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ProASIC3L FPGA Fabric User's Guide



Table of Contents

Introduction	7
Contents	7
Revision History	7
Related Information	7
1 FPGA Array Architecture in Low Power Flash Devices	9
Device Architecture	9
FPGA Array Architecture Support	10
Device Overview	11
Related Documents	20
List of Changes	20
2 Flash*Freeze Technology and Low Power Modes	21
Flash*Freeze Technology and Low Power Modes	21
Flash Families Support the Flash*Freeze Feature	22
Low Power Modes Overview	23
Static (Idle) Mode	23
Flash*Freeze Mode	24
Sleep and Shutdown Modes	32
Flash*Freeze Design Guide	34
Conclusion	42
Related Documents	42
List of Changes	42
3 Global Resources in Low Power Flash Devices	47
Introduction	47
Global Architecture	47
Global Resource Support in Flash-Based Devices	48
VersaNet Global Network Distribution	49
Chip and Quadrant Global I/Os	51
Spine Architecture	57
Using Clock Aggregation	60
Design Recommendations	62
Conclusion	74
Related Documents	74
List of Changes	75
4 Clock Conditioning Circuits in Low Power Flash Devices and Mixed Signal FPGAs	77
Introduction	77
Overview of Clock Conditioning Circuitry	77
CCC Support in Microsemi's Flash Devices	79
Global Buffers with No Programmable Delays	80
Global Buffer with Programmable Delay	80
Global Buffers with PLL Function	83
Global Input Selections	87

Device-Specific Layout	94
PLL Core Specifications	100
Functional Description	101
Software Configuration	112
Detailed Usage Information	120
Recommended Board-Level Considerations	128
Conclusion	129
Related Documents	129
List of Changes	129
5 FlashROM in Microsemi's Low Power Flash Devices	133
Introduction	133
Architecture of User Nonvolatile FlashROM	133
FlashROM Support in Flash-Based Devices	134
FlashROM Applications	136
FlashROM Security	137
Programming and Accessing FlashROM	138
FlashROM Design Flow	140
Custom Serialization Using FlashROM	145
Conclusion	146
Related Documents	146
List of Changes	146
6 SRAM and FIFO Memories in Microsemi's Low Power Flash Devices	147
Introduction	147
Device Architecture	147
SRAM/FIFO Support in Flash-Based Devices	150
SRAM and FIFO Architecture	151
Memory Blocks and Macros	151
Initializing the RAM/FIFO	164
Software Support	170
Conclusion	173
List of Changes	173
7 I/O Structures in IGLOO and ProASIC3 Devices	175
Introduction	175
Low Power Flash Device I/O Support	176
Advanced I/Os—IGLOO, ProASIC3L, and ProASIC3	177
I/O Architecture	181
I/O Standards	184
I/O Features	188
Simultaneously Switching Outputs (SSOs) and Printed Circuit Board Layout	204
I/O Software Support	205
User I/O Naming Convention	206
Board-Level Considerations	208
Conclusion	209
Related Documents	210
List of Changes	210
8 I/O Structures in IGLOOe and ProASIC3E Devices	213

Introduction	213
Low Power Flash Device I/O Support	214
Pro I/Os—IGLOOe, ProASIC3EL, and ProASIC3E	215
I/O Architecture	220
I/O Standards	223
I/O Features	227
Simultaneously Switching Outputs (SSOs) and Printed Circuit Board Layout	241
I/O Software Support	242
User I/O Naming Convention	245
Board-Level Considerations	246
Conclusion	248
Related Documents	248
List of Changes	249
9 I/O Software Control in Low Power Flash Devices	251
Flash FPGAs I/O Support	252
Software-Controlled I/O Attributes	253
Implementing I/Os in Microsemi Software	254
Assigning Technologies and VREF to I/O Banks	264
Conclusion	269
Related Documents	269
List of Changes	270
10 DDR for Microsemi's Low Power Flash Devices	271
Introduction	271
Double Data Rate (DDR) Architecture	271
DDR Support in Flash-Based Devices	272
I/O Cell Architecture	273
Input Support for DDR	275
Output Support for DDR	275
Instantiating DDR Registers	276
Design Example	282
Conclusion	284
List of Changes	285
11 Programming Flash Devices	287
Introduction	287
Summary of Programming Support	287
Programming Support in Flash Devices	288
General Flash Programming Information	289
Important Programming Guidelines	295
Related Documents	297
List of Changes	298
12 Security in Low Power Flash Devices	301
Security in Programmable Logic	301
Security Support in Flash-Based Devices	302
Security Architecture	303
Security Features	304
Security in Action	308

FlashROM Security Use Models	311
Generating Programming Files	313
Conclusion	324
Glossary	324
References	324
Related Documents	325
List of Changes	325
13 In-System Programming (ISP) of Microsemi's Low Power Flash Devices Using FlashPro4/3/3X . . .	327
Introduction	327
ISP Architecture	327
ISP Support in Flash-Based Devices	328
Programming Voltage (VPUMP) and VJTAG	329
Nonvolatile Memory (NVM) Programming Voltage	329
IEEE 1532 (JTAG) Interface	330
Security	330
Security in ARM-Enabled Low Power Flash Devices	331
FlashROM and Programming Files	333
Programming Solution	334
ISP Programming Header Information	335
Board-Level Considerations	337
Conclusion	338
Related Documents	338
List of Changes	339
14 Core Voltage Switching Circuit for IGLOO and ProASIC3L In-System Programming	341
Introduction	341
Microsemi's Flash Families Support Voltage Switching Circuit	342
Circuit Description	343
Circuit Verification	344
DirectC	346
Conclusion	346
List of Changes	347
15 Microprocessor Programming of Microsemi's Low Power Flash Devices	349
Introduction	349
Microprocessor Programming Support in Flash Devices	350
Programming Algorithm	351
Implementation Overview	351
Hardware Requirement	354
Security	354
Conclusion	355
List of Changes	356
16 Boundary Scan in Low Power Flash Devices.	357
Boundary Scan	357
TAP Controller State Machine	357
Microsemi's Flash Devices Support the JTAG Feature	358
Boundary Scan Support in Low Power Devices	359
Boundary Scan Opcodes	359

Boundary Scan Chain	359
Board-Level Recommendations	360
Advanced Boundary Scan Register Settings	361
List of Changes	362
17 UJTAG Applications in Microsemi's Low Power Flash Devices	363
Introduction	363
UJTAG Support in Flash-Based Devices	364
UJTAG Macro	365
UJTAG Operation	366
Typical UJTAG Applications	368
Conclusion	372
Related Documents	372
List of Changes	372
18 Power-Up/-Down Behavior of Low Power Flash Devices	373
Introduction	373
Flash Devices Support Power-Up Behavior	374
Power-Up/-Down Sequence and Transient Current	375
I/O Behavior at Power-Up/-Down	377
Cold-Sparing	382
Hot-Swapping	383
Conclusion	383
Related Documents	384
List of Changes	384
A Summary of Changes	385
History of Revision to Chapters	385
B Product Support	387
Customer Service	387
Customer Technical Support Center	387
Technical Support	387
Website	387
Contacting the Customer Technical Support Center	387
ITAR Technical Support	388
Index	389

Introduction

Contents

This user's guide contains information to help designers understand and use Microsemi's ProASIC[®]3L devices. Each chapter addresses a specific topic. Most of these chapters apply to other Microsemi device families as well. When a feature or description applies only to a specific device family, this is made clear in the text.

Revision History

The revision history for each chapter is listed at the end of the chapter. Most of these chapters were formerly included in device handbooks. Some were originally application notes or information included in device datasheets.

A "[Summary of Changes](#)" table at the end of this user's guide lists the chapters that were changed in each revision of the document, with links to the "List of Changes" sections for those chapters.

Related Information

Refer to the *ProASIC3L Flash Family FPGAs* datasheet for detailed specifications, timing, and package and pin information.

