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Understanding Embedded - FPGAs (Field Programmable Gate Array)

Embedded - FPGAs, or Field Programmable Gate Arrays, are advanced integrated circuits that offer unparalleled flexibility and performance for digital systems. Unlike traditional fixed-function logic devices, FPGAs can be programmed and reprogrammed to execute a wide array of logical operations, enabling customized functionality tailored to specific applications. This reprogrammability allows developers to iterate designs quickly and implement complex functions without the need for custom hardware.

Applications of Embedded - FPGAs

The versatility of Embedded - FPGAs makes them indispensable in numerous fields. In telecommunications.

Details

| | |
|--------------------------------|---|
| Product Status | Obsolete |
| Number of LABs/CLBs | 1024 |
| Number of Logic Elements/Cells | 2432 |
| Total RAM Bits | 32768 |
| Number of I/O | 256 |
| Number of Gates | 28000 |
| Voltage - Supply | 3V ~ 3.6V |
| Mounting Type | Surface Mount |
| Operating Temperature | -40°C ~ 100°C (Tj) |
| Package / Case | 352-LBGA Exposed Pad, Metal |
| Supplier Device Package | 352-MBGA (35x35) |
| Purchase URL | https://www.e-xfl.com/product-detail/xilinx/xc4028xl-1bg352i |

XC4000E and XC4000X Series Compared to the XC4000

For readers already familiar with the XC4000 family of Xilinx Field Programmable Gate Arrays, the major new features in the XC4000 Series devices are listed in this section. The biggest advantages of XC4000E and XC4000X devices are significantly increased system speed, greater capacity, and new architectural features, particularly Select-RAM memory. The XC4000X devices also offer many new routing features, including special high-speed clock buffers that can be used to capture input data with minimal delay.

Any XC4000E device is pinout- and bitstream-compatible with the corresponding XC4000 device. An existing XC4000 bitstream can be used to program an XC4000E device. However, since the XC4000E includes many new features, an XC4000E bitstream cannot be loaded into an XC4000 device.

XC4000X Series devices are not bitstream-compatible with equivalent array size devices in the XC4000 or XC4000E families. However, equivalent array size devices, such as the XC4025, XC4025E, XC4028EX, and XC4028XL, are pinout-compatible.

Improvements in XC4000E and XC4000X

Increased System Speed

XC4000E and XC4000X devices can run at synchronous system clock rates of up to 80 MHz, and internal performance can exceed 150 MHz. This increase in performance over the previous families stems from improvements in both device processing and system architecture. XC4000 Series devices use a sub-micron multi-layer metal process. In addition, many architectural improvements have been made, as described below.

The XC4000XL family is a high performance 3.3V family based on 0.35 μ SRAM technology and supports system speeds to 80 MHz.

PCI Compliance

XC4000 Series -2 and faster speed grades are fully PCI compliant. XC4000E and XC4000X devices can be used to implement a one-chip PCI solution.

Carry Logic

The speed of the carry logic chain has increased dramatically. Some parameters, such as the delay on the carry chain through a single CLB (T_{BYP}), have improved by as

much as 50% from XC4000 values. See [“Fast Carry Logic” on page 18](#) for more information.

Select-RAM Memory: Edge-Triggered, Synchronous RAM Modes

The RAM in any CLB can be configured for synchronous, edge-triggered, write operation. The read operation is not affected by this change to an edge-triggered write.

Dual-Port RAM

A separate option converts the 16x2 RAM in any CLB into a 16x1 dual-port RAM with simultaneous Read/Write.

The function generators in each CLB can be configured as either level-sensitive (asynchronous) single-port RAM, edge-triggered (synchronous) single-port RAM, edge-triggered (synchronous) dual-port RAM, or as combinatorial logic.

Configurable RAM Content

The RAM content can now be loaded at configuration time, so that the RAM starts up with user-defined data.

H Function Generator

In current XC4000 Series devices, the H function generator is more versatile than in the original XC4000. Its inputs can come not only from the F and G function generators but also from up to three of the four control input lines. The H function generator can thus be totally or partially independent of the other two function generators, increasing the maximum capacity of the device.

IOB Clock Enable

The two flip-flops in each IOB have a common clock enable input, which through configuration can be activated individually for the input or output flip-flop or both. This clock enable operates exactly like the EC pin on the XC4000 CLB. This new feature makes the IOBs more versatile, and avoids the need for clock gating.

Output Drivers

The output pull-up structure defaults to a TTL-like totem-pole. This driver is an n-channel pull-up transistor, pulling to a voltage one transistor threshold below V_{cc} , just like the XC4000 family outputs. Alternatively, XC4000 Series devices can be globally configured with CMOS outputs, with p-channel pull-up transistors pulling to V_{cc} . Also, the configurable pull-up resistor in the XC4000 Series is a p-channel transistor that pulls to V_{cc} , whereas in the original XC4000 family it is an n-channel transistor that pulls to a voltage one transistor threshold below V_{cc} .

Input Thresholds

The input thresholds of 5V devices can be globally configured for either TTL (1.2 V threshold) or CMOS (2.5 V threshold), just like XC2000 and XC3000 inputs. The two global adjustments of input threshold and output level are independent of each other. The XC4000XL family has an input threshold of 1.6V, compatible with both 3.3V CMOS and TTL levels.

Global Signal Access to Logic

There is additional access from global clocks to the F and G function generator inputs.

Configuration Pin Pull-Up Resistors

During configuration, these pins have weak pull-up resistors. For the most popular configuration mode, Slave Serial, the mode pins can thus be left unconnected. The three mode inputs can be individually configured with or without weak pull-up or pull-down resistors. A pull-down resistor value of 4.7 k Ω is recommended.

The three mode inputs can be individually configured with or without weak pull-up or pull-down resistors after configuration.

The `PROGRAM` input pin has a permanent weak pull-up.

Soft Start-up

Like the XC3000A, XC4000 Series devices have “Soft Start-up.” When the configuration process is finished and the device starts up, the first activation of the outputs is automatically slew-rate limited. This feature avoids potential ground bounce when all outputs are turned on simultaneously. Immediately after start-up, the slew rate of the individual outputs is, as in the XC4000 family, determined by the individual configuration option.

XC4000 and XC4000A Compatibility

Existing XC4000 bitstreams can be used to configure an XC4000E device. XC4000A bitstreams must be recompiled for use with the XC4000E due to improved routing resources, although the devices are pin-for-pin compatible.

Additional Improvements in XC4000X Only

Increased Routing

New interconnect in the XC4000X includes twenty-two additional vertical lines in each column of CLBs and twelve new horizontal lines in each row of CLBs. The twelve “Quad Lines” in each CLB row and column include optional repowering buffers for maximum speed. Additional high-performance routing near the IOBs enhances pin flexibility.

Faster Input and Output

A fast, dedicated early clock sourced by global clock buffers is available for the IOBs. To ensure synchronization with the regular global clocks, a Fast Capture latch driven by the early clock is available. The input data can be initially loaded into the Fast Capture latch with the early clock, then transferred to the input flip-flop or latch with the low-skew global clock. A programmable delay on the input can be used to avoid hold-time requirements. See “[IOB Input Signals](#)” on page 20 for more information.

