# Blackfin Embedded Processor

# ADSP-BF512/BF512F, BF514/BF514F, BF516/BF516F, BF518/BF518F

## FEATURES

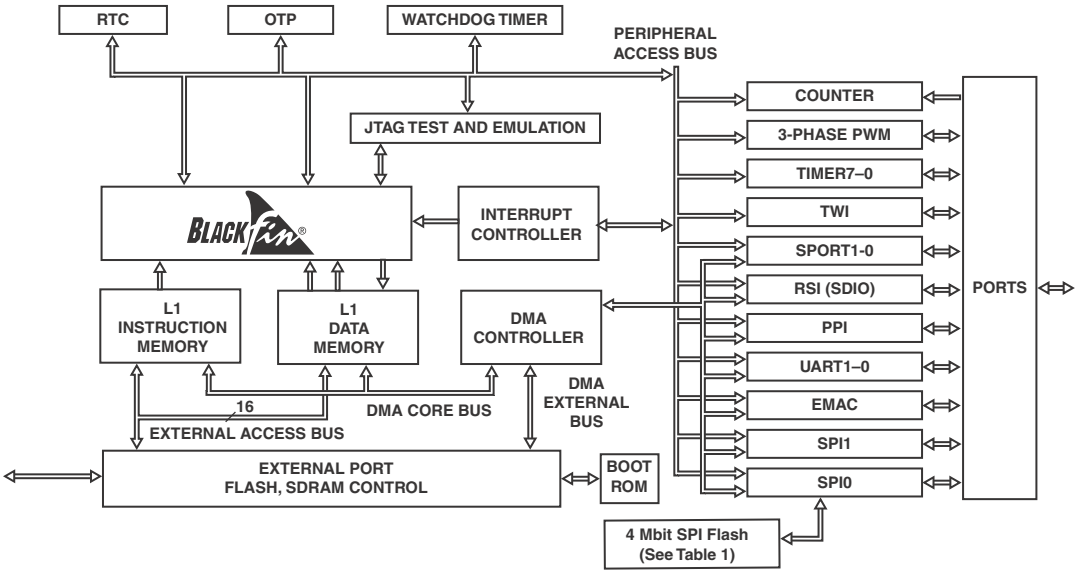
- Up to 400 MHz high performance Blackfin processor
  - Two 16-bit MACs, two 40-bit ALUs, four 8-bit video ALUs, 40-bit shifter
  - RISC-like register and instruction model for ease of programming and compiler-friendly support
  - Advanced debug, trace, and performance monitoring
- Wide range of operating voltages. See Operating Conditions on Page 20
- Qualified for Automotive Applications. See Automotive Products on Page 65
- 168-ball CSP_BGA or 176-lead LQFP with exposed pad

## MEMORY

- 116K bytes of on-chip memory
- External memory controller with glueless support for SDRAM and asynchronous 8-bit and 16-bit memories
- Optional 4M bit SPI flash with boot option
- Flexible booting options from internal SPI flash, OTP memory, external SPI/parallel memories, or from SPI/UART host devices
- Code security with Lockbox secure technology
- One-time-programmable (OTP) memory
- Memory management unit providing memory protection

## PERIPHERALS

- IEEE 802.3-compliant 10/100 Ethernet MAC with IEEE 1588 support (ADSP-BF518/ADSP-BF518F only)
- Parallel peripheral interface (PPI), supporting ITU-R 656 video data formats
- 2 dual-channel, full-duplex synchronous serial ports (SPORTs), supporting 8 stereo $I^2S$ channels
- 12 peripheral DMAs, 2 mastered by the Ethernet MAC
- 2 memory-to-memory DMAs with external request lines
- Event handler with 56 interrupt inputs
- 2 serial peripheral interfaces (SPI)
- Removable storage interface (RSI) controller for MMC, SD, SDIO, and CE-ATA
- 2 UARTs with IrDA support
- 2-wire interface (TWI) controller
- Eight 32-bit timers/counters with PWM support
- 3-phase 16-bit center-based PWM unit
- 32-bit general-purpose counter
- Real-time clock (RTC) and watchdog timer
- 32-bit core timer
- 40 general-purpose I/Os (GPIOs)
- Debug/JTAG interface
- On-chip PLL capable of frequency multiplication

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**Rev. B**

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**One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106 U.S.A.**
**Tel: 781.329.4700** **www.analog.com**
**Fax: 781.461.3113** **© 2011 Analog Devices, Inc. All rights reserved.**

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## REVISION HISTORY

**1/11—Rev. A to Rev. B**

This data sheet release coincides with the release of the revised ADSP-BF51x Blackfin Processor Hardware Reference. All redundant information has been removed.

Revised several specifications in Operating Conditions ... 20

Revised $f_{VCO}$ specification in Phase-Locked Loop Operating Conditions ..... 21

Revised several specifications in Electrical Characteristics 22

Added additional $f_{CKIN}$ specification for automotive models in Clock and Reset Timing ..... 27

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Revised $t_{HFSPE}$ specification in Parallel Peripheral Interface Timing ..... 33

Revised $t_{HFSPE}$ specification and added the $t_{PSUD}$ specification in Parallel Peripheral Interface Timing ..... 33

Revised the $t_{WL}$ and $t_{WH}$ specifications in RSI Controller Timing ..... 35

Revised $t_{WL}$, $t_{WH}$ and $t_{OH}$ specification in RSI Controller Timing (High Speed Mode) ..... 36

Revised $t_{MDCIH}$ and $t_{MDCOH}$ specifications in 10/100 Ethernet MAC Controller Timing: MII Station Management ..... 48

Corrected dimensions in 168-Ball Chip Scale Package Ball Grid Array [CSP_BGA] (BC-168-1) ..... 64

# GENERAL DESCRIPTION

The ADSP-BF512/ADSP-BF512F, ADSP-BF514/ADSP-BF514F, ADSP-BF516/ADSP-BF516F, ADSP-BF518/ADSP-BF518F processors are members of the Blackfin® family of products, incorporating the Analog Devices/Intel Micro Signal Architecture (MSA). Blackfin processors combine a dual-MAC state-of-the-art signal processing engine, the advantages of a clean, orthogonal RISC-like microprocessor instruction set, and single-instruction, multiple-data (SIMD) multimedia capabilities into a single instruction-set architecture.

The processors are completely code compatible with other Blackfin processors.

**Table 1. Processor Comparison**

| | Feature | ADSP-BF512 | ADSP-BF512F | ADSP-BF514 | ADSP-BF514F | ADSP-BF516 | ADSP-BF516F | ADSP-BF518 | ADSP-BF518F |
|---|---|---|---|---|---|---|---|---|---|
| | IEEE-1588 | – | – | – | – | – | – | 1 | 1 |
| | Ethernet MAC | – | – | – | – | 1 | 1 | 1 | 1 |
| | RSI | – | – | 1 | 1 | 1 | 1 | 1 | 1 |
| | TWI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | SPORTs | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | UARTs | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | SPIs | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | GP Timers | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| | Watchdog Timers | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | RTC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | PPI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Internal 4 Mbit SPI flash | – | 1 | – | 1 | – | 1 | – | 1 |
| | Rotary Counter | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 3-Phase PWM Pairs | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | GPIOs | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| Memory (bytes) | L1 Instruction SRAM | 32K | | | | | | | |
| | L1 Instruction SRAM/Cache | 16K | | | | | | | |
| | L1 Data SRAM | 32K | | | | | | | |
| | L1 Data SRAM/Cache | 32K | | | | | | | |
| | L1 Scratchpad | 4K | | | | | | | |
| | L3 Boot ROM | 32K | | | | | | | |
| | Maximum Speed Grade | 400 MHz | | | | | | | |
| | Package Options | 176-Lead LQFP with Exposed Pad<br>168-Ball CSP_BGA | | | | | | | |

By integrating a rich set of industry-leading system peripherals and memory, Blackfin processors are the platform of choice for next-generation applications that require RISC-like programmability, multimedia support, and leading-edge signal processing in one integrated package.

## PORTABLE LOW POWER ARCHITECTURE

Blackfin processors provide world-class power management and performance. They are produced with a low power and low voltage design methodology and feature on-chip dynamic power management, which is the ability to vary both the voltage and frequency of operation to significantly lower overall power consumption. This capability can result in a substantial reduction in power consumption, compared with just varying the frequency of operation. This allows longer battery life for portable appliances.

## SYSTEM INTEGRATION

The ADSP-BF51x processors are highly integrated system-on-a-chip solutions for the next generation of embedded network connected applications. By combining industry-standard interfaces with a high performance signal processing core, cost-effective applications can be developed quickly, without the need for costly external components. The system peripherals include an IEEE-compliant 802.3 10/100 Ethernet MAC with IEEE-1588 support (ADSP-BF518/ADSP-BF518F only), an RSI controller, a TWI controller, two UART ports, two SPI ports, two serial ports (SPORTs), nine general-purpose 32-bit timers (eight with PWM capability), 3-phase PWM for motor control, a real-time clock, a watchdog timer, and a parallel peripheral interface (PPI).

## BLACKFIN PROCESSOR CORE

As shown in Figure 1, the Blackfin processor core contains two 16-bit multipliers, two 40-bit accumulators, two 40-bit ALUs, four video ALUs, and a 40-bit shifter. The computation units process 8-, 16-, or 32-bit data from the register file.

The compute register file contains eight 32-bit registers. When performing compute operations on 16-bit operand data, the register file operates as 16 independent 16-bit registers. All operands for compute operations come from the multiported register file and instruction constant fields.

Each MAC can perform a 16-bit by 16-bit multiply in each cycle, accumulating the results into the 40-bit accumulators. Signed and unsigned formats, rounding, and saturation are supported.

The ALUs perform a traditional set of arithmetic and logical operations on 16-bit or 32-bit data. In addition, many special instructions are included to accelerate various signal processing tasks. These include bit operations such as field extract and population count, modulo $2^{32}$ multiply, divide primitives, saturation and rounding, and sign/exponent detection. The set of video instructions include byte alignment and packing operations, 16-bit and 8-bit adds with clipping, 8-bit average operations, and 8-bit subtract/absolute value/accumulate (SAA) operations. The compare/select and vector search instructions are also provided.

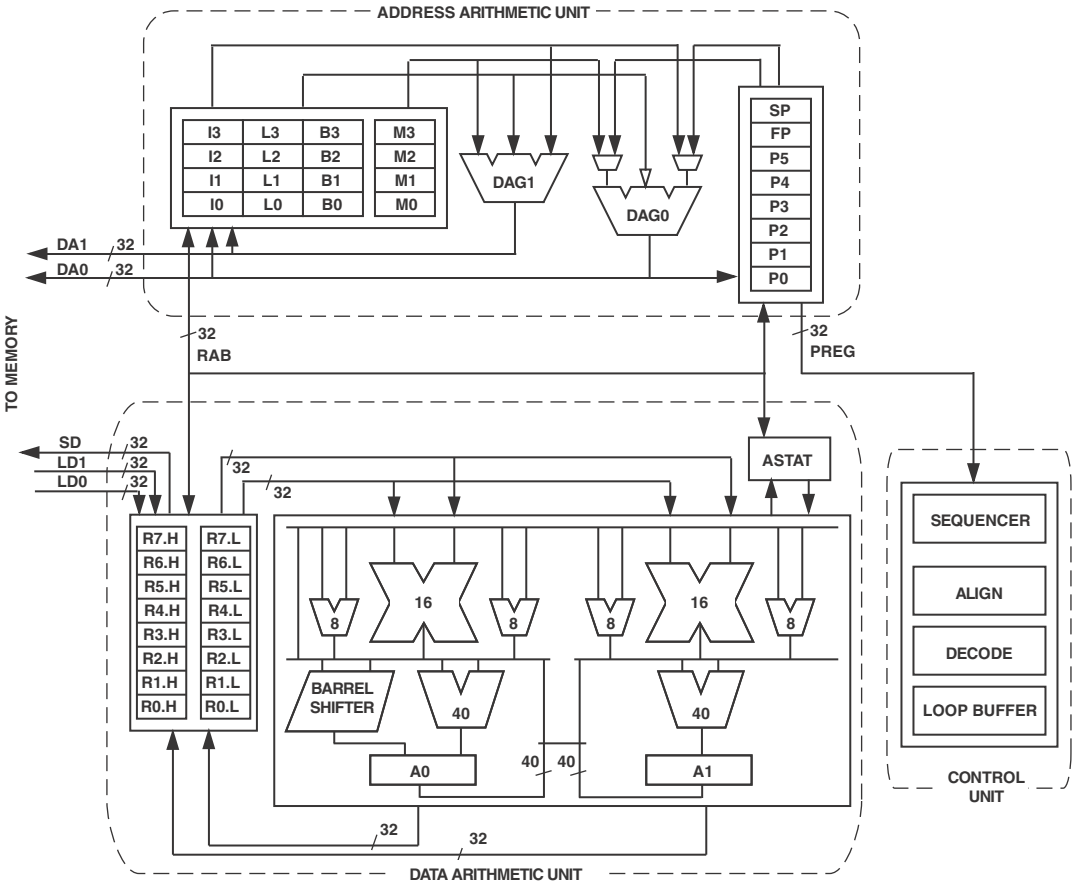



*Figure 1. Blackfin Processor Core*

For certain instructions, two 16-bit ALU operations can be performed simultaneously on register pairs (a 16-bit high half and 16-bit low half of a compute register). If the second ALU is used, quad 16-bit operations are possible.

The 40-bit shifter can perform shifts and rotates and is used to support normalization, field extract, and field deposit instructions.

The program sequencer controls the flow of instruction execution, including instruction alignment and decoding. For program flow control, the sequencer supports PC relative and indirect conditional jumps (with static branch prediction), and subroutine calls. Hardware is provided to support zero-overhead looping. The architecture is fully interlocked, meaning that the programmer need not manage the pipeline when executing instructions with data dependencies.

The address arithmetic unit provides two addresses for simultaneous dual fetches from memory. It contains a multiported register file consisting of four sets of 32-bit index, modify, length, and base registers (for circular buffering), and eight additional 32-bit pointer registers (for C-style indexed stack manipulation).

Blackfin processors support a modified Harvard architecture in combination with a hierarchical memory structure. Level 1 (L1) memories are those that typically operate at the full processor speed with little or no latency. At the L1 level, the instruction memory holds instructions only. The two data memories hold data, and a dedicated scratchpad data memory stores stack and local variable information.

In addition, multiple L1 memory blocks are provided, offering a configurable mix of SRAM and cache. The memory management unit (MMU) provides memory protection for individual tasks that may be operating on the core and can protect system registers from unintended access.

The architecture provides three modes of operation: user mode, supervisor mode, and emulation mode. User mode has restricted access to certain system resources, thus providing a protected software environment, while supervisor mode has unrestricted access to the system and core resources.

The Blackfin processor instruction set has been optimized so that 16-bit opcodes represent the most frequently used instructions, resulting in excellent compiled code density. Complex DSP instructions are encoded into 32-bit opcodes, representing fully featured multifunction instructions. Blackfin processors support a limited multi-issue capability, where a 32-bit

instruction can be issued in parallel with two 16-bit instructions, allowing the programmer to use many of the core resources in a single instruction cycle.

The Blackfin processor assembly language uses an algebraic syntax for ease of coding and readability. The architecture has been optimized for use in conjunction with the C/C++ compiler, resulting in fast and efficient software implementations.

## MEMORY ARCHITECTURE

The ADSP-BF51x processors view memory as a single unified 4G byte address space, using 32-bit addresses. All resources, including internal memory, external memory, and I/O control registers, occupy separate sections of this common address space. The memory portions of this address space are arranged in a hierarchical structure to provide a good cost/performance balance of some very fast, low-latency on-chip memory as cache or SRAM, and larger, lower-cost and performance off-chip memory systems. The memory map for both internal and external memory space is shown in Figure 2.

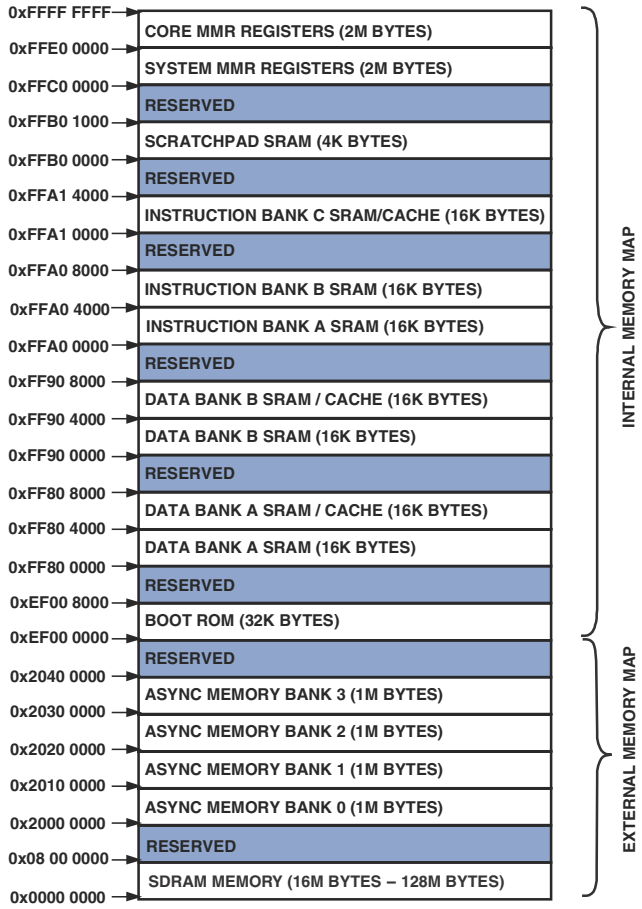



*Figure 2. ADSP-BF51x Internal/External Memory Map*

The on-chip L1 memory system is the highest-performance memory available to the Blackfin processor. The off-chip memory system, accessed through the external bus interface unit (EBIU), provides expansion with SDRAM, flash memory, and SRAM, optionally accessing up to 132M bytes of physical memory.

The memory DMA controller provides high bandwidth data-movement capability. It can perform block transfers of code or data between the internal memory and the external memory spaces.

### *Internal (On-Chip) Memory*

The ADSP-BF51x processors have three blocks of on-chip memory that provide high bandwidth access to the core.

The first block is the L1 instruction memory, consisting of 48K bytes SRAM, of which 16K bytes can be configured as a four-way set-associative cache. This memory is accessed at full processor speed.

The second on-chip memory block is the L1 data memory, consisting of up to two banks of up to 32K bytes each. Each memory bank is configurable, offering both cache and SRAM functionality. This memory block is accessed at full processor speed.

The third memory block is a 4K byte scratchpad SRAM which runs at the same speed as the L1 memories, but is only accessible as data SRAM and cannot be configured as cache memory.

### *External (Off-Chip) Memory*

External memory is accessed via the EBIU. This 16-bit interface provides a glueless connection to a bank of synchronous DRAM (SDRAM) as well as up to four banks of asynchronous memory devices including flash, EPROM, ROM, SRAM, and memory mapped I/O devices.

The SDRAM controller can be programmed to interface to up to 128M bytes of SDRAM. A separate row can be open for each SDRAM internal bank, and the SDRAM controller supports up to four internal SDRAM banks, improving overall performance.

The asynchronous memory controller can be programmed to control up to four banks of devices with very flexible timing parameters for a wide variety of devices. Each bank occupies a 1M byte segment regardless of the size of the devices used, so that these banks are only contiguous if each is fully populated with 1M byte of memory.

### *Flash Memory*

The ADSP-BF512F/ADSP-BF514F/ADSP-BF516F/ ADSP-BF518F processors contain a SPI flash memory within the package of the processor and connected to SPI0.

The SPI flash memory has a 4M bit capacity and 1.8V (nominal) operating voltage. The program/erase endurance is 100,000 cycles per block, and this memory has greater than 100 years of data retention capability. Also included are support for software write protection and for fast erase and byte-program.

The processors internally connect to the flash memory die with the SPI0SCK, SPI0SEL4 or PH8, SPI0MOSI, and SPI0MISO signals similar to an external SPI flash. To further provide a secure processing environment, these internally connected signals are not exposed outside of the package. For this reason, programming the ADSP-BF51xF flash memory is performed by running code on the processor andcannot be programmed from external signals. Data transfers between the SPI flash and the processor cannot be probed externally. The flash memory has the following additional features

- Serial Interface Architecture—SPI compatible with Mode 0 and Mode 3
- Superior Reliability—Endurance of 100,000 cycles and greater than 100 years data retention
- Flexible Erase Capability—Uniform 4K Byte sectors and uniform 32 and 64K Byte overlay blocks
- Fast Erase and Byte-Program—Chip-erase time = 125 ms (typical), Sector-/Block-Erase Time = 62 ms (typical) Byte-Program Time = 50 µS (typical)
- Auto Address Increment (AAI) Programming—Decreases total chip programming time over byte-program operations
- End-of-Write Detection—Software polling the BUSY bit in status register, busy status readout on SO pin
- Software Write Protection—Write protection through block-protection bits in status register

### *One-Time Programmable Memory*

The processors have 64K bits of one-time programmable non-volatile memory that can be programmed by the developer only once. It includes the array and logic to support read access and programming. Additionally, its pages can be write protected.

The OTP memory allows both public and private data to be stored on-chip. In addition to storing public and private key data for applications requiring security, OTP allows developers to store completely user-definable data such as customer ID, product ID, and MAC address. Therefore, generic parts can be supplied which are then programmed and protected by the developer within this non-volatile memory.

### *I/O Memory Space*

The processors do not define a separate I/O space. All resources are mapped through the flat 32-bit address space. On-chip I/O devices have their control registers mapped into memory-mapped registers (MMRs) at addresses near the top of the 4G byte address space. These are separated into two smaller blocks, one which contains the control MMRs for all core functions, and the other which contains the registers needed for setup and control of the on-chip peripherals outside of the core. The MMRs are accessible only in supervisor mode and appear as reserved space to on-chip peripherals.

### *Booting from ROM*

The processors contain a small on-chip boot kernel, which configures the appropriate peripheral for booting. If the processors are configured to boot from boot ROM memory space, the processor starts executing from the on-chip boot ROM. For more information, see Booting Modes on Page 14.

## EVENT HANDLING

The event controller handles all asynchronous and synchronous events to the processor. The processors provide event handling that supports both nesting and prioritization. Nesting allows multiple event service routines to be active simultaneously. Prioritization ensures that servicing of a higher priority event takes precedence over servicing of a lower priority event. The controller provides support for five different types of events:

- Emulation—An emulation event causes the processor to enter emulation mode, allowing command and control of the processor through the JTAG interface.
- Reset—This event resets the processor.
- Nonmaskable Interrupt (NMI)—The NMI event can be generated by the software watchdog timer or by the NMI input signal to the processor. The NMI event is frequently used as a power-down indicator to initiate an orderly shutdown of the system.
- Exceptions—Events that occur synchronously to program flow; that is, the exception is taken before the instruction is allowed to complete. Conditions such as data alignment violations and undefined instructions cause exceptions.
- Interrupts—Events that occur asynchronously to program flow. They are caused by input signals, timers, and other peripherals, as well as by an explicit software instruction.

Each event type has an associated register to hold the return address and an associated return-from-event instruction. When an event is triggered, the state of the processor is saved on the supervisor stack.

The event controller consists of two stages, the core event controller (CEC) and the system interrupt controller (SIC). The core event controller works with the system interrupt controller to prioritize and control all system events. Conceptually, interrupts from the peripherals enter into the SIC, and are then routed directly into the general-purpose interrupts of the CEC.

### *Core Event Controller (CEC)*

The CEC supports nine general-purpose interrupts (IVG15–7), in addition to the dedicated interrupt and exception events. Of these general-purpose interrupts, the two lowest priority interrupts (IVG15–14) are recommended to be reserved for software interrupt handlers, leaving seven prioritized interrupt inputs to support the peripherals of the processors. The inputs to the CEC, identifies their names in the event vector table (EVT), and lists their priorities are described in the *ADSP-BF51x Blackfin Processor Hardware Reference Manual* “System Interrupts” chapter.

### *System Interrupt Controller (SIC)*

The system interrupt controller provides the mapping and routing of events from the many peripheral interrupt sources to the prioritized general-purpose interrupt inputs of the CEC. Although the processors provide a default mapping, the user can alter the mappings and priorities of interrupt events by writing the appropriate values into the interrupt assignment registers (SIC_IARx). See the *ADSP-BF51x Blackfin Processor Hardware Reference Manual* "System Interrupts" chapter for the inputs into the SIC and the default mappings into the CEC.

The SIC allows further control of event processing by providing three pairs of 32-bit interrupt control and status registers. Each register contains a bit corresponding to each of the peripheral interrupt events. For more information, see the *ADSP-BF51x Blackfin Processor Hardware Reference Manual* "System Interrupts" chapter.

## DMA CONTROLLERS

The ADSP-BF51x processors have multiple independent DMA channels that support automated data transfers with minimal overhead for the processor core. DMA transfers can occur between the processor's internal memories and any of its DMA-capable peripherals. Additionally, DMA transfers can be accomplished between any of the DMA-capable peripherals and external devices connected to the external memory interfaces, including the SDRAM controller and the asynchronous memory controller. DMA-capable peripherals include the Ethernet MAC, RSI, SPORTs, SPIs, UARTs, and PPI. Each individual DMA-capable peripheral has at least one dedicated DMA channel.

The processors' DMA controller supports both one-dimensional (1-D) and two-dimensional (2-D) DMA transfers. DMA transfer initialization can be implemented from registers or from sets of parameters called descriptor blocks.

The 2-D DMA capability supports arbitrary row and column sizes up to 64K elements by 64K elements, and arbitrary row and column step sizes up to ±32K elements. Furthermore, the column step size can be less than the row step size, allowing implementation of interleaved data streams. This feature is especially useful in video applications where data can be de-interleaved on the fly.

Examples of DMA types supported by the DMA controller include:

- A single, linear buffer that stops upon completion
- A circular, auto-refreshing buffer that interrupts on each full or fractionally full buffer
- 1-D or 2-D DMA using a linked list of descriptors
- 2-D DMA using an array of descriptors, specifying only the base DMA address within a common page

In addition to the dedicated peripheral DMA channels, there are two memory DMA channels that transfer data between the various memories of the processor system. This enables transfers of blocks of data between any of the memories—including external SDRAM, ROM, SRAM, and flash memory—with minimal processor intervention. Memory DMA transfers can be controlled by a very flexible descriptor-based methodology or by a standard register-based autobuffer mechanism.

The processors also have an external DMA controller capability via dual external DMA request signals when used in conjunction with the external bus interface unit (EBIU). This functionality can be used when a high speed interface is required for external FIFOs and high bandwidth communications peripherals. It allows control of the number of data transfers for memory DMA. The number of transfers per edge is programmable. This feature can be programmed to allow memory DMA to have an increased priority on the external bus relative to the core.

## PROCESSOR PERIPHERALS

The ADSP-BF51x processors contain a rich set of peripherals connected to the core via several high bandwidth buses, providing flexibility in system configuration as well as excellent overall system performance (see Figure 1 on Page 4). The processors contain dedicated network communication modules and high speed serial and parallel ports, an interrupt controller for flexible management of interrupts from the on-chip peripherals or external sources, and power management control functions to tailor the performance and power characteristics of the processor and system to many application scenarios.

All of the peripherals, except for the general-purpose I/O, rotary counter, TWI, three-phase PWM, real-time clock, and timers, are supported by a flexible DMA structure. There are also separate memory DMA channels dedicated to data transfers between the processor's various memory spaces, including external SDRAM and asynchronous memory. Multiple on-chip buses provide enough bandwidth to keep the processor core running along with activity on all of the on-chip and external peripherals.

### *Real-Time Clock*

The real-time clock (RTC) provides a robust set of digital watch features, including current time, stopwatch, and alarm. The RTC is clocked by a 32.768 kHz crystal external to the processors. The RTC peripheral has a dedicated power supply so that it can remain powered up and clocked even when the rest of the processor is in a low power state. The RTC provides several programmable interrupt options, including interrupt per second, minute, hour, or day clock ticks, interrupt on programmable stopwatch countdown, or interrupt at a programmed alarm time.

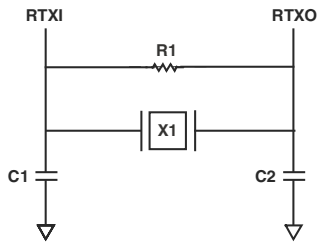
The 32.768 kHz input clock frequency is divided down to a 1 Hz signal by a prescaler. The counter function of the timer consists of four counters: a 60-second counter, a 60-minute counter, a 24-hour counter, and an 32,768-day counter.

When enabled, the alarm function generates an interrupt when the output of the timer matches the programmed value in the alarm control register. There are two alarms: The first alarm is for a time of day. The second alarm is for a day and time of that day.

The stopwatch function counts down from a programmed value, with one-second resolution. When the stopwatch is enabled and the counter underflows, an interrupt is generated.

Like the other peripherals, the RTC can wake up the processor from sleep mode upon generation of any RTC wakeup event. Additionally, an RTC wakeup event can wake up the processor from deep sleep mode or cause a transition from the hibernate state.

Connect RTC signals RTXI and RTXO with external components as shown in Figure 3.




SUGGESTED COMPONENTS:
X1 = ECLIPTEK EC38J (THROUGH-HOLE PACKAGE) OR
EPSON MC405 12 pF LOAD (SURFACE-MOUNT PACKAGE)
C1 = 22 pF
C2 = 22 pF
R1 = 10 MΩ

NOTE: C1 AND C2 ARE SPECIFIC TO CRYSTAL SPECIFIED FOR X1. CONTACT CRYSTAL MANUFACTURER FOR DETAILS. C1 AND C2 SPECIFICATIONS ASSUME BOARD TRACE CAPACITANCE OF 3 pF.

*Figure 3. External Components for RTC*

### Watchdog Timer

The ADSP-BF51x processors include a 32-bit timer that can be used to implement a software watchdog function. A software watchdog can improve system availability by forcing the processor to a known state through generation of a hardware reset, nonmaskable interrupt (NMI), or general-purpose interrupt, if the timer expires before being reset by software. The programmer initializes the count value of the timer, enables the appropriate interrupt, then enables the timer. Thereafter, the software must reload the counter before it counts to zero from the programmed value. This protects the system from remaining in an unknown state where software, which would normally reset the timer, has stopped running due to an external noise condition or software error.

If configured to generate a hardware reset, the watchdog timer resets both the core and the processor peripherals. After a reset, software can determine if the watchdog was the source of the hardware reset by interrogating a status bit in the watchdog timer control register.

The timer is clocked by the system clock (SCLK) at a maximum frequency of $f_{SCLK}$.

### Timers

There are nine general-purpose programmable timer units in the ADSP-BF51x processors. Eight timers have an external signal that can be configured either as a pulse width modulator (PWM) or timer output, as an input to clock the timer, or as a mechanism for measuring pulse widths and periods of external events. These timers can be synchronized to an external clock input to the several other associated PF signals, an external clock input to the PPI_CLK input signal, or to the internal SCLK.

The timer units can be used in conjunction with the two UARTs to measure the width of the pulses in the data stream to provide a software auto-baud detect function for the respective serial channels.

The timers can generate interrupts to the processor core providing periodic events for synchronization, either to the system clock or to a count of external signals.

In addition to the eight general-purpose programmable timers, a ninth timer is also provided. This extra timer is clocked by the internal processor clock and is typically used as a system tick clock for generation of operating system periodic interrupts.

### 3-Phase PWM

The processors integrate a flexible and programmable 3-phase PWM waveform generator that can be programmed to generate the required switching patterns to drive a 3-phase voltage source inverter for ac induction (ACIM) or permanent magnet synchronous (PMSM) motor control. In addition, the PWM block contains special functions that considerably simplify the generation of the required PWM switching patterns for control of the electronically commutated motor (ECM) or brushless dc motor (BDCM). Software can enable a special mode for switched reluctance motors (SRM).

Features of the 3-phase PWM generation unit are:

- 16-bit center-based PWM generation unit
- Programmable PWM pulse width
- Single/double update modes
- Programmable dead time and switching frequency
- Twos-complement implementation which permits smooth transition to full ON and full OFF states
- Possibility to synchronize the PWM generation to an external synchronization
- Special provisions for BDCM operation (crossover and output enable functions)
- Wide variety of special switched reluctance (SR) operating modes
- Output polarity and clock gating control
- Dedicated asynchronous PWM shutdown signal

### General-Purpose (GP) Counter

A 32-bit GP counter is provided that can sense 2-bit quadrature or binary codes as typically emitted by industrial drives or manual thumb wheels. The counter can also operate in general-purpose up/down count modes. Then, count direction is either controlled by a level-sensitive input signal or by two edge detectors.

A third input can provide flexible zero marker support and can alternatively be used to input the push-button signal of thumb wheels. All three signals have a programmable debouncing circuit.

An internal signal forwarded to the GP timer unit enables one timer to measure the intervals between count events. Boundary registers enable auto-zero operation or simple system warning by interrupts when programmable count values are exceeded.