The website page for ProASIC3L devices is [/www.microsemi.com/soc/products/pa3l/default.aspx](http://www.microsemi.com/soc/products/pa3l/default.aspx).

1 – FPGA Array Architecture in Low Power Flash Devices

Device Architecture

Advanced Flash Switch

Unlike SRAM FPGAs, the low power flash devices use a live-at-power-up ISP flash switch as their programming element. Flash cells are distributed throughout the device to provide nonvolatile, reconfigurable programming to connect signal lines to the appropriate VersaTile inputs and outputs. In the flash switch, two transistors share the floating gate, which stores the programming information (Figure 1-1). One is the sensing transistor, which is only used for writing and verification of the floating gate voltage. The other is the switching transistor. The latter is used to connect or separate routing nets, or to configure VersaTile logic. It is also used to erase the floating gate. Dedicated high-performance lines are connected as required using the flash switch for fast, low-skew, global signal distribution throughout the device core. Maximum core utilization is possible for virtually any design. The use of the flash switch technology also removes the possibility of firm errors, which are increasingly common in SRAM-based FPGAs.

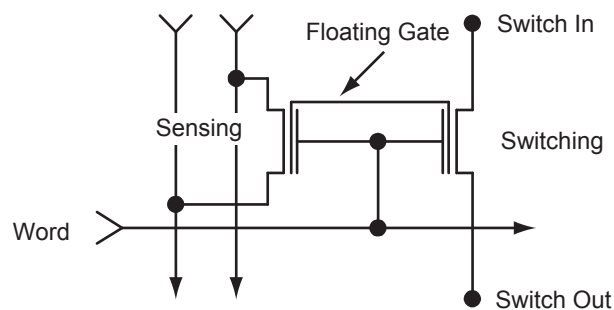


Figure 1-1 • Flash-Based Switch

FPGA Array Architecture Support

The flash FPGAs listed in [Table 1-1](#) support the architecture features described in this document.

Table 1-1 • Flash-Based FPGAs

Series	Family*	Description
IGLOO®	IGLOO	Ultra-low power 1.2 V to 1.5 V FPGAs with Flash*Freeze technology
	IGLOOe	Higher density IGLOO FPGAs with six PLLs and additional I/O standards
	IGLOO nano	The industry's lowest-power, smallest-size solution
	IGLOO PLUS	IGLOO FPGAs with enhanced I/O capabilities
ProASIC®3	ProASIC3	Low power, high-performance 1.5 V FPGAs
	ProASIC3E	Higher density ProASIC3 FPGAs with six PLLs and additional I/O standards
	ProASIC3 nano	Lowest-cost solution with enhanced I/O capabilities
	ProASIC3L	ProASIC3 FPGAs supporting 1.2 V to 1.5 V with Flash*Freeze technology
	RT ProASIC3	Radiation-tolerant RT3PE600L and RT3PE3000L
	Military ProASIC3/EL	Military temperature A3PE600L, A3P1000, and A3PE3000L
	Automotive ProASIC3	ProASIC3 FPGAs qualified for automotive applications
Fusion	Fusion	Mixed signal FPGA integrating ProASIC3 FPGA fabric, programmable analog block, support for ARM® Cortex™-M1 soft processors, and flash memory into a monolithic device

Note: *The device names link to the appropriate datasheet, including product brief, DC and switching characteristics, and packaging information.

IGLOO Terminology

In documentation, the terms IGLOO series and IGLOO devices refer to all of the IGLOO devices as listed in [Table 1-1](#). Where the information applies to only one product line or limited devices, these exclusions will be explicitly stated.

ProASIC3 Terminology

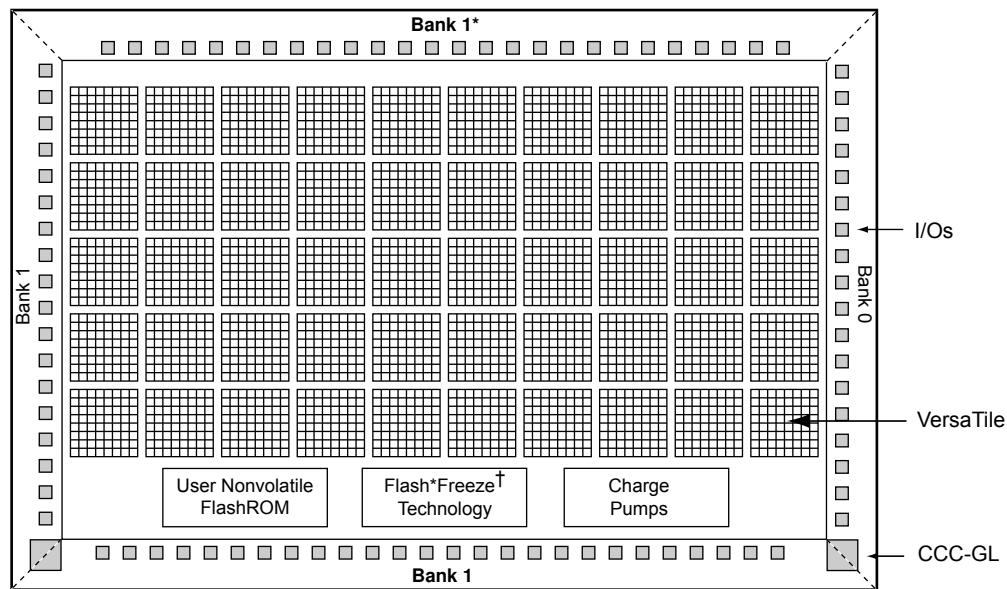
In documentation, the terms ProASIC3 series and ProASIC3 devices refer to all of the ProASIC3 devices as listed in [Table 1-1](#). Where the information applies to only one product line or limited devices, these exclusions will be explicitly stated.

To further understand the differences between the IGLOO and ProASIC3 devices, refer to the [Industry's Lowest Power FPGAs Portfolio](#).

Device Overview

Low power flash devices consist of multiple distinct programmable architectural features (Figure 1-5 on page 13 through Figure 1-7 on page 14):

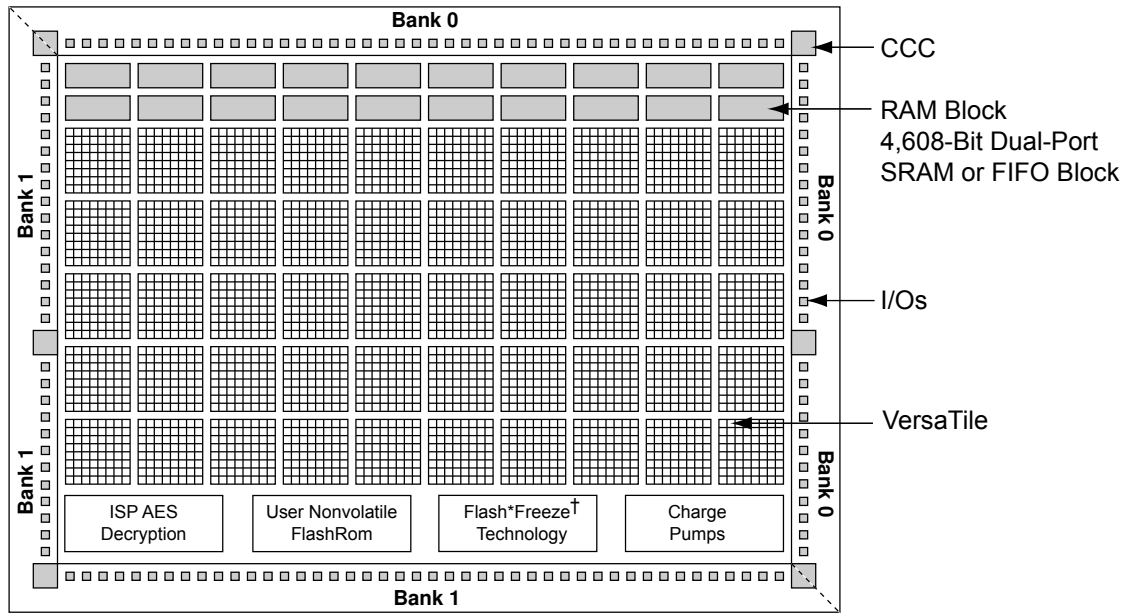
- FPGA fabric/core (VersaTiles)
- Routing and clock resources (VersaNets)
- FlashROM
- Dedicated SRAM and/or FIFO
 - 30 k gate and smaller device densities do not support SRAM or FIFO.
 - Automotive devices do not support FIFO operation.
- I/O structures
- Flash*Freeze technology and low power modes