Latch Capability in CLBs

Storage elements in the XC4000X CLB can be configured as either flip-flops or latches. This capability makes the FPGA highly synthesis-compatible.

IOB Output MUX From Output Clock

A multiplexer in the IOB allows the output clock to select either the output data or the IOB clock enable as the output to the pad. Thus, two different data signals can share a single output pad, effectively doubling the number of device outputs without requiring a larger, more expensive package. This multiplexer can also be configured as an AND-gate to implement a very fast pin-to-pin path. See “[IOB Output Signals](#)” on page 23 for more information.

Additional Address Bits

Larger devices require more bits of configuration data. A daisy chain of several large XC4000X devices may require a PROM that cannot be addressed by the eighteen address bits supported in the XC4000E. The XC4000X Series therefore extends the addressing in Master Parallel configuration mode to 22 bits.

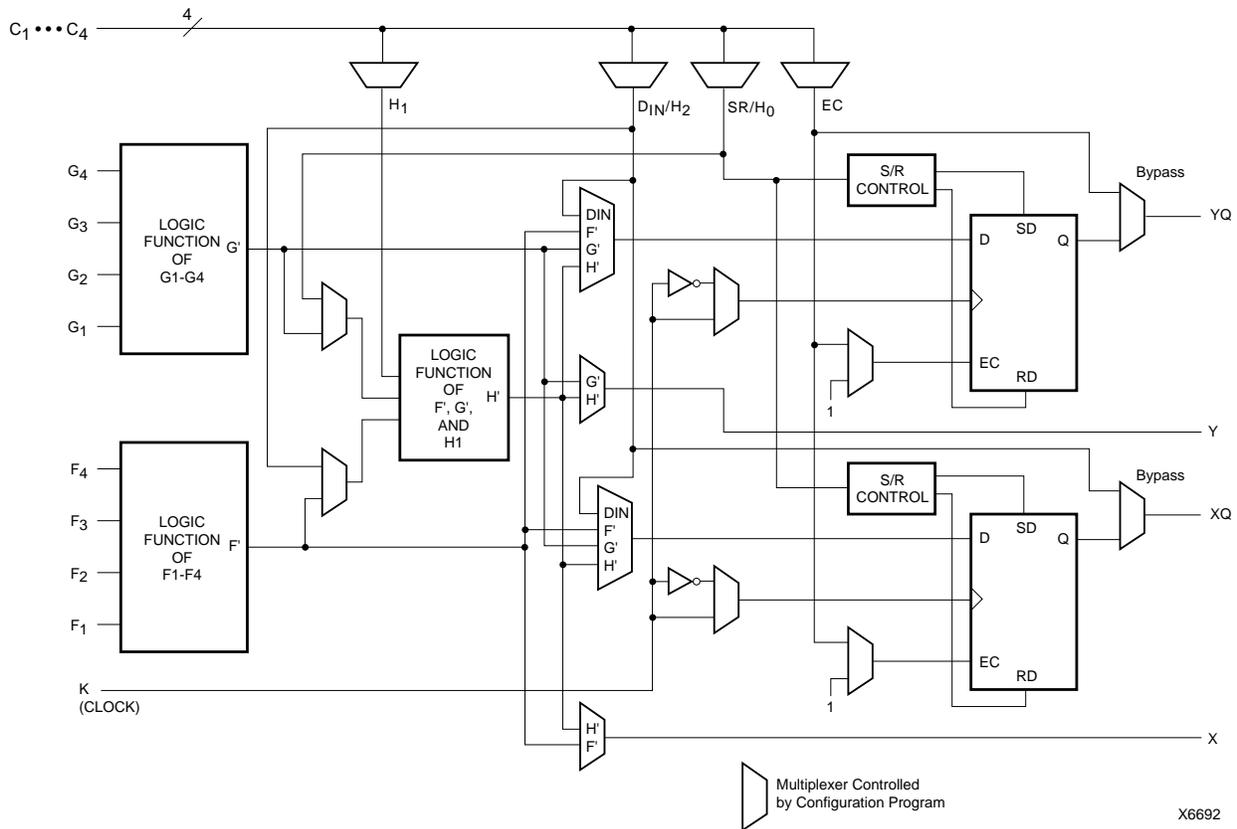


Figure 1: Simplified Block Diagram of XC4000 Series CLB (RAM and Carry Logic functions not shown)

Flip-Flops

The CLB can pass the combinational output(s) to the interconnect network, but can also store the combinational results or other incoming data in one or two flip-flops, and connect their outputs to the interconnect network as well.

The two edge-triggered D-type flip-flops have common clock (K) and clock enable (EC) inputs. Either or both clock inputs can also be permanently enabled. Storage element functionality is described in [Table 2](#).

Latches (XC4000X only)

The CLB storage elements can also be configured as latches. The two latches have common clock (K) and clock enable (EC) inputs. Storage element functionality is described in [Table 2](#).

Clock Input

Each flip-flop can be triggered on either the rising or falling clock edge. The clock pin is shared by both storage elements. However, the clock is individually invertible for each storage element. Any inverter placed on the clock input is automatically absorbed into the CLB.