### *Serial Ports*

The ADSP-BF51x processors incorporate two dual-channel synchronous serial ports (SPORT0 and SPORT1) for serial and multiprocessor communications. The SPORTs support the following features:

Serial port data can be automatically transferred to and from on-chip memory/external memory via dedicated DMA channels. Each of the serial ports can work in conjunction with another serial port to provide TDM support. In this configuration, one SPORT provides two transmit signals while the other SPORT provides the two receive signals. The frame sync and clock are shared.

Serial ports operate in five modes:

- Standard DSP serial mode
- Multichannel (TDM) mode
- $I^2S$ mode
- Packed $I^2S$ mode
- Left-justified mode

### *Serial Peripheral Interface (SPI) Ports*

The processors have two SPI-compatible ports (SPI0 and SPI1) that enable the processor to communicate with multiple SPI-compatible devices.

The SPI interface uses three signals for transferring data: two data signals (master output-slave input–MOSI, and master input-slave output–MISO) and a clock signal (serial clock–SCK). An SPI chip select input signal ($\overline{\text{SPIxSS}}$) lets other SPI devices select the processor, and multiple SPI chip select output signals let the processor select other SPI devices. The SPI select signals are reconfigured general-purpose I/O signals. Using these signals, the SPI port provides a full-duplex, synchronous serial interface, which supports both master/slave modes and multimaster environments.

The SPI port baud rate and clock phase/polarities are programmable, and it has an integrated DMA channel, configurable to support transmit or receive data streams. The SPI's DMA channel can only service unidirectional accesses at any given time.

### *UART Ports*

The processors provide two full-duplex universal asynchronous receiver/transmitter (UART) ports, which are fully compatible with PC-standard UARTs. Each UART port provides a simplified UART interface to other peripherals or hosts, supporting full-duplex, DMA-supported, asynchronous transfers of serial data. A UART port includes support for five to eight data bits, and none, even, or odd parity. Optionally, an additional address bit can be transferred to interrupt only addressed nodes in multi-drop bus (MDB) systems. A frame is terminates by one, one and a half, two or two and a half stop bits.

The UART ports support automatic hardware flow control through the Clear To Send (CTS) input and Request To Send (RTS) output with programmable assertion FIFO levels.

To help support the Local Interconnect Network (LIN) protocols, a special command causes the transmitter to queue a break command of programmable bit length into the transmit buffer. Similarly, the number of stop bits can be extended by a programmable inter-frame space.

The capabilities of the UARTs are further extended with support for the Infrared Data Association (IrDA®) serial infrared physical layer link specification (SIR) protocol.

### *2-Wire Interface (TWI)*

The processors include a TWI module for providing a simple exchange method of control data between multiple devices. The TWI is compatible with the widely used $I^2C$® bus standard. The TWI module offers the capabilities of simultaneous master and slave operation, support for both 7-bit addressing and multimedia data arbitration. The TWI interface utilizes two signals for transferring clock (SCL) and data (SDA) and supports the protocol at speeds up to 400k bits/sec. The TWI interface signals are compatible with 5 V logic levels.

Additionally, the processor's TWI module is fully compatible with serial camera control bus (SCCB) functionality for easier control of various CMOS camera sensor devices.

### *Removable Storage Interface (RSI)*

The RSI controller, available on the ADSP-BF514, ADSP-BF516, ADSP-BF518, and ADSP-BF518F acts as the host interface for multi-media cards (MMC), secure digital memory cards (SD Card), secure digital input/output cards (SDIO), and CE-ATA hard disk drives. The following list describes the main features of the RSI controller.

- Support for a single MMC, SD memory, SDIO card or CE-ATA hard disk drive
- Support for 1-bit and 4-bit SD modes
- Support for 1-bit, 4-bit and 8-bit MMC modes
- Support for 4-bit and 8-bit CE-ATA hard disk drives
- A ten-signal external interface with clock, command, and up to eight data lines
- Card detection using one of the data signals
- Card interface clock generation from SCLK
- SDIO interrupt and read wait features
- CE-ATA command completion signal recognition and disable

### *10/100 Ethernet MAC*

The ADSP-BF516/ADSP-BF516F and ADSP-BF518/ADSPBF518F processors offer the capability to directly connect to a network by way of an embedded fast Ethernet media access controller (MAC) that supports both 10-BaseT (10M bits/sec) and 100-BaseT (100M bits/sec) operation. The 10/100 Ethernet MAC peripheral on the processor is fully compliant to the IEEE 802.3-2002 standard and it provides programmable features designed to minimize supervision, bus use, or message processing by the rest of the processor system.

Some standard features are:

- Support of MII and RMII protocols for external PHYs
- Full duplex and half duplex modes
- Data framing and encapsulation: generation and detection of preamble, length padding, and FCS
- Media access management (in half-duplex operation): collision and contention handling, including control of retransmission of collision frames and of back-off timing
- Flow control (in full-duplex operation): generation and detection of pause frames
- Station management: generation of MDC/MDIO frames for read-write access to PHY registers
- Operating range for active and sleep operating modes, see Table 43 on Page 45 and Table 44 on Page 46
- Internal loopback from transmit to receive

Some advanced features are:

- Buffered crystal output to external PHY for support of a single crystal system
- Automatic checksum computation of IP header and IP payload fields of Rx frames
- Independent 32-bit descriptor-driven receive and transmit DMA channels
- Frame status delivery to memory through DMA, including frame completion semaphores for efficient buffer queue management in software
- Tx DMA support for separate descriptors for MAC header and payload to eliminate buffer copy operations
- Convenient frame alignment modes support even 32-bit alignment of encapsulated receive or transmit IP packet data in memory after the 14-byte MAC header
- Programmable Ethernet event interrupt supports any combination of:
  - Selected receive or transmit frame status conditions
  - PHY interrupt condition
  - Wakeup frame detected
  - Selected MAC management counter(s) at half-full
  - DMA descriptor error
- 47 MAC management statistics counters with selectable clear-on-read behavior and programmable interrupts on half maximum value
- Programmable receive address filters, including a 64-bin address hash table for multicast and/or unicast frames, and programmable filter modes for broadcast, multicast, unicast, control, and damaged frames
- Advanced power management supporting unattended transfer of receive and transmit frames and status to/from external memory via DMA during low power sleep mode
- System wakeup from sleep operating mode upon magic packet or any of four user-definable wakeup frame filters
- Support for 802.3Q tagged VLAN frames
- Programmable MDC clock rate and preamble suppression
- In RMII operation, seven unused signals may be configured as GPIO signals for other purposes

### *IEEE 1588 Support*

The IEEE 1588 standard is a precision clock synchronization protocol for networked measurement and control systems. The ADSP-BF518/ADSP-BF518F processors include hardware support for IEEE 1588 with an integrated precision time protocol synchronization engine (PTP_TSYNC). This engine provides hardware assisted time stamping to improve the accuracy of clock synchronization between PTP nodes. The main features of the PTP_SYNC engine are:

- Support for both IEEE 1588-2002 and IEEE 1588-2008 protocol standards
- Hardware assisted time stamping capable of up to 12.5 ns resolution
- Lock adjustment
- Programmable PTM message support
- Dedicated interrupts
- Programmable alarm
- Multiple input clock sources (SCLK, MII clock, external clock)
- Programmable pulse per second (PPS) output
- Auxiliary snapshot to time stamp external events

### *Ports*

Because of the rich set of peripherals, the processors group the many peripheral signals to four ports—port F, port G, port H, and port J. Most of the associated pins/balls are shared by multiple signals. The ports function as multiplexer controls.

#### General-Purpose I/O (GPIO)

The ADSP-BF51x processors have 40 bidirectional, general-purpose I/O (GPIO) signals allocated across three separate GPIO modules—PORTFIO, PORTGIO, and PORTHIO, associated with Port F, Port G, and Port H, respectively. Each GPIO-capable signal shares functionality with other peripherals via a multiplexing scheme; however, the GPIO functionality is the default state of the device upon power-up. Neither GPIO output nor input drivers are active by default. Each general-purpose port signal can be individually controlled by manipulation of the port control, status, and interrupt registers.

### *Parallel Peripheral Interface (PPI)*

The ADSP-BF51x processors provide a parallel peripheral interface (PPI) that can connect directly to parallel analog-to-digital and digital-to-analog converters, ITU-R-601/656 video encoders and decoders, and other general-purpose peripherals. The PPI consists of a dedicated input clock signal, up to three frame synchronization signals, and up to 16 data signals.

In ITU-R-656 modes, the PPI receives and parses a data stream of 8-bit or 10-bit data elements. On-chip decode of embedded preamble control and synchronization information is supported.

Three distinct ITU-R-656 modes are supported:

- Active video only mode—The PPI does not read in any data between the End of Active Video (EAV) and Start of Active Video (SAV) preamble symbols, or any data present during the vertical blanking intervals. In this mode, the control byte sequences are not stored to memory; they are filtered by the PPI.
- Vertical blanking only mode—The PPI only transfers vertical blanking interval (VBI) data, as well as horizontal blanking information and control byte sequences on VBI lines.
- Entire field mode—The entire incoming bitstream is read in through the PPI. This includes active video, control preamble sequences, and ancillary data that may be embedded in horizontal and vertical blanking intervals.

Though not explicitly supported, ITU-R-656 output functionality can be achieved by setting up the entire frame structure (including active video, blanking, and control information) in memory and streaming the data out the PPI in a frame sync-less mode. The processor's 2-D DMA features facilitate this transfer by allowing the static frame buffer (blanking and control codes) to be placed in memory once, and simply updating the active video information on a per-frame basis.

The general-purpose modes of the PPI are intended to suit a wide variety of data capture and transmission applications. The modes are divided into four main categories, each allowing up to 16 bits of data transfer per PPI_CLK cycle:

- Data receive with internally generated frame syncs
- Data receive with externally generated frame syncs
- Data transmit with internally generated frame syncs
- Data transmit with externally generated frame syncs

These modes support ADC/DAC connections, as well as video communication with hardware signalling. Many of the modes support more than one level of frame synchronization. If desired, a programmable delay can be inserted between assertion of a frame sync and reception/transmission of data.

### *Code Security with Lockbox Secure Technology*

A security system consisting of a blend of hardware and software provides customers with a flexible and rich set of code security features with Lockbox® secure technology. Key features include:

- OTP memory
- Unique chip ID
- Code authentication
- Secure mode of operation

The security scheme is based upon the concept of authentication of digital signatures using standards-based algorithms and provides a secure processing environment in which to execute code and protect assets.

## DYNAMIC POWER MANAGEMENT

The ADSP-BF51x processors provide four operating modes, each with a different performance/power profile. In addition, dynamic power management provides the control functions to dynamically alter the processor core supply voltage, further reducing power dissipation. When configured for a 0 V core supply voltage, the processor enters the hibernate state. Control of clocking to each of the processor peripherals also reduces power consumption. See Table 2 for a summary of the power settings for each mode.

**Table 2. Power Settings**

| Mode/State | PLL | PLL Bypassed | Core Clock (CCLK) | System Clock (SCLK) | Core Power |
|---|---|---|---|---|---|
| Full On | Enabled | No | Enabled | Enabled | On |
| Active | Enabled/ Disabled | Yes | Enabled | Enabled | On |
| Sleep | Enabled | — | Disabled | Enabled | On |
| Deep Sleep | Disabled | — | Disabled | Disabled | On |
| Hibernate | Disabled | — | Disabled | Disabled | Off |

### *Full-On Operating Mode—Maximum Performance*

In the full-on mode, the PLL is enabled and is not bypassed, providing capability for maximum operational frequency. This is the power-up default execution state in which maximum performance can be achieved. The processor core and all enabled peripherals run at full speed.

### *Active Operating Mode—Moderate Power Savings*

In the active mode, the PLL is enabled but bypassed. Because the PLL is bypassed, the processor's core clock (CCLK) and system clock (SCLK) run at the input clock (CLKIN) frequency. In this mode, the CLKIN to CCLK multiplier ratio can be changed, although the changes are not realized until the full-on mode is entered. DMA access is available to appropriately configured L1 memories.

In the active mode, it is possible to disable the PLL through the PLL control register (PLL_CTL). If disabled, the PLL must be re-enabled before transitioning to the full-on or sleep modes.

### Sleep Operating Mode—High Dynamic Power Savings

The sleep mode reduces dynamic power dissipation by disabling the clock to the processor core (CCLK). The PLL and system clock (SCLK), however, continue to operate in this mode. Typically an external event or RTC activity wakes up the processor. When in the sleep mode, asserting wakeup causes the processor to sense the value of the BYPASS bit in the PLL control register (PLL_CTL). If BYPASS is disabled, the processor transitions to the full on mode. If BYPASS is enabled, the processor transitions to the active mode.

System DMA access to L1 memory is not supported in sleep mode.

### Deep Sleep Operating Mode—Maximum Dynamic Power Savings

The deep sleep mode maximizes dynamic power savings by disabling the clocks to the processor core (CCLK) and to all synchronous peripherals (SCLK). Asynchronous peripherals, such as the RTC, may still be running but cannot access internal resources or external memory. This powered-down mode can only be exited by assertion of the reset interrupt ($\overline{\text{RESET}}$) or by an asynchronous interrupt generated by the RTC. When in deep sleep mode, an RTC asynchronous interrupt causes the processor to transition to the Active mode. Assertion of $\overline{\text{RESET}}$ while in deep sleep mode causes the processor to transition to the full on mode.

### Hibernate State—Maximum Static Power Savings

The hibernate state maximizes static power savings by disabling the voltage and clocks to the processor core (CCLK) and system blocks (SCLK). Any critical information stored internally (for example memory contents, register contents) must be written to a non-volatile storage device prior to removing power if the processor state is to be preserved. Writing b#00 to the FREQ bits in the VR_CTL register also causes the EXT_WAKE signal to transition low, which can be used to signal an external voltage regulator to shut down.

Since $V_{DDEXT}$ is still supplied in this mode, all of the external signals three-state, unless otherwise specified. This allows other devices that may be connected to the processor to still have power applied without drawing unwanted current.

The Ethernet module can signal an external regulator to wake up using the EXT_WAKE signal. If PF15 does not connect as a $\overline{\text{PHYINT}}$ signal to an external PHY device, it can be pulled low by any other device to wake the processor up. The processor can also be woken up by a real-time clock wakeup event or by asserting the $\overline{\text{RESET}}$ pin. All hibernate wakeup events initiate the hardware reset sequence. Individual sources are enabled by the VR_CTL register. The EXT_WAKE signal is provided to indicate the occurrence of wakeup events.

With the exception of the VR_CTL and the RTC registers, all internal registers and memories lose their content in the hibernate state. State variables may be held in external SRAM or SDRAM. The SCKELOW bit in the VR_CTL register controls whether or not SDRAM operates in self-refresh mode, which allows it to retain its content while the processor is in hibernation and through the subsequent reset sequence.

### Power Savings

As shown in Table 3, the processors support up to six different power domains, which maximizes flexibility while maintaining compliance with industry standards and conventions. By isolating the internal logic of the processor into its own power domain, separate from the RTC and other I/O, the processor can take advantage of dynamic power management without affecting the RTC or other I/O devices. There are no sequencing requirements for the various power domains, but all domains must be powered according to the appropriate Specifications table for processor Operating Conditions; even if the feature/peripheral is not used.

**Table 3. Power Domains**

| Power Domain | $V_{DD}$ Range |
|---|---|
| All internal logic, except RTC, Memory, OTP | $V_{DDINT}$ |
| RTC internal logic and crystal I/O | $V_{DDRTC}$ |
| Memory logic | $V_{DDMEM}$ |
| OTP logic | $V_{DDOTP}$ |
| Optional internal flash | $V_{DDFLASH}$ |
| All other I/O | $V_{DDEXT}$ |

The dynamic power management feature of the processor allows both the processor's input voltage ($V_{DDINT}$) and clock frequency ($f_{CCLK}$) to be dynamically controlled.

The power dissipated by a processor is largely a function of its clock frequency and the square of the operating voltage. For example, reducing the clock frequency by 25% results in a 25% reduction in dynamic power dissipation, while reducing the voltage by 25% reduces dynamic power dissipation by more than 40%. Further, these power savings are additive, in that if the clock frequency and supply voltage are both reduced, the power savings can be dramatic, as shown in the following equations.

$$\textit{Power Savings Factor} = \frac{f_{CCLKRED}}{f_{CCLKNOM}} \times \left(\frac{V_{DDINTRED}}{V_{DDINTNOM}}\right)^2 \times \left(\frac{T_{RED}}{T_{NOM}}\right)$$

$$\textit{\% Power Savings} = (1 - \textit{Power Savings Factor}) \times 100\%$$

where the variables in the equations are:

$f_{CCLKNOM}$ is the nominal core clock frequency

$f_{CCLKRED}$ is the reduced core clock frequency

$V_{DDINTNOM}$ is the nominal internal supply voltage

$V_{DDINTRED}$ is the reduced internal supply voltage

$T_{NOM}$ is the duration running at $f_{CCLKNOM}$

$T_{RED}$ is the duration running at $f_{CCLKRED}$

## VOLTAGE REGULATION INTERFACE

The ADSP-BF51x processors require an external voltage regulator to power the $V_{DDINT}$ domain. To reduce standby power consumption in the hibernate state, the external voltage regulator can be signaled through EXT_WAKE to remove power from the processor core. The EXT_WAKE signal is high-true for power-up and may be connected directly to the low-true shut down input of many common regulators.

The Power Good ($\overline{PG}$) input signal allows the processor to start only after the internal voltage has reached a chosen level. In this way, the startup time of the external regulator is detected after hibernation. For a complete description of the $\overline{PG}$ functionality, refer to the *ADSP-BF51x Blackfin Processor Hardware Reference*.

## CLOCK SIGNALS

The ADSP-BF51x processors can be clocked by an external crystal, a sine wave input, or a buffered, shaped clock derived from an external clock oscillator.

If an external clock is used, it should be a TTL compatible signal and must not be halted, changed, or operated below the specified frequency during normal operation. This signal is connected to the processor CLKIN signal. When an external clock is used, the XTAL pin/ball must be left unconnected.

Alternatively, because the processor includes an on-chip oscillator circuit, an external crystal may be used. For fundamental frequency operation, use the circuit shown in Figure 4. A parallel-resonant, fundamental frequency, microprocessor-grade crystal is connected across the CLKIN and XTAL pins/balls. The on-chip resistance between the CLKIN pin/ball and the XTAL pin/ball is in the 500 kΩ range. Further parallel resistors are typically not recommended. The two capacitors and the series resistor shown in Figure 4 fine tune phase and amplitude of the sine frequency.

The capacitor and resistor values shown in Figure 4 are typical values only. The capacitor values are dependent upon the crystal manufacturers' load capacitance recommendations and the PCB physical layout. The resistor value depends on the drive level specified by the crystal manufacturer. The user should verify the customized values based on careful investigations on multiple devices over temperature range.

A third-overtone crystal can be used for frequencies above 25 MHz. The circuit is then modified to ensure crystal operation only at the third overtone, by adding a tuned inductor circuit as shown in Figure 4. A design procedure for third-overtone operation is discussed in detail in application note *(EE-168) Using Third Overtone Crystals with the ADSP-218x DSP* on the Analog Devices website (www.analog.com)—use site search on "EE-168."

The CLKBUF signal is an output signal, which is a buffered version of the input clock. This signal is particularly useful in Ethernet applications to limit the number of required clock sources in the system. In this type of application, a single

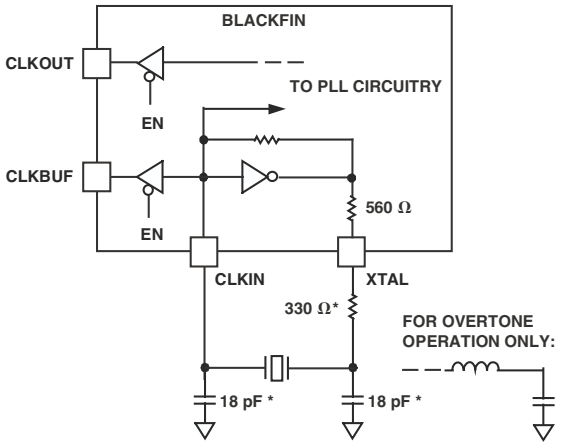



*Figure 4. External Crystal Connections*

25 MHz or 50 MHz crystal may be applied directly to the processor. The 25 MHz or 50 MHz output of CLKBUF can then be connected to an external Ethernet MII or RMII PHY device.

The Blackfin core runs at a different clock rate than the on-chip peripherals. As shown in Figure 5, the core clock (CCLK) and system peripheral clock (SCLK) are derived from the input clock (CLKIN) signal. An on-chip PLL is capable of multiplying the CLKIN signal by a programmable 5× to 64× multiplication factor (bounded by specified minimum and maximum VCO frequencies). The default multiplier is 6×, but it can be modified by a software instruction sequence.

On-the-fly frequency changes can be done simply by writing to the PLL_DIV register. The maximum allowed CCLK and SCLK rates depend on the applied voltages $V_{DDINT}$, $V_{DDEXT}$, and $V_{DDMEM}$, and the VCO is always permitted to run up to the frequency specified by the part's speed grade. The CLKOUT signal reflects the SCLK frequency to the off-chip world. It belongs to the SDRAM interface, but it functions as a reference signal in other timing specifications as well. While active by default, it can be disabled using the EBIU_SDGCTL and EBIU_AMGCTL registers.

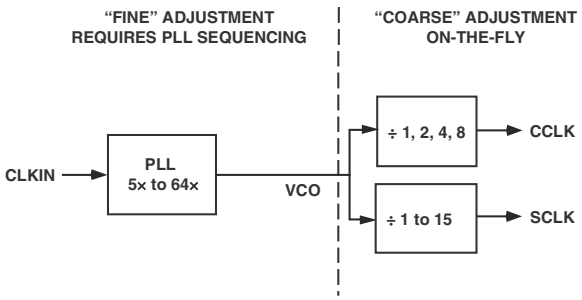



*Figure 5. Frequency Modification Methods*

All on-chip peripherals are clocked by the system clock (SCLK). The system clock frequency is programmable by means of the SSEL3–0 bits of the PLL_DIV register. The values programmed into the SSEL fields define a divide ratio between the PLL output (VCO) and the system clock. SCLK divider values are 1 through 15. Table 4 illustrates typical system clock ratios.

Note that the divisor ratio must be chosen to limit the system clock frequency to its maximum of $f_{SCLK}$. The SSEL value can be changed dynamically without any PLL lock latencies by writing the appropriate values to the PLL divisor register (PLL_DIV).

The core clock (CCLK) frequency can also be dynamically changed by means of the CSEL1–0 bits of the PLL_DIV register. Supported CCLK divider ratios are 1, 2, 4, and 8, as shown in Table 5. This programmable core clock capability is useful for fast core frequency modifications.

**Table 5. Core Clock Ratios**

| Signal Name CSEL1–0 | Divider Ratio VCO/CCLK | Example Frequency Ratios (MHz) | |
|---|---|---|---|
| | | VCO | CCLK |
| 00 | 1:1 | 300 | 300 |
| 01 | 2:1 | 300 | 150 |
| 10 | 4:1 | 400 | 100 |
| 11 | 8:1 | 200 | 25 |

**Table 4. Example System Clock Ratios**

| Signal Name SSEL3–0 | Divider Ratio VCO/SCLK | Example Frequency Ratios (MHz) | |
|---|---|---|---|
| | | VCO | SCLK |
| 0010 | 2:1 | 100 | 50 |
| 0110 | 6:1 | 300 | 50 |
| 1010 | 10:1 | 400 | 40 |

The maximum CCLK frequency not only depends on the part's speed grade (see Page 65), it also depends on the applied $V_{DDINT}$ voltage. See Table 9 for details. The maximal system clock rate (SCLK) depends on the chip package and the applied $V_{DDINT}$, $V_{DDEXT}$, and $V_{DDMEM}$ voltages (see Table 11 on Page 21).

## BOOTING MODES

The processor has several mechanisms (listed in Table 6) for automatically loading internal and external memory after a reset. The boot mode is defined by three BMODE input bits dedicated to this purpose. There are two categories of boot modes. In master boot modes the processor actively loads data from parallel or serial memories. In slave boot modes the processor receives data from external host devices.

The boot modes listed in Table 6 provide a number of mechanisms for automatically loading the processor's internal and external memories after a reset. By default, all boot modes use the slowest meaningful configuration settings. Default settings can be altered via the initialization code feature at boot time or by proper OTP programming at pre-boot time. The BMODE bits of the reset configuration register, sampled during power-on resets and software-initiated resets, implement the modes shown in Table 6.

**Table 6. Booting Modes**

| BMODE2–0 | Description |
|---|---|
| 000 | Idle - No boot |
| 001 | Boot from 8- or 16-bit external flash memory |
| 010 | Boot from internal SPI memory |
| 011 | Boot from external SPI memory (EEPROM or flash) |
| 100 | Boot from SPI0 host |
| 101 | Boot from OTP memory |
| 110 | Boot from SDRAM |
| 111 | Boot from UART0 Host |

- Idle/no boot mode (BMODE = 0x0)—In this mode, the processor goes into idle. The idle boot mode helps recover from illegal operating modes, such as when the user has mis configured the OTP memory.
- Boot from 8-bit or 16-bit external flash memory (BMODE = 0x1)—In this mode, the boot kernel loads the first block header from address 0x2000 0000 and—depending on instructions containing in the header—the boot kernel performs 8-bit or 16-bit boot or starts program execution at the address provided by the header. By default, all configuration settings are set for the slowest device possible (3-cycle hold time, 15-cycle R/W access times, 4-cycle setup).

  The ARDY is not enabled by default, but it can be enabled by OTP programming. Similarly, all interface behavior and timings can be customized by OTP programming. This includes activation of burst-mode or page-mode operation. In this mode, all signals belonging to the asynchronous interface are enabled at the port muxing level.
- Boot from internal SPI memory (BMODE = 0x2)—The processor uses the internal PH8 GPIO signal to load code previously loaded to the 4 Mbit internal SPI flash connected to SPI0. Only available on the ADSP-BF512F/ADSP-BF514F/ADSP-BF516F/ADSP-BF518F.
- Boot from external SPI EEPROM or flash (BMODE = 0x3)—8-bit, 16-bit, 24-bit or 32-bit addressable devices are supported. The processor uses the PG15 GPIO signal (at $\overline{\text{SPI0SEL2}}$) to select a single SPI EEPROM/flash device connected to the SPI0 interface; then submits a read command and successive address bytes (0x00) until a valid 8-, 16-, 24-, or 32-bit addressable device is detected. Pull-up resistors are required on the SSEL and MISO signals. By default, a value of 0x85 is written to the SPI0_BAUD register.
- Boot from SPI0 host device (BMODE = 0x4)—The processor operates in SPI slave mode and is configured to receive the bytes of the LDR file from an SPI host (master) agent. In the host, the HWAIT signal must be interrogated by the

host before every transmitted byte. A pull-up resistor is required on the $\overline{\text{SPI0SS}}$ input. A pull-down on the serial clock may improve signal quality and booting robustness.

- Boot from OTP memory (BMODE = 0x5)—This provides a stand-alone booting method. The boot stream is loaded from on-chip OTP memory. By default the boot stream is expected to start from OTP page 0x40 on and can occupy all public OTP memory up to page 0xDF. This is 2560 bytes. Since the start page is programmable the maximum size of the boot stream can be extended to 3072 bytes.
- Boot from SDRAM (BMODE = 0x6)—This is a warm boot scenario, where the boot kernel starts booting from address 0x0000 0010. The SDRAM is expected to contain a valid boot stream and the SDRAM controller must be configured by the OTP settings.
- Boot from UART0 host (BMODE = 0x7)—Using an autobaud handshake sequence, a boot-stream formatted program is downloaded by the host. The host selects a bit rate within the UART clocking capabilities.

  When performing the autobaud, the UART expects a "@" (0x40) character (eight bits data, one start bit, one stop bit, no parity bit) on the RX0 signal to determine the bit rate. The UART then replies with an acknowledgement composed of 4 bytes (0xBF—the value of UART0_DLL and 0x00—the value of UART0_DLH). The host can then download the boot stream. To hold off the host the Blackfin processor signals the host with the boot host wait (HWAIT) signal. Therefore, the host must monitor HWAIT before every transmitted byte.

For each of the boot modes, a 16-byte header is first read from an external memory device. The header specifies the number of bytes to be transferred and the memory destination address. Multiple memory blocks may be loaded by any boot sequence. Once all blocks are loaded, program execution commences from the address stored in the EVT1 register.

Prior to booting, the pre-boot routine interrogates the OTP memory. Individual boot modes can be customized or even disabled based on OTP programming. External hardware, especially booting hosts may watch the HWAIT signal to determine when the pre-boot has finished and the boot kernel starts the boot process. By programming OTP memory, the user can instruct the preboot routine to also customize the PLL, the SDRAM Controller, and the Asynchronous Interface.

The boot kernel differentiates between a regular hardware reset and a wakeup-from-hibernate event to speed up booting in the later case. Bits 6-4 in the system reset configuration (SYSCR) register can be used to bypass pre-boot routine and/or boot kernel in case of a software reset. They can also be used to simulate a wakeup-from-hibernate boot in the software reset case.

The boot process can be further customized by "initialization code." This is a piece of code that is loaded and executed prior to the regular application boot. Typically, this is used to configure the SDRAM controller or to speed up booting by managing PLL, clock frequencies, wait states, or serial bit rates.

The boot ROM also features C-callable function entries that can be called by the user application at run time. This enables second-stage boot or boot management schemes to be implemented with ease.

## INSTRUCTION SET DESCRIPTION

The Blackfin processor family assembly language instruction set employs an algebraic syntax designed for ease of coding and readability. The instructions have been specifically tuned to provide a flexible, densely encoded instruction set that compiles to a very small final memory size. The instruction set also provides fully featured multifunction instructions that allow the programmer to use many of the processor core resources in a single instruction. Coupled with many features more often seen on microcontrollers, this instruction set is very efficient when compiling C and C++ source code. In addition, the architecture supports both user (algorithm/application code) and supervisor (O/S kernel, device drivers, debuggers, ISRs) modes of operation, allowing multiple levels of access to core processor resources.

The assembly language, which takes advantage of the processor's unique architecture, offers the following advantages:

- Seamlessly integrated DSP/MCU features are optimized for both 8-bit and 16-bit operations.
- A multi-issue load/store modified-harvard architecture, which supports two 16-bit MACs or four 8-bit ALUs plus two load/store plus two pointer updates per cycle.
- All registers, I/O, and memory are mapped into a unified 4G byte memory space, providing a simplified programming model.
- Microcontroller features, such as arbitrary bit and bit-field manipulation, insertion, and extraction; integer operations on 8-, 16-, and 32-bit data-types; and separate user and supervisor stack pointers.
- Code density enhancements, which include intermixing of 16-bit and 32-bit instructions (no mode switching, no code segregation). Frequently used instructions are encoded in 16 bits.

## DEVELOPMENT TOOLS

The ADSP-BF51x processors are supported with a complete set of CROSSCORE® software and hardware development tools, including Analog Devices emulators and VisualDSP++® development environment. The same emulator hardware that supports other Blackfin processors also fully emulates the ADSP-BF51x processors. For more information about development tools, visit www.analog.com.

### *EZ-KIT Lite Evaluation Board*

For evaluation of the processors, use the EZ-KIT Lite® board being developed by Analog Devices. The board comes with on-chip emulation capabilities and is equipped to enable software development. Multiple daughter cards are available.

## DESIGNING AN EMULATOR-COMPATIBLE PROCESSOR BOARD (TARGET)

The Analog Devices family of emulators are tools that every system developer needs in order to test and debug hardware and software systems. Analog Devices has supplied an IEEE 1149.1 JTAG Test Access Port (TAP) on each JTAG processor. The emulator uses the TAP to access the internal features of the processor, allowing the developer to load code, set breakpoints, observe variables, observe memory, and examine registers. The processor must be halted to send data and commands, but once an operation has been completed by the emulator, the processor system is set running at full speed with no impact on system timing.

To use these emulators, the target board must include a header that connects the processor's JTAG port to the emulator.

For details on target board design issues including mechanical layout, single processor connections, multiprocessor scan chains, signal buffering, signal termination, and emulator pod logic, see *(EE-68) Analog Devices JTAG Emulation Technical Reference* on the Analog Devices website (www.analog.com)—use site search on "EE-68." This document is updated regularly to keep pace with improvements to emulator support.

## RELATED DOCUMENTS

The following publications that describe the ADSP-BF512/ADSP-BF514/ADSP-BF516/ADSP-BF518 processors (and related processors) can be ordered from any Analog Devices sales office or accessed electronically on our website:

- *Getting Started With Blackfin Processors*
- *ADSP-BF512/BF512F, BF514/BF514F, BF516/BF516F, BF518/BF518F Blackfin Processor Hardware Reference*
- *ADSP-BF53x/BF56x Blackfin Processor Programming Reference*
- *ADSP-BF512/BF512F, BF514/BF514F, BF516/BF516F, BF518/BF518F Blackfin Processor Anomaly List*

## RELATED SIGNAL CHAINS

A *signal chain* is a series of signal-conditioning electronic components that receive input (data acquired from sampling either real-time phenomena or from stored data) in tandem, with the output of one portion of the chain supplying input to the next. Signal chains are often used in signal processing applications to gather and process data or to apply system controls based on analysis of real-time phenomena. For more information about this term and related topics, see the "signal chain" entry in Wikipedia or the Glossary of EE Terms on the Analog Devices website.