Notes: * Bank 0 for the 30 k devices

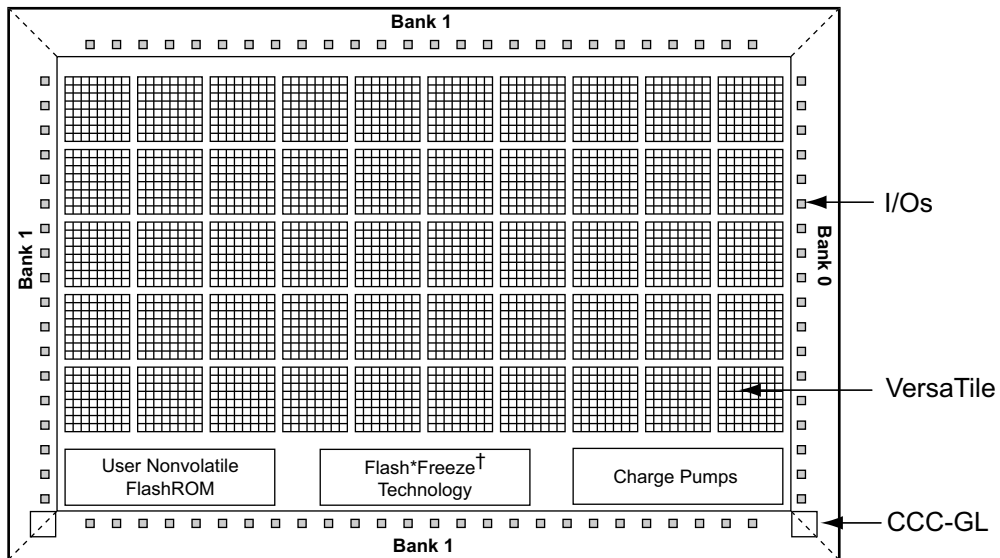
† Flash*Freeze mode is supported on IGLOO devices.

Figure 1-2 • IGLOO and ProASIC3 nano Device Architecture Overview with Two I/O Banks (applies to 10 k and 30 k device densities, excluding IGLOO PLUS devices)



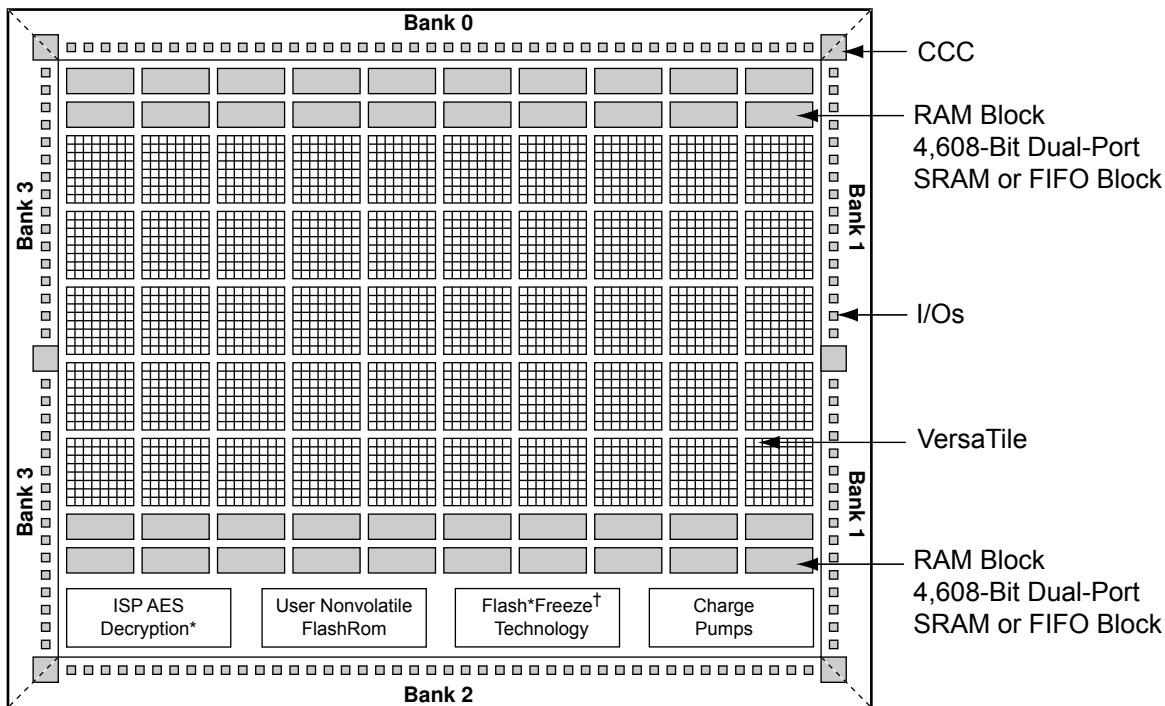
Note: † Flash*Freeze mode is supported on IGLOO devices.

**Figure 1-3 • IGLOO Device Architecture Overview with Two I/O Banks with RAM and PLL
(60 k and 125 k gate densities)**



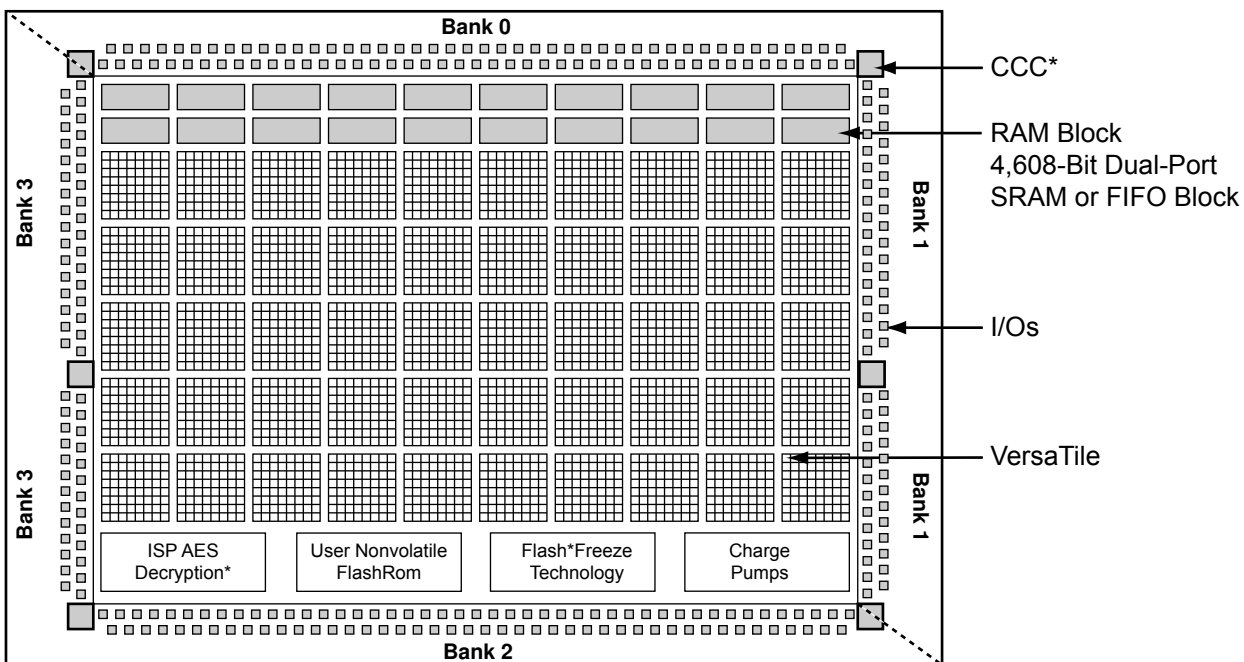
Note: † Flash*Freeze mode is supported on IGLOO devices.