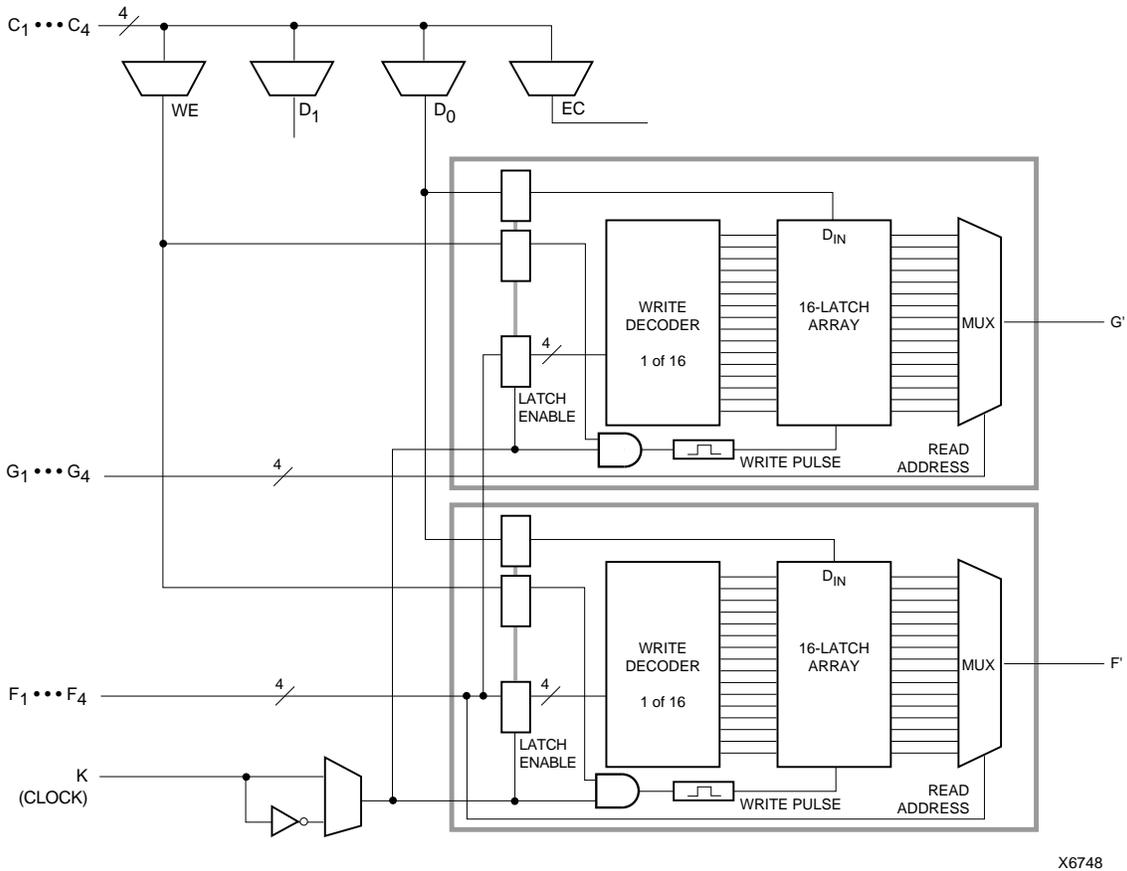
Clock Enable

The clock enable signal (EC) is active High. The EC pin is shared by both storage elements. If left unconnected for either, the clock enable for that storage element defaults to the active state. EC is not invertible within the CLB.

Table 2: CLB Storage Element Functionality (active rising edge is shown)

| Mode | K | EC | SR | D | Q |
|-----------------|---|----|----|---|----|
| Power-Up or GSR | X | X | X | X | SR |
| Flip-Flop | X | X | 1 | X | SR |
| | | 1* | 0* | D | D |
| Latch | 0 | X | 0* | X | Q |
| | 1 | 1* | 0* | X | Q |
| Both | 0 | 1* | 0* | D | D |
| | X | 0 | 0* | X | Q |

Legend:
 X Don't care
 Rising edge
 SR Set or Reset value. Reset is default.
 0* Input is Low or unconnected (default value)
 1* Input is High or unconnected (default value)



X6748

Figure 7: 16x1 Edge-Triggered Dual-Port RAM

Figure 8 shows the write timing for level-sensitive, single-port RAM.

The relationships between CLB pins and RAM inputs and outputs for single-port level-sensitive mode are shown in Table 7.

Figure 9 and Figure 10 show block diagrams of a CLB configured as 16x2 and 32x1 level-sensitive, single-port RAM.

Initializing RAM at Configuration

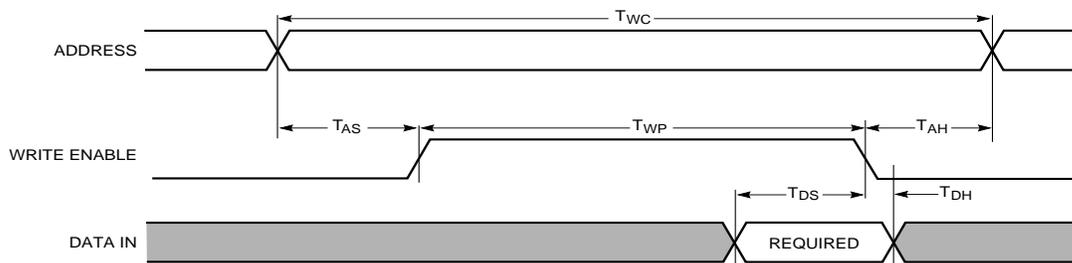
Both RAM and ROM implementations of the XC4000 Series devices are initialized during configuration. The initial contents are defined via an INIT attribute or property

attached to the RAM or ROM symbol, as described in the schematic library guide. If not defined, all RAM contents are initialized to all zeros, by default.

RAM initialization occurs only during configuration. The RAM content is not affected by Global Set/Reset.

Table 7: Single-Port Level-Sensitive RAM Signals

| RAM Signal | CLB Pin | Function |
|------------|----------------|--------------|
| D | D0 or D1 | Data In |
| A[3:0] | F1-F4 or G1-G4 | Address |
| WE | WE | Write Enable |
| O | F' or G' | Data Out |



