax

```
[trustzone=<options>] <partition>
```

Description

Configures the core to be Trustzone secure or nonsecure. Options are:

- secure
- nonsecure

Example

```
Sample BIF - test.bif
all:
  {
    [bootloader,destination_cpu=a53-0] fsbl.elf
    [exception_level=el-3,trustzone = secure] bl31.elf
  }
```

udf_bh

Syntax

```
[udf_bh] <filename>
```

Description

Imports a file of data to be copied to the user defined field (UDF) of the Boot Header. The input user defined data is provided through a text file in the form of a hex string. Total number of bytes in UDF in Xilinx® SoCs:

- `zynq` : 76 bytes
- `zynqmp` : 40 bytes

Arguments

Specified file name.

Example

```
Sample BIF - test.bif
all:
    {
        [udf_bh]test.txt
        [bootloader]fsbl.elf
        hello.elf
    }
```

The following is an example of the input file for udf_bh:

```
Sample input file for udf_bh - test.txt
123456789abcdef85072696e6365303003014404087 06d616c6c6164000508
266431530102030405060708090a0b0c0d0e0f101112131415161718191a1b
1c1d1
```

udf_data

Syntax

```
[udf_data=<filename>] <partition>
```

Description

Imports a file containing up to 56 bytes of data into user defined field (UDF) of the Authentication Certificate. For more information, see Authentication for more information about authentication certificates.

Arguments

Specified file name.

Example

```
 Sample BIF - test.bif
all:
    {
        [pskfile] primary0.pem
        [sskfile]secondary0.pem
        [bootloader, destination_cpu=a53-0,
authentication=rsa,udf_data=udf.txt]fsbl.elf
        [destination_cpu=a53-0,authentication=rsa] hello.elf
    }
```

xip_mode

Syntax

```
[xip_mode] <partition>
```

Description

Indicates 'eXecute In Place' for FSBL to be executed directly from QSPI flash.

***Note*:** This attribute is only applicable for an FSBL/Bootloader partition.

Arguments

Specified partition.

Example

This example shows how to create a boot image that executes in place for a Zynq® UltraScale+™ MPSoCdevice.

```
 Sample BIF - test.bif
all:
    {
        [bootloader, xip_mode] fsbl.elf
        application.elf
    }
```

Command Reference

arch

Syntax

```
-arch [options]
```

Description

Xilinx® family architecture for which the boot image needs to be created.

Arguments

- `zynq`:Zynq®-7000 device architecture.
- `zynqmp`: Zynq® UltraScale+™ MPSoC device architecture.
- `fpga`: Image is targeted for other FPGA architectures.

Return Value

None

Example

```
bootgen -arch zynq -image test.bif -o boot.bin
```

bif_help

Syntax

```
bootgen -bif_help
```

```
bootgen -bif_help aeskeyfile
```

Description

Lists the supported BIF file attributes. For a more detailed explanation of each bif attribute, specify the attribute name as argument to `-bif_help` on the command line.

encrypt

Syntax

```
bootgen -image test.bif -o boot.bin -encrypt <efuse|bbram|>
```

Description

This option specifies how to perform encryption and where the keys are stored. The `.nky` key file is passed through the BIF file attribute `aeskeyfile`. Only the source is specified using command line.

Arguments

Key source arguments:
`efuse`: The AES key is stored in eFUSE
`bbram`: The AES key is stored in BBRAM.

dual_qspi_mode

Syntax

```
bootgen -dual_qspi_mode [parallel]|[stacked <size>
```

Description

Generates two output files for dual QSPI configurations. In the case of stacked configuration, size (in MB) of the flash needs to be mentioned (16 or 32 or 64 or 128).

Examples

This example generates two output files for independently programming to both flashes in QSPI dual parallel configuration.

```
bootgen -image test.bif -o -boot.bin -dual_qspi_mode parallel
```

This example generates two output files for independently programming to both flashes in a QSPI dual stacked configuration. The first 64 MB of the actual image is written to first file and the remainder to the second file. In case the actual image itself is less than 64 MB, only one file is generated.

```
bootgen -image test.bif -o -boot.bin -dual_qspi_mode stacked 64
```

Arguments

- parallel
- stacked <size>

efuseppkbits

Syntax

```
bootgen -image test.bif -o boot.bin -efuseppkbits efusefile.txt
```

Arguments

`efusefile.txt`

Description

This option specifies the name of the eFUSE file to be written to contain the PPK hash. This option generates a direct hash without any padding. The `efusefile.txt` file is generated containing the hash of the PPK key. Where:

- Zynq®-7000 uses the `SHA2`protocol for hashing.