**Figure 1-4 • IGLOO Device Architecture Overview with Three I/O Banks
(AGLN015, AGLN020, A3PN015, and A3PN020)**



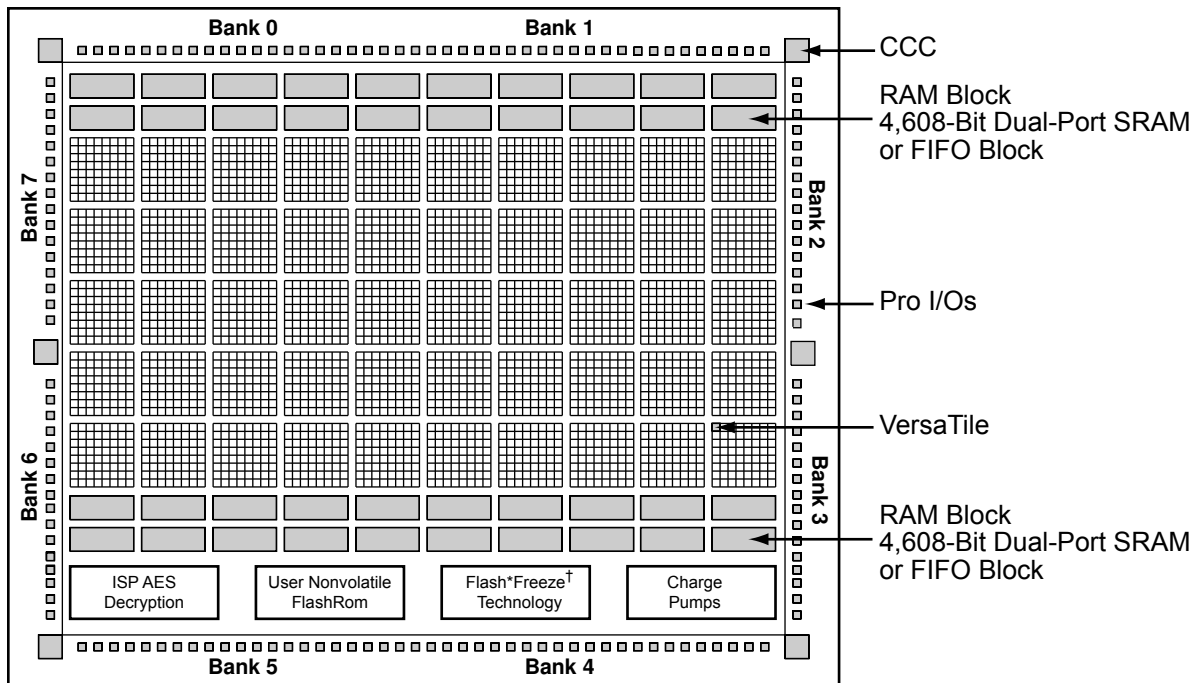
*Note: Flash*Freeze technology only applies to IGLOO and ProASIC3L families.*

Figure 1-5 • IGLOO, IGLOO nano, ProASIC3 nano, and ProASIC3/L Device Architecture Overview with Four I/O Banks (AGL600 device is shown)



*Note: * AGLP030 does not contain a PLL or support AES security.*

Figure 1-6 • IGLOO PLUS Device Architecture Overview with Four I/O Banks



*Note: Flash*Freeze technology only applies to IGLOOe devices.*

Figure 1-7 • IGLOOe and ProASIC3E Device Architecture Overview (AGLE600 device is shown)

I/O State of Newly Shipped Devices

Devices are shipped from the factory with a test design in the device. The power-on switch for VCC is OFF by default in this test design, so I/Os are tristated by default. Tristated means the I/O is not actively driven and floats. The exact value cannot be guaranteed when it is floating. Even in simulation software, a tristate value is marked as unknown. Due to process variations and shifts, tristated I/Os may float toward High or Low, depending on the particular device and leakage level.

If there is concern regarding the exact state of unused I/Os, weak pull-up/pull-down should be added to the floating I/Os so their state is controlled and stabilized.

Core Architecture

VersaTile

The proprietary IGLOO and ProASIC3 device architectures provide granularity comparable to gate arrays. The device core consists of a sea-of-VersaTiles architecture.

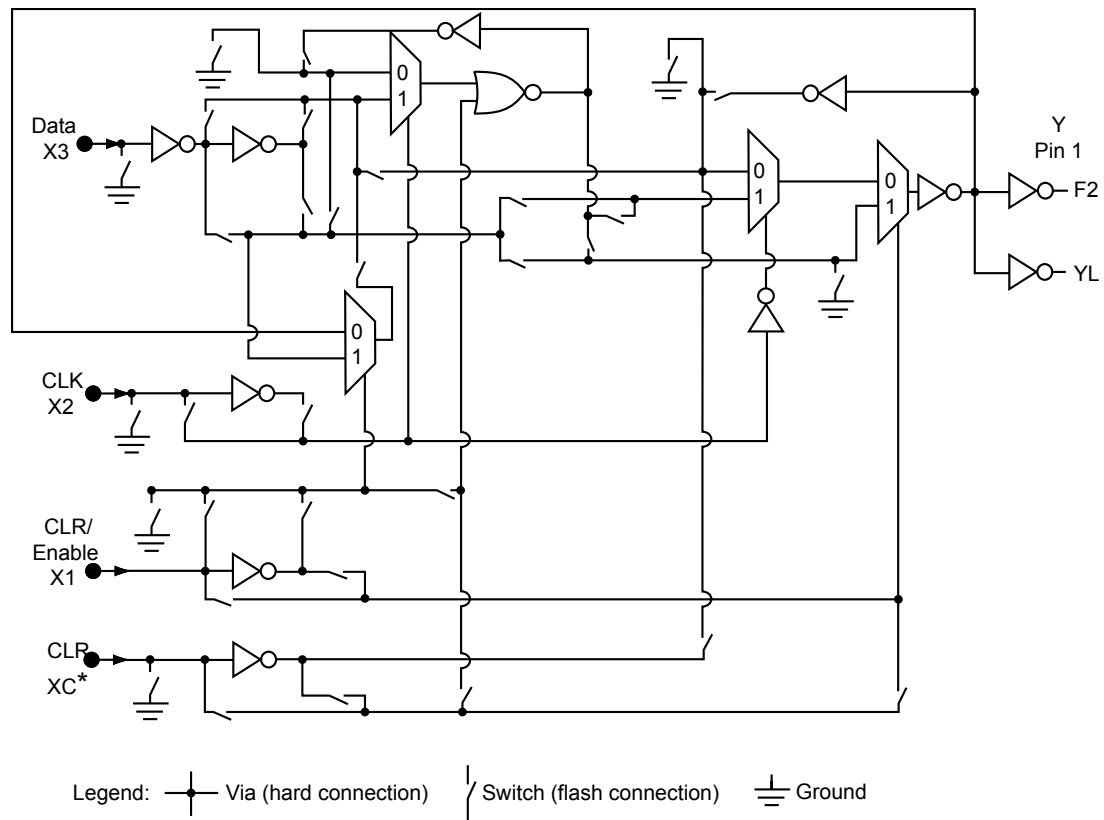
As illustrated in [Figure 1-8](#), there are four inputs in a logic VersaTile cell, and each VersaTile can be configured using the appropriate flash switch connections:

- Any 3-input logic function
- Latch with clear or set
- D-flip-flop with clear or set
- Enable D-flip-flop with clear or set (on a 4th input)

VersaTiles can flexibly map the logic and sequential gates of a design. The inputs of the VersaTile can be inverted (allowing bubble pushing), and the output of the tile can connect to high-speed, very-long-line routing resources. VersaTiles and larger functions can be connected with any of the four levels of routing hierarchy.