X6462

Figure 8: Level-Sensitive RAM Write Timing

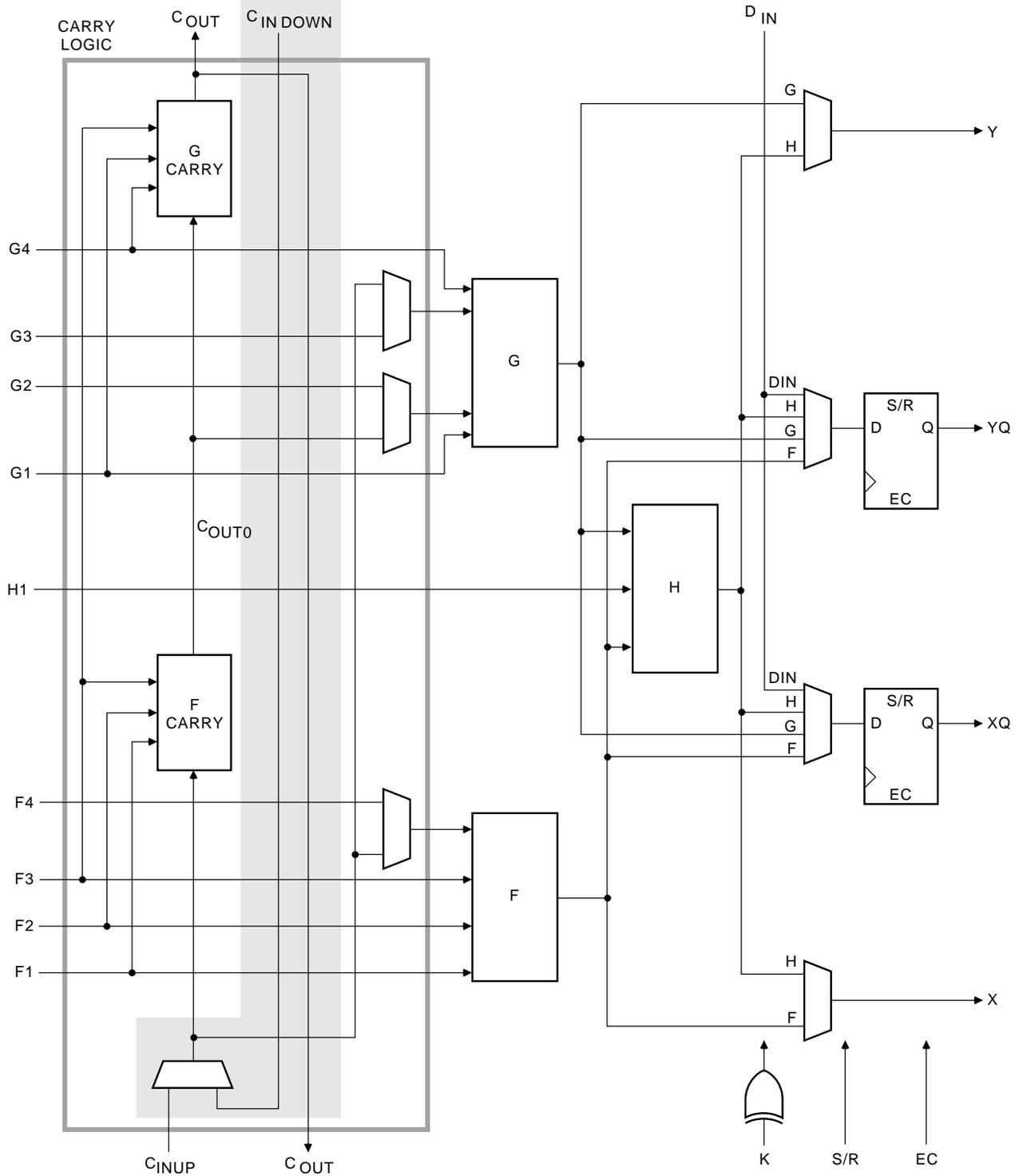


Figure 13: Fast Carry Logic in XC4000E CLB (shaded area not present in XC4000X)

X6699

Additional Input Latch for Fast Capture (XC4000X only)

The XC4000X IOB has an additional optional latch on the input. This latch, as shown in [Figure 16](#), is clocked by the output clock — the clock used for the output flip-flop — rather than the input clock. Therefore, two different clocks can be used to clock the two input storage elements. This additional latch allows the very fast capture of input data, which is then synchronized to the internal clock by the IOB flip-flop or latch.

To use this Fast Capture technique, drive the output clock pin (the Fast Capture latching signal) from the output of one of the Global Early buffers supplied in the XC4000X. The second storage element should be clocked by a Global Low-Skew buffer, to synchronize the incoming data to the internal logic. (See [Figure 17](#).) These special buffers are described in “[Global Nets and Buffers \(XC4000X only\)](#)” on [page 37](#).

The Fast Capture latch (FCL) is designed primarily for use with a Global Early buffer. For Fast Capture, a single clock signal is routed through both a Global Early buffer and a Global Low-Skew buffer. (The two buffers share an input pad.) The Fast Capture latch is clocked by the Global Early buffer, and the standard IOB flip-flop or latch is clocked by the Global Low-Skew buffer. This mode is the safest way to use the Fast Capture latch, because the clock buffers on both storage elements are driven by the same pad. There is no external skew between clock pads to create potential problems.

To place the Fast Capture latch in a design, use one of the special library symbols, ILFFX or ILFLX. ILFFX is a transparent-Low Fast Capture latch followed by an active-High input flip-flop. ILFLX is a transparent-Low Fast Capture latch followed by a transparent-High input latch. Any of the clock inputs can be inverted before driving the library element, and the inverter is absorbed into the IOB. If a single BUFG output is used to drive both clock inputs, the software automatically runs the clock through both a Global Low-Skew buffer and a Global Early buffer, and clocks the Fast Capture latch appropriately.

[Figure 16 on page 21](#) also shows a two-tap delay on the input. By default, if the Fast Capture latch is used, the Xilinx software assumes a Global Early buffer is driving the clock, and selects MEDDELAY to ensure a zero hold time. Select

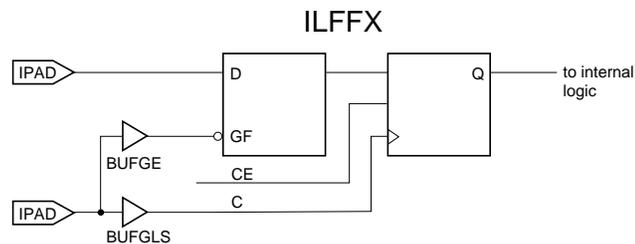


Figure 17: Examples Using XC4000X FCL

the desired delay based on the discussion in the previous subsection.

IOB Output Signals

Output signals can be optionally inverted within the IOB, and can pass directly to the pad or be stored in an edge-triggered flip-flop. The functionality of this flip-flop is shown in [Table 11](#).

An active-High 3-state signal can be used to place the output buffer in a high-impedance state, implementing 3-state outputs or bidirectional I/O. Under configuration control, the output (OUT) and output 3-state (T) signals can be inverted. The polarity of these signals is independently configured for each IOB.

The 4-mA maximum output current specification of many FPGAs often forces the user to add external buffers, which are especially cumbersome on bidirectional I/O lines. The XC4000E and XC4000EX/XL devices solve many of these problems by providing a guaranteed output sink current of 12 mA. Two adjacent outputs can be interconnected externally to sink up to 24 mA. The XC4000E and XC4000EX/XL FPGAs can thus directly drive buses on a printed circuit board.

By default, the output pull-up structure is configured as a TTL-like totem-pole. The High driver is an n-channel pull-up transistor, pulling to a voltage one transistor threshold below Vcc. Alternatively, the outputs can be globally configured as CMOS drivers, with p-channel pull-up transistors pulling to Vcc. This option, applied using the bitstream generation software, applies to all outputs on the device. It is not individually programmable. In the XC4000XL, all outputs are pulled to the positive supply rail.

Table 11: Output Flip-Flop Functionality (active rising edge is shown)

| Mode | Clock | Clock Enable | T | D | Q |
|-----------------|-------|--------------|----|---|----|
| Power-Up or GSR | X | X | 0* | X | SR |
| Flip-Flop | X | 0 | 0* | X | Q |
| | | 1* | 0* | D | D |
| | X | X | 1 | X | Z |
| | 0 | X | 0* | X | Q |

Legend:
 X Don't care
 Rising edge
 SR Set or Reset value. Reset is default.
 0* Input is Low or unconnected (default value)
 1* Input is High or unconnected (default value)
 Z 3-state

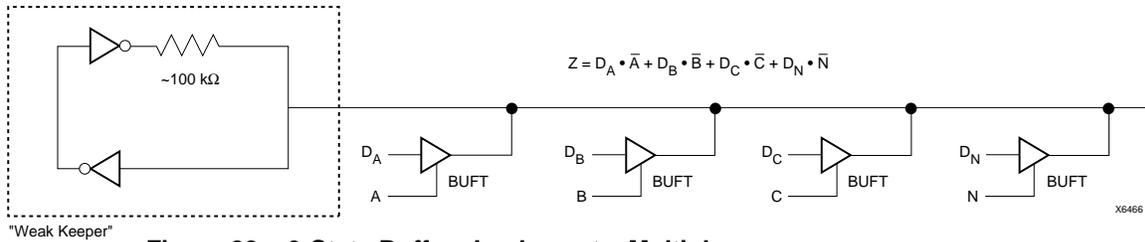


Figure 22: 3-State Buffers Implement a Multiplexer

Wide Edge Decoders

Dedicated decoder circuitry boosts the performance of wide decoding functions. When the address or data field is wider than the function generator inputs, FPGAs need multi-level decoding and are thus slower than PALs. XC4000 Series CLBs have nine inputs. Any decoder of up to nine inputs is, therefore, compact and fast. However, there is also a need for much wider decoders, especially for address decoding in large microprocessor systems.