Analog Devices eases signal processing system development by providing signal processing components that are designed to work together well. A tool for viewing relationships between specific applications and related components is available on the www.analog.com website.

The Application Signal Chains page in the Circuits from the Lab™ site (http://www.analog.com/circuits) provides:

- Graphical circuit block diagram presentation of signal chains for a variety of circuit types and applications
- Drill down links for components in each chain to selection guides and application information
- Reference designs applying best practice design techniques

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# SIGNAL DESCRIPTIONS

The processors' signal definitions are listed in Table 7. In order to maintain maximum function and reduce package size and signal count, some signals have dual, multiplexed functions. In cases where signal function is reconfigurable, the default state is shown in plain text, while the alternate function is shown in italics.

All pins are three-stated during and immediately after reset, with the exception of the external memory interface, asynchronous and synchronous memory control, and the buffered XTAL output pin (CLKBUF). On the external memory interface, the control and address lines are driven high, with the exception of CLKOUT, which toggles at the system clock rate. During hibernate all outputs are three-stated unless otherwise noted in Table 7.

All I/O signals have their input buffers disabled with the exception of the signals noted in the data sheet that need pull-ups or pull downs if unused.

The SDA (serial data) and SCL (serial clock) pins/balls are open drain and therefore require a pullup resistor. Consult version 2.1 of the $I^2C$ specification for the proper resistor value.

It is strongly advised to use the available IBIS models to ensure that a given board design meets overshoot/undershoot and signal integrity requirements. If no IBIS simulation is performed, it is strongly recommended to add series resistor terminations for all Driver Types A, C and D. The termination resistors should be placed near the processor to reduce transients and improve signal integrity. The resistance value, typically 33 Ω or 47 Ω, should be chosen to match the average board trace impedance. Additionally, adding a parallel termination to CLKOUT may prove useful in further enhancing signal integrity. Be sure to verify overshoot/undershoot and signal integrity specifications on actual hardware.

**Table 7. Signal Descriptions**

| Signal Name | Type | Function | Driver Type[1] |
|---|---|---|---|
| *EBIU* | | | |
| ADDR19–1 | O | Address Bus | A |
| DATA15–0 | I/O | Data Bus | A |
| $\overline{\text{ABE1–0}}$/*SDQM1–0* | O | Byte Enable or Data Mask | A |
| $\overline{\text{AMS1–0}}$ | O | Asynchronous Memory Bank Selects (Require pull-ups if hibernate is used) | A |
| $\overline{\text{ARE}}$ | O | Asynchronous Memory Read Enable | A |
| $\overline{\text{AWE}}$ | O | Asynchronous Memory Write Enable | A |
| $\overline{\text{SRAS}}$ | O | SDRAM Row Address Strobe | A |
| $\overline{\text{SCAS}}$ | O | SDRAM Column Address Strobe | A |
| $\overline{\text{SWE}}$ | O | SDRAM Write Enable | A |
| SCKE | O | SDRAM Clock Enable (Requires a pull-down if hibernate with SDRAM self-refresh is used) | A |
| CLKOUT | O | SDRAM Clock Output | B |
| SA10 | O | SDRAM A10 Signal | A |
| $\overline{\text{SMS}}$ | O | SDRAM Bank Select | A |
| *Port F: GPIO and Multiplexed Peripherals* | | | |
| PF0/*ETxD2/PPI D0/*$\overline{\textit{SPI1SEL2}}$*/TACLK6* | I/O | GPIO/*Ethernet MII Transmit D2/PPI Data 0/SPI1 Slave Select 2/Timer6 Alternate Clock* | C |
| PF1/*ERxD2/PPI D1/PWM AH/TACLK7* | I/O | GPIO/*Ethernet MII Receive D2/PPI Data 1/PWM AH Output/Timer7 Alternate Clock* | C |
| PF2/*ETxD3/PPI D2/PWM AL* | I/O | GPIO/*Ethernet Transmit D3/PPI Data 2/PWM AL Output* | C |
| PF3/*ERxD3/PPI D3/PWM BH/TACLK0* | I/O | GPIO/*Ethernet MII Data Receive D3/PPI Data 3/PWM BH Output/Timer0 Alternate Clock* | C |
| PF4/*ERxCLK/PPI D4/PWM BL/TACLK1* | I/O | GPIO/*Ethernet MII Receive Clock/PPI Data 4/PWM BL Out/Timer1 Alternate CLK* | C |
| PF5/*ERxDV/PPI D5/PWM CH/TACI0* | I/O | GPIO/*Ethernet MII Receive Data Valid/PPI Data 5/PWM CH Out /Timer0 Alternate Capture Input* | C |
| PF6/*COL/PPI D6/PWM CL/TACI1* | I/O | GPIO/*Ethernet MII Collision/PPI Data 6/PWM CL Out/Timer1 Alternate Capture Input* | C |
| PF7/$\overline{\textit{SPI0SEL1}}$*/PPI D7/PWMSYNC* | I/O | GPIO/*SPI0 Slave Select 1/PPI Data 7/PWM Sync* | C |

**Table 7. Signal Descriptions**

| Signal Name | Type | Function | Driver Type[1] |
|---|---|---|---|
| PF8/*MDC*/PPI D8/*SPI1SEL4* | I/O | GPIO/*Ethernet Management Channel Clock/PPI Data 8/SPI1 Slave Select 4* | C |
| PF9/*MDIO*/*PPI D9*/*TMR2* | I/O | GPIO/*Ethernet Management Channel Serial Data/PPI Data 9/Timer 2* | C |
| PF10/*ETxD0*/*PPI D10*/*TMR3* | I/O | GPIO/*Ethernet MII or RMII Transmit D0/PPI Data 10/Timer 3* | C |
| PF11/*ERxD0*/*PPI D11*/*PWM AH*/*TACI3* | I/O | GPIO/*Ethernet MII Receive D0/PPI Data 11/PWM AH output /Timer3 Alternate Capture Input* | C |
| PF12/*ETxD1*/*PPI D12*/*PWM AL* | I/O | GPIO/*Ethernet MII Transmit D1/PPI Data 12/PWM AL Output* | C |
| PF13/*ERxD1*/*PPI D13*/*PWM BH* | I/O | GPIO/*Ethernet MII or RMII Receive D1/PPI Data 13/PWM BH Output* | C |
| PF14/*ETxEN*/*PPI D14*/*PWM BL* | I/O | GPIO/*Ethernet MII Transmit Enable/PPI Data 14/PWM BL Out* | C |
| PF15[2]/*RMII PHYINT*/*PPI D15*/*PWM_SYNCA* | I/O | GPIO/*Ethernet MII PHY Interrupt/PPI Data 15/Alternate PWM Sync* | C |
| *Port G: GPIO and Multiplexed Peripherals* | | | |
| PG0/*MIICRS*/*RMIICRS*/*HWAIT*[3]/*SPI1SEL3* | I/O | GPIO/*Ethernet MII or RMII Carrier Sense or RMII Data Valid/HWAIT/SPI1 Slave Select3* | C |
| PG1/*ERxER*/*DMAR1*/*PWM CH* | I/O | GPIO/*Ethernet MII or RMII Receive Error/DMA Req 1/PWM CH Out* | C |
| PG2/*MIITxCLK*/*RMIIREF_CLK*/*DMAR0*/*PWM CL* | I/O | GPIO/*Ethernet MII or RMII Reference Clock/DMA Req 0/PWM CL Out* | C |
| PG3/*DR0PRI*/*RSI_DATA0*/*SPI0SEL5*/*TACLK3* | I/O | GPIO/*SPORT0 Primary Rx Data/RSI Data 0/SPI0 Slave Select 5/Timer3 Alternate CLK* | C |
| PG4/*RSCLK0*/*RSI_DATA1*/*TMR5*/*TACI5* | I/O | GPIO/*SPORT0 Rx Clock/RSI Data 1/Timer 5/Timer5 Alternate Capture Input* | D |
| PG5/*RFS0*/*RSI_DATA2*/*PPICLK*/*TMRCLK* | I/O | GPIO/*SPORT0 Rx Frame Sync/RSI Data 2/PPI Clock/External Timer Reference* | C |
| PG6/*TFS0*/*RSI_DATA3*/*TMR0*/*PPIFS1* | I/O | GPIO/*SPORT0 Tx Frame Sync/RSI Data 3/Timer0/PPI Frame Sync1* | C |
| PG7/*DT0PRI*/*RSI_CMD*/*TMR1*/*PPIFS2* | I/O | GPIO/*SPORT0 Tx Primary Data/RSI Command/Timer 1/PPI Frame Sync2* | C |
| PG8/*TSCLK0*/*RSI_CLK*/*TMR6*/*TACI6* | I/O | GPIO/*SPORT0 Tx Clock/RSI Clock/Timer 6/Timer6 Alternate Capture Input* | D |
| PG9/*DT0SEC*/*UART0TX*/*TMR4* | I/O | GPIO/*SPORT0 Secondary Tx Data/UART0 Transmit/Timer 4* | C |
| PG10/*DR0SEC*/*UART0RX*/*TACI4* | I/O | GPIO/*SPORT0 Secondary Rx Data/UART0 Receive/Timer4 Alternate Capture Input* | C |
| PG11/*SPI0SS*/*AMS2*/*SPI1SEL5*/*TACLK2* | I/O | GPIO/*SPI0 Slave Device Select/Asynchronous Memory Bank Select 2/SPI1 Slave Select 5/Timer2 Alternate CLK* | C |
| PG12/*SPI0SCK*/*PPICLK*/*TMRCLK*/*PTP_PPS* | I/O | GPIO/*SPI0 Clock/PPI Clock/External Timer Reference/PTP Pulse Per Second Out* | D |
| PG13/*SPI0MISO*[4]/*TMR0*/*PPIFS1*/ *PTP_CLKOUT* | I/O | GPIO/*SPI0 Master In Slave Out/Timer0/PPI Frame Sync1/PTP Clock Out* | C |
| PG14/*SPI0MOSI*/*TMR1*/*PPIFS2*/*PWM TRIP* /*PTP_AUXIN* | I/O | GPIO/*SPI0 Master Out Slave In/Timer 1/PPI Frame Sync2/PWM Trip/PTP Auxiliary Snapshot Trigger Input* | C |
| PG15/*SPI0SEL2*/*PPIFS3*/*AMS3* | I/O | GPIO/*SPI0 Slave Select 2/PPI Frame Sync3/Asynchronous Memory Bank Select 3* | C |
| *Port H: GPIO and Multiplexed Peripherals* | | | |
| PH0/*DR1PRI*/*SPI1SS*/*RSI_DATA4* | I/O | GPIO/*SPORT1 Primary Rx Data/SPI1 Device Select/RSI Data 4* | C |
| PH1/*RFS1*/*SPI1MISO*/*RSI_DATA5* | I/O | GPIO/*SPORT1 Rx Frame Sync/SPI1 Master In Slave Out/RSI Data 5* | C |
| PH2/*RSCLK1*/*SPI1SCK*/*RSI DATA6* | I/O | GPIO/*SPORT1 Rx Clock/SPI1 Clock/RSI Data 6* | D |
| PH3/*DT1PRI*/*SPI1MOSI*/*RSI DATA7* | I/O | GPIO/*SPORT1 Primary Tx Data/SPI1 Master Out Slave In/RSI Data 7* | C |
| PH4/*TFS1*/*AOE*/*SPI0SEL3*/*CUD* | I/O | GPIO/*SPORT1 Tx Frame Sync/Asynchronous Memory Output Enable/SPI0 Slave Select 3/Counter Up Direction* | C |
| PH5/*TSCLK1*/*ARDY*/*PTP_EXT_CLKIN*/*CDG* | I/O | GPIO/*SPORT1 Tx Clock/Asynchronous Memory Hardware Ready Control/ External Clock for PTP TSYNC/Counter Down Gate* | D |
| PH6/*DT1SEC*/*UART1TX*/*SPI1SEL1*/*CZM* | I/O | GPIO/*SPORT1 Secondary Tx Data/UART1 Transmit/SPI1 Slave Select 1 /Counter Zero Marker* | C |
| PH7/*DR1SEC*/*UART1RX*/*TMR7*/*TACI2* | I/O | GPIO/*SPORT1 Secondary Rx Data/UART1 Receive/Timer 7/Timer2 Alternate Clock Input* | C |

**Table 7. Signal Descriptions**

| Signal Name | Type | Function | Driver Type[1] |
|---|---|---|---|
| *Port J* | | | |
| PJ0:SCL | I/O 5V | TWI Serial Clock (This signal is an open-drain output and requires a pull-up resistor. Consult version 2.1 of the $I^2C$ specification for the proper resistor value.) | E |
| PJ1:SDA | I/O 5V | TWI Serial Data (This signal is an open-drain output and requires a pull-up resistor. Consult version 2.1 of the $I^2C$ specification for the proper resistor value.) | E |
| *Real Time Clock* | | | |
| RTXI | I | RTC Crystal Input (This ball should be pulled low when not used.) | |
| RTXO | O | RTC Crystal Output (Does not three-state during hibernate) | |
| *JTAG Port* | | | |
| TCK | I | JTAG Clock | |
| TDO | O | JTAG Serial Data Out | C |
| TDI | I | JTAG Serial Data In | |
| TMS | I | JTAG Mode Select | |
| $\overline{\text{TRST}}$ | I | JTAG Reset (This signal should be pulled low if the JTAG port is not used.) | |
| $\overline{\text{EMU}}$ | O | Emulation Output | C |
| *Clock* | | | |
| CLKIN | I | Clock/Crystal Input | |
| XTAL | O | Crystal Output (If CLKBUF is enabled, does not three-state during hibernate) | |
| CLKBUF | O | Buffered XTAL Output (If enabled, does not three-state during hibernate) | C |
| *Mode Controls* | | | |
| $\overline{\text{RESET}}$ | I | Reset | |
| $\overline{\text{NMI}}$ | I | Non-maskable Interrupt (This signal should be pulled high when not used.) | |
| BMODE2-0 | I | Boot Mode Strap 2-0 | |
| Voltage Regulation Interface | | | |
| $\overline{\text{PG}}$ | I | Power Good (This signal should be pulled low when not used.) | |
| EXT_WAKE | O | Wake up Indication (Does not three-state during hibernate) | C |
| *Power Supplies* | | **ALL SUPPLIES MUST BE POWERED** See Operating Conditions on Page 20. | |
| $V_{DDEXT}$ | P | I/O Power Supply | |
| $V_{DDINT}$ | P | Internal Power Supply | |
| $V_{DDRTC}$ | P | Real Time Clock Power Supply | |
| $V_{DDFLASH}$ | P | Internal SPI Flash Power Supply | |
| $V_{DDMEM}$ | P | MEM Power Supply | |
| $V_{PPOTP}$ | P | OTP Programming Voltage | |
| $V_{DDOTP}$ | P | OTP Power Supply | |
| GND | G | Ground for All Supplies | |

[1] See Output Drive Currents on Page 50 for more information about each driver type.
[2] When driven low, the PF15 signal can be used to wake up the processor from the hibernate state, either in normal GPIO mode or in Ethernet mode as $\overline{\text{PHYINT}}$. If the pin/ball is used for wake up, enable the feature with the PHYWE bit in the VR_CTL register, and pull-up the signal with a resistor.
[3] Boot host wait is a GPIO signal toggled by the boot kernel. The mandatory external pull-up/pull-down resistor defines the signal polarity.
[4] A pull-up resistor is required for the boot from external SPI EEPROM or flash (BMODE = 0x3).

# SPECIFICATIONS

Note that component specifications are subject to change without notice.

## OPERATING CONDITIONS

| Parameter | | Conditions | Min | Nominal | Max | Unit |
|---|---|---|---|---|---|---|
| $V_{DDINT}$ | Internal Supply Voltage | Industrial Models | 1.14 | | 1.47 | V |
| | Internal Supply Voltage | Commercial Models | 1.10 | | 1.47 | V |
| | Internal Supply Voltage | Automotive Models | 1.33 | | 1.47 | V |
| $V_{DDEXT}$[1, 2] | External Supply Voltage | 1.8 V I/O, Nonautomotive Models | 1.7 | 1.8 | 1.9 | V |
| | External Supply Voltage | 2.5 V I/O, Nonautomotive Models | 2.25 | 2.5 | 2.75 | V |
| | External Supply Voltage | 3.3 V I/O, All Models | 3.0 | 3.3 | 3.6 | V |
| $V_{DDMEM}$[3] | MEM Supply Voltage | 1.8 V I/O, Nonautomotive Models | 1.7 | 1.8 | 1.9 | V |
| | MEM Supply Voltage | 2.5 V I/O, Nonautomotive Models | 2.25 | 2.5 | 2.75 | V |
| | MEM Supply Voltage | 3.3 V I/O, All Models | 3.0 | 3.3 | 3.6 | V |
| $V_{DDRTC}$[4] | RTC Power Supply Voltage | | 2.25 | | 3.6 | V |
| $V_{DDFLASH}$[4] | Internal SPI Flash Supply Voltage | | 1.7 | 1.8 | 1.9 | V |
| $V_{DDOTP}$ | OTP Supply Voltage | | 2.25 | 2.5 | 2.75 | V |
| $V_{PPOTP}$ | OTP Programming Voltage | | | | | |
| | For Reads[1] | | 2.25 | 2.5 | 2.75 | V |
| | For Writes[5] | | 6.9 | 7.0 | 7.1 | V |
| $V_{IH}$ | High Level Input Voltage[6, 7] | $V_{DDEXT}/V_{DDMEM}$ = 1.90 V | 1.2 | | | V |
| | High Level Input Voltage[6, 7] | $V_{DDEXT}/V_{DDMEM}$ = 2.75 V | 1.7 | | | V |
| | High Level Input Voltage[6, 7] | $V_{DDEXT}/V_{DDMEM}$ = 3.6 V | 2 | | | V |
| $V_{IHTWI}$ | High Level Input Voltage | $V_{DDEXT}$ = 1.90 V/2.75 V/3.6 V | 0.7 x $V_{BUSTWI}$ | | $V_{BUSTWI}$[8] | V |
| $V_{IL}$ | Low Level Input Voltage[6, 7] | $V_{DDEXT}/V_{DDMEM}$ = 1.7 V | | | 0.6 | V |
| | Low Level Input Voltage[6, 7] | $V_{DDEXT}/V_{DDMEM}$ = 2.25 V | | | 0.7 | V |
| | Low Level Input Voltage[6, 7] | $V_{DDEXT}/V_{DDMEM}$ = 3.0 V | | | 0.8 | V |
| $V_{ILTWI}$ | Low Level Input Voltage | $V_{DDEXT}$ = Minimum | | | 0.3 x $V_{BUSTWI}$[9] | V |
| | Junction Temperature | 168-Ball CSP_BGA @ $T_{AMBIENT}$ = 0°C to +70°C | 0 | | +95 | °C |
| | Junction Temperature | 168-Ball CSP_BGA @ $T_{AMBIENT}$ = –40°C to +85°C | –40 | | +105 | °C |
| | Junction Temperature | 176-Lead LQFP @ $T_{AMBIENT}$ = 0°C to +70°C | 0 | | +95 | °C |
| | Junction Temperature | 176-Lead LQFP @ $T_{AMBIENT}$ = –40°C to +85°C | –40 | | +105 | °C |

[1] Must remain powered (even if the associated function is not used).

[2] $V_{DDEXT}$ is the supply to the GPIO.

[3] Pins/balls that use $V_{DDMEM}$ are DATA15–0, ADDR19–1, $\overline{ABE1–0}$, $\overline{ARE}$, $\overline{AWE}$, $\overline{AMS1–0}$, SA10, $\overline{SWE}$, $\overline{SCAS}$, CLKOUT, $\overline{SRAS}$, $\overline{SMS}$, SCKE. These pins/balls are not tolerant to voltages higher than $V_{DDMEM}$. When using any of the asynchronous memory signals $\overline{AMS3–2}$, ARDY, or $\overline{AOE}$ $V_{DDMEM}$ and $V_{DDEXT}$ must be shorted externally.

[4] If not used, power with $V_{DDEXT}$.

[5] The $V_{PPOTP}$ voltage for writes must only be applied when programming OTP memory. There is a finite amount of cumulative time that this voltage may be applied (dependent on voltage and junction temperature) over the lifetime of the part.

[6] Bidirectional pins/balls (PF15–0, PG15–0, PH7–0) and input pins/balls (RTXI, TCK, TDI, TMS, $\overline{TRST}$, CLKIN, $\overline{RESET}$, $\overline{NMI}$, and BMODE2–0) of the ADSP-BF51x are 3.3 V tolerant (always accept up to 3.6 V maximum $V_{IH}$). Voltage compliance (on outputs, $V_{OH}$) is limited by the $V_{DDEXT}$ supply voltage.

[7] Parameter value applies to all input and bidirectional pins/balls except SDA and SCL.

[8] The $V_{IHTWI}$ min and max value vary with the selection in the TWI_DT field of the NONGPIO_DRIVE register. See $V_{BUSTWI}$ min and max values in Table 8.

[9] SDA and SCL are pulled up to $V_{BUSTWI}$. See Table 8.

Table 8 shows settings for TWI_DT in the NONGPIO_DRIVE register. Set this register prior to using the TWI port.

**Table 8. TWI_DT Field Selections and $V_{DDEXT}/V_{BUSTWI}$**

| TWI_DT | $V_{DDEXT}$ Nominal | $V_{BUSTWI}$ Minimum | $V_{BUSTWI}$ Nominal | $V_{BUSTWI}$ Maximum | Unit |
|---|---|---|---|---|---|
| 000 (default) | 3.3 | 2.97 | 3.3 | 3.63 | V |
| 001 | 1.8 | 1.7 | 1.8 | 1.98 | V |
| 010 | 2.5 | 2.97 | 3.3 | 3.63 | V |
| 011 | 1.8 | 2.97 | 3.3 | 3.63 | V |
| 100 | 3.3 | 4.5 | 5 | 5.5 | V |
| 101 | 1.8 | 2.25 | 2.5 | 2.75 | V |
| 110 | 2.5 | 2.25 | 2.5 | 2.75 | V |
| 111 (reserved) | — | — | — | — | — |

### *Clock Related Operating Conditions*

Table 9 describes the timing requirements for the processor clocks. Take care in selecting MSEL, SSEL, and CSEL ratios so as not to exceed the maximum core clock and system clock. Table 10 describes phase-locked loop operating conditions.

**Table 9. Core Clock (CCLK) Requirements**

| Parameter | | Nominal Voltage Setting | Maximum | Unit |
|---|---|---|---|---|
| $f_{CCLK}$ | Core Clock Frequency ($V_{DDINT}$ = 1.33 V Minimum, All Models) | 1.400 V | 400 | MHz |
| | Core Clock Frequency ($V_{DDINT}$ = 1.23 V Minimum, Industrial/Commercial Models) | 1.300 V | 300 | MHz |
| | Core Clock Frequency ($V_{DDINT}$ = 1.14 V Minimum, Industrial Models Only) | 1.200 V | 200 | MHz |
| | Core Clock Frequency ($V_{DDINT}$ = 1.10 V Minimum, Commercial Models Only) | 1.150 V | 200 | MHz |

**Table 10. Phase-Locked Loop Operating Conditions**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| $f_{VCO}$ | Voltage Controlled Oscillator (VCO) Frequency (Commercial/Industrial Models) | 72 | Instruction Rate[1] | MHz |
| | Voltage Controlled Oscillator (VCO) Frequency (Automotive Models) | 84 | Instruction Rate[1] | MHz |

[1] For more information, see Ordering Guide on Page 65.

**Table 11. SCLK Conditions**

| Parameter[1] | | $V_{DDEXT}/V_{DDMEM}$ 1.8 V Nominal Max | $V_{DDEXT}/V_{DDMEM}$ 2.5 V or 3.3 V Nominal Max | Unit |
|---|---|---|---|---|
| $f_{SCLK}$ | CLKOUT/SCLK Frequency ($V_{DDINT}$ ≥ 1.230 V Minimum) | 80 | 100 | MHz |
| $f_{SCLK}$ | CLKOUT/SCLK Frequency ($V_{DDINT}$ < 1.230 V) | 80 | 80 | MHz |

[1] $f_{SCLK}$ must be less than or equal to $f_{CCLK}$ and is subject to additional restrictions for SDRAM interface operation. See Table 28 on Page 31.

## ELECTRICAL CHARACTERISTICS

| Parameter | | Test Conditions | Min | Typical | Max | Unit |
|---|---|---|---|---|---|---|
| $V_{OH}$ | High Level Output Voltage | $V_{DDEXT}/V_{DDMEM}$ = 1.7 V, $I_{OH}$ = –0.5 mA | 1.35 | | | V |
| | High Level Output Voltage | $V_{DDEXT}/V_{DDMEM}$ = 2.25 V, $I_{OH}$ = –0.5 mA | 2 | | | V |
| | High Level Output Voltage | $V_{DDEXT}/V_{DDMEM}$ = 3.0 V, $I_{OH}$ = –0.5 mA | 2.4 | | | V |
| $V_{OL}$ | Low Level Output Voltage | $V_{DDEXT}/V_{DDMEM}$ = 1.7/2.25/3.0 V, $I_{OL}$ = 2.0 mA | | | 0.4 | V |
| $I_{IH}$[1] | High Level Input Current | $V_{DDEXT}/V_{DDMEM}$ = 3.6 V, $V_{IN}$ = 3.6 V | | | 10 | µA |
| $I_{IL}$[1] | Low Level Input Current | $V_{DDEXT}/V_{DDMEM}$ = 3.6 V, $V_{IN}$ = 0 V | | | 10 | µA |
| $I_{IHP}$[2] | High Level Input Current JTAG | $V_{DDEXT}$ = 3.6 V, $V_{IN}$ = 3.6 V | | | 75 | µA |
| $I_{OZH}$[3] | Three-State Leakage Current | $V_{DDEXT}/V_{DDMEM}$ = 3.6 V, $V_{IN}$ = 3.6 V | | | 10 | µA |
| $I_{OZHTWI}$[4] | Three-State Leakage Current | $V_{DDEXT}$ = 3.0 V, $V_{IN}$ = 5.5 V | | | 10 | µA |
| $I_{OZL}$[3] | Three-State Leakage Current | $V_{DDEXT}/V_{DDMEM}$ = 3.6 V, $V_{IN}$ = 0 V | | | 10 | µA |
| $C_{IN}$[5, 6] | Input Capacitance | $f_{IN}$ = 1 MHz, $T_{AMBIENT}$ = 25°C, $V_{IN}$ = 2.5 V | | 5 | 8 | pF |
| $C_{INTWI}$[4, 6] | Input Capacitance | $f_{IN}$ = 1 MHz, $T_{AMBIENT}$ = 25°C, $V_{IN}$ = 2.5 V | | | 15 | pF |
| $I_{DDDEEPSLEEP}$[7] | $V_{DDINT}$ Current in Deep Sleep Mode | $V_{DDINT}$ = 1.3 V, $f_{CCLK}$ = 0 MHz, $f_{SCLK}$ = 0 MHz, $T_J$ = 25°C, ASF = 0.00 | | 2.1 | | mA |
| $I_{DDSLEEP}$ | $V_{DDINT}$ Current in Sleep Mode | $V_{DDINT}$ = 1.3 V, $f_{SCLK}$ = 25 MHz, $T_J$ = 25°C | | 5.5 | | mA |
| $I_{DD-IDLE}$ | $V_{DDINT}$ Current in Idle | $V_{DDINT}$ = 1.3 V, $f_{CCLK}$ = 50 MHz, $f_{SCLK}$ = 25 MHz, $T_J$ = 25°C, ASF = 0.41 | | 12 | | mA |
| $I_{DD-TYP}$ | $V_{DDINT}$ Current | $V_{DDINT}$ = 1.3 V, $f_{CCLK}$ = 300 MHz, $f_{SCLK}$ = 25 MHz, $T_J$ = 25°C, ASF = 1.00 | | 77 | | mA |
| $I_{DD-TYP}$ | $V_{DDINT}$ Current | $V_{DDINT}$ = 1.4 V, $f_{CCLK}$ = 400 MHz, $f_{SCLK}$ = 25 MHz, $T_J$ = 25°C, ASF = 1.00 | | 108 | | mA |
| $I_{DDHIBERNATE}$[8] | Hibernate State Current | $V_{DDEXT}$=$V_{DDMEM}$=$V_{DDRTC}$ = 3.30 VV$_{DDOTP}$=$V_{PPOTP}$=2.5 V, $T_J$ = 25°C, CLKIN = 0 MHz @ $T_J$ = 25°C | | 40 | | µA |
| $I_{DDRTC}$ | $V_{DDRTC}$ Current | $V_{DDRTC}$ = 3.3 V, $T_J$ = 25°C | | 20 | | µA |
| $I_{DDSLEEP}$[8, 9] | $V_{DDINT}$ Current in Sleep Mode | $f_{CCLK}$ = 0 MHz, $f_{SCLK}$ > 0 MHz | | | Table 13 + (0.20 × $V_{DDINT}$ × $f_{SCLK}$) | mA[10] |
| $I_{DDDEEPSLEEP}$[8, 10] | $V_{DDINT}$ Current in Deep Sleep Mode | $f_{CCLK}$ = 0 MHz, $f_{SCLK}$ = 0 MHz | | | Table 13 | mA |

| Parameter | | Test Conditions | Min | Typical | Max | Unit |
|---|---|---|---|---|---|---|
| $I_{DDINT}$[10, 11] | $V_{DDINT}$ Current | $f_{CCLK}$> 0 MHz, $f_{SCLK} \geq$ 0 MHz | | | Table 13 + (Table 14 × ASF) + (0.20 × $V_{DDINT}$ × $f_{SCLK}$) | mA |
| $I_{DDFLASH1}$ | Flash Memory Supply Current 1—Asynchronous Read | | | 10 | 6 | mA |
| $I_{DDFLASH2}$ | Flash Memory Supply Current 2—Standby | | | 4 | 12 | µA |
| $I_{DDFLASH3}$ | Flash Memory Supply Current 3—Program and Erase | | | 11 | 16 | mA |
| $I_{DDOTP}$ | $V_{DDOTP}$ Current | $V_{DDOTP}$ = 2.5 V, $T_J$ = 25°C, OTP Memory Read | | 2 | | mA |
| $I_{DDOTP}$ | $V_{DDOTP}$ Current | $V_{DDOTP}$ = 2.5 V, $T_J$ = 25°C, OTP Memory Write | | 2 | | mA |
| $I_{PPOTP}$ | $V_{PPOTP}$ Current | $V_{PPOTP}$ = 2.5 V, $T_J$ = 25°C, OTP Memory Read | | 100 | | µA |
| $I_{PPOTP}$ | $V_{PPOTP}$ Current | $V_{PPOTP}$ = Table 19 V, $T_J$ = 25°C, OTP Memory Write | | 3 | | mA |

[1] Applies to input balls.
[2] Applies to JTAG input balls (TCK, TDI, TMS, $\overline{TRST}$).
[3] Applies to three-statable balls.
[4] Applies to bidirectional balls SCL and SDA.
[5] Applies to all signal balls, except SCL and SDA.
[6] Guaranteed, but not tested.
[7] See the *ADSP-BF51x Blackfin Processor Hardware Reference Manual* for definition of sleep, deep sleep, and hibernate operating modes.
[8] Includes current on $V_{DDEXT}$, $V_{DDMEM}$, $V_{DDOTP}$, and $V_{PPOTP}$ supplies. Clock inputs are tied high or low.
[9] Guaranteed maximum specifications.
[10] Unit for $V_{DDINT}$ is V (Volts). Unit for $f_{SCLK}$ is MHz.
[11] See Table 12 for the list of $I_{DDINT}$ power vectors covered.

### *Total Power Dissipation*

Total power dissipation has two components:

1. Static, including leakage current
2. Dynamic, due to transistor switching characteristics

Many operating conditions can also affect power dissipation, including temperature, voltage, operating frequency, and processor activity. Electrical Characteristics on Page 22 shows the current dissipation for internal circuitry ($V_{DDINT}$). $I_{DDDEEPSLEEP}$ specifies static power dissipation as a function of voltage ($V_{DDINT}$) and temperature (see Table 13), and $I_{DDINT}$ specifies the total power specification for the listed test conditions, including the dynamic component as a function of voltage ($V_{DDINT}$) and frequency (Table 14).

There are two parts to the dynamic component. The first part is due to transistor switching in the core clock (CCLK) domain. This part is subject to an Activity Scaling Factor (ASF) which represents application code running on the processor core and L1 memories (Table 12).

The ASF is combined with the CCLK Frequency and $V_{DDINT}$ dependent data in Table 14 to calculate this part. The second part is due to transistor switching in the system clock (SCLK) domain, which is included in the $I_{DDINT}$ specification equation.