- Zynq® UltraScale+™ MPSoC uses the `SHA3` for hashing.

encryption_dump

Syntax

```
bootgen -arch zynqmp -image test.bif -encryption_dump
```

Description

Generates an encryption log file, `aes_log.txt`. The `aes_log.txt` generated has the details of AES Key/IV pairs used for encrypting each block of data. It also logs the partition and the AES key file used to encrypt it.

***Note*:** This option is supported only for Zynq® UltraScale+™ MPSoC

Example

```
Sample BIF - test.bif
all:
    {
        [aeskeyfile] test.nky
        [bootloader, encryption=aes] fsbl.elf
        [encryption=aes] hello.elf
    {
```

fill

Syntax

```
bootgen -arch zynq -image test.bif -fill 0xAB -o boot.bin
```

Description

This option specifies the byte to use for filling padded/reserved memory in `<hex byte>` format.

Outputs

The `boot.bin` file in the `0xAB` byte.

Example

The output image is generated with name `boot.bin`. The format of the output image is determined based on the file extension of the file given with `-o` option, where `-fill:` Specifies the Byte to be padded. The `<hex byte>` is padded in the header tables instead of `0xFF`.

```
bootgen -arch zynq -image test.bif -fill 0xAB -o boot.bin
```

generate_keys

Syntax

```
bootgen -image test.bif -generate_keys <rsa|pem|obfuscated>
```

Description

This option generates keys for authentication and obfuscated key used for encryption.

***Note*:** For more information on generating encryption keys, see Key Generation.

Authentication Key Generation Example

Authentication key generation example. This example generates the authentication keys in the paths specified in the BIF file.

Examples

```
test.bif
image:
  {
    [ppkfile] <path/ppkgenfile.txt>
    [pskfile] <path/pskgenfile.txt>
    [spkfile] <path/spkgenfile.txt>
    [sskfile] <path/sskgenfile.txt>
   }
```

Obfuscated Key Generation Example

This example generates the obfuscated in the same path as that of the `familykey.txt`.

Command:

```
bootgen -image test.bif -generata_keys rsa
```

The Sample BIF file is shown in the following example:

```
image:
      {
         [aeskeyfile] aes.nky
         [bh_key_iv] bhkeyiv.txt
         [familykey] familykey.txt
      }
```

Arguments

- `rsa`
- `pem`
- `obfuscated`

generate_hashes

Syntax

```
bootgen -image test.bif -generate_hashes
```

Description

This option generates hash files for all the partitions and other components to be signed like boot header, image and partition headers. This option generates a file containing PKCS#1v1.5 padded hash for the Zynq®-7000 format:

Table 22: **Zynq: SHA-2 (256-bytes)**

Value	SHA-2 Hash*	T-Padding	0x0	0xFF	0x01	0x00
Number of bytes	32	19	1	202	1	1

This option generates the file containing PKCS#1v1.5 padded hash for the Zynq® UltraScale+™ MPSoC format:

Table 23: **ZynqMP: SHA-3 (384-bytes)**

Value	0x0	0x1	0xFF	0xFF	T-Padding	SHA-3 Hash
Number of bytes	1	1	314	1	19	48

Example

```
test:
      {
            [pskfile] ppk.txt
            [sskfile] spk.txt
            [bootloader, authentication=rsa] fsbl.elf
            [authentication=rsa] hello.elf
      }
```

Bootgen generates the following hash files with the specified BIF:

- bootheader hash
- spk hash
- header table hash
- `fsbl.elf` partition hash
- `hello.elf` partition hash

image

Syntax

```
-image <BIF_filename>
```

Description

This option specifies the input BIF file name. The BIF file specifies each component of the boot image in the order of boot and allows optional attributes to be specified to each image component. Each image component is usually mapped to a partition, but in some cases an image component can be mapped to more than one partition if the image component is not contiguous in memory.

Arguments

bif_filename

Example

```
bootgen -arch zynq -image test.bif -o boot.bin
```

The Sample BIF file is shown in the following example:

```
the_ROM_image:
{
    [init] init_data.int
    [bootloader] fsbl.elf
    Partition1.bit
    Partition2.elf
}
```

log

Syntax

```
bootgen -image test.bif -o -boot.bin -log trace
```

Description

Generates a log while generating the boot image. There are various options for choosing the level of information. The information is displayed on the console as well as in the log file, named `bootgen_log.txt` is generated in the current working directory.