An XC4000 Series FPGA has four programmable decoders located on each edge of the device. The inputs to each decoder are any of the IOB I1 signals on that edge plus one local interconnect per CLB row or column. Each row or column of CLBs provides up to three variables or their complements., as shown in Figure 23. Each decoder generates a High output (resistor pull-up) when the AND condition of the selected inputs, or their complements, is true. This is analogous to a product term in typical PAL devices.

Each of these wired-AND gates is capable of accepting up to 42 inputs on the XC4005E and 72 on the XC4013E. There are up to 96 inputs for each decoder on the XC4028X and 132 on the XC4052X. The decoders may also be split in two when a larger number of narrower decoders are required, for a maximum of 32 decoders per device.

The decoder outputs can drive CLB inputs, so they can be combined with other logic to form a PAL-like AND/OR structure. The decoder outputs can also be routed directly to the chip outputs. For fastest speed, the output should be on the same chip edge as the decoder. Very large PALs can be emulated by ORing the decoder outputs in a CLB. This decoding feature covers what has long been considered a weakness of older FPGAs. Users often resorted to external PALs for simple but fast decoding functions. Now, the dedicated decoders in the XC4000 Series device can implement these functions fast and efficiently.

To use the wide edge decoders, place one or more of the WAND library symbols (WAND1, WAND4, WAND8, WAND16). Attach a DECODE attribute or property to each WAND symbol. Tie the outputs together and attach a PUL-

LUP symbol. Location attributes or properties such as L (left edge) or TR (right half of top edge) should also be used to ensure the correct placement of the decoder inputs.

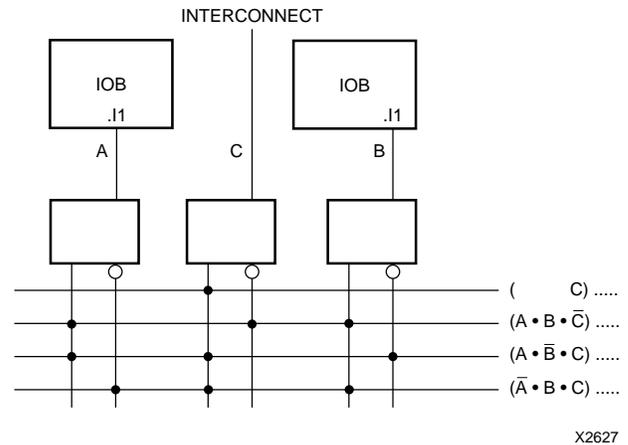


Figure 23: XC4000 Series Edge Decoding Example

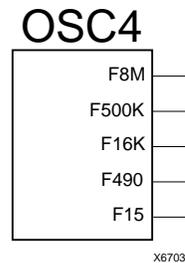
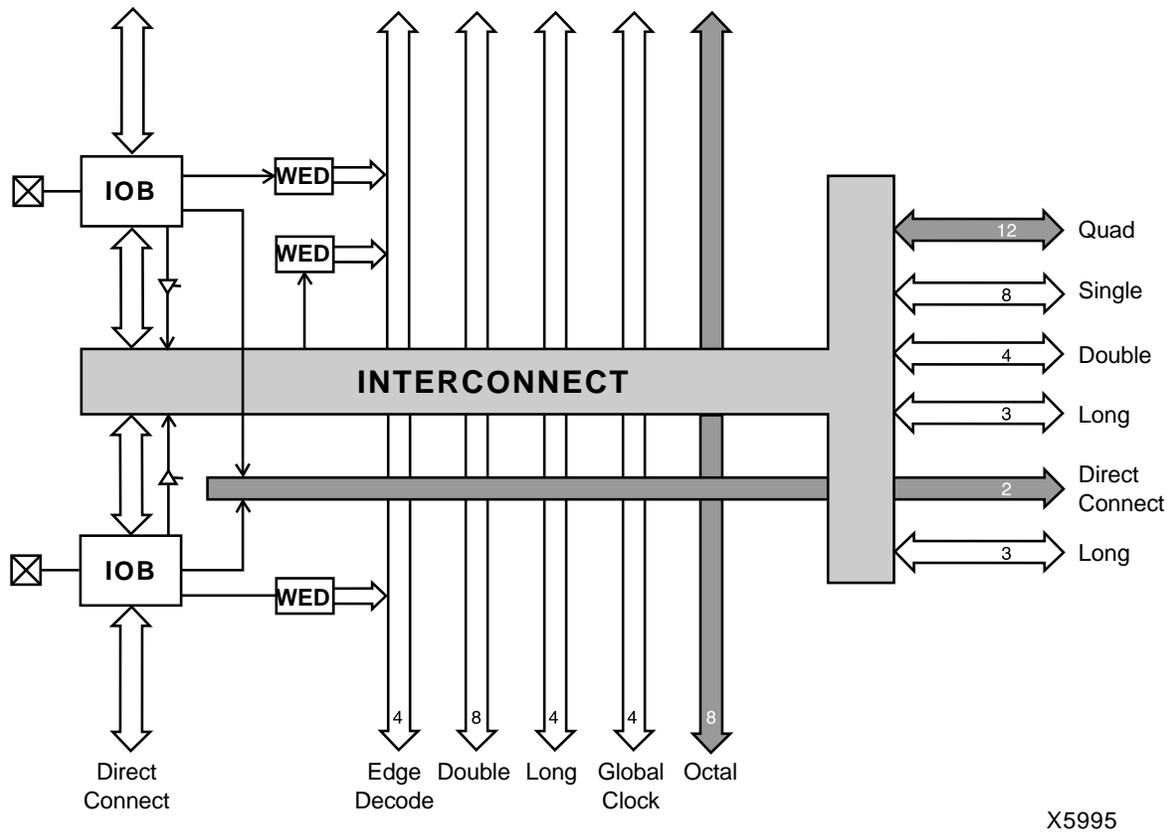