**Table 12. Activity Scaling Factors (ASF)[1]**

| $I_{DDINT}$ Power Vector | Activity Scaling Factor (ASF) |
|---|---|
| $I_{DD-PEAK}$ | 1.29 |
| $I_{DD-HIGH}$ | 1.25 |
| $I_{DD-TYP}$ | 1.00 |
| $I_{DD-APP}$ | 0.85 |
| $I_{DD-NOP}$ | 0.70 |
| $I_{DD-IDLE}$ | 0.41 |

[1] See *Estimating Power for ASDP-BF534/BF536/BF537 Blackfin Processors (EE-297)*. The power vector information also applies to the ADSP-BF51x processors.

**Table 13. Static Current—$I_{DD\text{-}DEEPSLEEP}$ (mA)**

| $T_J$ (°C)[1] | Voltage ($V_{DDINT}$)[1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1.10 V | 1.15 V | 1.20 V | 1.25 V | 1.30 V | 1.35 V | 1.40 V | 1.45 V | 1.50 V |
| –40 | 0.9 | 1.0 | 1.0 | 1.1 | 1.1 | 1.2 | 1.3 | 1.7 | 1.9 |
| –20 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.6 | 1.7 | 1.9 | 2.0 |
| 0 | 1.2 | 1.3 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 | 2.3 | 2.5 |
| 25 | 1.8 | 1.9 | 2.1 | 2.3 | 2.5 | 2.8 | 3.1 | 3.3 | 3.7 |
| 40 | 2.4 | 2.6 | 2.8 | 3.0 | 3.3 | 3.7 | 4.0 | 4.4 | 4.9 |
| 55 | 3.3 | 3.5 | 3.8 | 4.3 | 4.6 | 5.0 | 5.5 | 6.1 | 6.7 |
| 70 | 4.6 | 5.0 | 5.4 | 6.0 | 6.4 | 7.0 | 7.7 | 8.4 | 9.2 |
| 85 | 6.5 | 7.1 | 7.7 | 8.3 | 9.1 | 9.9 | 10.8 | 11.8 | 12.8 |
| 100 | 9.2 | 10.0 | 10.8 | 11.7 | 12.7 | 13.7 | 15.0 | 16.1 | 17.5 |
| 105 | 10.3 | 11.1 | 12.1 | 13.1 | 14.2 | 15.3 | 16.6 | 18.0 | 19.4 |

[1] Valid frequency and voltage ranges are model-specific. See Operating Conditions on Page 20.

**Table 14. Dynamic Current in CCLK Domain (mA, with ASF = 1.0)[1]**

| $f_{CCLK}$ (MHz)[2] | Voltage ($V_{DDINT}$)[2] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1.10 V | 1.15 V | 1.20 V | 1.25 V | 1.30 V | 1.35 V | 1.40 V | 1.45 V | 1.50 V |
| 400 | N/A | N/A | N/A | N/A | 93.4 | 97.7 | 102.1 | 106.5 | 111.0 |
| 350 | N/A | N/A | N/A | N/A | 82.4 | 86.2 | 90.1 | 94.0 | 98.0 |
| 300 | N/A | N/A | 64.8 | 68.1 | 71.4 | 74.7 | 78.1 | 81.5 | 85.0 |
| 250 | N/A | N/A | 54.8 | 57.5 | 60.4 | 63.2 | 66.1 | 69.0 | 71.9 |
| 200 | 40.2 | 42.5 | 44.7 | 47.0 | 49.4 | 51.7 | 54.1 | 56.5 | 58.9 |
| 150 | 31.1 | 32.9 | 34.7 | 36.5 | 38.4 | 40.2 | 42.1 | 44.0 | 45.9 |
| 100 | 22.0 | 23.4 | 24.7 | 26.0 | 27.4 | 28.7 | 30.1 | 31.5 | 33.0 |

[1] The values are not guaranteed as standalone maximum specifications. They must be combined with static current per the equations of Electrical Characteristics on Page 22.
[2] Valid frequency and voltage ranges are model-specific. See Operating Conditions on Page 20.

## FLASH MEMORY CHARACTERISTICS

**Table 15. Reliability Characteristics**

| Parameter | | Min | Units | Test Method |
|---|---|---|---|---|
| $N_{END}$ | Endurance | 100,000 | Cycles | JEDEC Standard A117 |
| $T_{DR}$ | Data Retention | 100 | Years | JEDEC Standard A103 |

**Table 16. AC Operating Characteristics**

| Parameter | | Min | Max | Units |
|---|---|---|---|---|
| $f_{CLK}$[1] | Serial Clock Frequency | | 25 | MHz |
| $T_{SE}$ | Sector-Erase | | 75 | ms |
| $T_{BE}$ | Block-Erase | | 75 | ms |
| $T_{SCE}$ | Chip-Erase | | 150 | ms |
| $T_{BP}$[2] | Byte-Program | | 60 | µs |

[1] Maximum clock frequency for Read instruction, 0x03, is 20 MHz.
[2] AAI-Word Program TBP maximum specification is also at 60 µs maximum time.

## ABSOLUTE MAXIMUM RATINGS

Stresses greater than those listed in Table 17 may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions greater than those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

**Table 17. Absolute Maximum Ratings**

| Parameter | Rating |
|---|---|
| Internal Supply Voltage ($V_{DDINT}$) | –0.3 V to +1.50 V |
| External (I/O) Supply Voltage ($V_{DDEXT}$/$V_{DDMEM}$) | –0.3 V to +3.8 V |
| Input Voltage[1, 2] | –0.5 V to +3.6 V |
| Input Voltage[1, 3] | –0.5 V to +5.5 V |
| Output Voltage Swing | –0.5 V to $V_{DDEXT}$/$V_{DDMEM}$ + 0.5 V |
| $I_{OH}$/$I_{OL}$ Current per Pin Group[4] | 80 mA (max) |
| Storage Temperature Range | –65°C to +150°C |
| Junction Temperature While biased | +110°C |

[1] Applies to 100% transient duty cycle. For other duty cycles see Table 18.
[2] Applies only when $V_{DDEXT}$ is within specifications. When $V_{DDEXT}$ is outside specifications, the range is $V_{DDEXT}$ ± 0.2.
[3] Applies to signals SCL, SDA.
[4] For more information, see the information preceding Table 20 and Table 21.

**Table 18. Maximum Duty Cycle for Input Transient Voltage[1]**

| $V_{IN}$ Min (V)[2] | $V_{IN}$ Max (V)[2] | Maximum Duty Cycle[3] |
|---|---|---|
| –0.50 | +3.80 | 100% |
| –0.70 | +4.00 | 40% |
| –0.80 | +4.10 | 25% |
| –0.90 | +4.20 | 15% |
| –1.00 | +4.30 | 10% |

[1] Applies to all signal pins/balls with the exception of CLKIN, XTAL.
[2] The individual values cannot be combined for analysis of a single instance of overshoot or undershoot. The worst case observed value must fall within one of the voltages specified and the total duration of the overshoot or undershoot (exceeding the 100% case) must be less than or equal to the corresponding duty cycle.
[3] Duty cycle refers to the percentage of time the signal exceeds the value for the 100% case. The is equivalent to the measured duration of a single instance of overshoot or undershoot as a percentage of the period of occurrence.

When programming OTP memory on the ADSP-BF51x processor, the $V_{PPOTP}$ pin/ball must be set to the write value specified in the Operating Conditions on Page 20. There is a finite amount of cumulative time that the write voltage may be applied (dependent on voltage and junction temperature) to $V_{PPOTP}$ over the lifetime of the part. Therefore, maximum OTP memory programming time for the processor is shown in Table 19.

**Table 19. Maximum OTP Memory Programming Time**

| VPPOTP Voltage (V) | Temperature | | |
|---|---|---|---|
| | 25°C | 85°C | 110°C |
| 6.9 | 6000 sec | 100 sec | 25 sec |
| 7.0 | 2400 sec | 44 sec | 12 sec |
| 7.1 | 1000 sec | 18 sec | 4.5 sec |

Table 20 and Table 21 specify the maximum total source/sink ($I_{OH}$/$I_{OL}$) current for a group of pins. Permanent damage can occur if this value is exceeded. To understand this specification, if pins PF9, PF8, PF7, PF6, and PF5 from Group 1 in Table 21 table were sourcing or sinking 2 mA each, the total current for those pins would be 10 mA. This would allow up to 70 mA total that could be sourced or sunk by the remaining pins in the group without damaging the device. Note that the $V_{OH}$ and $V_{OL}$ specifications have separate per-pin maximum current requirements as shown in the Electrical Characteristics table.

**Table 20. Total Current Pin Groups–$V_{DDMEM}$ Groups**

| Group | Pins in Group |
|---|---|
| 1 | DATA15, DATA14, DATA13, DATA12, DATA11, DATA10 |
| 2 | DATA9, DATA8, DATA7, DATA6, DATA5, DATA4 |
| 3 | DATA3, DATA2, DATA1, DATA0, ADDR19, ADDR18 |
| 4 | ADDR17, ADDR16, ADDR15, ADDR14, ADDR13 |
| 5 | ADDR12, ADDR11, ADDR10, ADDR9, ADDR8, ADDR7 |
| 6 | ADDR6, ADDR5, ADDR4, ADDR3, ADDR2, ADDR1 |
| 7 | $\overline{ABE1}$, $\overline{ABE0}$, SA10, $\overline{SWE}$, $\overline{SCAS}$, $\overline{SRAS}$ |
| 8 | $\overline{SMS}$, SCKE, $\overline{AMS1}$, $\overline{ARE}$, $\overline{AWE}$, $\overline{AMS0}$, CLKOUT |

**Table 21. Total Current Pin Groups–$V_{DDEXT}$ Groups**

| Group | Pins in Group |
|---|---|
| 1 | PF9, PF8, PF7, PF6, PF5, PF4, PF3, PF2 |
| 2 | PF1, PF0, PG15, PG14, PG13, PG12, PG11, PG10 |
| 3 | PG9, PG8, PG7, PG6, PG5, PG4, PG3, PG2, BMODE0, BMODE1, BMODE2 |
| 4 | PG1, PG0, TDO, $\overline{EMU}$, TDI, TCK, $\overline{TRST}$, TMS |
| 5 | $\overline{RESET}$, $\overline{NMI}$, CLKBUF |
| 6 | PH7, PH6, PH5, PH4, PH3, PH2, PH1, PH0 |
| 7 | PF15, PF14, PF13, PF12, PF11, SDA, SCL, PF10 |

## PACKAGE INFORMATION

The information presented in Figure 6 and Table 22 provides details about the package branding for the processor. For a complete listing of product availability, see Ordering Guide on Page 65.

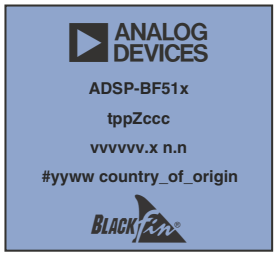



*Figure 6. Product Information on Package*

**Table 22. Package Brand Information**

| Brand Key | Field Description |
|---|---|
| ADSP-BF51x | Product Name |
| t | Temperature Range |
| pp | Package Type |
| Z | Lead Free Option |
| ccc | See Ordering Guide |
| vvvvvv.x | Assembly Lot Code |
| n.n | Silicon Revision |
| # | RoHS Compliance Designator |
| yyww | Date Code |

## ESD SENSITIVITY

**ESD (electrostatic discharge) sensitive device.** Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

## TIMING SPECIFICATIONS

### *Clock and Reset Timing*

Table 23 and Figure 7 describe clock and reset operations. Per the CCLK and SCLK timing specifications in Table 9 , Table 10, and Table 11 on Page 21, combinations of CLKIN and clock multipliers must not select core/peripheral clocks in excess of the processor's speed grade.

**Table 23. Clock and Reset Timing**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| *Timing Requirements* | | | | |
| $f_{CKIN}$ | CLKIN Frequency (Commercial/Industrial Models[1, 2, 3, 4] | 12 | 50 | MHz |
| $f_{CKIN}$ | CLKIN Frequency (Automotive Models)[1, 2, 3, 4] | 14 | 50 | MHz |
| $t_{CKINL}$ | CLKIN Low Pulse[1] | 10 | | ns |
| $t_{CKINH}$ | CLKIN High Pulse[1] | 10 | | ns |
| $t_{WRST}$ | $\overline{\text{RESET}}$ Asserted Pulse Width Low[5] | 11 × $t_{CKIN}$ | | ns |
| *Switching Characteristic* | | | | |
| $t_{BUFDLAY}$ | CLKIN to CLKBUF Delay | | 11 | ns |

[1] Applies to PLL bypass mode and PLL nonbypass mode.
[2] Combinations of the CLKIN frequency and the PLL clock multiplier must not exceed the allowed $f_{VCO}$, $f_{CCLK}$, and $f_{SCLK}$ settings discussed in Table 9 through Table 11 on Page 21.
[3] The $t_{CKIN}$ period (see Figure 7) equals $1/f_{CKIN}$.
[4] If the DF bit in the PLL_CTL register is set, the minimum $f_{CKIN}$ specification is 24 MHz for commercial/industrial models and 28 MHz for automotive models.
[5] Applies after power-up sequence is complete. See Table 24 and Figure 8 for power-up reset timing.

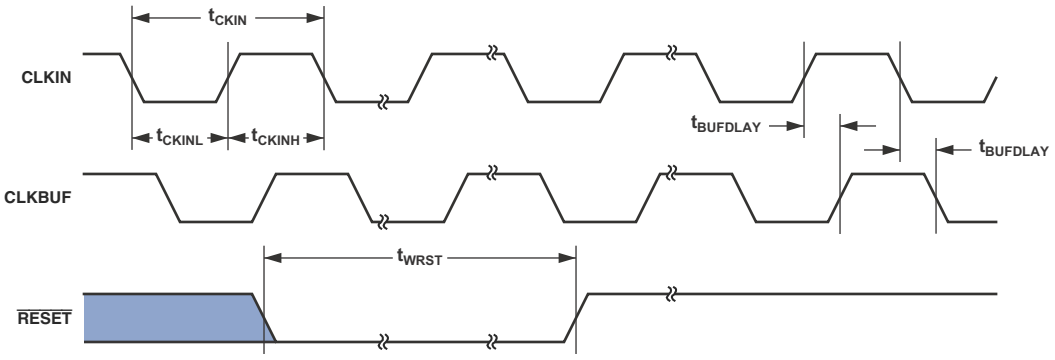



*Figure 7. Clock and Reset Timing*

**Table 24. Power-Up Reset Timing**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| *Timing Requirements* | | | | |
| $t_{RST_IN_PWR}$ | $\overline{\text{RESET}}$ Deasserted after the $V_{DDINT}$, $V_{DDEXT}$, $V_{DDRTC}$, $V_{DDMEM}$, $V_{DDOTP}$, and CLKIN Pins are Stable and Within Specification | 3500 × $t_{CKIN}$ | | ns |

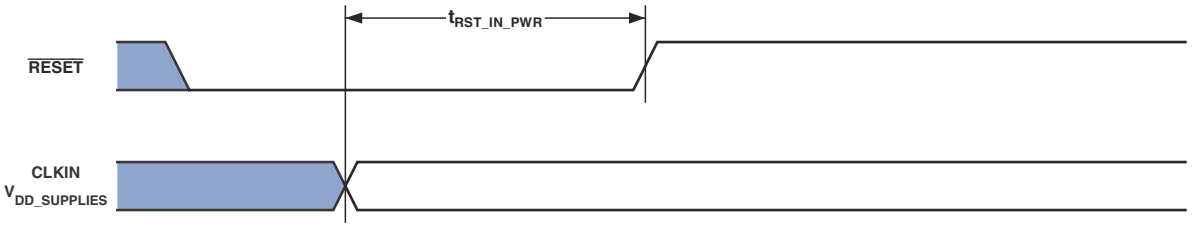



*Figure 8. Power-Up Reset Timing*

### *Flash Reset Timing*

Driving the $\overline{\text{RESET}}$ pin low resets the Flash device. Driving the $\overline{\text{RESET}}$ pin high puts the device in normal operating mode. The SO pin is in high impedance state while the device is in reset. A successful reset will reset the status register to its power-up state. See Table 25 for default power-up modes. A device reset during an active Program or Erase operation aborts the operation and data of the targeted address range may be corrupted or lost due to the aborted erase or program operation. The device exits AAI Programming Mode in progress and places the SO pin in high impedance state.

**Table 25. RESET Timing**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| *Timing Requirements* | | | | |
| $t_{RECR}$ | Reset Recovery from Read | | 100 | ns |
| $t_{RECP}$ | Reset Recovery from Program | | 10 | µs |
| $f_{RECE}$ | Reset Recovery from Erase | | 1 | ms |

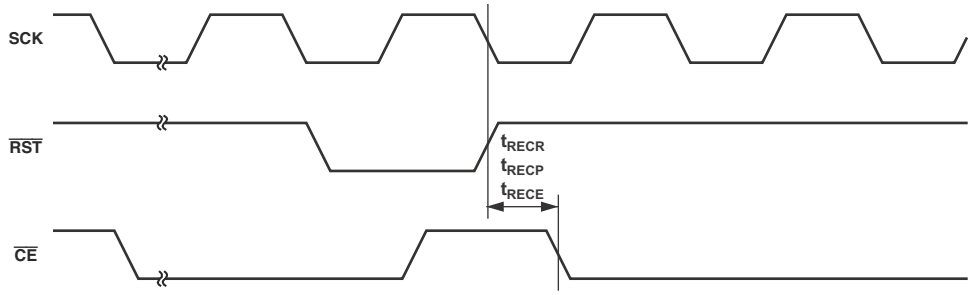



*Figure 9. Flash Reset Timing*

### *Asynchronous Memory Read Cycle Timing*

**Table 26. Asynchronous Memory Read Cycle Timing**

| Parameter | | $V_{DDMEM}$ 1.8 V Nominal Min | $V_{DDMEM}$ 1.8 V Nominal Max | $V_{DDMEM}$ 2.5 V/3.3 V Nominal Min | $V_{DDMEM}$ 2.5 V/3.3 V Nominal Max | Unit |
|---|---|---|---|---|---|---|
| *Timing Requirements* | | | | | | |
| $t_{SDAT}$ | DATA15–0 Setup Before CLKOUT | 2.1 | | 2.1 | | ns |
| $t_{HDAT}$ | DATA15–0 Hold After CLKOUT | 1.2 | | 0.8 | | ns |
| $t_{SARDY}$ | ARDY Setup Before CLKOUT | 4 | | 4 | | ns |
| $t_{HARDY}$ | ARDY Hold After CLKOUT | 0.2 | | 0.2 | | ns |
| *Switching Characteristics* | | | | | | |
| $t_{DO}$ | Output Delay After CLKOUT[1] | | 6 | | 6 | ns |
| $t_{HO}$ | Output Hold After CLKOUT [1] | 0.8 | | 0.8 | | ns |

[1] Output pins/balls include $\overline{AMS3-0}$, $\overline{ABE1-0}$, ADDR19–1, $\overline{AOE}$, $\overline{ARE}$.

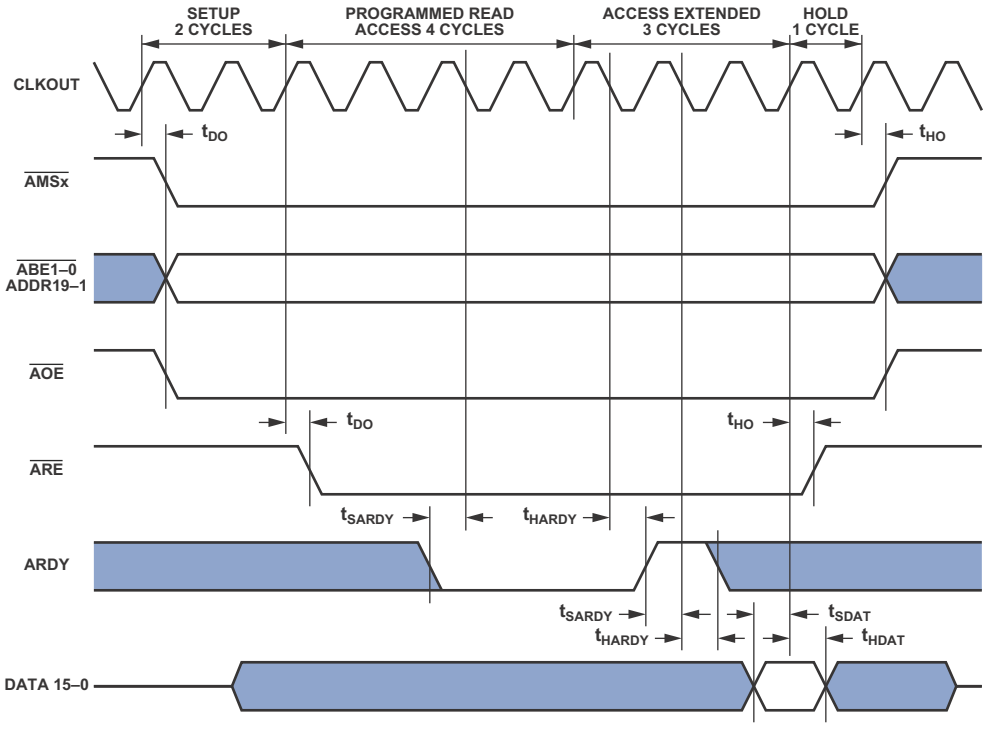



*Figure 10. Asynchronous Memory Read Cycle Timing*

### *Asynchronous Memory Write Cycle Timing*

**Table 27. Asynchronous Memory Write Cycle Timing**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| *Timing Requirements* | | | | |
| $t_{SARDY}$ | ARDY Setup Before CLKOUT | 4 | | ns |
| $t_{HARDY}$ | ARDY Hold After CLKOUT | 0.2 | | ns |
| *Switching Characteristics* | | | | |
| $t_{DDAT}$ | DATA15–0 Disable After CLKOUT | | 6 | ns |
| $t_{ENDAT}$ | DATA15–0 Enable After CLKOUT | 0 | | ns |
| $t_{DO}$ | Output Delay After CLKOUT[1] | | 6 | ns |
| $t_{HO}$ | Output Hold After CLKOUT [1] | 0.8 | | ns |

[1] Output pins/balls include $\overline{AMS3-0}$, $\overline{ABE1-0}$, ADDR19–1, DATA15–0, $\overline{AOE}$, $\overline{AWE}$.

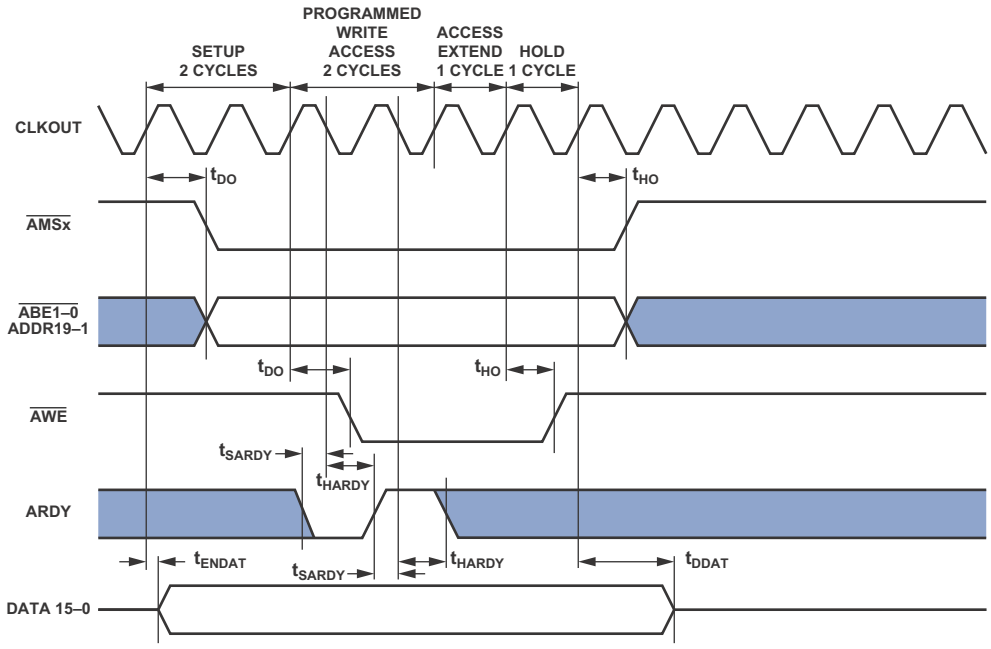



*Figure 11. Asynchronous Memory Write Cycle Timing*

### *SDRAM Interface Timing*

**Table 28. SDRAM Interface Timing**

| Parameter | | $V_{DDMEM}$ 1.8 V Nominal | | $V_{DDMEM}$ 2.5 V/3.3 V Nominal | | Unit |
|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | |
| *Timing Requirements* | | | | | | |
| $t_{SSDAT}$ | Data Setup Before CLKOUT | 1.5 | | 1.5 | | ns |
| $t_{HSDAT}$ | Data Hold After CLKOUT | 1.3 | | 0.8 | | ns |
| *Switching Characteristics* | | | | | | |
| $t_{SCLK}$ | CLKOUT Period[1] | 12.5 | | 10 | | ns |
| $t_{SCLKH}$ | CLKOUT Width High | 5 | | 4 | | ns |
| $t_{SCLKL}$ | CLKOUT Width Low | 5 | | 4 | | ns |
| $t_{DCAD}$ | Command, Address, Data Delay After CLKOUT[2] | | 5 | | 4 | ns |
| $t_{HCAD}$ | Command, Address, Data Hold After CLKOUT[2] | 1 | | 1 | | ns |
| $t_{DSDAT}$ | Data Disable After CLKOUT | | 5.5 | | 5 | ns |
| $t_{ENSDAT}$ | Data Enable After CLKOUT | 0 | | 0 | | ns |

[1] The $t_{SCLK}$ value is the inverse of the $f_{SCLK}$ specification discussed in Table 11 on Page 21. Package type and reduced supply voltages affect the best-case value listed here.
[2] Command pins/balls include: $\overline{SRAS}$, $\overline{SCAS}$, $\overline{SWE}$, SDQM, $\overline{SMS}$, SA10, SCKE.

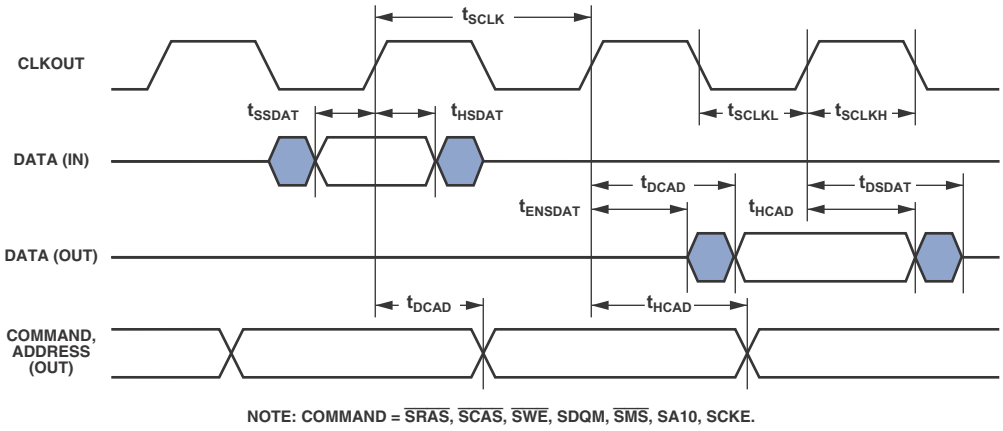



*Figure 12. SDRAM Interface Timing*

### *External DMA Request Timing*

Table 29 and Figure 13 describe the External DMA Request operations.

**Table 29. External DMA Request Timing[1]**

| Parameter | | $V_{DDMEM}/V_{DDEXT}$ 1.8 V Nominal | | $V_{DDMEM}/V_{DDEXT}$ 2.5 V/3.3 V Nominal | | Unit |
|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | |
| *Timing PRequirements* | | | | | | |
| $t_{DR}$ | DMARx Asserted to CLKOUT High Setup | 9 | | 7.2 | | ns |
| $t_{DH}$ | CLKOUT High to DMARx Deasserted Hold Time | 0 | | 0 | | ns |
| $t_{DMARACT}$ | DMARx Active Pulse Width | $t_{SCLK} + 1$ | | $t_{SCLK} + 1$ | | ns |
| $t_{DMARINACT}$ | DMARx Inactive Pulse Width | $1.75 \times t_{SCLK}$ | | $1.75 \times t_{SCLK}$ | | ns |

[1] Because the external DMA control pins are part of the $V_{DDEXT}$ power domain and the CLKOUT signal is part of the $V_{DDMEM}$ power domain, systems in which $V_{DDEXT}$ and $V_{DDMEM}$ are NOT equal may require level shifting logic for correct operation.

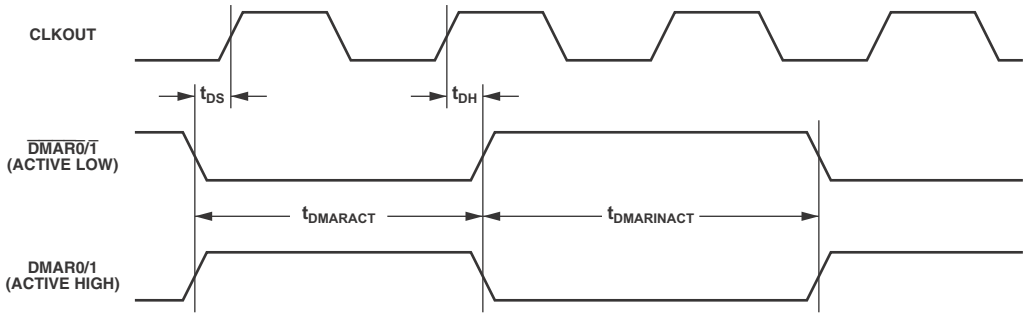



*Figure 13. External DMA Request Timing*

### *Parallel Peripheral Interface Timing*

Table 30 and Figure 15 on Page 33, Figure 21 on Page 38, and Figure 24 on Page 40 describe parallel peripheral interface operations.

**Table 30. Parallel Peripheral Interface Timing**

| Parameter | | $V_{DDEXT}$ 1.8 V Nominal Min | $V_{DDEXT}$ 1.8 V Nominal Max | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Min | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Max | Unit |
|---|---|---|---|---|---|---|
| *Timing Requirements* | | | | | | |
| $t_{PCLKW}$ | PPI_CLK Width | $t_{SCLK} - 1.5$ | | $t_{SCLK} - 1.5$ | | ns |
| $t_{PCLK}$ | PPI_CLK Period | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| *Timing Requirements - GP Input and Frame Capture Modes* | | | | | | |
| $t_{PSUD}$ | External Frame Sync Startup Delay[1] | $4 \times t_{PCLK}$ | | $4 \times t_{PCLK}$ | | ns |
| $t_{SFSPE}$ | External Frame Sync Setup Before PPI_CLK (Nonsampling Edge for Rx, Sampling Edge for Tx) | 6.7 | | 6.7 | | ns |
| $t_{HFSPE}$ | External Frame Sync Hold After PPI_CLK | 1.75 | | 1.75 | | ns |
| $t_{SDRPE}$ | Receive Data Setup Before PPI_CLK | 4.1 | | 3.5 | | ns |
| $t_{HDRPE}$ | Receive Data Hold After PPI_CLK | 2 | | 1.6 | | ns |
| *Switching Characteristics - GP Output and Frame Capture Modes* | | | | | | |
| $t_{DFSPE}$ | Internal Frame Sync Delay After PPI_CLK | | 8 | | 8 | ns |
| $t_{HOFSPE}$ | Internal Frame Sync Hold After PPI_CLK | 1.7 | | 1.7 | | ns |
| $t_{DDTPE}$ | Transmit Data Delay After PPI_CLK | | 8.2 | | 8 | ns |
| $t_{HDTPE}$ | Transmit Data Hold After PPI_CLK | 2.3 | | 1.9 | | ns |

[1] The PPI port is fully enabled 4 PPI clock cycles after the PAB write to the PPI port enable bit. Only after the PPI port is fully enabled are external frame syncs and data words guaranteed to be received correctly by the PPI peripheral.