Arguments

- `error`: Only the error information is captured.
- `warning`: The warnings and error information is captured. This is by default.
- `info`: The general information and all the above info is captured.
- `trace`: More detailed information is captured along with the information above.

nonbooting

Syntax

```
bootgen -arch zynq -image test.bif -o test.bin -nonbooting
```

Description

This option is used to create an intermediate boot image. An intermediate `test.bin` image is generated as output even in the absence of secret key, which is required to generate an authenticated image. This intermediate image cannot be booted.

Example

```
Sample BIF - test.bif
all:
    {
        [ppkfile]primary.pub
        [spkfile]secondary.pub
        [spksignature]secondary.pub.sha256.sig

[bootimage,authentication=rsa,presign=fsbl_0.elf.0.sha256.sig]fsbl_e.bin
    }
```

o

Syntax

```
bootgen -arch zynq -image test.bif -o boot.<bin|mcs>
```

Description

This option specifies the name of the output image file with a `.bin` or `.mcs` extension.

Outputs

A full boot image file in either BIN or MCS format.

Example

```
bootgen -arch zynq -image test.bif -o boot.mcs
```

The boot image is output in an MCS format.

p

Syntax

```
bootgen -image test.bif -o boot.bin -p xc7z020clg48 -encrypt efuse
```

Description

This option specifies the partname of the Xilinx® device. This is needed for generating a encryption key. It is copied verbatim to the `*.nky` file in the `Device` line of the nky file. This is applicable only when encryption is enabled. If the key file is not present in the path specified in BIF file, then a new encryption key is generated in the same path and `xc7z020clg484` is copied along side the `Device` field in the `nky` file. The generated image is an encrypted image.

padimageheader

Syntax

```
bootgen -image test.bif -w on -o boot.bin -padimageheader=<0|1>
```

Description

This option pads the Image Header Table and Partition Header Table to maximum partitions allowed, to force alignment of following partitions. This feature is enabled by default. Specifying a 0 disables this feature. The `boot.bin` has the image header tables and partition header tables in actual and no extra tables are padded. If nothing is specified or if `-padimageheader=1`, the total image header tables and partition header tables are padded to max partitions.

Arguments

- `1`: Pad the header tables to max partitions.
- `0`: Do not pad the header tables.

Image or Partition Header Lengths

- `zynq`: Maximum Partitions - 14
- `zynqmp`: Maximum Partitions - 32 partitions

process_bitstream

Syntax

```
-process_bitstream <bin|mcs>
```

Description

Processes only the bitstream from the BIF and outputs it as an `MCS` or a `BIN` file. For example: If encryption is selected for bitstream in the BIF file, the output is an encrypted bitstream.

Arguments

- `bin`: Output in BIN format.
- `mcs`: Output in MCS format.

Returns

Output generated is bitstream in BIN or MCS format; a processed file without any headers attached.

split

Syntax

```
bootgen -arch zynq -image test.bif -split bin
```

Description

This option outputs each data partition with headers as a new file in MCS or BIN format.

Outputs

- Output files generated are:
- Bootheader + Image Headers + Partition Headers + `Fsbl.elf`
- `Partition1.bit`
- `Partition2.elf`

Example

```
the_ROM_image:
    {
        [bootloader] Fsbl.elf
        Partition1.bit
        Partition2.elf
    }
```

spksignature

Syntax

```
bootgen -image test.bif -w on -o boot.bin -spksignature spksignfile.txt
```

Description

This option is used to generate the SPK signature file. This option must be used only when `spkfile` and `pskfile` are specified in BIF. The SPK signature file (`spksignfile.txt`) is generated.

Option

Specifies the name of the signature file to be generated.

w

Syntax

```
bootgen -image test.bif -w on -o boot.bin
or
bootgen -image test.bif -w -o boot.bin
```

Description

This option specifies whether to overwrite an existing file or not. If the file `boot.bin` already exists in the path, then it is overwritten. Options `-w on` and `-w` are treated as same. If the `-w` option is not specified, the file will not be overwritten by default.