Figure 24: XC4000 Series Oscillator Symbol

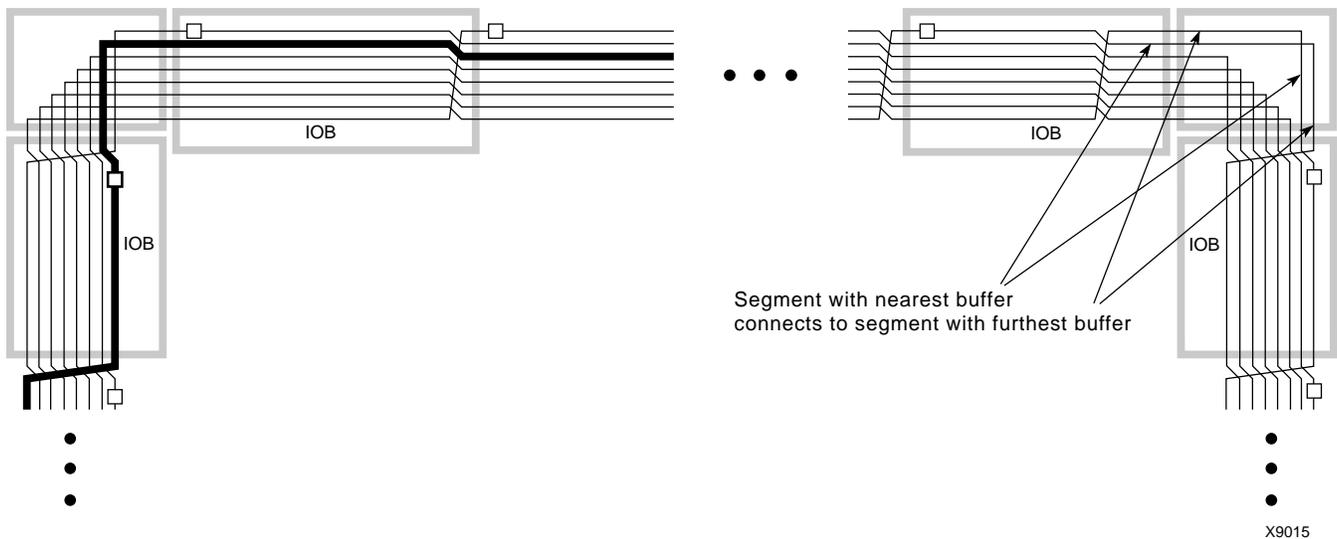
On-Chip Oscillator

XC4000 Series devices include an internal oscillator. This oscillator is used to clock the power-on time-out, for configuration memory clearing, and as the source of CCLK in Master configuration modes. The oscillator runs at a nominal 8 MHz frequency that varies with process, V_{cc}, and temperature. The output frequency falls between 4 and 10 MHz.



X5995

Figure 31: High-Level Routing Diagram of XC4000 Series VersaRing (Left Edge)
WED = Wide Edge Decoder, IOB = I/O Block (shaded arrows indicate XC4000X only)



X9015

Figure 32: XC4000X Octal I/O Routing

IOB inputs and outputs interface with the octal lines via the single-length interconnect lines. Single-length lines are also used for communication between the octals and double-length lines, quads, and longlines within the CLB array.

Segmentation into buffered octals was found to be optimal for distributing signals over long distances around the device.

Global Nets and Buffers

Both the XC4000E and the XC4000X have dedicated global networks. These networks are designed to distribute clocks and other high fanout control signals throughout the devices with minimal skew. The global buffers are described in detail in the following sections. The text descriptions and diagrams are summarized in [Table 15](#). The table shows which CLB and IOB clock pins can be sourced by which global buffers.

In both XC4000E and XC4000X devices, placement of a library symbol called BUFG results in the software choosing the appropriate clock buffer, based on the timing requirements of the design. The detailed information in these sections is included only for reference.

Global Nets and Buffers (XC4000E only)

Four vertical longlines in each CLB column are driven exclusively by special global buffers. These longlines are in addition to the vertical longlines used for standard interconnect. The four global lines can be driven by either of two types of global buffers. The clock pins of every CLB and IOB can also be sourced from local interconnect.

Two different types of clock buffers are available in the XC4000E:

- Primary Global Buffers (BUFGP)
- Secondary Global Buffers (BUFGS)

Four Primary Global buffers offer the shortest delay and negligible skew. Four Secondary Global buffers have slightly longer delay and slightly more skew due to potentially heavier loading, but offer greater flexibility when used to drive non-clock CLB inputs.

The Primary Global buffers must be driven by the semi-dedicated pads. The Secondary Global buffers can be sourced by either semi-dedicated pads or internal nets.

Each CLB column has four dedicated vertical Global lines. Each of these lines can be accessed by one particular Primary Global buffer, or by any of the Secondary Global buffers, as shown in [Figure 34](#). Each corner of the device has one Primary buffer and one Secondary buffer.

IOBs along the left and right edges have four vertical global longlines. Top and bottom IOBs can be clocked from the global lines in the adjacent CLB column.

A global buffer should be specified for all timing-sensitive global signal distribution. To use a global buffer, place a BUFGP (primary buffer), BUFGS (secondary buffer), or BUFG (either primary or secondary buffer) element in a schematic or in HDL code. If desired, attach a LOC attribute or property to direct placement to the designated location. For example, attach a LOC=L attribute or property to a BUFGS symbol to direct that a buffer be placed in one of the two Secondary Global buffers on the left edge of the device, or a LOC=BL to indicate the Secondary Global buffer on the bottom edge of the device, on the left.

Table 15: Clock Pin Access

| | XC4000E | | XC4000X | | | Local Interconnect |
|---|---------|-------|---------|-------------|-------------|--------------------|
| | BUFGP | BUFGS | BUFGLS | L & R BUFGS | T & B BUFGS | |
| All CLBs in Quadrant | √ | √ | √ | √ | √ | √ |
| All CLBs in Device | √ | √ | √ | | | √ |
| IOBs on Adjacent Vertical Half Edge | √ | √ | √ | √ | √ | √ |
| IOBs on Adjacent Vertical Full Edge | √ | √ | √ | √ | | √ |
| IOBs on Adjacent Horizontal Half Edge (Direct) | | | | √ | | √ |
| IOBs on Adjacent Horizontal Half Edge (through CLB globals) | √ | √ | √ | √ | √ | √ |
| IOBs on Adjacent Horizontal Full Edge (through CLB globals) | √ | √ | √ | | | √ |

L = Left, R = Right, T = Top, B = Bottom

Figure 41 on page 44 is a diagram of the XC4000 Series boundary scan logic. It includes three bits of Data Register per IOB, the IEEE 1149.1 Test Access Port controller, and the Instruction Register with decodes.

XC4000 Series devices can also be configured through the boundary scan logic. See "Readback" on page 55.

Data Registers

The primary data register is the boundary scan register. For each IOB pin in the FPGA, bonded or not, it includes three bits for In, Out and 3-State Control. Non-IOB pins have appropriate partial bit population for In or Out only. PROGRAM, CCLK and DONE are not included in the boundary scan register. Each EXTEST CAPTURE-DR state captures all In, Out, and 3-state pins.

The data register also includes the following non-pin bits: TDO.T, and TDO.O, which are always bits 0 and 1 of the

data register, respectively, and BSCANT.UPD, which is always the last bit of the data register. These three boundary scan bits are special-purpose Xilinx test signals.

The other standard data register is the single flip-flop BYPASS register. It synchronizes data being passed through the FPGA to the next downstream boundary scan device.

The FPGA provides two additional data registers that can be specified using the BSCAN macro. The FPGA provides two user pins (BSCAN.SEL1 and BSCAN.SEL2) which are the decodes of two user instructions. For these instructions, two corresponding pins (BSCAN.TDO1 and BSCAN.TDO2) allow user scan data to be shifted out on TDO. The data register clock (BSCAN.DRCK) is available for control of test logic which the user may wish to implement with CLBs. The NAND of TCK and RUN-TEST-IDLE is also provided (BSCAN.IDLE).