When the VersaTile is used as an enable D-flip-flop, SET/CLR is supported by a fourth input. The SET/CLR signal can only be routed to this fourth input over the VersaNet (global) network. However, if, in the user's design, the SET/CLR signal is not routed over the VersaNet network, a compile warning will be given, and the intended logic function will be implemented by two VersaTiles instead of one.

The output of the VersaTile is F2 when the connection is to the ultra-fast local lines, or YL when the connection is to the efficient long-line or very-long-line resources.



* This input can only be connected to the global clock distribution network.

Figure 1-8 • Low Power Flash Device Core VersaTile

Array Coordinates

During many place-and-route operations in the Microsemi Designer software tool, it is possible to set constraints that require array coordinates. Table 1-2 provides array coordinates of core cells and memory blocks for IGLOO and ProASIC3 devices. Table 1-3 provides the information for IGLOO PLUS devices. Table 1-4 on page 17 provides the information for IGLOO nano and ProASIC3 nano devices. The array coordinates are measured from the lower left (0, 0). They can be used in region constraints for specific logic groups/blocks, designated by a wildcard, and can contain core cells, memories, and I/Os.

I/O and cell coordinates are used for placement constraints. Two coordinate systems are needed because there is not a one-to-one correspondence between I/O cells and core cells. In addition, the I/O coordinate system changes depending on the die/package combination. It is not listed in Table 1-2. The Designer ChipPlanner tool provides the array coordinates of all I/O locations. I/O and cell coordinates are used for placement constraints. However, I/O placement is easier by package pin assignment.

Figure 1-9 on page 17 illustrates the array coordinates of a 600 k gate device. For more information on how to use array coordinates for region/placement constraints, see the *Designer User's Guide* or online help (available in the software) for software tools.

Table 1-2 • IGLOO and ProASIC3 Array Coordinates

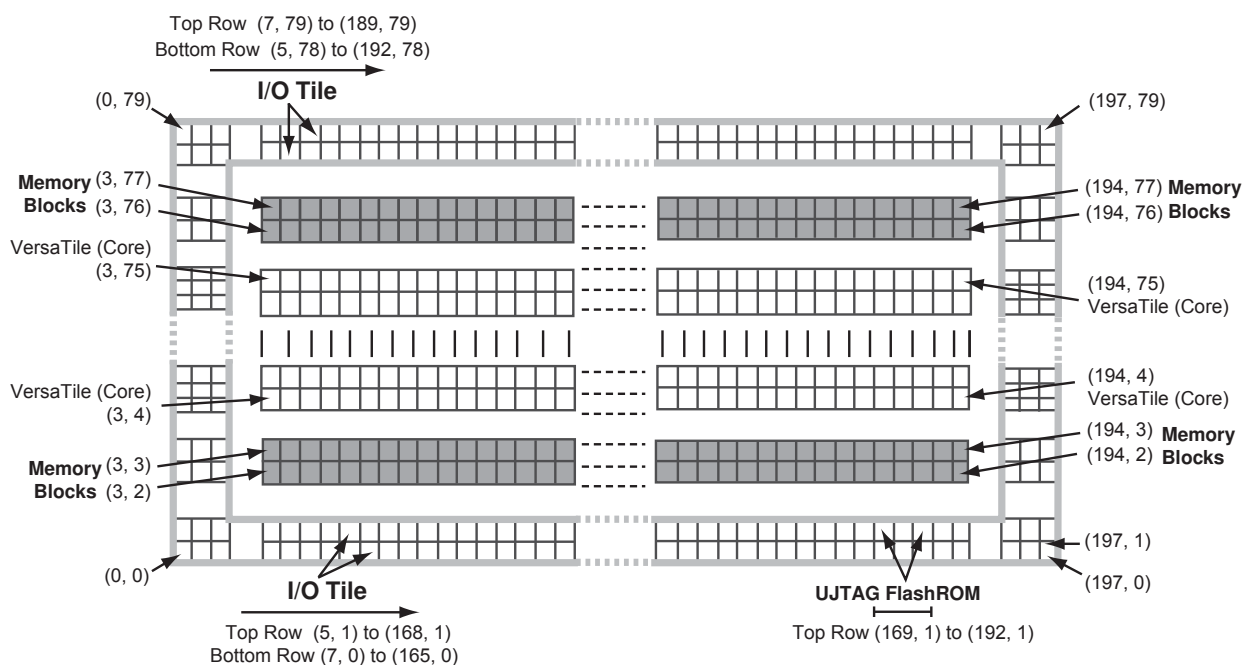
Device		VersaTiles				Memory Rows		Entire Die	
		Min.		Max.		Bottom	Top	Min.	Max.
IGLOO	ProASIC3/ ProASIC3L	x	y	x	y	(x, y)	(x, y)	(x, y)	(x, y)
AGL015	A3P015	3	2	34	13	None	None	(0, 0)	(37, 15)
AGL030	A3P030	3	3	66	13	None	None	(0, 0)	(69, 15)
AGL060	A3P060	3	2	66	25	None	(3, 26)	(0, 0)	(69, 29)
AGL125	A3P125	3	2	130	25	None	(3, 26)	(0, 0)	(133, 29)
AGL250	A3P250/L	3	2	130	49	None	(3, 50)	(0, 0)	(133, 53)
AGL400	A3P400	3	2	194	49	None	(3, 50)	(0, 0)	(197, 53)
AGL600	A3P600/L	3	4	194	75	(3, 2)	(3, 76)	(0, 0)	(197, 79)
AGL1000	A3P1000/L	3	4	258	99	(3, 2)	(3, 100)	(0, 0)	(261, 103)
AGLE600	A3PE600/L, RT3PE600L	3	4	194	75	(3, 2)	(3, 76)	(0, 0)	(197, 79)
	A3PE1500	3	4	322	123	(3, 2)	(3, 124)	(0, 0)	(325, 127)
AGLE3000	A3PE3000/L, RT3PE3000L	3	6	450	173	(3, 2) or (3, 4)	(3, 174) or (3, 176)	(0, 0)	(453, 179)

Table 1-3 • IGLOO PLUS Array Coordinates

Device		VersaTiles				Memory Rows		Entire Die	
		Min.		Max.		Bottom	Top	Min.	Max.
IGLOO PLUS		x	y	x	y	(x, y)	(x, y)	(x, y)	(x, y)
AGLP030		2	3	67	13	None	None	(0, 0)	(69, 15)
AGLP060		2	2	67	25	None	(3, 26)	(0, 0)	(69, 29)
AGLP125		2	2	131	25	None	(3, 26)	(0, 0)	(133, 29)

Table 1-4 • IGLOO nano and ProASIC3 nano Array Coordinates

Device		VersaTiles		Memory Rows		Entire Die	
		Min.	Max.	Bottom	Top	Min.	Max.
IGLOO nano	ProASIC3 nano	(x, y)	(x, y)	(x, y)	(x, y)	(x, y)	(x, y)
AGLN010	A3P010	(0, 2)	(32, 5)	None	None	(0, 0)	(34, 5)
AGLN015	A3PN015	(0, 2)	(32, 9)	None	None	(0, 0)	(34, 9)
AGLN020	A3PN020	(0, 2)	32, 13)	None	None	(0, 0)	(34, 13)
AGLN060	A3PN060	(3, 2)	(66, 25)	None	(3, 26)	(0, 0)	(69, 29)
AGLN125	A3PN125	(3, 2)	(130, 25)	None	(3, 26)	(0, 0)	(133, 29)
AGLN250	A3PN250	(3, 2)	(130, 49)	None	(3, 50)	(0, 0)	(133, 49)



Note: The vertical I/O tile coordinates are not shown. West-side coordinates are {(0, 2) to (2, 2)} to {(0, 77) to (2, 77)}; east-side coordinates are {(195, 2) to (197, 2)} to {(195, 77) to (197, 77)}.