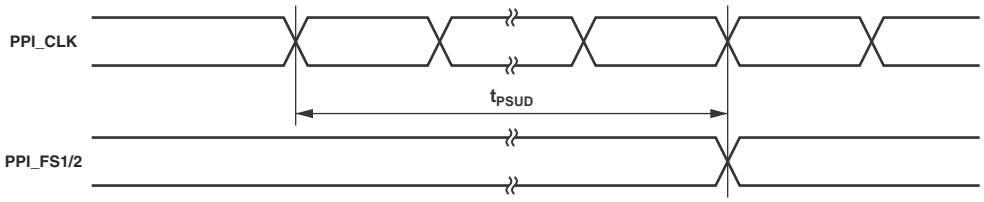



*Figure 14. PPI with External Frame Sync Timing*

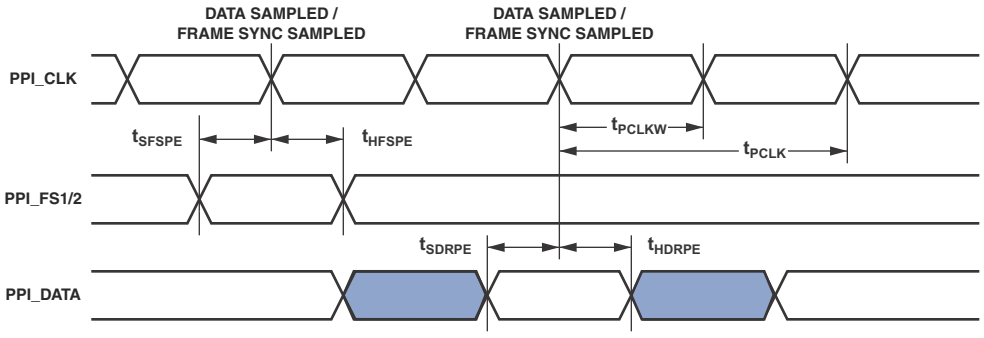



*Figure 15. PPI GP Rx Mode with External Frame Sync Timing*

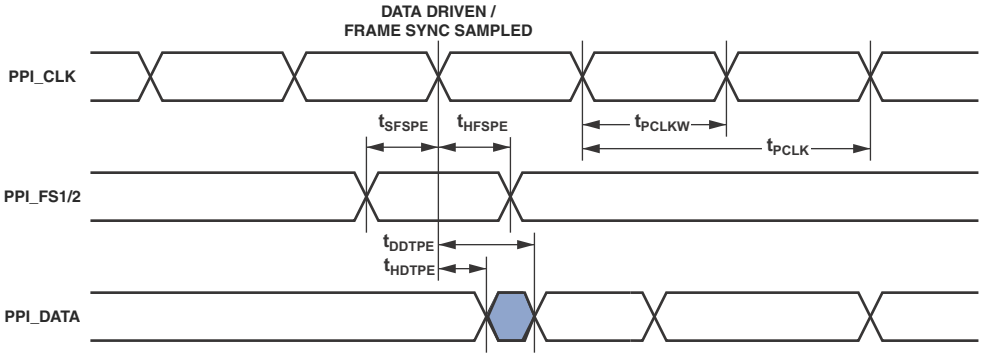



*Figure 16. PPI GP Tx Mode with External Frame Sync Timing*

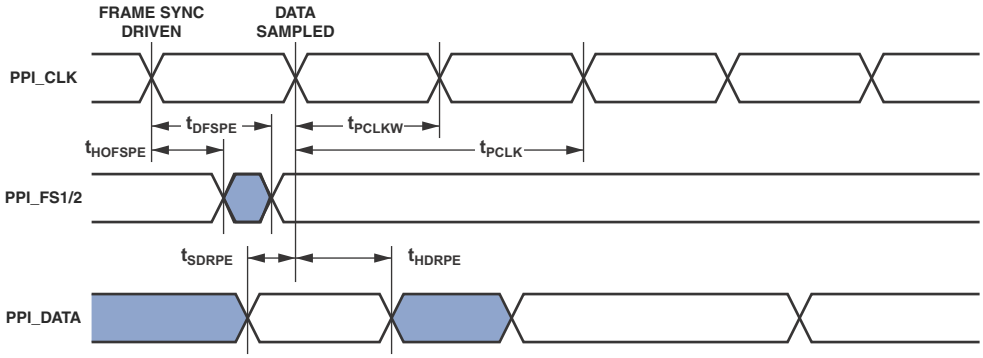



*Figure 17. PPI GP Rx Mode with Internal Frame Sync Timing*

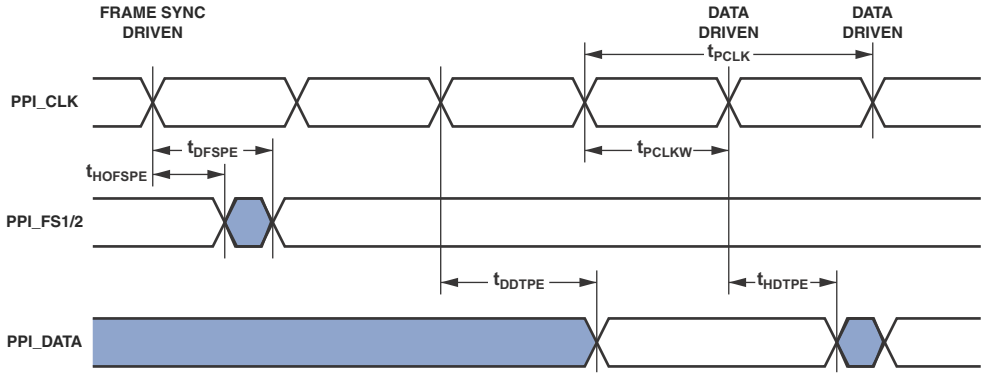



*Figure 18. PPI GP Tx Mode with Internal Frame Sync Timing*

### *RSI Controller Timing*

Table 31 and Figure 19 describe RSI controller timing. Table 32 and Figure 20 describe RSI controller (high speed) timing.

**Table 31. RSI Controller Timing**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| *Timing Requirements* | | | | |
| $t_{ISU}$ | Input Setup Time | 5.6 | | ns |
| $t_{IH}$ | Input Hold Time | 2 | | ns |
| *Switching Characteristics* | | | | |
| $f_{PP}$[1] | Clock Frequency Data Transfer Mode | 0 | 25 | MHz |
| $f_{OD}$ | Clock Frequency Identification Mode | 100[2] | 400 | kHz |
| $t_{WL}$ | Clock Low Time | 10 | | ns |
| $t_{WH}$ | Clock High Time | 10 | | ns |
| $t_{TLH}$ | Clock Rise Time | | 10 | ns |
| $t_{THL}$ | Clock Fall Time | | 10 | ns |
| $t_{ODLY}$ | Output Delay Time During Data Transfer Mode | | 14 | ns |
| $t_{ODLY}$ | Output Delay Time During Identification Mode | | 50 | ns |

[1] $t_{PP} = 1/f_{PP}$

[2] Specification can be 0 kHz, which means to stop the clock. The given minimum frequency range is for cases where a continuous clock is required.

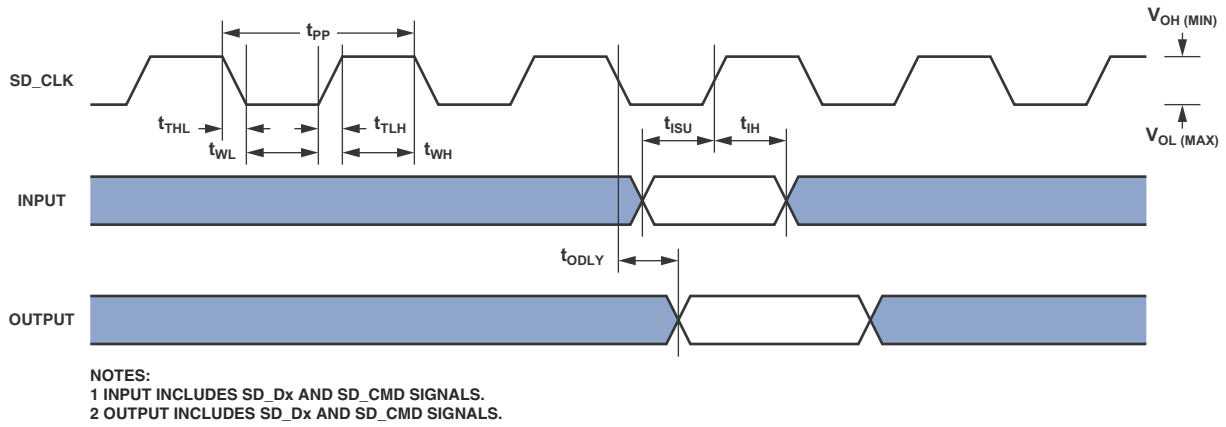



*Figure 19. RSI Controller Timing*

**Table 32. RSI Controller Timing (High Speed Mode)**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| *Timing Requirements* | | | | |
| $t_{ISU}$ | Input Setup Time | 5.6 | | ns |
| $t_{IH}$ | Input Hold Time | 2 | | ns |
| *Switching Characteristics* | | | | |
| $f_{PP}$[1] | Clock Frequency Data Transfer Mode | 0 | 50 | MHz |
| $t_{WL}$ | Clock Low Time | 7 | | ns |
| $t_{WH}$ | Clock High Time | 7 | | ns |
| $t_{TLH}$ | Clock Rise Time | | 3 | ns |
| $t_{THL}$ | Clock Fall Time | | 3 | ns |
| $t_{ODLY}$ | Output Delay Time During Data Transfer Mode | | 4 | ns |
| $t_{OH}$ | Output Hold Time | 2.75 | | ns |

[1] $t_{PP} = 1/f_{PP}$

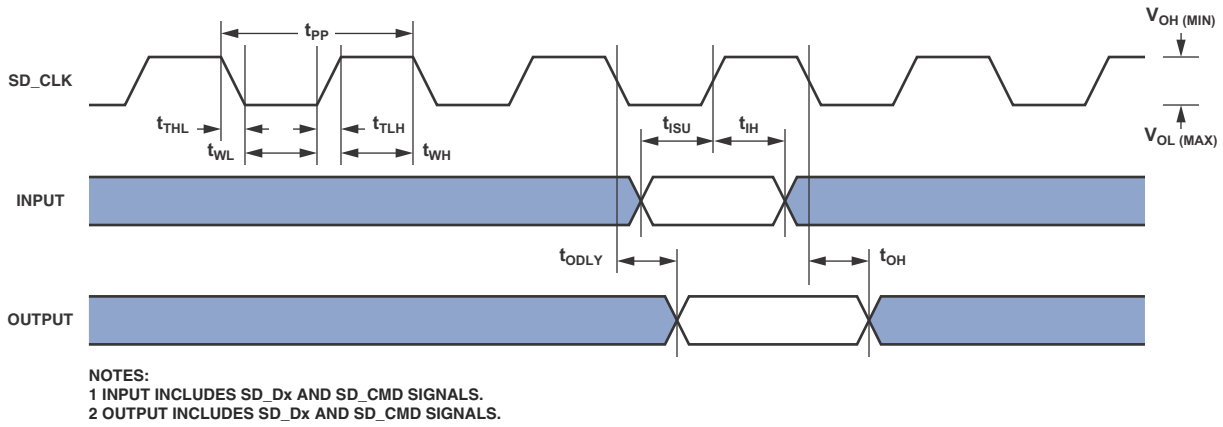



*Figure 20. RSI Controller Timing (High Speed Mode)*

### *Serial Ports*

Table 33 through Table 36 on Page 40 and Figure 21 on Page 38 through Figure 24 on Page 40 describe serial port operations.

**Table 33. Serial Ports—External Clock**

| Parameter | | $V_{DDEXT}$ 1.8 V Nominal | | $V_{DDEXT}$ 2.5 V/3.3 V Nominal | | Unit |
|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | |
| *Timing Requirements* | | | | | | |
| $t_{SFSE}$[1] | TFSx/RFSx Setup Before TSCLKx/RSCLKx | 3 | | 3 | | ns |
| $t_{HFSE}$[1] | TFSx/RFSx Hold After TSCLKx/RSCLKx | 3 | | 3 | | ns |
| $t_{SDRE}$[1] | Receive Data Setup Before RSCLKx | 3 | | 3 | | ns |
| $t_{HDRE}$[1] | Receive Data Hold After RSCLKx | 3.5 | | 3 | | ns |
| $t_{SCLKEW}$ | TSCLKx/RSCLKx Width | 7 | | 4.5 | | ns |
| $t_{SCLKE}$ | TSCLKx/RSCLKx Period | $2 \times t_{SCLK}$ | | $2 \times t_{SCLK}$ | | ns |
| $t_{SUDTE}$[2] | Start-Up Delay From SPORT Enable To First External TFSx | $4 \times t_{SCLKE}$ | | $4 \times t_{SCLKE}$ | | ns |
| $t_{SUDRE}$[2] | Start-Up Delay From SPORT Enable To First External RFSx | $4 \times t_{SCLKE}$ | | $4 \times t_{SCLKE}$ | | ns |
| *Switching Characteristics* | | | | | | |
| $t_{DFSE}$[3] | TFSx/RFSx Delay After TSCLKx/RSCLKx (Internally Generated TFSx/RFSx) | | 10 | | 10 | ns |
| $t_{HOFSE}$[3] | TFSx/RFSx Hold After TSCLKx/RSCLKx (Internally Generated TFSx/RFSx) | 0 | | 0 | | ns |
| $t_{DDTE}$[3] | Transmit Data Delay After TSCLKx | | 10 | | 10 | ns |
| $t_{HDTE}$[3] | Transmit Data Hold After TSCLKx | 0 | | 0 | | ns |

[1] Referenced to sample edge.
[2] Verified in design but untested.
[3] Referenced to drive edge.

**Table 34. Serial Ports—Internal Clock**

| Parameter | | $V_{DDEXT}$ 1.8 V Nominal | | $V_{DDEXT}$ 2.5 V/3.3 V Nominal | | Unit |
|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | |
| *Timing Requirements* | | | | | | |
| $t_{SFSI}$[1] | TFSx/RFSx Setup Before TSCLKx/RSCLKx | 11 | | 9.6 | | ns |
| $t_{HFSI}$[1] | TFSx/RFSx Hold After TSCLKx/RSCLKx | –1.5 | | –1.5 | | ns |
| $t_{SDRI}$[1] | Receive Data Setup Before RSCLKx | 11 | | 9.6 | | ns |
| $t_{HDRI}$[1] | Receive Data Hold After RSCLKx | –1.5 | | –1.5 | | ns |
| *Switching Characteristics* | | | | | | |
| $t_{DFSI}$[2] | TFSx/RFSx Delay After TSCLKx/RSCLKx (Internally Generated TFSx/RFSx) | | 3 | | 3 | ns |
| $t_{HOFSI}$[2] | TFSx/RFSx Hold After TSCLKx/RSCLKx (Internally Generated TFSx/RFSx) | –2 | | –1 | | ns |
| $t_{DDTI}$[2] | Transmit Data Delay After TSCLKx | | 3 | | 3 | ns |
| $t_{HDTI}$[2] | Transmit Data Hold After TSCLKx | –1.8 | | –1.5 | | ns |
| $t_{SCLKIW}$ | TSCLKx/RSCLKx Width | 10 | | 8 | | ns |

[1] Referenced to sample edge.
[2] Referenced to drive edge.

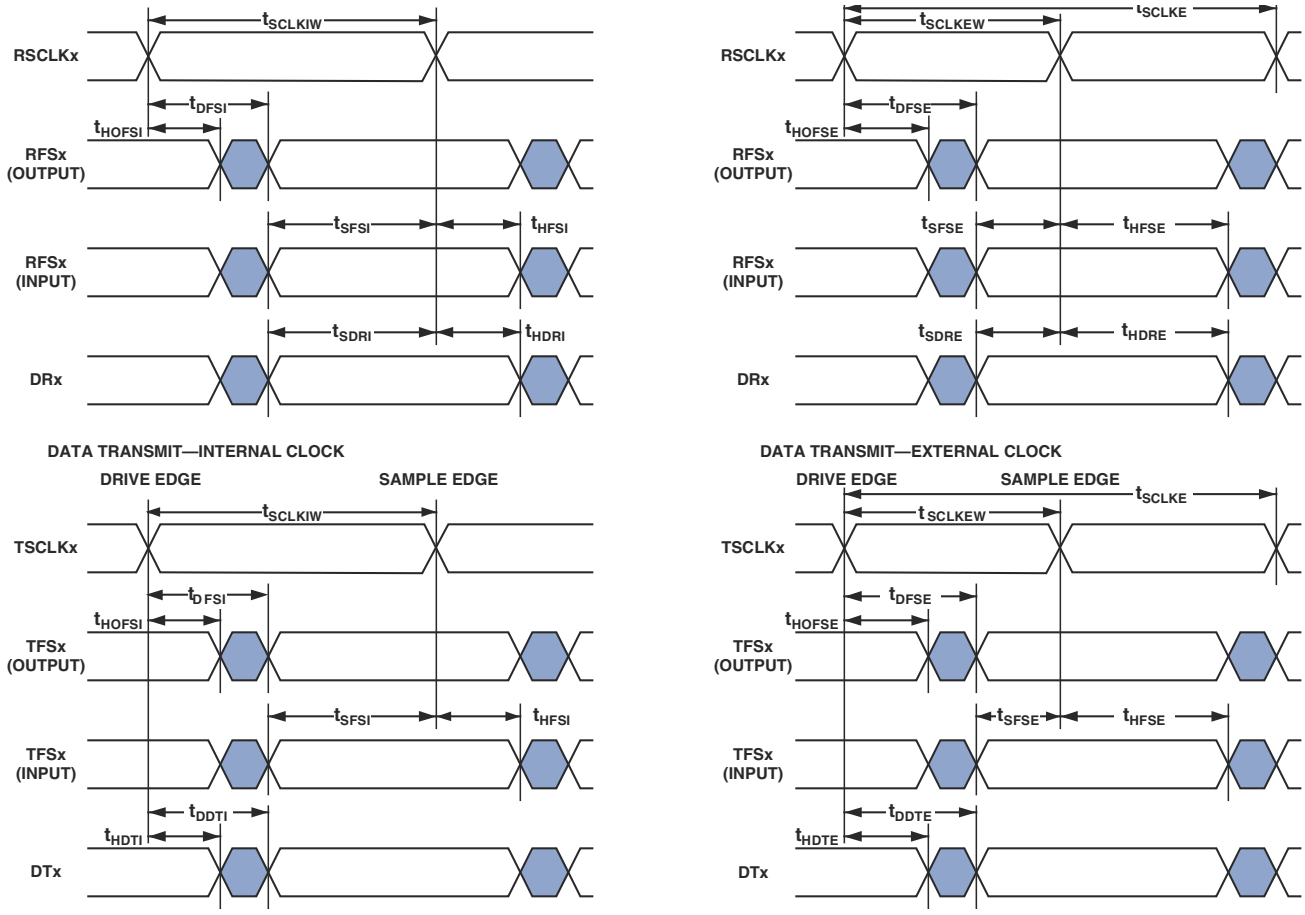



*Figure 21. Serial Ports*

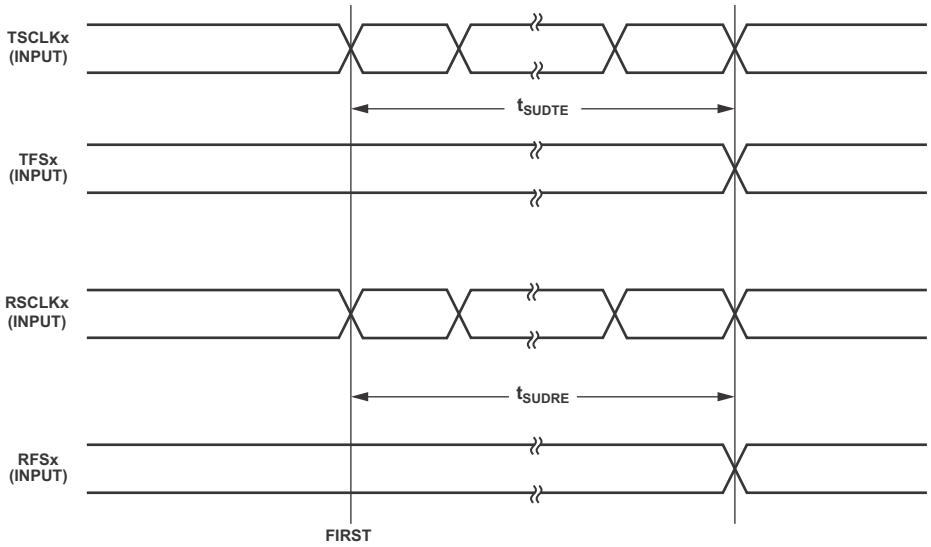



*Figure 22. Serial Port Start Up with External Clock and Frame Sync*

**Table 35. Serial Ports—Enable and Three-State[1]**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| *Switching Characteristics* | | | | |
| $t_{DTENE}$ | Data Enable Delay from External TSCLKx | 0 | | ns |
| $t_{DDTTE}$ | Data Disable Delay from External TSCLKx | | $t_{SCLK}$ + 1 | ns |
| $t_{DTENI}$ | Data Enable Delay from Internal TSCLKx | –2.0 | | ns |
| $t_{DDTTI}$ | Data Disable Delay from Internal TSCLKx | | $t_{SCLK}$ + 1 | ns |

[1] Referenced to drive edge.

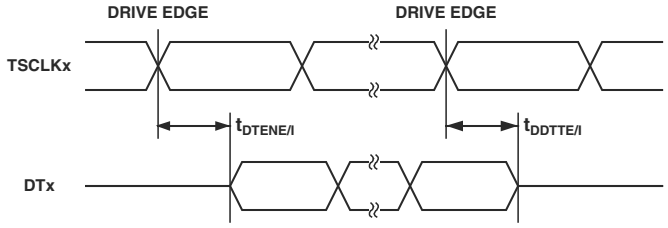



*Figure 23. Enable and Three-State*

**Table 36. External Late Frame Sync**

| Parameter | | $V_{DDEXT}$ 1.8 V Nominal Min | $V_{DDEXT}$ 1.8 V Nominal Max | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Min | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Max | Unit |
|---|---|---|---|---|---|---|
| *Switching Characteristics* | | | | | | |
| $t_{DDTLFSE}$[1, 2] | Data Delay from Late External TFSx or External RFSx with MCE = 1, MFD = 0 | | 12 | | 10 | ns |
| $t_{DTENLFSE}$[1, 2] | Data Enable from Late FS or MCE = 1, MFD = 0 | 0 | | 0 | | ns |

[1] MCE = 1, TFSx enable and TFSx valid follow $t_{DDTENFS}$ and $t_{DDTLFSE}$.
[2] If external RFSx/TFSx setup to RSCLKx/TSCLKx > $t_{SCLKE}/2$ then $t_{DDTTE/I}$ and $t_{DTENE/I}$ apply, otherwise $t_{DDTLFSE}$ and $t_{DTENLFS}$ apply.

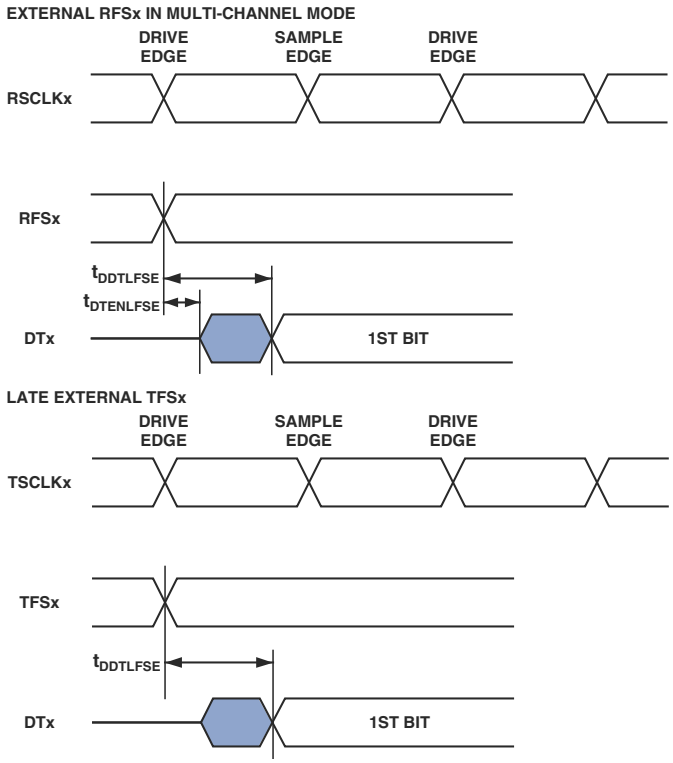



*Figure 24. External Late Frame Sync*

### *Serial Peripheral Interface (SPI) Port—Master Timing*

Table 37 and Figure 25 describe SPI port master operations.

**Table 37. Serial Peripheral Interface (SPI) Port—Master Timing**

| Parameter | | $V_{DDEXT}$ 1.8 V Nominal | | $V_{DDEXT}$ 2.5 V/3.3 V Nominal | | Unit |
|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | |
| *Timing Requirements* | | | | | | |
| $t_{SSPIDM}$ | Data Input Valid to SCK Edge (Data Input Setup) | 11.6 | | 9.6 | | ns |
| $t_{HSPIDM}$ | SCK Sampling Edge to Data Input Invalid | –1.5 | | –1.5 | | ns |
| *Switching Characteristics* | | | | | | |
| $t_{SDSCIM}$ | $\overline{SPISELx}$ low to First SCK Edge | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| $t_{SPICHM}$ | Serial Clock High Period | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| $t_{SPICLM}$ | Serial Clock Low Period | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| $t_{SPICLK}$ | Serial Clock Period | $4 \times t_{SCLK}$ | | $4 \times t_{SCLK}$ | | ns |
| $t_{HDSM}$ | Last SCK Edge to $\overline{SPISELx}$ High | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| $t_{SPITDM}$ | Sequential Transfer Delay | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| $t_{DDSPIDM}$ | SCK Edge to Data Out Valid (Data Out Delay) | | 6 | | 6 | ns |
| $t_{HDSPIDM}$ | SCK Edge to Data Out Invalid (Data Out Hold) | –1 | | –1 | | ns |

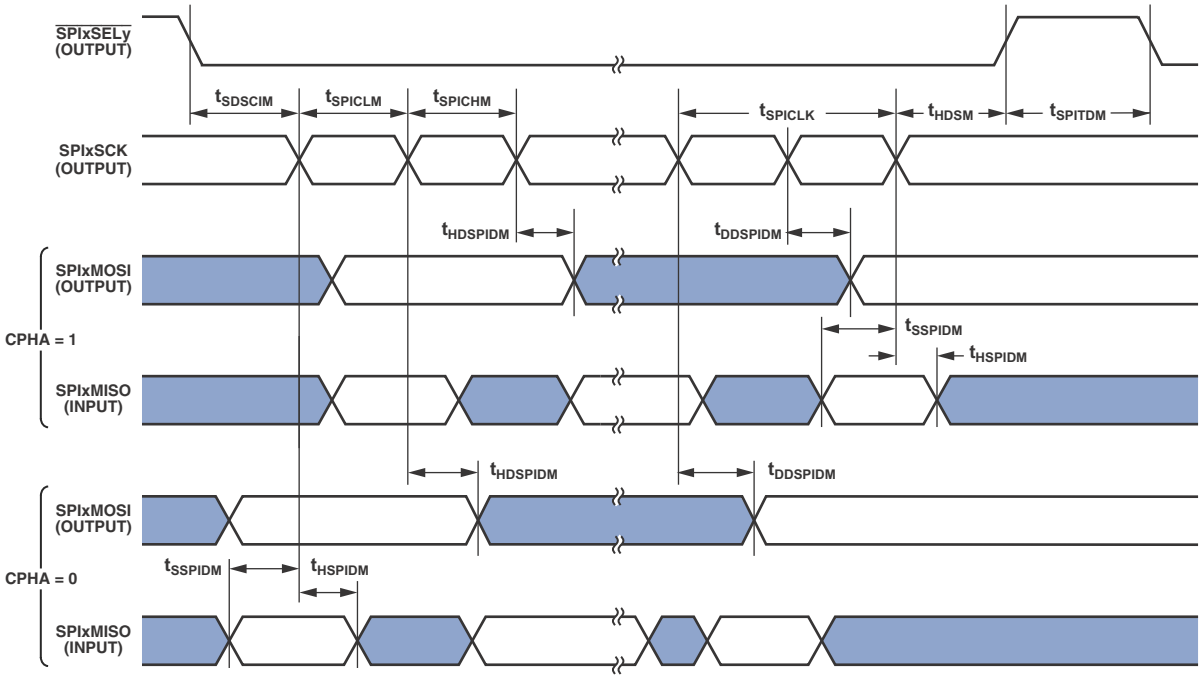



*Figure 25. Serial Peripheral Interface (SPI) Port—Master Timing*

### *Serial Peripheral Interface (SPI) Port—Slave Timing*

Table 38 and Figure 26 describe SPI port slave operations.

**Table 38. Serial Peripheral Interface (SPI) Port—Slave Timing**

| Parameter | | $V_{DDEXT}$ 1.8 V Nominal Min | $V_{DDEXT}$ 1.8 V Nominal Max | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Min | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Max | Unit |
|---|---|---|---|---|---|---|
| *Timing Requirements* | | | | | | |
| $t_{SPICHS}$ | Serial Clock High Period | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| $t_{SPICLS}$ | Serial Clock Low Period | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| $t_{SPICLK}$ | Serial Clock Period | $4 \times t_{SCLK} - 1.5$ | | $4 \times t_{SCLK} - 1.5$ | | ns |
| $t_{HDS}$ | Last SCK Edge to $\overline{SPISS}$ Not Asserted | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| $t_{SPITDS}$ | Sequential Transfer Delay | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| $t_{SDSCI}$ | $\overline{SPISS}$ Assertion to First SCK Edge | $2 \times t_{SCLK} - 1.5$ | | $2 \times t_{SCLK} - 1.5$ | | ns |
| $t_{SSPID}$ | Data Input Valid to SCK Edge (Data Input Setup) | 1.6 | | 1.6 | | ns |
| $t_{HSPID}$ | SCK Sampling Edge to Data Input Invalid | 2 | | 1.6 | | ns |
| *Switching Characteristics* | | | | | | |
| $t_{DSOE}$ | $\overline{SPISS}$ Assertion to Data Out Active | 0 | 12 | 0 | 10.3 | ns |
| $t_{DSDHI}$ | $\overline{SPISS}$ Deassertion to Data High Impedance | 0 | 11 | 0 | 9 | ns |
| $t_{DDSPID}$ | SCK Edge to Data Out Valid (Data Out Delay) | | 10 | | 10 | ns |
| $t_{HDSPID}$ | SCK Edge to Data Out Invalid (Data Out Hold) | 0 | | 0 | | ns |

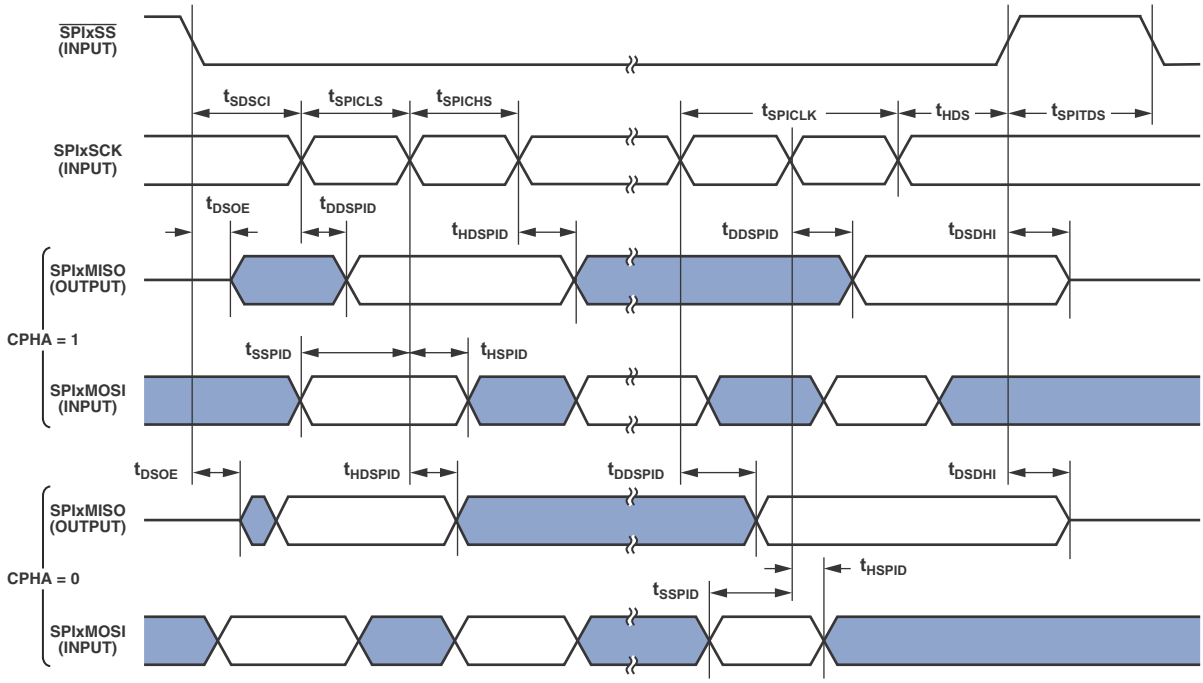



*Figure 26. Serial Peripheral Interface (SPI) Port—Slave Timing*

### *Universal Asynchronous Receiver-Transmitter (UART) Ports—Receive and Transmit Timing*

The UART ports receive and transmit operations are described in the *ADSP-BF51x Hardware Reference Manual*.