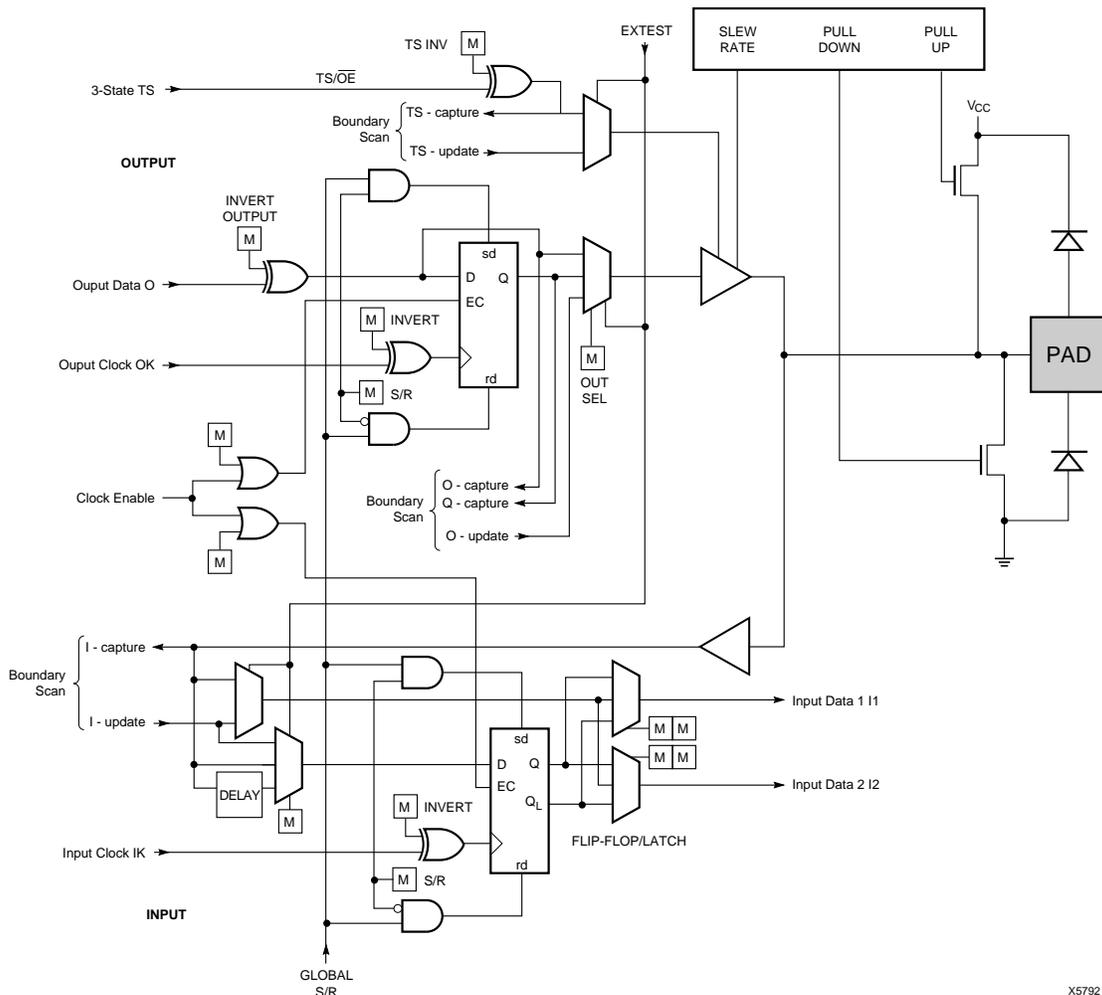


Figure 40: Block Diagram of XC4000E IOB with Boundary Scan (some details not shown). XC4000X Boundary Scan Logic is Identical.

Setting CCLK Frequency

For Master modes, CCLK can be generated in either of two frequencies. In the default slow mode, the frequency ranges from 0.5 MHz to 1.25 MHz for XC4000E and XC4000EX devices and from 0.6 MHz to 1.8 MHz for XC4000XL devices. In fast CCLK mode, the frequency ranges from 4 MHz to 10 MHz for XC4000E/EX devices and from 5 MHz to 15 MHz for XC4000XL devices. The frequency is selected by an option when running the bitstream generation software. If an XC4000 Series Master is driving an XC3000- or XC2000-family slave, slow CCLK mode must be used. In addition, an XC4000XL device driving a XC4000E or XC4000EX should use slow mode. Slow mode is the default.

Table 19: XC4000 Series Data Stream Formats

| Data Type | All Other Modes (D0...) |
|-----------------------------|-------------------------|
| Fill Byte | 11111111b |
| Preamble Code | 0010b |
| Length Count | COUNT(23:0) |
| Fill Bits | 1111b |
| Start Field | 0b |
| Data Frame | DATA(n-1:0) |
| CRC or Constant Field Check | xxxx (CRC) or 0110b |
| Extend Write Cycle | — |
| Postamble | 01111111b |
| Start-Up Bytes | xxh |
| Legend: | |
| Not shaded | Once per bitstream |
| Light | Once per data frame |
| Dark | Once per device |

Data Stream Format

The data stream (“bitstream”) format is identical for all configuration modes.

The data stream formats are shown in [Table 19](#). Bit-serial data is read from left to right, and byte-parallel data is effectively assembled from this serial bitstream, with the first bit in each byte assigned to D0.

The configuration data stream begins with a string of eight ones, a preamble code, followed by a 24-bit length count and a separator field of ones. This header is followed by the actual configuration data in frames. The length and number of frames depends on the device type (see [Table 20](#) and [Table 21](#)). Each frame begins with a start field and ends with an error check. A postamble code is required to signal the end of data for a single device. In all cases, additional start-up bytes of data are required to provide four clocks for the startup sequence at the end of configuration. Long daisy chains require additional startup bytes to shift the last data through the chain. All startup bytes are don’t-cares; these bytes are not included in bitstreams created by the Xilinx software.

A selection of CRC or non-CRC error checking is allowed by the bitstream generation software. The non-CRC error checking tests for a designated end-of-frame field for each frame. For CRC error checking, the software calculates a running CRC and inserts a unique four-bit partial check at the end of each frame. The 11-bit CRC check of the last frame of an FPGA includes the last seven data bits.

Detection of an error results in the suspension of data loading and the pulling down of the $\overline{\text{INIT}}$ pin. In Master modes, CCLK and address signals continue to operate externally. The user must detect $\overline{\text{INIT}}$ and initialize a new configuration by pulsing the $\overline{\text{PROGRAM}}$ pin Low or cycling Vcc.

used), and if RAM is present, the RAM content must be unchanged.

Statistically, one error out of 2048 might go undetected.

Configuration Sequence

There are four major steps in the XC4000 Series power-up configuration sequence.

- Configuration Memory Clear
- Initialization
- Configuration
- Start-Up

The full process is illustrated in Figure 46.