Figure 1-9 • Array Coordinates for AGL600, AGL600, A3P600, and A3PE600

Routing Architecture

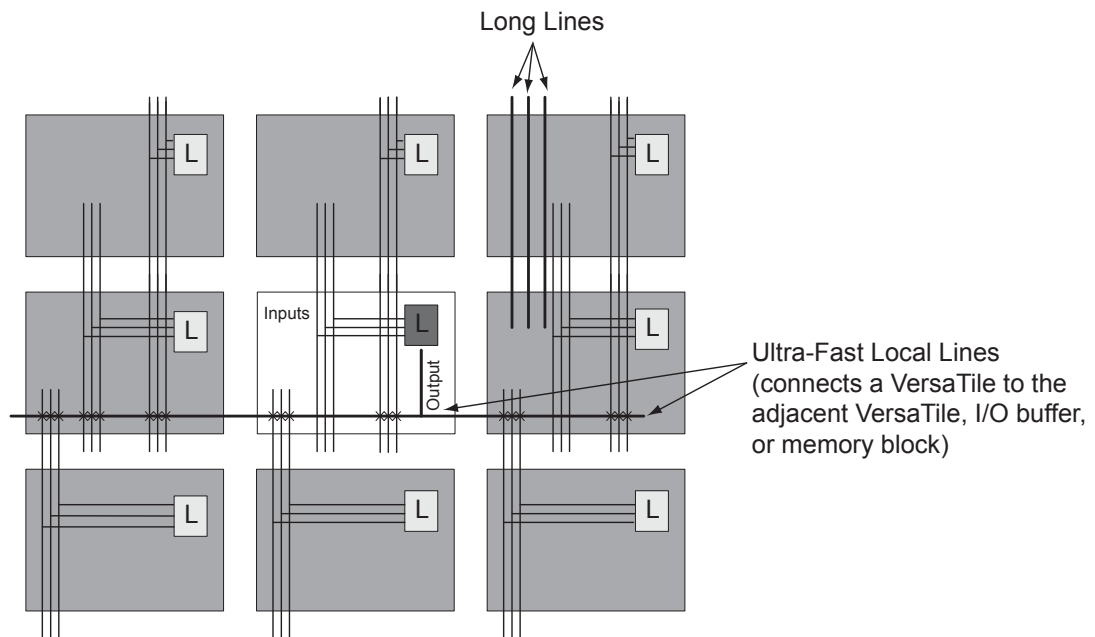
The routing structure of low power flash devices is designed to provide high performance through a flexible four-level hierarchy of routing resources: ultra-fast local resources; efficient long-line resources; high-speed, very-long-line resources; and the high-performance VersaNet networks.

The ultra-fast local resources are dedicated lines that allow the output of each VersaTile to connect directly to every input of the eight surrounding VersaTiles (Figure 1-10). The exception to this is that the SET/CLR input of a VersaTile configured as a D-flip-flop is driven only by the VersaNet global network.

The efficient long-line resources provide routing for longer distances and higher-fanout connections. These resources vary in length (spanning one, two, or four VersaTiles), run both vertically and horizontally, and cover the entire device (Figure 1-11 on page 19). Each VersaTile can drive signals onto the efficient long-line resources, which can access every input of every VersaTile. Routing software automatically inserts active buffers to limit loading effects.

The high-speed, very-long-line resources, which span the entire device with minimal delay, are used to route very long or high-fanout nets: length ± 12 VersaTiles in the vertical direction and length ± 16 in the horizontal direction from a given core VersaTile (Figure 1-12 on page 19). Very long lines in low power flash devices have been enhanced over those in previous ProASIC families. This provides a significant performance boost for long-reach signals.

The high-performance VersaNet global networks are low-skew, high-fanout nets that are accessible from external pins or internal logic. These nets are typically used to distribute clocks, resets, and other high-fanout nets requiring minimum skew. The VersaNet networks are implemented as clock trees, and signals can be introduced at any junction. These can be employed hierarchically, with signals accessing every input of every VersaTile. For more details on VersaNets, refer to the "Global Resources in Low Power Flash Devices" section on page 47.



Note: Input to the core cell for the D-flip-flop set and reset is only available via the VersaNet global network connection.