### General-Purpose Port Timing

Table 39 and Figure 27 describe general-purpose port operations.

**Table 39. General-Purpose Port Timing**

| Parameter | | $V_{DDEXT}$ 1.8 V Nominal Min | $V_{DDEXT}$ 1.8 V Nominal Max | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Min | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Max | Unit |
|---|---|---|---|---|---|---|
| *Timing Requirement* | | | | | | |
| $t_{WFI}$ | General-Purpose Port Signal Input Pulse Width | $t_{SCLK}$ + 1 | | $t_{SCLK}$ + 1 | | ns |
| *Switching Characteristics* | | | | | | |
| $t_{GPOD}$ | General-Purpose Port Signal Output Delay from CLKOUT Low | 0 | 11 | 0 | 8.5 | ns |

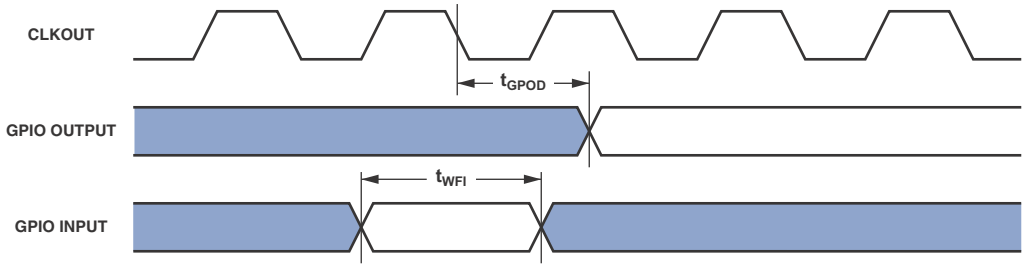



*Figure 27. General-Purpose Port Timing*

### Timer Clock Timing

Table 40 and Figure 28 describe timer clock timing.

**Table 40. Timer Clock Timing**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| *Switching Characteristic* | | | | |
| $t_{TODP}$ | Timer Output Update Delay After PPICLK High | | 12 | ns |

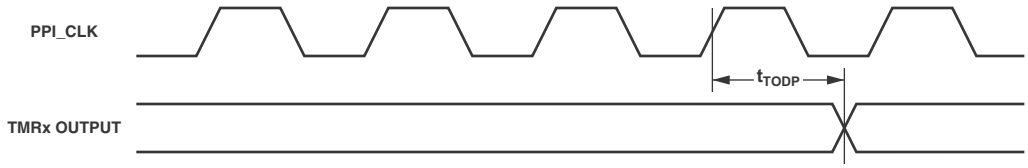



*Figure 28. Timer Clock Timing*

### *Timer Cycle Timing*

Table 41 and Figure 29 describe timer expired operations. The input signal is asynchronous in "width capture mode" and "external clock mode" and has an absolute maximum input frequency of ($f_{SCLK}$/2) MHz.

**Table 41. Timer Cycle Timing**

| | | $V_{DDEXT}$ 1.8 V Nominal | | $V_{DDEXT}$ 2.5 V/3.3 V Nominal | | |
|---|---|---|---|---|---|---|
| **Parameter** | | **Min** | **Max** | **Min** | **Max** | **Unit** |
| *Timing Characteristics* | | | | | | |
| $t_{WL}$[1] | Timer Pulse Width Input Low (Measured In SCLK Cycles) | $t_{SCLK}$ | | $t_{SCLK}$ | | ns |
| $t_{WH}$[1] | Timer Pulse Width Input High (Measured In SCLK Cycles) | $t_{SCLK}$ | | $t_{SCLK}$ | | ns |
| $t_{TIS}$[2] | Timer Input Setup Time Before CLKOUT Low | 10 | | 7 | | ns |
| $t_{TIH}$[2] | Timer Input Hold Time After CLKOUT Low | –2 | | –2 | | ns |
| *Switching Characteristics* | | | | | | |
| $t_{HTO}$ | Timer Pulse Width Output (Measured In SCLK Cycles) | $t_{SCLK}$ – 1.5 | $(2^{32}–1)t_{SCLK}$ | $t_{SCLK}$ – 1 | $(2^{32}–1)t_{SCLK}$ | ns |
| $t_{TOD}$ | Timer Output Update Delay After CLKOUT High | | 6 | | 6 | ns |

[1] The minimum pulse widths apply for TMRx signals in width capture and external clock modes. They also apply to the PF15 or PPI_CLK signals in PWM output mode.
[2] Either a valid setup and hold time or a valid pulse width is sufficient. There is no need to resynchronize programmable flag inputs.

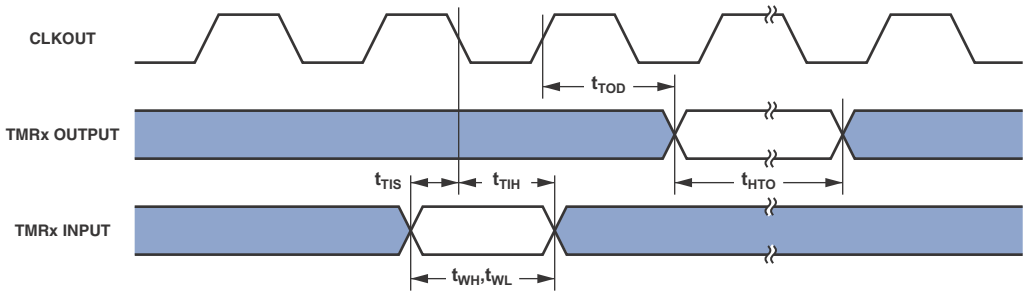



*Figure 29. Timer Cycle Timing*

### *Up/Down Counter/Rotary Encoder Timing*

**Table 42. Up/Down Counter/Rotary Encoder Timing**

| Parameter | | $V_{DDEXT}$ 1.8 V Nominal Min | $V_{DDEXT}$ 1.8 V Nominal Max | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Min | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Max | Unit |
|---|---|---|---|---|---|---|
| *Timing Requirements* | | | | | | |
| $t_{WCOUNT}$ | Up/Down Counter/Rotary Encoder Input Pulse Width | $t_{SCLK}$ + 1 | | $t_{SCLK}$ + 1 | | ns |
| $t_{CIS}$ | Counter Input Setup Time Before CLKOUT Low[1] | 9 | | 7 | | ns |
| $t_{CIH}$ | Counter Input Hold Time After CLKOUT Low[1] | 0 | | 0 | | ns |

[1] Either a valid setup and hold time or a valid pulse width is sufficient. There is no need to resynchronize counter inputs.

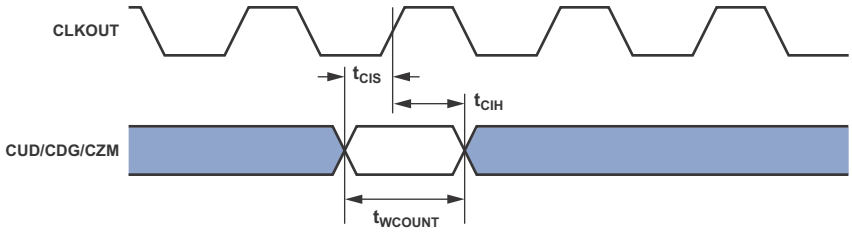



*Figure 30. Up/Down Counter/Rotary Encoder Timing*

### *10/100 Ethernet MAC Controller Timing*

Table 43 through Table 48 and Figure 31 through Figure 36 describe the 10/100 Ethernet MAC Controller operations.

**Table 43. 10/100 Ethernet MAC Controller Timing: MII Receive Signal**

| Parameter[1] | | $V_{DDEXT}$ 1.8 V Nominal Min | $V_{DDEXT}$ 1.8 V Nominal Max | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Min | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Max | Unit |
|---|---|---|---|---|---|---|
| *Timing Requirements* | | | | | | |
| $t_{ERXCLKF}$ | ERxCLK Frequency ($f_{SCLK}$ = SCLK Frequency) | None | 25 + 1% | None | 25 + 1% | MHz |
| $t_{ERXCLKW}$ | ERxCLK Width ($t_{ERxCLK}$ = ERxCLK Period) | $t_{ERxCLK}$ x 40% | $t_{ERxCLK}$ x 60% | $t_{ERxCLK}$ x 35% | $t_{ERxCLK}$ x 65% | ns |
| $t_{ERXCLKIS}$ | Rx Input Valid to ERxCLK Rising Edge (Data In Setup) | 7.5 | | 7.5 | | ns |
| $t_{ERXCLKIH}$ | ERxCLK Rising Edge to Rx Input Invalid (Data In Hold) | 7.5 | | 7.5 | | ns |

[1] MII inputs synchronous to ERxCLK are ERxD3–0, ERxDV, and ERxER.

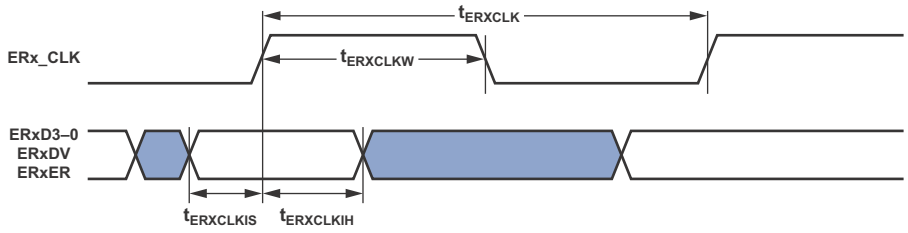



*Figure 31. 10/100 Ethernet MAC Controller Timing: MII Receive Signal*

**Table 44. 10/100 Ethernet MAC Controller Timing: MII Transmit Signal**

| Parameter[1] | | $V_{DDEXT}$ 1.8 V Nominal Min | $V_{DDEXT}$ 1.8 V Nominal Max | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Min | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Max | Unit |
|---|---|---|---|---|---|---|
| *Switching Characteristics* | | | | | | |
| $t_{ETF}$ | ETxCLK Frequency ($f_{SCLK}$ = SCLK Frequency) | None | 25 + 1% | None | 25 + 1% | MHz |
| $t_{ETXCLKW}$ | ETxCLK Width ($t_{ETxCLK}$ = ETxCLK Period) | $t_{ETxCLK} \times 40\%$ | $t_{ETxCLK} \times 60\%$ | $t_{ETxCLK} \times 35\%$ | $t_{ETxCLK} \times 65\%$ | ns |
| $t_{ETXCLKOV}$ | ETxCLK Rising Edge to Tx Output Valid (Data Out Valid) | | 20 | | 20 | ns |
| $t_{ETXCLKOH}$ | ETxCLK Rising Edge to Tx Output Invalid (Data Out Hold) | 0 | | 0 | | ns |

[1] MII outputs synchronous to ETxCLK are ETxD3–0.

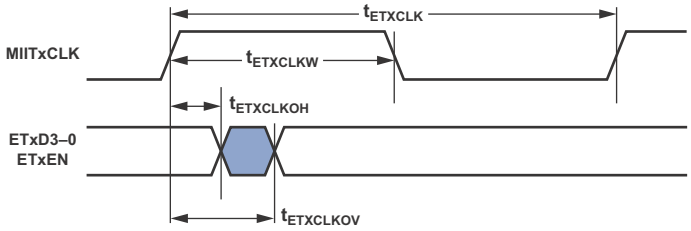



*Figure 32. 10/100 Ethernet MAC Controller Timing: MII Transmit Signal*

**Table 45. 10/100 Ethernet MAC Controller Timing: RMII Receive Signal**

| Parameter[1] | | $V_{DDEXT}$ 1.8 V Nominal Min | $V_{DDEXT}$ 1.8 V Nominal Max | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Min | $V_{DDEXT}$ 2.5 V/3.3 V Nominal Max | Unit |
|---|---|---|---|---|---|---|
| *Timing Requirements* | | | | | | |
| $t_{EREFCLKF}$ | REF_CLK Frequency ($f_{SCLK}$ = SCLK Frequency) | None | 50 + 1% | None | 50 + 1% | MHz |
| $t_{EREFCLKW}$ | EREF_CLK Width ($t_{EREFCLK}$ = EREFCLK Period) | $t_{EREFCLK} \times 40\%$ | $t_{EREFCLK} \times 60\%$ | $t_{EREFCLK} \times 35\%$ | $t_{EREFCLK} \times 65\%$ | ns |
| $t_{EREFCLKIS}$ | Rx Input Valid to RMII REF_CLK Rising Edge (Data In Setup) | 4 | | 4 | | ns |
| $t_{EREFCLKIH}$ | RMII REF_CLK Rising Edge to Rx Input Invalid (Data In Hold) | 2 | | 2 | | ns |

[1] RMII inputs synchronous to RMII REF_CLK are ERxD1–0, RMII CRS_DV, and ERxER.

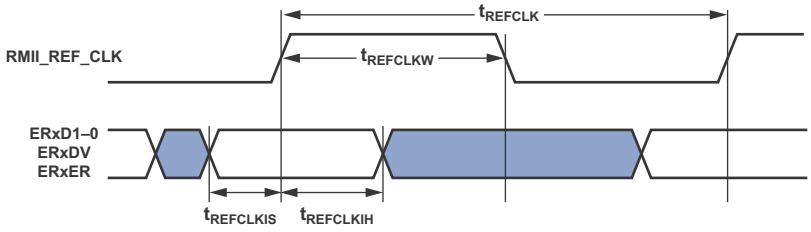



*Figure 33. 10/100 Ethernet MAC Controller Timing: RMII Receive Signal*

**Table 46. 10/100 Ethernet MAC Controller Timing: RMII Transmit Signal**

| Parameter[1] | | Min | Max | Unit |
|---|---|---|---|---|
| *Switching Characteristics* | | | | |
| $t_{EREFCLKOV}$ | RMII REF_CLK Rising Edge to Tx Output Valid (Data Out Valid) | | 8.1 | ns |
| $t_{EREFCLKOH}$ | RMII REF_CLK Rising Edge to Tx Output Invalid (Data Out Hold) | 2 | | ns |

[1] RMII outputs synchronous to RMII REF_CLK are ETxD1–0.

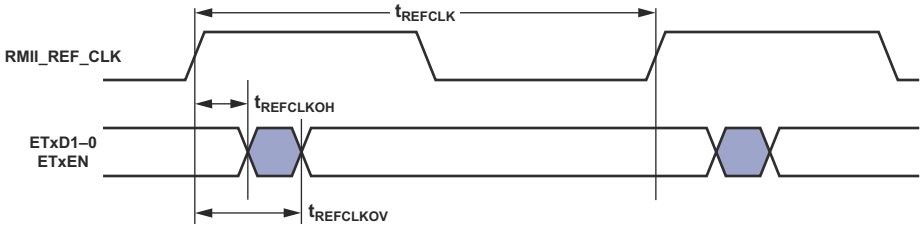



*Figure 34. 10/100 Ethernet MAC Controller Timing: RMII Transmit Signal*

**Table 47. 10/100 Ethernet MAC Controller Timing: MII/RMII Asynchronous Signal**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| *Timing Requirements* | | | | |
| $t_{ECOLH}$ | COL Pulse Width High[1] | $t_{ETxCLK} \times 1.5$ | | ns |
| | | $t_{ERxCLK} \times 1.5$ | | ns |
| $t_{ECOLL}$ | COL Pulse Width Low[1] | $t_{ETxCLK} \times 1.5$ | | ns |
| | | $t_{ERxCLK} \times 1.5$ | | ns |
| $t_{ECRSH}$ | CRS Pulse Width High[2] | $t_{ETxCLK} \times 1.5$ | | ns |
| $t_{ECRSL}$ | CRS Pulse Width Low[2] | $t_{ETxCLK} \times 1.5$ | | ns |

[1] MII/RMII asynchronous signals are COL, CRS. These signals are applicable in both MII and RMII modes. The asynchronous COL input is synchronized separately to both the ETxCLK and the ERxCLK, and must have a minimum pulse width high or low at least 1.5 times the period of the slower of the two clocks.
[2] The asynchronous CRS input is synchronized to the ETxCLK, and must have a minimum pulse width high or low at least 1.5 times the period of ETxCLK.

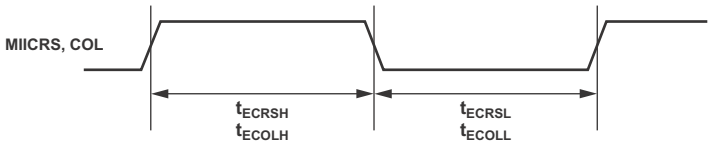



*Figure 35. 10/100 Ethernet MAC Controller Timing: Asynchronous Signal*

**Table 48. 10/100 Ethernet MAC Controller Timing: MII Station Management**

| Parameter[1] | | Min | Max | Unit |
|---|---|---|---|---|
| *Timing Requirements* | | | | |
| $t_{MDIOS}$ | MDIO Input Valid to MDC Rising Edge (Setup) | 11.5 | | ns |
| $t_{MDCIH}$ | MDC Rising Edge to MDIO Input Invalid (Hold) | 0 | | ns |
| *Switching Characteristics* | | | | |
| $t_{MDCOV}$ | MDC Falling Edge to MDIO Output Valid | | 25 | ns |
| $t_{MDCOH}$ | MDC Falling Edge to MDIO Output Invalid (Hold) | –1.25 | | ns |

[1] MDC/MDIO is a 2-wire serial bidirectional port for controlling one or more external PHYs. MDC is an output clock whose minimum period is programmable as a multiple of the system clock SCLK. MDIO is a bidirectional data line.

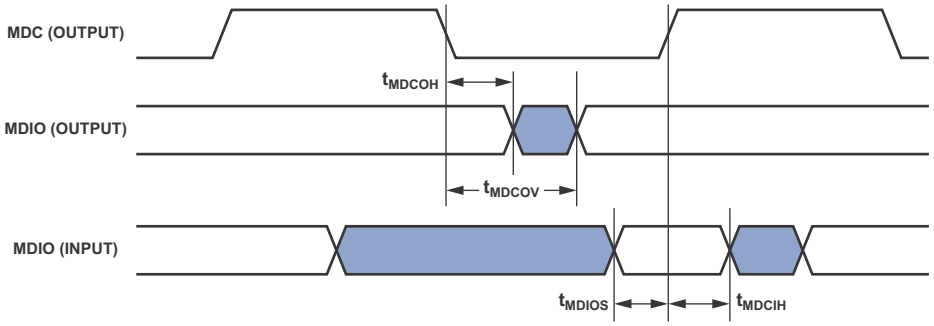



*Figure 36. 10/100 Ethernet MAC Controller Timing: MII Station Management*

### *JTAG Test And Emulation Port Timing*

Table 49 and Figure 37 describe JTAG port operations.

**Table 49. JTAG Port Timing**

| Parameter | | Min | Max | Unit |
|---|---|---|---|---|
| *Timing Requirements* | | | | |
| $t_{TCK}$ | TCK Period | 20 | | ns |
| $t_{STAP}$ | TDI, TMS Setup Before TCK High | 4 | | ns |
| $t_{HTAP}$ | TDI, TMS Hold After TCK High | 4 | | ns |
| $t_{SSYS}$[1] | System Inputs Setup Before TCK High | 4 | | ns |
| $t_{HSYS}$[1] | System Inputs Hold After TCK High | 5 | | ns |
| $t_{TRSTW}$ | $\overline{TRST}$ Pulse Width[2] (measured in TCK cycles) | 4 | | TCK |
| *Switching Characteristics* | | | | |
| $t_{DTDO}$ | TDO Delay from TCK Low | | 10 | ns |
| $t_{DSYS}$[3] | System Outputs Delay After TCK Low | 0 | 13 | ns |

[1] System Inputs = DATA15–0, SCL, SDA, TFS0, TSCLK0, RSCLK0, RFS0, DR0PRI, DR0SEC, PF15–0, PG15–0, PH7–0, MDIO, TD1, TMS, $\overline{RESET}$, $\overline{NMI}$, BMODE2–0.
[2] 50 MHz Maximum
[3] System Outputs = DATA15–0, ADDR19–1, $\overline{ABE1–0}$, $\overline{ARE}$, $\overline{AWE}$, $\overline{AMS1–0}$, $\overline{SRAS}$, $\overline{SCAS}$, $\overline{SWE}$, SCKE, CLKOUT, SA10, $\overline{SMS}$, SCL, SDA, TSCLK0, TFS0, RFS0, RSCLK0, DT0PRI, DT0SEC, PF15–0, PG15–0, PH7–0, MDC, MDIO.

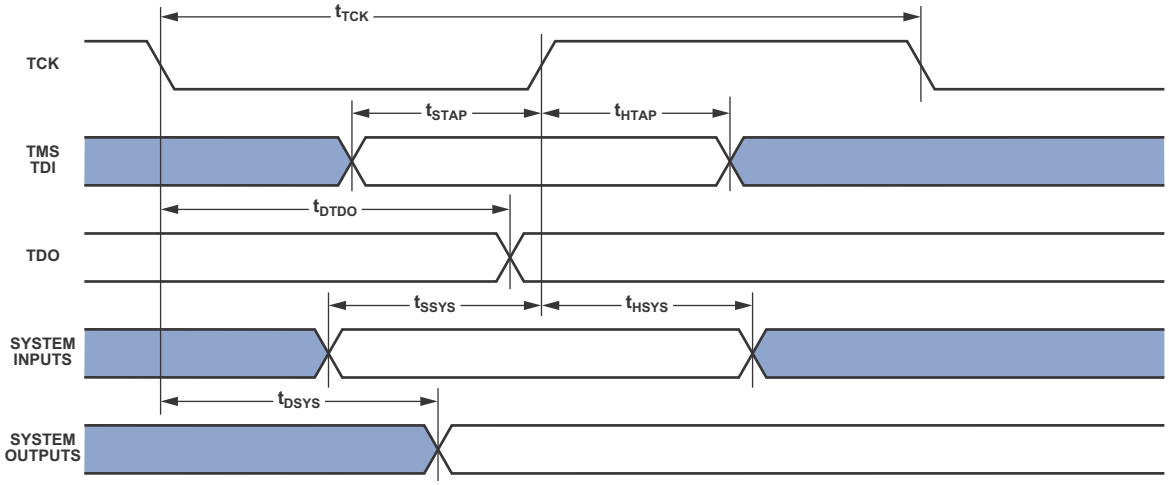



*Figure 37. JTAG Port Timing*

## OUTPUT DRIVE CURRENTS

Figure 38 through Figure 52 show typical current-voltage characteristics for the output drivers of the ADSP-BF51xF processors.

The curves represent the current drive capability of the output drivers. See Table 7 on Page 17 for information about which driver type corresponds to a particular ball.