Arguments

- `on`: Specified with the `-w on` command with or `-w` with no argument.
- `off`: Specifies to not overwrite an existing file.

zynqmpes1

Syntax

```
bootgen -arch zynqmp -image test.bif -o boot.bin -zynqmpes1
```

Description

This option specifies that the image generated will be used on ES1 (1.0). This option makes a difference only when generating an Authenticated image; otherwise, it is ignored. The default padding scheme is for (2.0) ES2 and above.

About Initialization Pairs and INT File Attribute

Initialization pairs let you easily initialize Processor Systems (PS) registers for the MIO multiplexer and flash clocks. This allows the MIO multiplexer to be fully configured before the FSBL image is copied into OCM or executed from flash with eXecute in place (XIP), and allows for flash device clocks to be set to maximum bandwidth speeds.

There are 256 initialization pairs at the end of the fixed portion of the boot image header. Initialization pairs are designated as such because a pair consists of a 32-bit address value and a 32-bit data value. When no initialization is to take place, all of the address values contain `0xFFFFFFFF`, and the data values contain `0x00000000`. Set initialization pairs with a text file that has an `.int` file extension by default, but can have any file extension.

The `[init]` file attribute precedes the file name to identify it as the `INIT` file in the BIF file. The data format consists of an operation directive followed by:

- An address value
- an = character
- a data value

The line is terminated with a semicolon (;). This is one `.set. operation directive;` for example:

```
.set. 0xE0000018 = 0x00000411; // This is the 9600 uart setting.
```

Bootgen fills the boot header initialization from the `INT` file up to the 256 pair limit. When the BootROM runs, it looks at the address value. If it is not `0xFFFFFFFF`, the BootROM uses the next 32-bit value following the address value to write the value of address. The BootROM loops through the initialization pairs, setting values, until it encounters a `0xFFFFFFFF` address, or it reaches the 256th initialization pair.

Bootgen provides a full expression evaluator (including nested parenthesis to enforce precedence) with the following operators:

```
* = multiply/
 = divide
% = mod
an address value
ulo divide
+ = addition
- = subtraction
~ = negation
>> = shift right
<< = shift left
& = binary and
  = binary or
^ = binary nor
```

The numbers can be hex (`0x`), octal (`0o`), or decimal digits. Number expressions are maintained as 128-bit fixed-point integers. You can add white space around any of the expression operators for readability.

Bootgen Utility

The `bootgen_utility` is a tool used to dump the contents of a Boot Image generated by Bootgen, into a human-readable log file. This is useful in debugging and understanding the contents of the different header tables of a boot image.

The utility generates the following files as output:

- Dump of all header tables.
- Dump of register init table.
- Dump of individual partitions.

***Note*:** If the partitions are encrypted, the dump will be the encrypted partition and not the decrypted one

Usage:

```
bootgen_utility
        -arch <zynq | zynqmp> -bin <binary input file name>  -out <output
text file>
```

Example:

```
bootgen_utility
        -arch zynqmp -bin boot.bin -out info.txt
```

Sample output file looks like the following:

Figure 22: **Example Output**

```
Xilinx Bootgen Debug Utility
Version: 2018.2    Date: Jan 03, 2018

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::   B O O T    H E A D E R   :::::::::::::::::::::
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
<Flash Address>    <Offset>         <Description>                  <Interpretation>

[0x00000000]        (0x00)      ARM Vector Table                  - 0xeaffffe
[0x00000004]        (0x04)      ARM Vector Table                  - 0xeaffffe
[0x00000008]        (0x08)      ARM Vector Table                  - 0xeaffffe
[0x0000000c]        (0x0C)      ARM Vector Table                  - 0xeaffffe
[0x00000010]        (0x10)      ARM Vector Table                  - 0xeaffffe
[0x00000014]        (0x14)      ARM Vector Table                  - 0xeaffffe
[0x00000018]        (0x18)      ARM Vector Table                  - 0xeaffffe
[0x0000001c]        (0x1C)      ARM Vector Table                  - 0xeaffffe
[0x00000020]        (0x20)      Width Detection Word              - 0xaa995566
[0x00000024]        (0x24)      Header Signature                  - 0x584c4e58
[0x00000028]        (0x24)      Encryption Key Source             - 0x00      (Not Encrypted)
[0x0000002c]        (0x24)      Header Version                    - 0x1010000
[0x00000030]        (0x30)      Load Image Byte Offset            - 0x202000
[0x00000034]        (0x34)      Load Image Byte Length            - 0x00
[0x00000038]        (0x38)      Image Load Byte Address           - 0x00
[0x0000003c]        (0x3C)      Image Execution Byte Address      - 0xfc202000
[0x00000040]        (0x40)      Total Image Byte Length           - 0x00
[0x00000044]        (0x44)      QSPI Config Word                  - 0x01
[0x00000048]        (0x48)      Header Checksum                   - 0xffd51c40
[0x00000098]        (0x98)      Image Header Table Offset         - 0x8c0
[0x0000009c]        (0x9C)      Partition Header Table Offset     - 0xc80

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
:::::::::::::::::::::::::::::::::::::::::::::   R E G I S T E R   I N I T I A L I Z A T I O N   T A B L E   :::
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

[0x000000a0]
        Refer file "info_boot_new_register_init_table.txt"
[0x000008a0]

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
:::::::::::::::::::::::::::::::::::::::::::::::::::::::   I M A G E   H E A D E R   T A B L E   ::::::::::::::
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
<Flash Address>    <Offset>         <Description>                  <Interpretation>

[0x000008c0]        (0x00)      Version                           - 0x1020000
[0x000008c4]        (0x04)      Count of Image Headers            - 0x01
[0x000008c8]        (0x08)      Offset to 1st Partition Header    - 0x320
[0x000008cc]        (0x0C)      Offset to 1st Image Header        - 0x240
[0x000008d0]        (0x10)      Offset to Header Auth. Cert.      - 0x00


~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::   I M A G E   H E A D E R   :::::::::::::::::::::
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~   Image 1   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
<Flash Address>    <Offset>         <Description>                  <Interpretation>

[0x00000900]        (0x00)      Next Image Header Pointer         - 0x00
[0x00000904]        (0x04)      Next 1st Partition Header Pointer - 0x320
[0x00000908]        (0x08)      Partition Count (Wrong Info)      - 0x00
[0x0000090c]        (0x0C)      Image Length (Wrong Info)         - 0x01
[0x00000910]        (0x10)      Image Name                        - fsbl_xip.elf
```

Appendix D

Additional Resources and Legal Notices

Documentation Navigator and Design Hubs

Xilinx® Documentation Navigator (DocNav) provides access to Xilinx documents, videos, and support resources, which you can filter and search to find information. To open DocNav:

- From the Vivado® IDE, select **Help** → **Documentation and Tutorials**.
- On Windows, select **Start** → **All Programs** → **Xilinx Design Tools** → **DocNav**.
- At the Linux command prompt, enter `docnav`.

Xilinx Design Hubs provide links to documentation organized by design tasks and other topics, which you can use to learn key concepts and address frequently asked questions. To access the Design Hubs:

- In DocNav, click the **Design Hubs View** tab.
- On the Xilinx website, see the Design Hubs page.

***Note*:** For more information on DocNav, see the Documentation Navigator page on the Xilinx website.

Xilinx Resources

For support resources such as Answers, Documentation, Downloads, and Forums, see Xilinx Support.

Bootgen Resources

Bootgen Document Resources

The following documents provide additional information on the processes that support the Bootgen process:

- For Zynq®-7000 SoC:
  - *Zynq-7000 SoC Software Developers Guide* (UG821)
  - *Zynq-7000 SoC Technical Reference Manual* (UG585)
  - Xilinx Zynq-7000 SoC Solution Center: https://www.xilinx.com/support/answers/52512.html
  - http://xkb/Pages/46/46913.aspx
- For Zynq® UltraScale+™ MPSoC:
  - *Zynq UltraScale+ MPSoC: Software Developers Guide* (UG1137)
  - *Zynq UltraScale+ Device Technical Reference Manual* (UG1085)
  - Xilinx Zynq UltraScale+ MPSoC Solution Center: http://www.wiki.xilinx.com/Solution+ZynqMP+PL+Programming
  - AR#46913 I

Other Document Resources for Bootgen

- *Zynq-7000 SoC Secure Boot Getting Started Guide* (UG1025)
- *Xilinx Software Command Line Tool (XSCT) Reference Guide* (UG1208)
- *Zynq UltraScale+ MPSoC: Embedded Design Tutorial* (UG1209)
- *Sector Boot of Zynq-7000 All Programmable SoC*(XAPP1175)
- *Run Time Integrity and Authentication Check of Zynq-7000 SoC System Memory* (XAPP1225)
- *Programming BBRAM and eFUSEs* (XAPP1319)

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