Figure 1-10 • Ultra-Fast Local Lines Connected to the Eight Nearest Neighbors

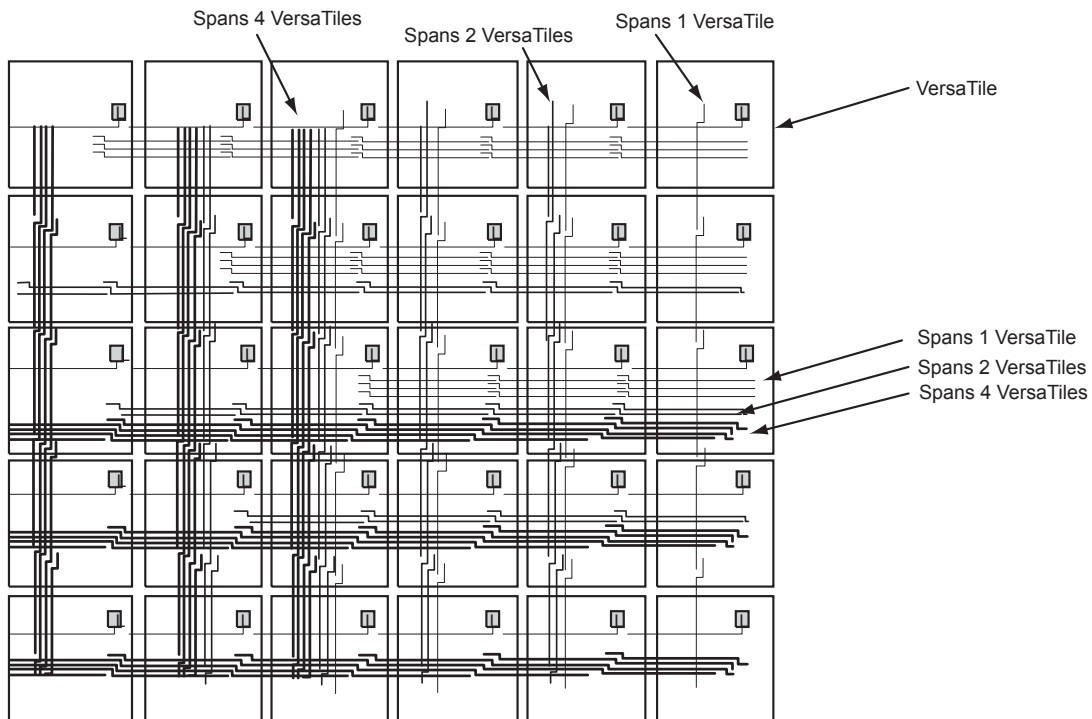


Figure 1-11 • Efficient Long-Line Resources

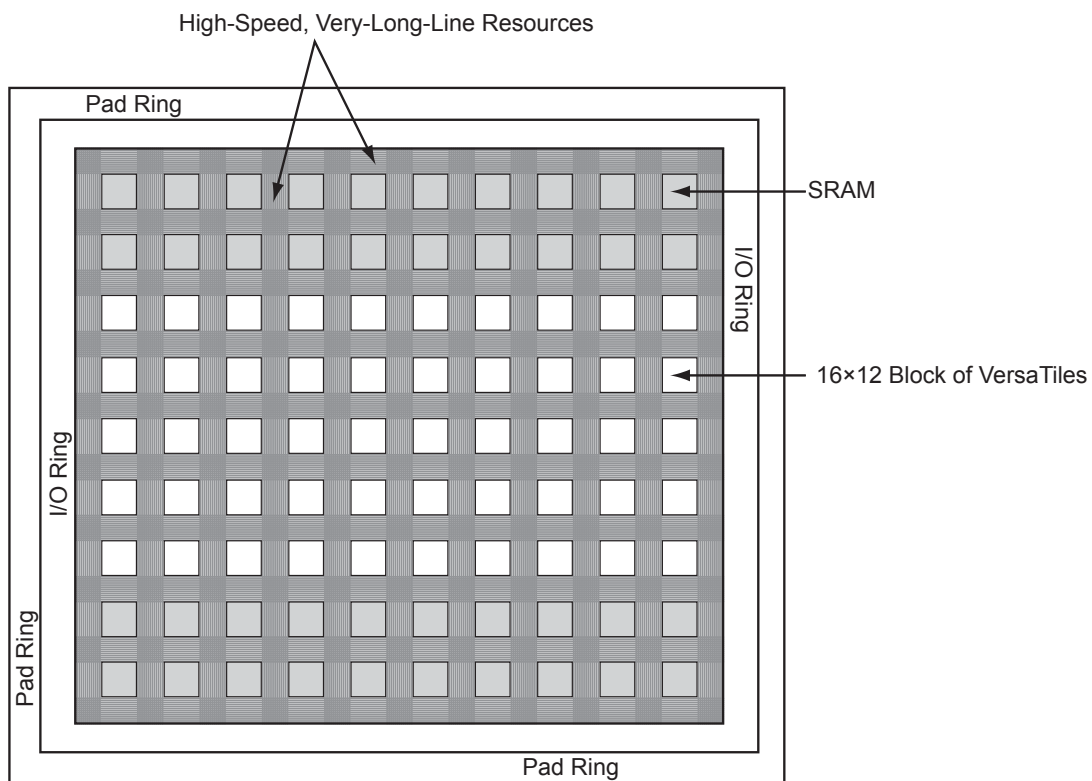


Figure 1-12 • Very-Long-Line Resources

Related Documents

User's Guides

Designer User's Guide

http://www.microsemi.com/soc/documents/designer_ug.pdf

List of Changes

The following table lists critical changes that were made in each revision of the chapter.

Date	Changes	Page
August 2012	The "I/O State of Newly Shipped Devices" section is new (SAR 39542).	14
July 2010	This chapter is no longer published separately with its own part number and version but is now part of several FPGA fabric user's guides.	N/A
v1.4 (December 2008)	IGLOO nano and ProASIC3 nano devices were added to Table 1-1 • Flash-Based FPGAs .	10
	Figure 1-2 • IGLOO and ProASIC3 nano Device Architecture Overview with Two I/O Banks (applies to 10 k and 30 k device densities, excluding IGLOO PLUS devices) through Figure 1-5 • IGLOO, IGLOO nano, ProASIC3 nano, and ProASIC3/L Device Architecture Overview with Four I/O Banks (AGL600 device is shown) are new.	11, 12
	Table 1-4 • IGLOO nano and ProASIC3 nano Array Coordinates is new.	17
v1.3 (October 2008)	The title of this document was changed from "Core Architecture of IGLOO and ProASIC3 Devices" to "FPGA Array Architecture in Low Power Flash Devices."	9
	The "FPGA Array Architecture Support" section was revised to include new families and make the information more concise.	10
	Table 1-2 • IGLOO and ProASIC3 Array Coordinates was updated to include Military ProASIC3/EL and RT ProASIC3 devices.	16
v1.2 (June 2008)	The following changes were made to the family descriptions in Table 1-1 • Flash-Based FPGAs : <ul style="list-style-type: none"> ProASIC3L was updated to include 1.5 V. The number of PLLs for ProASIC3E was changed from five to six. 	10
v1.1 (March 2008)	Table 1-1 • Flash-Based FPGAs and the accompanying text was updated to include the IGLOO PLUS family. The "IGLOO Terminology" section and "Device Overview" section are new.	10
	The "Device Overview" section was updated to note that 15 k devices do not support SRAM or FIFO.	11
	Figure 1-6 • IGLOO PLUS Device Architecture Overview with Four I/O Banks is new.	13
	Table 1-2 • IGLOO and ProASIC3 Array Coordinates was updated to add A3P015 and AGL015.	16
	Table 1-3 • IGLOO PLUS Array Coordinates is new.	16

2 – Flash*Freeze Technology and Low Power Modes

Flash*Freeze Technology and Low Power Modes

Microsemi IGLOO,[®] IGLOO nano, IGLOO PLUS, ProASIC[®]3L, and Radiation-Tolerant (RT) ProASIC3 FPGAs with Flash*Freeze technology are designed to meet the most demanding power and area challenges of today's portable electronics products with a reprogrammable, small-footprint, full-featured flash FPGA. These devices offer lower power consumption in static and dynamic modes, utilizing the unique Flash*Freeze technology, than any other FPGA or CPLD.

IGLOO, IGLOO nano, IGLOO PLUS, ProASIC3L, and RT ProASIC3 devices offer various power-saving modes that enable every system to utilize modes that achieve the lowest total system power. Low Power Active capability (static idle) allows for ultra-low power consumption while the device is operational in the system by maintaining SRAM, registers, I/Os, and logic functions.

Flash*Freeze technology provides an ultra-low power static mode (Flash*Freeze mode) that retains all SRAM and register information with rapid recovery to Active (operating) mode. IGLOO nano and IGLOO PLUS devices have an additional feature when operating in Flash*Freeze mode, allowing them to retain I/O states as well as SRAM and register states. This mechanism enables the user to quickly (within 1 μ s) enter and exit Flash*Freeze mode by activating the Flash*Freeze (FF) pin while all power supplies are kept in their original states. In addition, I/Os and clocks connected to the FPGA can still be toggled without impact on device power consumption. While in Flash*Freeze mode, the device retains all core register states and SRAM information. This mode can be configured so that no power is consumed by the I/O banks, clocks, JTAG pins, or PLLs; and the IGLOO and IGLOO PLUS devices consume as little as 5 μ W, while IGLOO nano devices consume as little as 2 μ W. Microsemi offers a state management IP core to aid users in gating clocks and managing data before entering Flash*Freeze mode.

This document will guide users in selecting the best low power mode for their applications, and introduces Microsemi's Flash*Freeze management IP core.

Flash Families Support the Flash*Freeze Feature

The low power flash FPGAs listed in [Table 2-1](#) support the Flash*Freeze feature and the functions described in this document.

Table 2-1 • Flash-Based FPGAs

Series	Family*	Description
IGLOO	IGLOO	Ultra-low power 1.2 V to 1.5 V FPGAs with Flash*Freeze technology
	IGLOOe	Higher density IGLOO FPGAs with six PLLs and additional I/O standards
	IGLOO nano	The industry's lowest-power, smallest-size solution
	IGLOO PLUS	IGLOO FPGAs with enhanced I/O capabilities
ProASIC3	ProASIC3L	ProASIC3 FPGAs supporting 1.2 V to 1.5 V with Flash*Freeze technology
	RT ProASIC3	Radiation-tolerant RT3PE600L and RT3PE3000L
	Military ProASIC3/EL	Military temperature A3PE600L, A3P1000, and A3PE3000L

Note: *The device names link to the appropriate datasheet, including product brief, DC and switching characteristics, and packaging information.

IGLOO Terminology

In documentation, the terms IGLOO series and IGLOO devices refer to all of the IGLOO devices as listed in [Table 2-1](#). Where the information applies to only one product line or limited devices, these exclusions will be explicitly stated.

ProASIC3 Terminology

In documentation, the terms ProASIC3 series and ProASIC3 devices refer to all of the ProASIC3 devices as listed in [Table 2-1](#). Where the information applies to only one product line or limited devices, these exclusions will be explicitly stated.