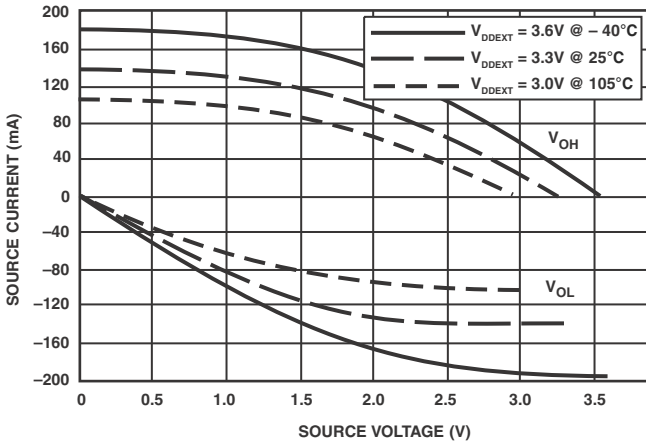



*Figure 38. Driver Type A Current (3.3V $V_{DDEXT}$/$V_{DDMEM}$)*

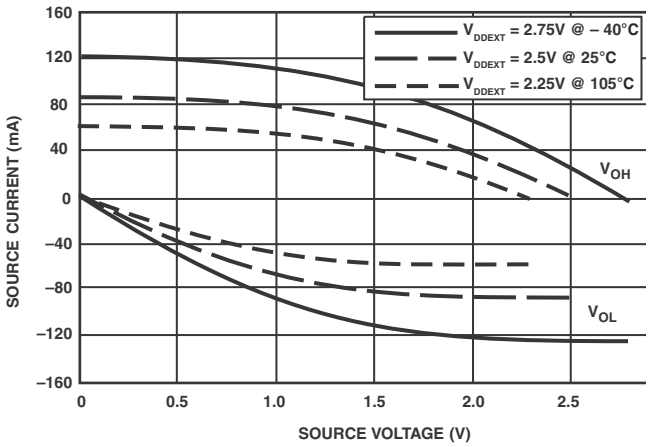



*Figure 39. Driver Type A Current (2.5V $V_{DDEXT}$/$V_{DDMEM}$)*

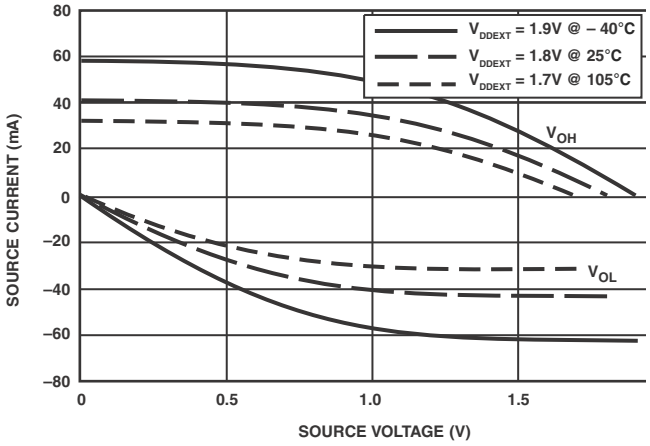



*Figure 40. Driver Type A Current (1.8V $V_{DDEXT}$/$V_{DDMEM}$)*

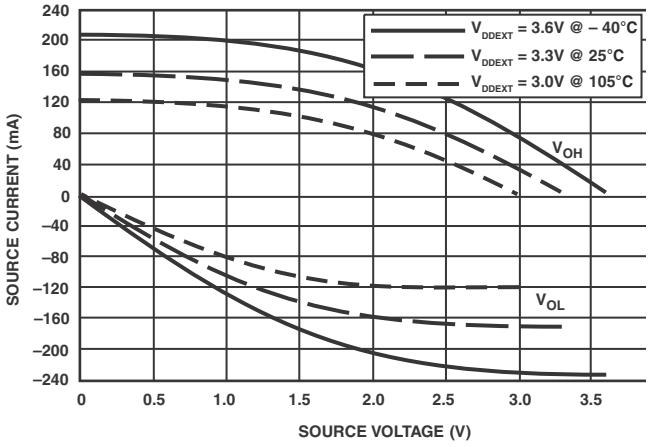



*Figure 41. Driver Type B Current (3.3V $V_{DDEXT}$/$V_{DDMEM}$)*

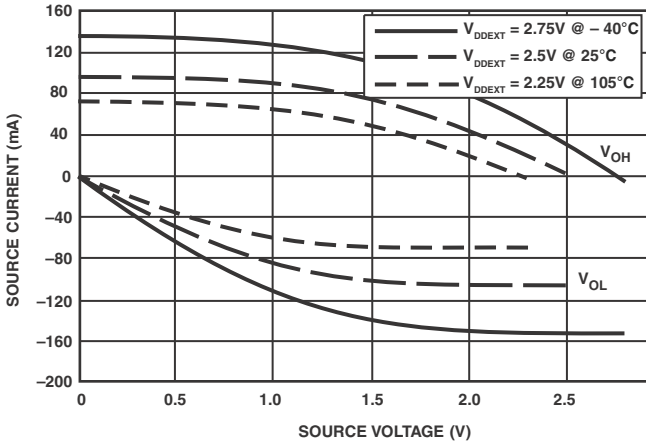



*Figure 42. Driver Type B Current (2.5V $V_{DDEXT}$/$V_{DDMEM}$)*

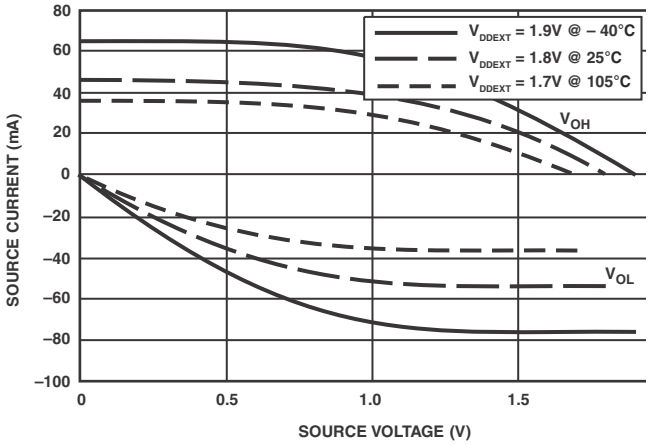



*Figure 43. Driver Type B Current (1.8V $V_{DDEXT}$/$V_{DDMEM}$)*

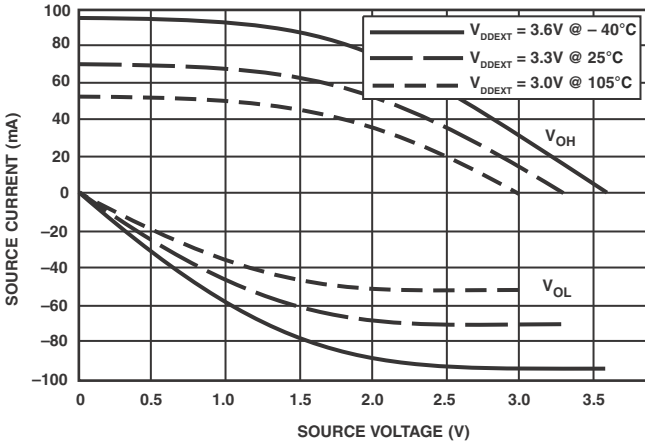



*Figure 44. Driver Type C Current (3.3V $V_{DDEXT}$/$V_{DDMEM}$)*

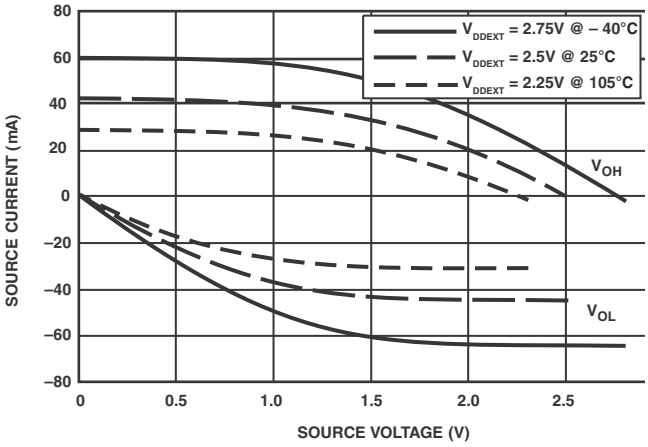



*Figure 45. Drive Type C Current (2.5V $V_{DDEXT}$/$V_{DDMEM}$)*

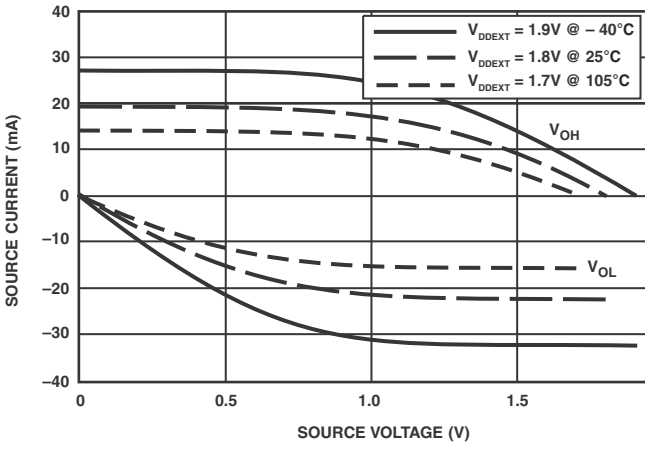



*Figure 46. Driver Type C Current (1.8V $V_{DDEXT}$/$V_{DDMEM}$)*

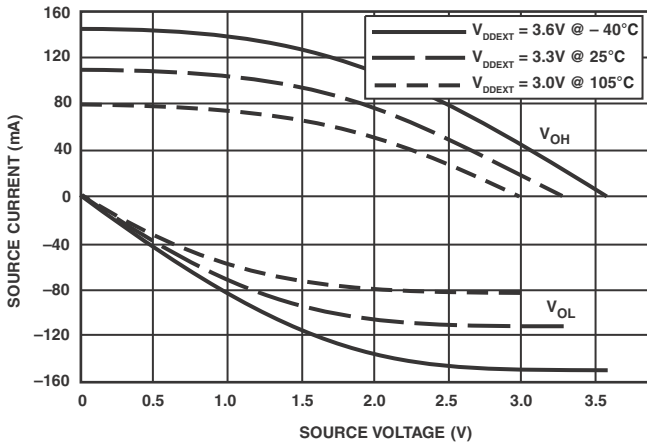



*Figure 47. Driver Type D Current (3.3V $V_{DDEXT}$/$V_{DDMEM}$)*

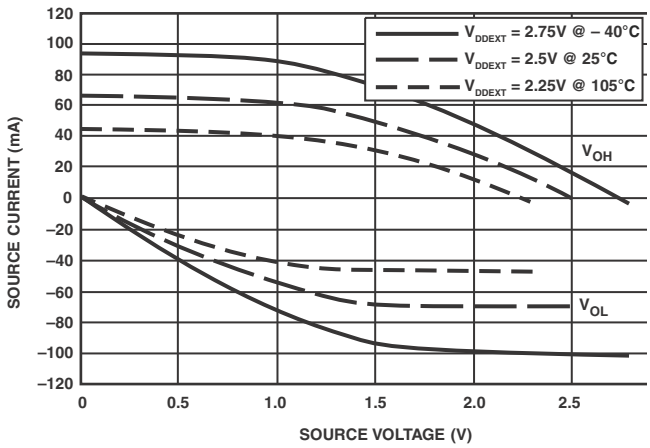



*Figure 48. Driver Type D Current (2.5V $V_{DDEXT}$/$V_{DDMEM}$)*

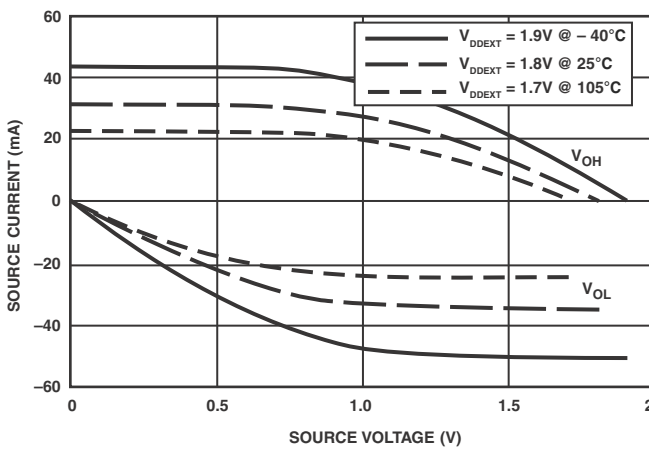



*Figure 49. Driver Type D Current (1.8V $V_{DDEXT}$/$V_{DDMEM}$)*

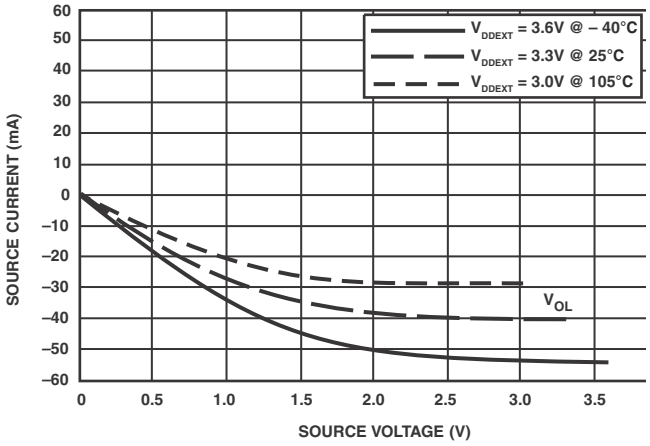



*Figure 50. Driver Type E Current (3.3V $V_{DDEXT}$/$V_{DDMEM}$)*

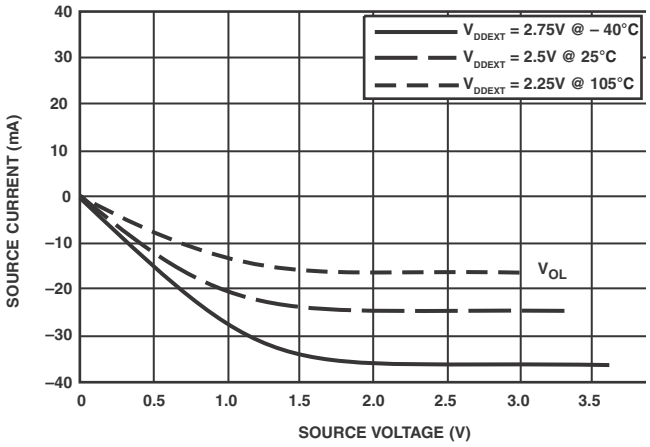



*Figure 51. Driver Type E Current (2.5V $V_{DDEXT}$/$V_{DDMEM}$)*

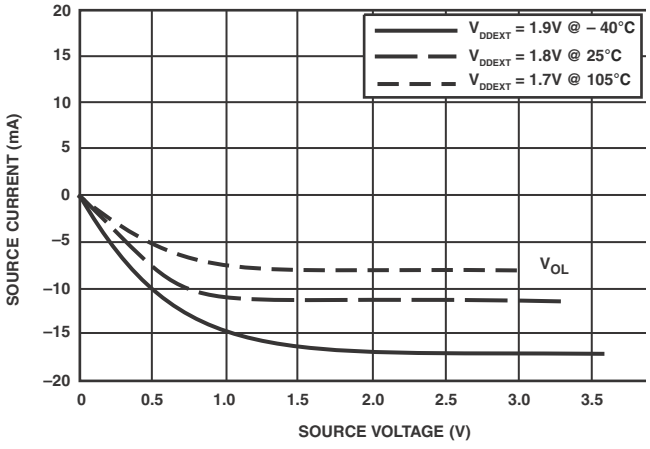



*Figure 52. Driver Type E Current (1.8V $V_{DDEXT}$/$V_{DDMEM}$)*

## TEST CONDITIONS

All timing parameters appearing in this data sheet were measured under the conditions described in this section. Figure 53 shows the measurement point for ac measurements (except output enable/disable). The measurement point $V_{MEAS}$ is $V_{DDEXT}$/2 or $V_{DDMEM}$/2 for $V_{DDEXT}$/$V_{DDMEM}$ (nominal) = 1.8 V/2.5 V/3.3 V.

*Figure 53. Voltage Reference Levels for AC Measurements (Except Output Enable/Disable)*

### *Output Enable Time Measurement*

Output signals are considered to be enabled when they have made a transition from a high impedance state to the point when they start driving.

The output enable time $t_{ENA}$ is the interval from the point when a reference signal reaches a high or low voltage level to the point when the output starts driving as shown on the right side of Figure 54.

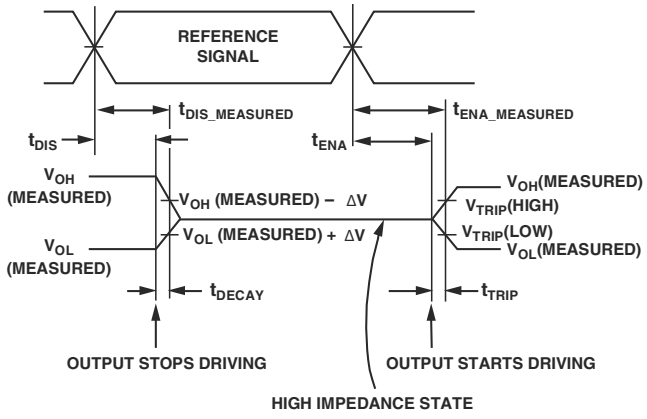



*Figure 54. Output Enable/Disable*

The time $t_{ENA_MEASURED}$ is the interval from when the reference signal switches to when the output voltage reaches $V_{TRIP}$(high) or $V_{TRIP}$(low). For $V_{DDEXT}$ (nominal) = 1.8 V, $V_{TRIP}$ (high) is 0.95 V, and $V_{TRIP}$ (low) is 0.85 V. For $V_{DDEXT}$ (nominal) = 2.5 V, $V_{TRIP}$ (high) is 1.3 V and $V_{TRIP}$ (low) is 1.2 V. For $V_{DDEXT}$ (nominal) = 3.3 V, $V_{TRIP}$ (high) is 1.7 V, and $V_{TRIP}$ (low) is 1.6 V. Time $t_{TRIP}$ is the interval from when the output starts driving to when the output reaches the $V_{TRIP}$(high) or $V_{TRIP}$(low) trip voltage.

Time $t_{ENA}$ is calculated as shown in the equation:

$$t_{ENA} = t_{ENA_MEASURED} - t_{TRIP}$$

If multiple signals (such as the data bus) are enabled, the measurement value is that of the first signal to start driving.

### Output Disable Time Measurement

Output signals are considered to be disabled when they stop driving, go into a high impedance state, and start to decay from their output high or low voltage. The output disable time $t_{DIS}$ is the difference between $t_{DIS_MEASURED}$ and $t_{DECAY}$ as shown on the left side of Figure 54.

$$t_{DIS} = t_{DIS_MEASURED} - t_{DECAY}$$

The time for the voltage on the bus to decay by ΔV is dependent on the capacitive load $C_L$ and the load current $I_L$. This decay time can be approximated by the equation:

$$t_{DECAY} = (C_L \Delta V)/I_L$$

The time $t_{DECAY}$ is calculated with test loads $C_L$ and $I_L$ and with ΔV equal to 0.25 V for $V_{DDEXT}/V_{DDMEM}$ (nominal) = 2.5 V/3.3 V and 0.15 V for $V_{DDEXT}/V_{DDMEM}$ (nominal) = 1.8 V.

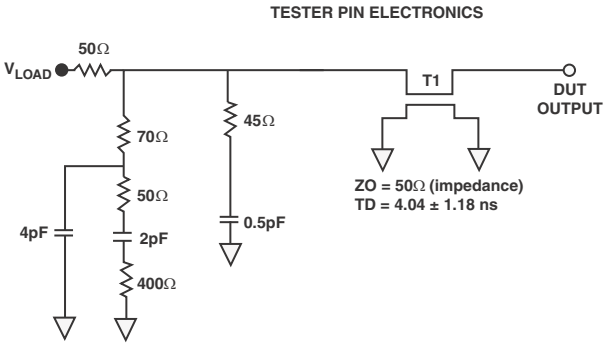
The time $t_{DIS_MEASURED}$ is the interval from when the reference signal switches to when the output voltage decays ΔV from the measured output high or output low voltage.

### Example System Hold Time Calculation

To determine the data output hold time in a particular system, first calculate $t_{DECAY}$ using the equation given above. Choose ΔV to be the difference between the ADSP-BF51x processor's output voltage and the input threshold for the device requiring the hold time. $C_L$ is the total bus capacitance (per data line), and $I_L$ is the total leakage or three-state current (per data line). The hold time is $t_{DECAY}$ plus the various output disable times as specified in the Timing Specifications on Page 27 (for example $t_{DSDAT}$ for an SDRAM write cycle as shown in SDRAM Interface Timing on Page 31).

### Capacitive Loading

Output delays and holds are based on standard capacitive loads of an average of 6 pF on all balls (see Figure 55). $V_{LOAD}$ is equal to $(V_{DDEXT}/V_{DDMEM})/2$. The graphs of Figure 56 through Figure 67 show how output rise time varies with capacitance. The delay and hold specifications given should be derated by a factor derived from these figures. The graphs in these figures may not be linear outside the ranges shown.




NOTES:
THE WORST CASE TRANSMISSION LINE DELAY IS SHOWN AND CAN BE USED FOR THE OUTPUT TIMING ANALYSIS TO REFLECT THE TRANSMISSION LINE EFFECT AND MUST BE CONSIDERED. THE TRANSMISSION LINE (TD) IS FOR LOAD ONLY AND DOES NOT AFFECT THE DATA SHEET TIMING SPECIFICATIONS.

ANALOG DEVICES RECOMMENDS USING THE IBIS MODEL TIMING FOR A GIVEN SYSTEM REQUIREMENT. IF NECESSARY, A SYSTEM MAY INCORPORATE EXTERNAL DRIVERS TO COMPENSATE FOR ANY TIMING DIFFERENCES.

*Figure 55. Equivalent Device Loading for AC Measurements (Includes All Fixtures)*

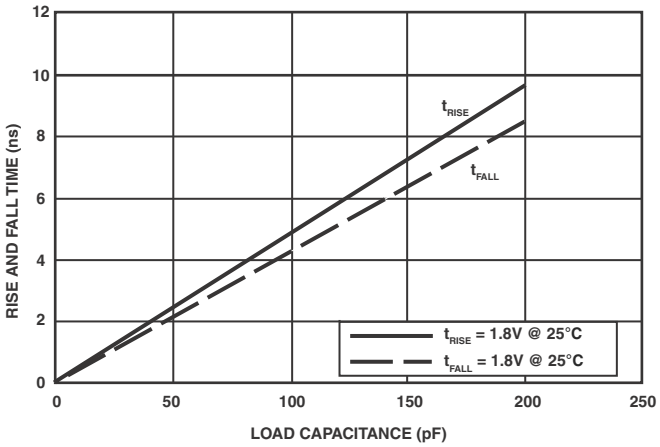



*Figure 56. Driver Type A Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (1.8V $V_{DDEXT}/V_{DDMEM}$)*

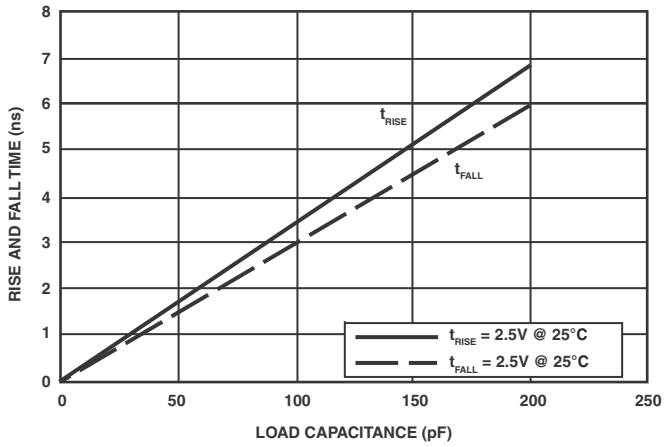



*Figure 57. Driver Type A Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (2.5V $V_{DDEXT}$/$V_{DDMEM}$)*

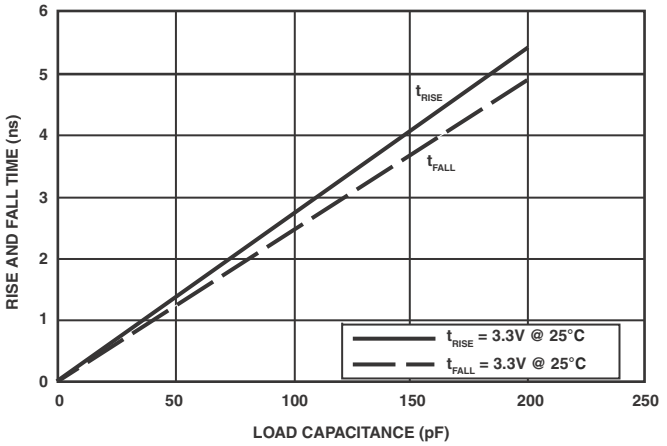



*Figure 58. Driver Type A Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (3.3V $V_{DDEXT}$/$V_{DDMEM}$)*

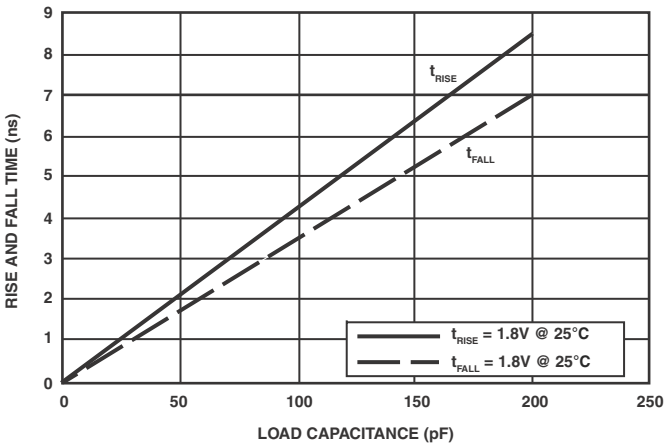



*Figure 59. Driver Type B Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (1.8V $V_{DDEXT}$/$V_{DDMEM}$)*

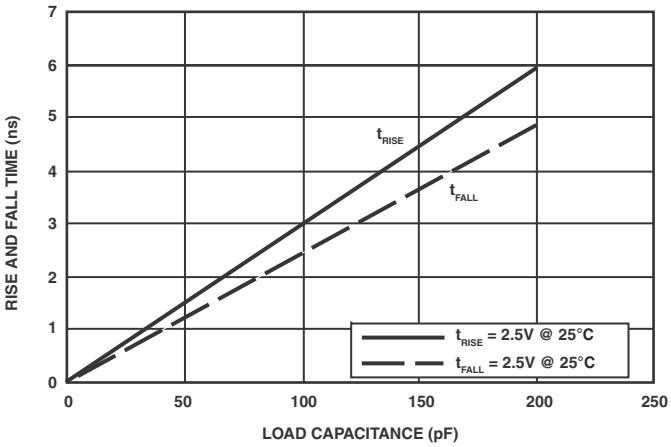



*Figure 60. Driver Type B Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (2.5V $V_{DDEXT}$/$V_{DDMEM}$)*

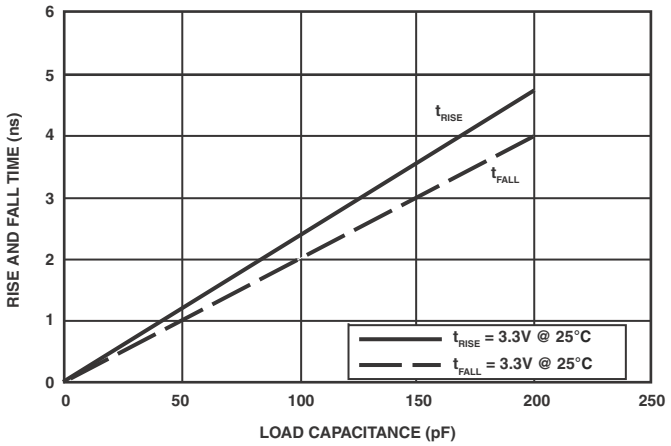



*Figure 61. Driver Type B Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (3.3V $V_{DDEXT}$/$V_{DDMEM}$)*

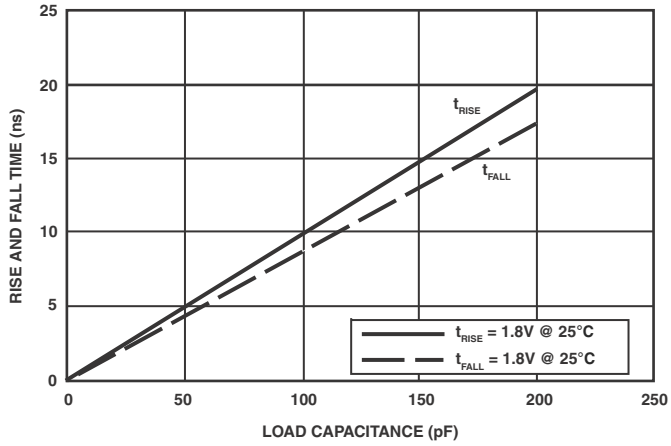



*Figure 62. Driver Type C Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (1.8V $V_{DDEXT}$/$V_{DDMEM}$)*

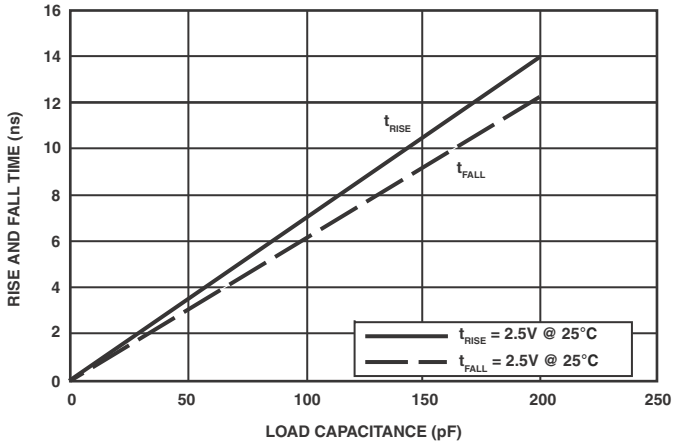



*Figure 63. Driver Type C Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (2.5V $V_{DDEXT}$/$V_{DDMEM}$)*

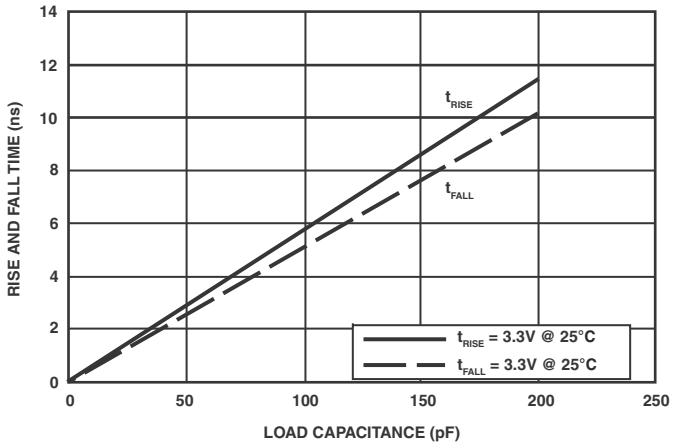



*Figure 64. Driver Type C Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (3.3V $V_{DDEXT}$/$V_{DDMEM}$)*

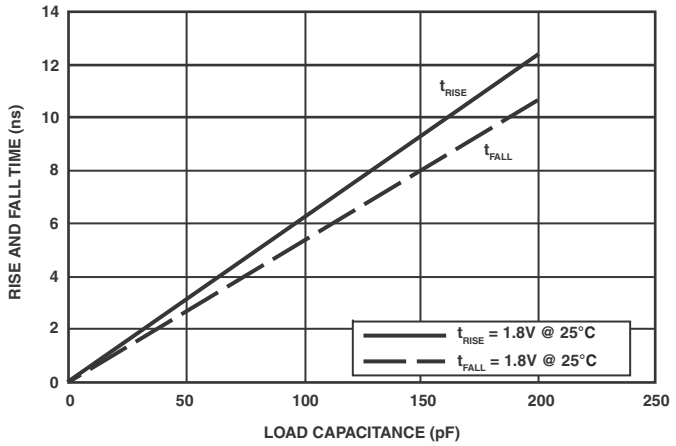



*Figure 65. Driver Type D Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (1.8V $V_{DDEXT}$/$V_{DDMEM}$)*

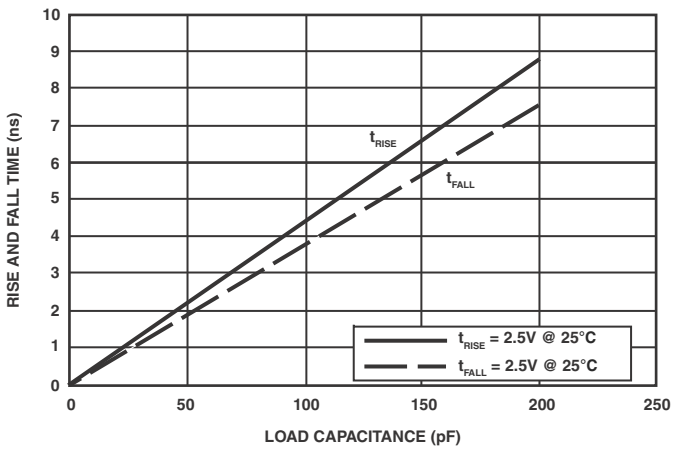



*Figure 66. Driver Type D Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (2.5V $V_{DDEXT}$/$V_{DDMEM}$)*

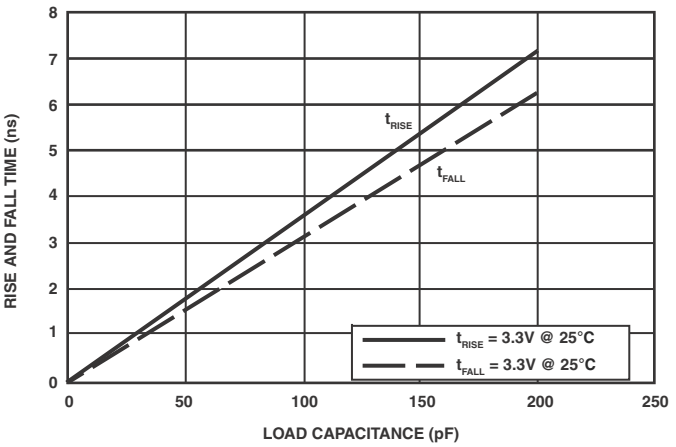



*Figure 67. Driver Type D Typical Rise and Fall Times (10%–90%) vs. Load Capacitance (3.3V $V_{DDEXT}$/$V_{DDMEM}$)*

## THERMAL CHARACTERISTICS

To determine the junction temperature on the application printed circuit board use:

$$T_J = T_{CASE} + (\Psi_{JT} \times P_D)$$

where:

$T_J$ = Junction temperature (°C)

$T_{CASE}$ = Case temperature (°C) measured by customer at top center of package.

$\Psi_{JT}$ = From Table 51

$P_D$ = Power dissipation (see Total Power Dissipation on Page 23 for the method to calculate $P_D$)

Values of $\theta_{JA}$ are provided for package comparison and printed circuit board design considerations. $\theta_{JA}$ can be used for a first order approximation of $T_J$ by the equation:

$$T_J = T_A + (\theta_{JA} \times P_D)$$

where:

$T_A$ = Ambient temperature (°C)

Values of $\theta_{JC}$ are provided for package comparison and printed circuit board design considerations when an external heat sink is required.

Values of $\theta_{JB}$ are provided for package comparison and printed circuit board design considerations.

In Table 51, airflow measurements comply with JEDEC standards JESD51-2 and JESD51-6, and the junction-to-board measurement complies with JESD51-8. The junction-to-case measurement complies with MIL-STD-883 (Method 1012.1). All measurements use a 2S2P JEDEC test board.

The LQFP_EP package requires thermal trace squares and thermal vias to an embedded ground plane in the PCB. The paddle must be connected to ground for proper operation to data sheet specifications. Refer to JEDEC standard JESD51-5 for more information.

**Table 50. Thermal Characteristics for SQ-176-2 Package**

| Parameter | Condition | Typical | Unit |
|---|---|---|---|
| $\theta_{JA}$ | 0 Linear m/s Airflow | 17.4 | °C/W |
| $\theta_{JMA}$ | 1 Linear m/s Airflow | 14.8 | °C/W |
| $\theta_{JMA}$ | 2 Linear m/s Airflow | 14.0 | °C/W |
| $\theta_{JC}$ | Not Applicable | 7.8 | °C/W |
| $\Psi_{JT}$ | 0 Linear m/s Airflow | 0.28 | °C/W |
| $\Psi_{JT}$ | 1 Linear m/s Airflow | 0.39 | °C/W |
| $\Psi_{JT}$ | 2 Linear m/s Airflow | 0.48 | °C/W |

**Table 51. Thermal Characteristics for BC-168-1 Package**

| Parameter | Condition | Typical | Unit |
|---|---|---|---|
| $\theta_{JA}$ | 0 Linear m/s Airflow | 30.5 | °C/W |
| $\theta_{JMA}$ | 1 Linear m/s Airflow | 27.6 | °C/W |
| $\theta_{JMA}$ | 2 Linear m/s Airflow | 26.3 | °C/W |
| $\theta_{JC}$ | Not Applicable | 11.1 | °C/W |
| $\Psi_{JT}$ | 0 Linear m/s Airflow | 0.20 | °C/W |
| $\Psi_{JT}$ | 1 Linear m/s Airflow | 0.35 | °C/W |
| $\Psi_{JT}$ | 2 Linear m/s Airflow | 0.45 | °C/W |

# 176-LEAD LQFP LEAD ASSIGNMENT

Table 52 lists the LQFP leads by lead number. Table 53 on Page 58 lists the LQFP by signal mnemonic.

**Table 52. 176-Lead LQFP Pin Assignment (Numerical by Lead Number)**

| Lead No. | Signal | Lead No. | Signal | Lead No. | Signal | Lead No. | Signal |
|---|---|---|---|---|---|---|---|
| 1 | GND | 45 | GND | 89 | GND | 133 | GND |
| 2 | GND | 46 | GND | 90 | GND | 134 | GND |
| 3 | PF9 | 47 | PG1 | 91 | A12 | 135 | $\overline{PG}$ |
| 4 | PF8 | 48 | PG0 | 92 | A11 | 136 | $V_{DDEXT}$ |
| 5 | PF7 | 49 | $V_{DDEXT}$ | 93 | A10 | 137 | GND |
| 6 | PF6 | 50 | TDO | 94 | A9 | 138 | $V_{DDINT}$ |
| 7 | $V_{DDEXT}$ | 51 | $\overline{EMU}$ | 95 | $V_{DDMEM}$ | 139 | GND |
| 8 | $V_{PPOTP}$ | 52 | TDI | 96 | A8 | 140 | RTXO |
| 9 | $V_{DDOTP}$ | 53 | TCK | 97 | A7 | 141 | RTXI |
| 10 | PF5 | 54 | $\overline{TRST}$ | 98 | $V_{DDINT}$ | 142 | $V_{DDRTC}$ |
| 11 | PF4 | 55 | TMS | 99 | GND | 143 | CLKIN |
| 12 | PF3 | 56 | D15 | 100 | $V_{DDINT}$ | 144 | XTAL |
| 13 | PF2 | 57 | D14 | 101 | A6 | 145 | $V_{DDEXT}$ |
| 14 | $V_{DDINT}$ | 58 | D13 | 102 | A5 | 146 | $\overline{RESET}$ |
| 15 | GND | 59 | $V_{DDMEM}$ | 103 | A4 | 147 | $\overline{NMI}$ |
| 16 | $V_{DDFLASH}$ | 60 | D12 | 104 | $V_{DDMEM}$ | 148 | $V_{DDEXT}$ |
| 17 | $V_{DDFLASH}$ | 61 | D11 | 105 | A3 | 149 | GND |
| 18 | PF1 | 62 | D10 | 106 | A2 | 150 | CLKBUF |
| 19 | PF0 | 63 | $V_{DDINT}$ | 107 | A1 | 151 | GND |
| 20 | PG15 | 64 | D9 | 108 | $\overline{ABE}$1 | 152 | $V_{DDINT}$ |
| 21 | PG14 | 65 | D8 | 109 | $\overline{ABE}$0 | 153 | PH7 |
| 22 | GND | 66 | D7 | 110 | SA10 | 154 | PH6 |
| 23 | $V_{DDINT}$ | 67 | GND | 111 | GND | 155 | PH5 |
| 24 | $V_{DDEXT}$ | 68 | $V_{DDMEM}$ | 112 | $V_{DDMEM}$ | 156 | PH4 |
| 25 | PG13 | 69 | D6 | 113 | $\overline{SWE}$ | 157 | GND |
| 26 | PG12 | 70 | D5 | 114 | $\overline{SCAS}$ | 158 | $V_{DDEXT}$ |
| 27 | PG11 | 71 | D4 | 115 | $\overline{SRAS}$ | 159 | PH3 |
| 28 | PG10 | 72 | D3 | 116 | $V_{DDINT}$ | 160 | PH2 |
| 29 | $V_{DDFLASH}$ | 73 | D2 | 117 | GND | 161 | PH1 |
| 30 | $V_{DDINT}$ | 74 | D1 | 118 | $\overline{SMS}$ | 162 | PH0 |
| 31 | PG9 | 75 | $V_{DDMEM}$ | 119 | SCKE | 163 | GND |
| 32 | PG8 | 76 | D0 | 120 | $\overline{AMS}$1 | 164 | $V_{DDINT}$ |
| 33 | PG7 | 77 | A19 | 121 | $\overline{ARE}$ | 165 | PF15 |
| 34 | PG6 | 78 | A18 | 122 | $\overline{AWE}$ | 166 | PF14 |
| 35 | $V_{DDEXT}$ | 79 | $V_{DDINT}$ | 123 | $\overline{AMS}$0 | 167 | PF13 |
| 36 | PG5 | 80 | A17 | 124 | $V_{DDMEM}$ | 168 | PF12 |
| 37 | PG4 | 81 | A16 | 125 | CLKOUT | 169 | GND |
| 38 | PG3 | 82 | $V_{DDMEM}$ | 126 | $V_{DDFLASH}$ | 170 | $V_{DDEXT}$ |
| 39 | PG2 | 83 | GND | 127 | NC[1] | 171 | PF11 |
| 40 | BMODE2 | 84 | A15 | 128 | $V_{DDEXT}$ | 172 | SDA |
| 41 | BMODE1 | 85 | A14 | 129 | $V_{DDEXT}$ | 173 | SCL |
| 42 | BMODE0 | 86 | A13 | 130 | EXT_WAKE | 174 | PF10 |
| 43 | GND | 87 | GND | 131 | GND | 175 | GND |
| 44 | GND | 88 | GND | 132 | GND | 176 | GND |
| | | | | | | GND | 177* |

* Pin no. 177 is the GND supply (see Figure 69) for the processor; this pad **must** connect to GND.

[1] This pin must not be connected.