To further understand the differences between the IGLOO and ProASIC3 devices, refer to the [Industry's Lowest Power FPGAs Portfolio](#).

Low Power Modes Overview

Table 2-2 summarizes the low power modes that achieve power consumption reduction when the FPGA or system is idle.

Table 2-2 • Power Modes Summary

Mode		VCCI	VCC	Core	Clocks	ULSICC Macro	To Enter Mode	To Resume Operation	Trigger
Active		On	On	On	On	N/A	Initiate clock	None	–
Static	Idle	On	On	On	Off	N/A	Stop clock	Initiate clock	External
	Flash*Freeze type 1	On	On	On	On*	N/A	Assert FF pin	Deassert FF pin	External
	Flash*Freeze type 2	On	On	On	On*	Used to enter Flash*Freeze mode	Assert FF pin and assert LSICC	Deassert FF pin	External
Sleep		On	Off	Off	Off	N/A	Shut down VCC	Turn on VCC supply	External
Shutdown		Off	Off	Off	Off	N/A	Shut down VCC and VCCI supplies	Turn on VCC and VCCI supplies	External

* External clocks can be left toggling while the device is in Flash*Freeze mode. Clocks generated by the embedded PLL will be turned off automatically.

Static (Idle) Mode

In Static (Idle) mode, none of the clock inputs is switching, and static power is the only power consumed by the device. This mode can be achieved by switching off the incoming clocks to the FPGA, thus benefitting from reduced power consumption. In addition, I/Os draw only minimal leakage current. In this mode, embedded SRAM, I/Os, and registers retain their values so the device can enter and exit this mode just by switching the clocks on or off.

If the device-embedded PLL is used as the clock source, Static (Idle) mode can easily be entered by pulling the PLL POWERDOWN pin LOW (active Low), which will turn off the PLL.

Flash*Freeze Mode

IGLOO, IGLOO nano, IGLOO PLUS, ProASIC3L, and RT ProASIC3 FPGAs offer an ultra-low static power mode to reduce power consumption while preserving the state of the registers, SRAM contents, and I/O states (IGLOO nano and IGLOO PLUS only) without switching off any power supplies, inputs, or input clocks.

Flash*Freeze technology enables the user to switch to Flash*Freeze mode within 1 μ s, thus simplifying low power design implementation. The Flash*Freeze (FF) pin (active Low) is a dedicated pin used to enter or exit Flash*Freeze mode directly; or the pin can be routed internally to the FPGA core and state management IP to allow the user's application to decide if and when it is safe to transition to this mode. If the FF pin is not used, it can be used as a regular I/O.

The FF pin has a built-in glitch filter and optional Schmitt trigger (not available for all devices) to prevent entering or exiting Flash*Freeze mode accidentally.

There are two ways to use Flash*Freeze mode. In Flash*Freeze type 1, entering and exiting the mode is exclusively controlled by the assertion and deassertion of the FF pin. This enables an external processor or human interface device to directly control Flash*Freeze mode; however, valid data must be preserved using standard procedures (refer to the "[Flash*Freeze Mode Device Behavior](#)" section on page 30). In Flash*Freeze mode type 2, entering and exiting the mode is controlled by both the FF pin AND user-defined logic. Flash*Freeze management IP may be used in type 2 mode for clock and data management while entering and exiting Flash*Freeze mode.

Flash*Freeze Type 1: Control by Dedicated Flash*Freeze Pin

Flash*Freeze type 1 is intended for systems where either the device will be reset upon exiting Flash*Freeze mode, or data and clock are managed externally. The device enters Flash*Freeze mode 1 μ s after the dedicated FF pin is asserted (active Low), and returns to normal operation when the FF pin is deasserted (High) ([Figure 2-1 on page 25](#)). In this mode, FF pin assertion or deassertion is the only condition that determines entering or exiting Flash*Freeze mode.

In Libero[®] System-on-Chip (SoC) software v8.2 and before, this mode is implemented by enabling Flash*Freeze mode (default setting) in the Compile options of the Microsemi Designer software. To simplify usage of Flash*Freeze mode, beginning with Libero software v8.3, an INBUF_FF I/O macro was introduced. An INBUF_FF I/O buffer must be used to identify the Flash*Freeze input. Microsemi recommends switching to the new implementation.

In Libero software v8.3 and later, the user must manually instantiate the INBUF_FF macro in the top level of the design to implement Flash*Freeze Type 1, as shown in [Figure 2-1 on page 25](#).

Figure 2-1 shows the concept of FF pin control in Flash*Freeze mode type 1.

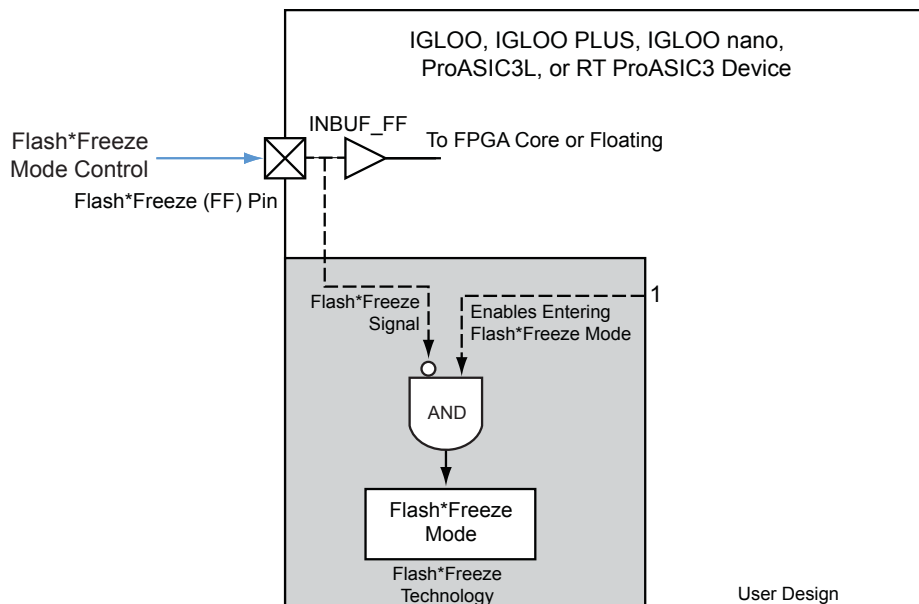


Figure 2-1 • Flash*Freeze Mode Type 1 – Controlled by the Flash*Freeze Pin

Figure 2-2 shows the timing diagram for entering and exiting Flash*Freeze mode type 1.

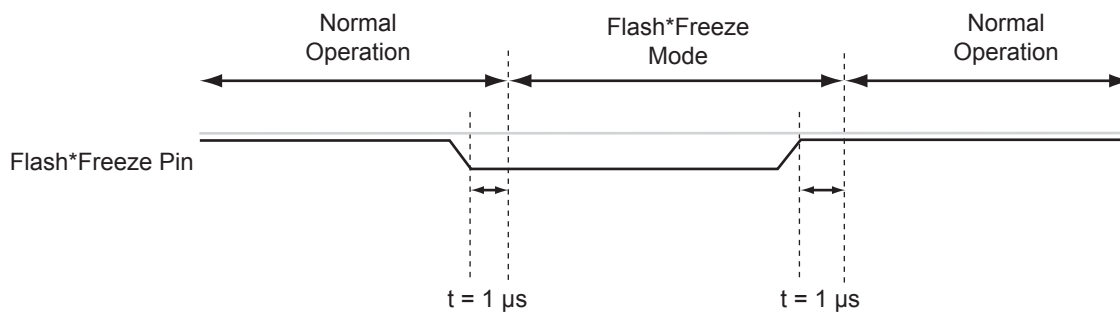


Figure 2-2 • Flash*Freeze Mode Type 1 – Timing Diagram