**Table 53. 176-Lead LQFP Pin Assignment (Alphabetical by Signal Mnemonic)**

| Lead No. | Signal | Lead No. | Signal | Lead No. | Signal | Lead No. | Signal |
|---|---|---|---|---|---|---|---|
| 107 | A1 | 58 | D13 | 5 | PF7 | 113 | $\overline{SWE}$ |
| 106 | A2 | 57 | D14 | 4 | PF8 | 53 | TCK |
| 105 | A3 | 56 | D15 | 3 | PF9 | 52 | TDI |
| 103 | A4 | 51 | $\overline{EMU}$ | 174 | PF10 | 50 | TDO |
| 102 | A5 | 130 | EXT_WAKE | 171 | PF11 | 55 | TMS |
| 101 | A6 | 1 | GND | 168 | PF12 | 54 | $\overline{TRST}$ |
| 97 | A7 | 2 | GND | 167 | PF13 | 7 | $V_{DDEXT}$ |
| 96 | A8 | 15 | GND | 166 | PF14 | 24 | $V_{DDEXT}$ |
| 94 | A9 | 22 | GND | 165 | PF15 | 35 | $V_{DDEXT}$ |
| 93 | A10 | 43 | GND | 135 | $\overline{PG}$ | 49 | $V_{DDEXT}$ |
| 92 | A11 | 44 | GND | 48 | PG0 | 128 | $V_{DDEXT}$ |
| 91 | A12 | 45 | GND | 47 | PG1 | 129 | $V_{DDEXT}$ |
| 86 | A13 | 46 | GND | 39 | PG2 | 136 | $V_{DDEXT}$ |
| 85 | A14 | 67 | GND | 38 | PG3 | 145 | $V_{DDEXT}$ |
| 84 | A15 | 83 | GND | 37 | PG4 | 148 | $V_{DDEXT}$ |
| 81 | A16 | 87 | GND | 36 | PG5 | 158 | $V_{DDEXT}$ |
| 80 | A17 | 88 | GND | 34 | PG6 | 170 | $V_{DDEXT}$ |
| 78 | A18 | 89 | GND | 33 | PG7 | 16 | $V_{DDFLASH}$ |
| 77 | A19 | 90 | GND | 32 | PG8 | 17 | $V_{DDFLASH}$ |
| 109 | $\overline{ABE}$0 | 99 | GND | 31 | PG9 | 29 | $V_{DDFLASH}$ |
| 108 | $\overline{ABE}$1 | 111 | GND | 28 | PG10 | 126 | $V_{DDFLASH}$ |
| 123 | $\overline{AMS}$0 | 131 | GND | 27 | PG11 | 14 | $V_{DDINT}$ |
| 120 | $\overline{AMS}$1 | 132 | GND | 26 | PG12 | 23 | $V_{DDINT}$ |
| 121 | $\overline{ARE}$ | 133 | GND | 25 | PG13 | 30 | $V_{DDINT}$ |
| 122 | $\overline{AWE}$ | 134 | GND | 21 | PG14 | 63 | $V_{DDINT}$ |
| 42 | BMODE0 | 137 | GND | 20 | PG15 | 79 | $V_{DDINT}$ |
| 41 | BMODE1 | 139 | GND | 162 | PH0 | 98 | $V_{DDINT}$ |
| 40 | BMODE2 | 149 | GND | 161 | PH1 | 100 | $V_{DDINT}$ |
| 150 | CLKBUF | 151 | GND | 160 | PH2 | 116 | $V_{DDINT}$ |
| 143 | CLKIN | 157 | GND | 159 | PH3 | 138 | $V_{DDINT}$ |
| 125 | CLKOUT | 163 | GND | 156 | PH4 | 152 | $V_{DDINT}$ |
| 76 | D0 | 169 | GND | 155 | PH5 | 164 | $V_{DDINT}$ |
| 74 | D1 | 175 | GND | 154 | PH6 | 59 | $V_{DDMEM}$ |
| 73 | D2 | 176 | GND | 153 | PH7 | 68 | $V_{DDMEM}$ |
| 72 | D3 | 117 | GND | 146 | $\overline{RESET}$ | 75 | $V_{DDMEM}$ |
| 71 | D4 | 127 | NC[1] | 141 | RTXI | 82 | $V_{DDMEM}$ |
| 70 | D5 | 147 | $\overline{NMI}$ | 140 | RTXO | 95 | $V_{DDMEM}$ |
| 69 | D6 | 19 | PF0 | 110 | SA10 | 104 | $V_{DDMEM}$ |
| 66 | D7 | 18 | PF1 | 114 | $\overline{SCAS}$ | 112 | $V_{DDMEM}$ |
| 65 | D8 | 13 | PF2 | 119 | SCKE | 124 | $V_{DDMEM}$ |
| 64 | D9 | 12 | PF3 | 173 | SCL | 9 | $V_{DDOTP}$ |
| 62 | D10 | 11 | PF4 | 172 | SDA | 142 | $V_{DDRTC}$ |
| 61 | D11 | 10 | PF5 | 118 | $\overline{SMS}$ | 8 | $V_{PPOTP}$ |
| 60 | D12 | 6 | PF6 | 115 | $\overline{SRAS}$ | 144 | XTAL |
| | | | | | | GND | 177* |

* Pin no. 177 is the GND supply (see Figure 69) for the processor; this pad **must** connect to GND.

[1] This pin must not be connected.

Figure 68 shows the top view of the LQFP_EP lead configuration. Figure 69 shows the bottom view of the LQFP_EP lead configuration.

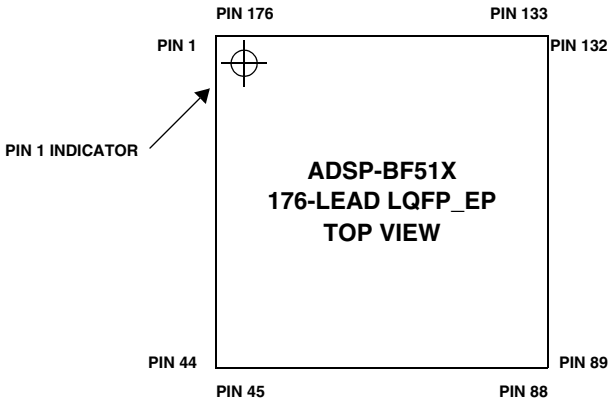



*Figure 68. 176-Lead LQFP_EP Lead Configuration (Top View)*

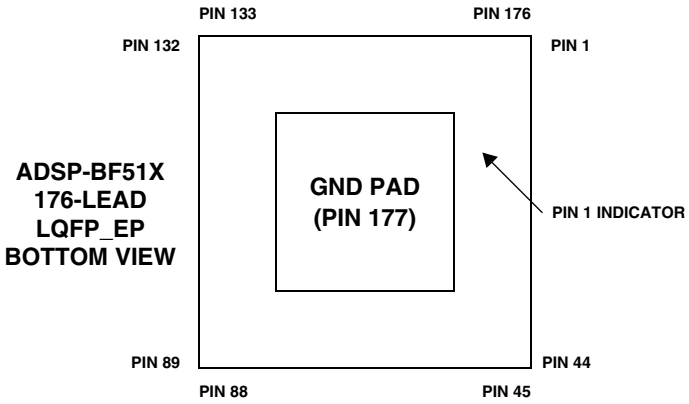



*Figure 69. 176-Lead LQFP_EP Lead Configuration (Bottom View)*

# 168-BALL CSP_BGA BALL ASSIGNMENT

Table 54 lists the CSP_BGA by ball number. Table 55 on Page 61 lists the CSP_BGA balls by signal mnemonic.

**Table 54. 168-Ball CSP_BGA Ball Assignment (Numerical by Ball Number)**

| Ball No. | Signal Name | Ball No. | Signal Name | Ball No. | Signal Name | Ball No. | Signal Name | Ball No. | Signal Name | Ball No. | Signal Name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | GND | C1 | PF4 | E10 | $V_{DDINT}$ | H1 | PG12 | K6 | $V_{DDMEM}$ | N1 | BMODE1 |
| A2 | SCL | C2 | PF7 | E12 | $V_{DDMEM}$ | H2 | PG13 | K7 | $V_{DDMEM}$ | N2 | PG1 |
| A3 | SDA | C3 | PF8 | E13 | $\overline{ARE}$ | H3 | PG11 | K8 | $V_{DDMEM}$ | N3 | TDO |
| A4 | PF13 | C4 | PF10 | E14 | $\overline{AWE}$ | H5 | $V_{DDEXT}$ | K9 | $V_{DDMEM}$ | N4 | $\overline{TRST}$ |
| A5 | PF15 | C5 | $V_{DDEXT}$ | F1 | PF0 | H6 | GND | K10 | $V_{DDMEM}$ | N5 | TMS |
| A6 | PH2 | C6 | $V_{DDEXT}$ | F2 | PF1 | H7 | GND | K12 | A8 | N6 | D13 |
| A7 | PH1 | C7 | PF11 | F3 | $V_{DDINT}$ | H8 | GND | K13 | A2 | N7 | D9 |
| A8 | PH5 | C8 | $V_{DDEXT}$ | F5 | $V_{DDEXT}$ | H9 | GND | K14 | A1 | N8 | D5 |
| A9 | PH6 | C9 | $V_{DDINT}$ | F6 | GND | H10 | $V_{DDINT}$ | L1 | PG5 | N9 | D1 |
| A10 | PH7 | C10 | $V_{DDEXT}$ | F7 | GND | H12 | A3 | L2 | PG3 | N10 | A18 |
| A11 | CLKBUF | C11 | RTXI | F8 | GND | H13 | $\overline{ABE}$0 | L3 | PG2 | N11 | A16 |
| A12 | XTAL | C12 | RTXO | F9 | GND | H14 | $\overline{SCAS}$ | L12 | A9 | N12 | A14 |
| A13 | CLKIN | C13 | $\overline{PG}$ | F10 | $V_{DDINT}$ | J1 | PG10 | L13 | A6 | N13 | A11 |
| A14 | GND | C14 | NC[1] | F12 | $\overline{SMS}$ | J2 | $V_{DDFLASH}$ | L14 | A4 | N14 | A7 |
| B1 | $V_{DDOTP}$ | D1 | PF3 | F13 | SCKE | J3 | PG9 | M1 | PG4 | P1 | GND |
| B2 | GND | D2 | PF5 | F14 | $\overline{AMS}$1 | J5 | $V_{DDMEM}$ | M2 | BMODE2 | P2 | TDI |
| B3 | PF9 | D3 | VPPOTP | G1 | PG15 | J6 | GND | M3 | BMODE0 | P3 | TCK |
| B4 | PF12 | D12 | $V_{DDFLASH}$ | G2 | PG14 | J7 | GND | M4 | PG0 | P4 | D15 |
| B5 | PF14 | D13 | CLKOUT | G3 | $V_{DDINT}$ | J8 | GND | M5 | $\overline{EMU}$ | P5 | D14 |
| B6 | PH0 | D14 | $\overline{AMS}$0 | G5 | $V_{DDEXT}$ | J9 | GND | M6 | D12 | P6 | D11 |
| B7 | PH3 | E1 | $V_{DDFLASH}$ | G6 | GND | J10 | $V_{DDINT}$ | M7 | D10 | P7 | D8 |
| B8 | PH4 | E2 | PF2 | G7 | GND | J12 | A15 | M8 | D2 | P8 | D7 |
| B9 | $V_{DDEXT}$ | E3 | PF6 | G8 | GND | J13 | $\overline{ABE}$1 | M9 | D0 | P9 | D6 |
| B10 | $\overline{RESET}$ | E5 | $V_{DDEXT}$ | G9 | GND | J14 | SA10 | M10 | A17 | P10 | D4 |
| B11 | $\overline{NMI}$ | E6 | $V_{DDEXT}$ | G10 | $V_{DDINT}$ | K1 | PG6 | M11 | A13 | P11 | D3 |
| B12 | $V_{DDRTC}$ | E7 | $V_{DDINT}$ | G12 | $\overline{SWE}$ | K2 | PG8 | M12 | A12 | P12 | A19 |
| B13 | $V_{DDEXT}$ | E8 | $V_{DDINT}$ | G13 | $\overline{SRAS}$ | K3 | PG7 | M13 | A10 | P13 | GND |
| B14 | EXT_WAKE | E9 | $V_{DDINT}$ | G14 | GND | K5 | $V_{DDMEM}$ | M14 | A5 | P14 | GND |

[1] This pin must not be connected.

**Table 55. 168-Ball CSP_BGA Ball Assignment (Alphabetical by Signal Mnemonic)**

| Ball No. | Signal Name | Ball No. | Signal Name | Ball No. | Signal Name | Ball No. | Signal Name | Ball No. | Signal Name | Ball No. | Signal Name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K14 | A1 | A11 | CLKBUF | G6 | GND | C4 | PF10 | A8 | PH5 | G5 | $V_{DDEXT}$ |
| K13 | A2 | A13 | CLKIN | G7 | GND | C7 | PF11 | A9 | PH6 | H5 | $V_{DDEXT}$ |
| H12 | A3 | D13 | CLKOUT | G8 | GND | B4 | PF12 | A10 | PH7 | D12 | $V_{DDFLASH}$ |
| L14 | A4 | M9 | D0 | G9 | GND | A4 | PF13 | B10 | $\overline{RESET}$ | E1 | $V_{DDFLASH}$ |
| M14 | A5 | N9 | D1 | H6 | GND | B5 | PF14 | C11 | RTXI | J2 | $V_{DDFLASH}$ |
| L13 | A6 | M8 | D2 | H7 | GND | A5 | PF15 | C12 | RTXO | C9 | $V_{DDINT}$ |
| N14 | A7 | P11 | D3 | H8 | GND | C13 | $\overline{PG}$ | J14 | SA10 | E7 | $V_{DDINT}$ |
| K12 | A8 | P10 | D4 | H9 | GND | M4 | PG0 | H14 | $\overline{SCAS}$ | E8 | $V_{DDINT}$ |
| L12 | A9 | N8 | D5 | J6 | GND | N2 | PG1 | F13 | SCKE | E9 | $V_{DDINT}$ |
| M13 | A10 | P9 | D6 | J7 | GND | L3 | PG2 | A2 | SCL | E10 | $V_{DDINT}$ |
| N13 | A11 | P8 | D7 | J8 | GND | L2 | PG3 | A3 | SDA | F3 | $V_{DDINT}$ |
| M12 | A12 | P7 | D8 | J9 | GND | M1 | PG4 | F12 | $\overline{SMS}$ | F10 | $V_{DDINT}$ |
| M11 | A13 | N7 | D9 | P1 | GND | L1 | PG5 | G13 | $\overline{SRAS}$ | G3 | $V_{DDINT}$ |
| N12 | A14 | M7 | D10 | P13 | GND | K1 | PG6 | G12 | $\overline{SWE}$ | G10 | $V_{DDINT}$ |
| J12 | A15 | P6 | D11 | P14 | GND | K3 | PG7 | P3 | TCK | H10 | $V_{DDINT}$ |
| N11 | A16 | M6 | D12 | G14 | GND | K2 | PG8 | P2 | TDI | J10 | $V_{DDINT}$ |
| M10 | A17 | N6 | D13 | C14 | NC[1] | J3 | PG9 | N3 | TDO | E12 | $V_{DDMEM}$ |
| N10 | A18 | P5 | D14 | B11 | $\overline{NMI}$ | J1 | PG10 | N5 | TMS | J5 | $V_{DDMEM}$ |
| P12 | A19 | P4 | D15 | F1 | PF0 | H3 | PG11 | N4 | $\overline{TRST}$ | K5 | $V_{DDMEM}$ |
| H13 | $\overline{ABE}$0 | M5 | $\overline{EMU}$ | F2 | PF1 | H1 | PG12 | B9 | $V_{DDEXT}$ | K6 | $V_{DDMEM}$ |
| J13 | $\overline{ABE}$1 | B14 | EXT_WAKE | E2 | PF2 | H2 | PG13 | B13 | $V_{DDEXT}$ | K7 | $V_{DDMEM}$ |
| D14 | $\overline{AMS}$0 | A1 | GND | D1 | PF3 | G2 | PG14 | C5 | $V_{DDEXT}$ | K8 | $V_{DDMEM}$ |
| F14 | $\overline{AMS}$1 | A14 | GND | C1 | PF4 | G1 | PG15 | C6 | $V_{DDEXT}$ | K9 | $V_{DDMEM}$ |
| E13 | $\overline{ARE}$ | B2 | GND | D2 | PF5 | B6 | PH0 | C8 | $V_{DDEXT}$ | K10 | $V_{DDMEM}$ |
| E14 | $\overline{AWE}$ | F6 | GND | E3 | PF6 | A7 | PH1 | C10 | $V_{DDEXT}$ | B1 | $V_{DDOTP}$ |
| M3 | BMODE0 | F7 | GND | C2 | PF7 | A6 | PH2 | E5 | $V_{DDEXT}$ | B12 | $V_{DDRTC}$ |
| N1 | BMODE1 | F8 | GND | C3 | PF8 | B7 | PH3 | E6 | $V_{DDEXT}$ | D3 | $V_{PPOTP}$ |
| M2 | BMODE2 | F9 | GND | B3 | PF9 | B8 | PH4 | F5 | $V_{DDEXT}$ | A12 | XTAL |

[1] This pin must not be connected.

Figure 70 shows the top view of the CSP_BGA ball configuration. Figure 71 shows the bottom view of the CSP_BGA ball configuration.

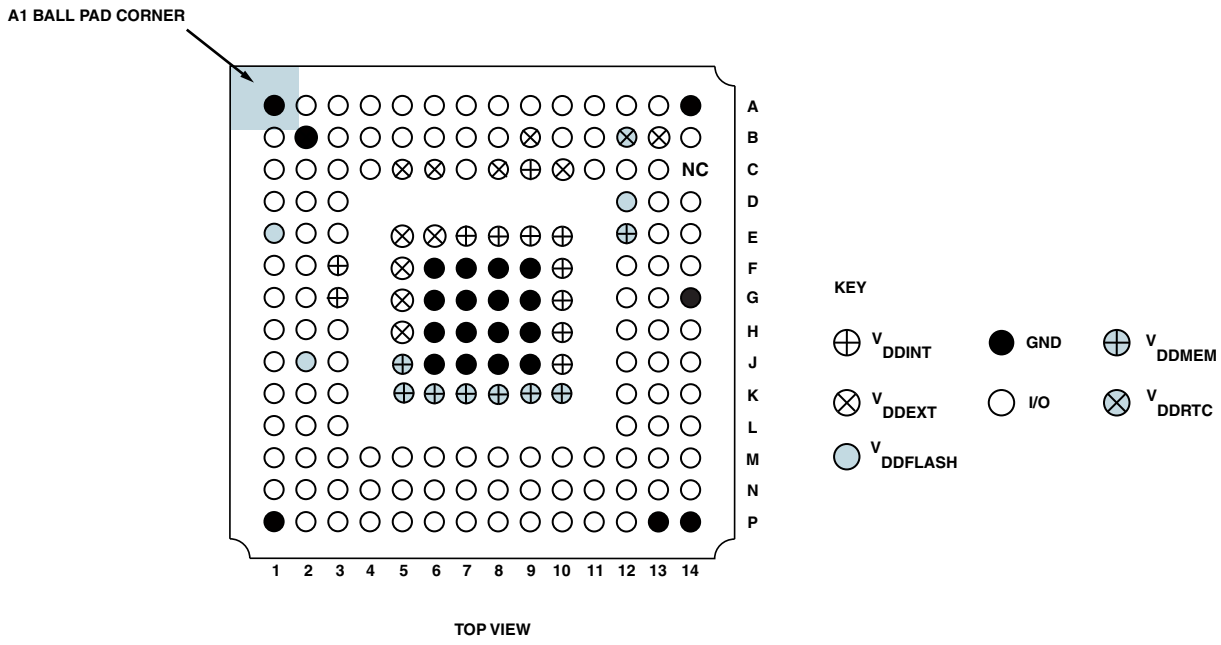



*Figure 70. 168-Ball CSP_BGA Ball Configuration (Top View)*

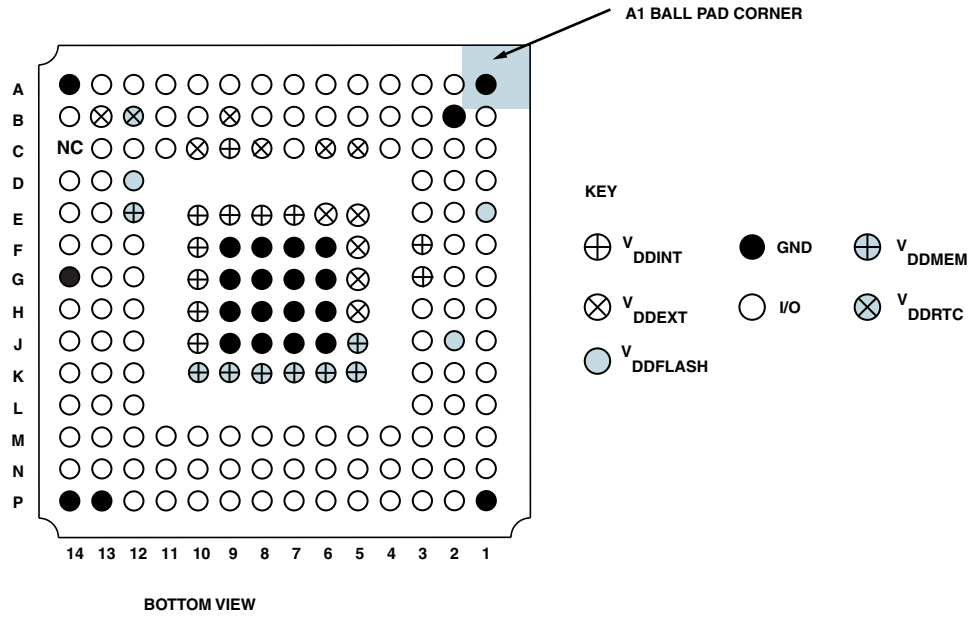



*Figure 71. 168-Ball CSP_BGA Ball Configuration (Bottom View)*

# OUTLINE DIMENSIONS

Dimensions in Figure 72 are shown in millimeters.

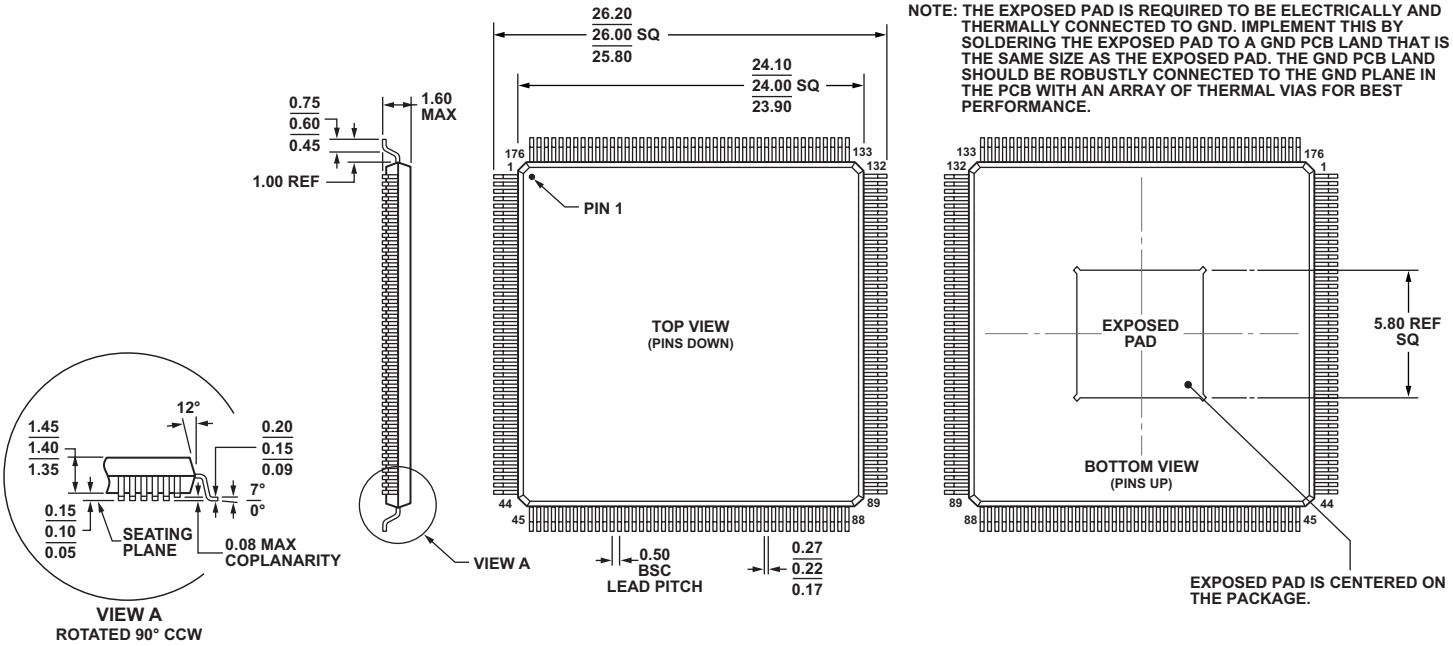



*Figure 72. 176-Lead Low Profile Quad Flat Package [LQFP_EP]*
*(SQ-176-2)*
*Dimensions shown in millimeters*

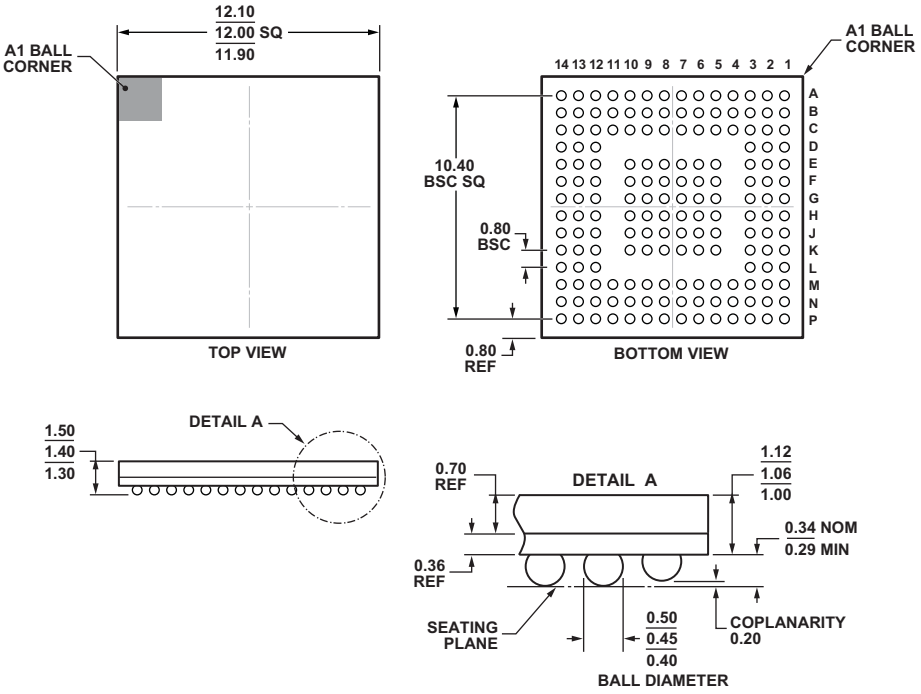



*Figure 73. 168-Ball Chip Scale Package Ball Grid Array [CSP_BGA]*
*(BC-168-1)*
*Dimensions shown in millimeters*

## SURFACE-MOUNT DESIGN

Table 56 is provided as an aid to PCB design. For industry standard design recommendations, refer to IPC-7351, *Generic Requirements for Surface Mount Design and Land Pattern Standard.*

**Table 56. BGA Data for Use with Surface-Mount Design**

| Package | Package Ball Attach Type | Package Solder Mask Opening | Package Ball Pad Size |
|---|---|---|---|
| 168-Ball CSP_BGA | Solder Mask Defined | 0.35 mm diameter | 0.48 mm diameter |

## AUTOMOTIVE PRODUCTS

The ADBF512W and ADBF518 models are available with controlled manufacturing to support the quality and reliability requirements of automotive applications. Note that these automotive models may have specifications that differ from the commercial models and designers should review the product Specifications section of this data sheet carefully. Only the automotive grade products shown in Table 57 are available for use in automotive applications. Contact your local ADI account representative for specific product ordering information and to obtain the specific Automotive Reliability reports for these models.

**Table 57. Automotive Products**

| Automotive Models[1,2] | Temperature Range[3] | Instruction Rate (Max) | Package Description | Package Option |
|---|---|---|---|---|
| ADBF512WBBCZ4xx | –40°C to +85°C | 400 MHz | 168-Ball CSP_BGA | BC-168-1 |
| ADBF518WBBCZ4xx | –40°C to +85°C | 400 MHz | 168-Ball CSP_BGA | BC-168-1 |
| ADBF512WBSWZ4xx | –40°C to +85°C | 400 MHz | 176-Lead LQFP_EP | SQ-176-2 |
| ADBF518WBSWZ4xx | –40°C to +85°C | 400 MHz | 176-Lead LQFP_EP | SQ-176-2 |

[1] Z = RoHS Compliant Part.
[2] The use of xx designates silicon revision.
[3] Referenced temperature is ambient temperature. The ambient temperature is not a specification. Please see Operating Conditions on Page 20 for junction temperature ($T_J$) specification which is the only temperature specification.

## ORDERING GUIDE

| Model[1] | Temperature Range[2] | Processor Instruction Rate (Max) | Flash Memory | Package Description | Package Option |
|---|---|---|---|---|---|
| ADSP-BF512BBCZ-3 | –40°C to +85°C | 300 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF512BBCZ-4 | –40°C to +85°C | 400 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF512BBCZ-4F4 | –40°C to +85°C | 400 MHz | 4M bit | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF512BSWZ-3 | –40°C to +85°C | 300 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF512BSWZ-4 | –40°C to +85°C | 400 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF512BSWZ-4F4 | –40°C to +85°C | 400 MHz | 4M bit | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF512KBCZ-3 | 0°C to +70°C | 300 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF512KBCZ-4 | 0°C to +70°C | 400 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF512KBCZ-4F4 | 0°C to +70°C | 400 MHz | 4M bit | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF512KSWZ-3 | 0°C to +70°C | 300 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF512KSWZ-4 | 0°C to +70°C | 400 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF512KSWZ-4F4 | 0°C to +70°C | 400 MHz | 4M bit | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF514BBCZ-3 | –40°C to +85°C | 300 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF514BBCZ-4 | –40°C to +85°C | 400 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF514BBCZ-4F4 | –40°C to +85°C | 400 MHz | 4M bit | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF514BSWZ-3 | –40°C to +85°C | 300 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF514BSWZ-4 | –40°C to +85°C | 400 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF514BSWZ-4F4 | –40°C to +85°C | 400 MHz | 4M bit | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF514KBCZ-3 | 0°C to +70°C | 300 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF514KBCZ-4 | 0°C to +70°C | 400 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF514KBCZ-4F4 | 0°C to +70°C | 400 MHz | 4M bit | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF514KSWZ-3 | 0°C to +70°C | 300 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |

| Model[1] | Temperature Range[2] | Processor Instruction Rate (Max) | Flash Memory | Package Description | Package Option |
|---|---|---|---|---|---|
| ADSP-BF514KSWZ-4 | 0°C to +70°C | 400 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF514KSWZ-4F4 | 0°C to +70°C | 400 MHz | 4M bit | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF516KSWZ-3 | 0°C to +70°C | 300 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF516KBCZ-3 | 0°C to +70°C | 300 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF516KSWZ-4 | 0°C to +70°C | 400 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF516KBCZ-4 | 0°C to +70°C | 400 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF516KSWZ-4F4 | 0°C to +70°C | 400 MHz | 4M bit | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF516KBCZ-4F4 | 0°C to +70°C | 400 MHz | 4M bit | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF516BBCZ-3 | –40°C to +85°C | 300 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF516BBCZ-4 | –40°C to +85°C | 400 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF516BBCZ-4F4 | –40°C to +85°C | 400 MHz | 4M bit | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF516BSWZ-3 | –40°C to +85°C | 300 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF516BSWZ-4 | –40°C to +85°C | 400 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF516BSWZ-4F4 | –40°C to +85°C | 400 MHz | 4M bit | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF518BBCZ-4 | –40°C to +85°C | 400 MHz | N/A | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF518BBCZ-4F4 | –40°C to +85°C | 400 MHz | 4M bit | 168-Ball CSP_BGA | BC-168-1 |
| ADSP-BF518BSWZ-4 | –40°C to +85°C | 400 MHz | N/A | 176-Lead LQFP_EP | SQ-176-2 |
| ADSP-BF518BSWZ-4F4 | –40°C to +85°C | 400 MHz | 4M bit | 176-Lead LQFP_EP | SQ-176-2 |

[1] Z = RoHS compliant part.

[2] Referenced temperature is ambient temperature. The ambient temperature is not a specification. Please see Operating Conditions on Page 20 for junction temperature ($T_J$) specification which is the only temperature specification.

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