Configuration Memory Clear

When power is first applied or is reapplied to an FPGA, an internal circuit forces initialization of the configuration logic. When Vcc reaches an operational level, and the circuit passes the write and read test of a sample pair of configuration bits, a time delay is started. This time delay is nominally 16 ms, and up to 10% longer in the low-voltage devices. The delay is four times as long when in Master Modes (M0 Low), to allow ample time for all slaves to reach a stable Vcc. When all \overline{INIT} pins are tied together, as recommended, the longest delay takes precedence. Therefore, devices with different time delays can easily be mixed and matched in a daisy chain.

This delay is applied only on power-up. It is not applied when re-configuring an FPGA by pulsing the PROGRAM pin

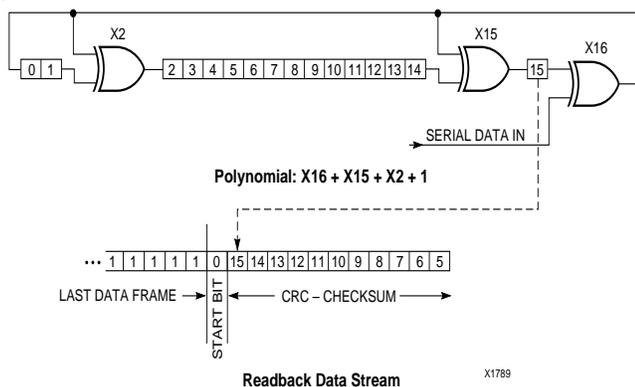


Figure 45: Circuit for Generating CRC-16

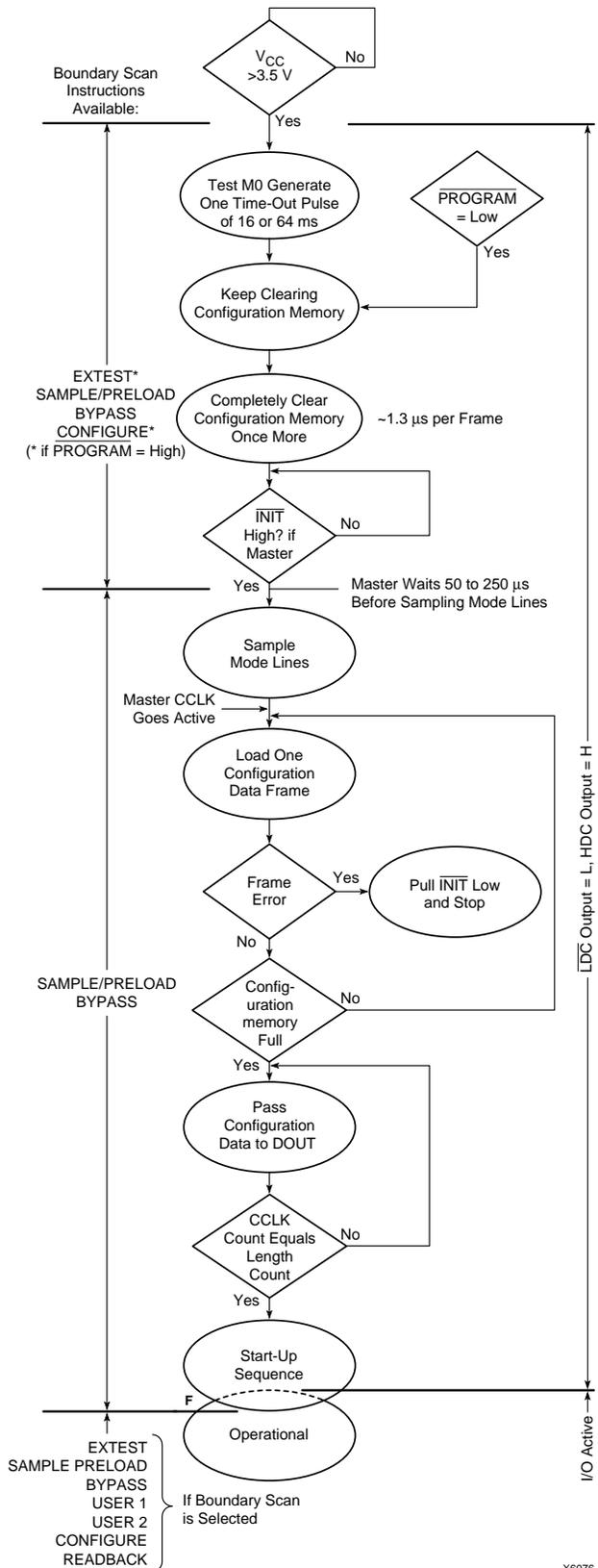


Figure 46: Power-up Configuration Sequence

Start-up from a User Clock (STARTUP.CLK)

When, instead of CCLK, a user-supplied start-up clock is selected, Q1 is used to bridge the unknown phase relationship between CCLK and the user clock. This arbitration causes an unavoidable one-cycle uncertainty in the timing of the rest of the start-up sequence.

DONE Goes High to Signal End of Configuration

XC4000 Series devices read the expected length count from the bitstream and store it in an internal register. The length count varies according to the number of devices and the composition of the daisy chain. Each device also counts the number of CCLKs during configuration.

Two conditions have to be met in order for the DONE pin to go high:

- the chip's internal memory must be full, and
- the configuration length count must be met, *exactly*.

This is important because the counter that determines when the length count is met begins with the very first CCLK, not the first one after the preamble.

Therefore, if a stray bit is inserted before the preamble, or the data source is not ready at the time of the first CCLK, the internal counter that holds the number of CCLKs will be one ahead of the actual number of data bits read. At the end of configuration, the configuration memory will be full, but the number of bits in the internal counter will not match the expected length count.

As a consequence, a Master mode device will continue to send out CCLKs until the internal counter turns over to zero, and then reaches the correct length count a second time. This will take several seconds [$2^{24} * \text{CCLK period}$] — which is sometimes interpreted as the device not configuring at all.

If it is not possible to have the data ready at the time of the first CCLK, the problem can be avoided by increasing the number in the length count by the appropriate value. The *XACT User Guide* includes detailed information about manually altering the length count.

Note that DONE is an open-drain output and does not go High unless an internal pull-up is activated or an external pull-up is attached. The internal pull-up is activated as the default by the bitstream generation software.

Release of User I/O After DONE Goes High

By default, the user I/O are released one CCLK cycle after the DONE pin goes High. If CCLK is not clocked after DONE goes High, the outputs remain in their initial state — 3-stated, with a 50 k Ω - 100 k Ω pull-up. The delay from DONE High to active user I/O is controlled by an option to the bitstream generation software.

Release of Global Set/Reset After DONE Goes High

By default, Global Set/Reset (GSR) is released two CCLK cycles after the DONE pin goes High. If CCLK is not clocked twice after DONE goes High, all flip-flops are held in their initial set or reset state. The delay from DONE High to GSR inactive is controlled by an option to the bitstream generation software.

Configuration Complete After DONE Goes High

Three full CCLK cycles are required after the DONE pin goes High, as shown in [Figure 47 on page 53](#). If CCLK is not clocked three times after DONE goes High, readback cannot be initiated and most boundary scan instructions cannot be used.

Configuration Through the Boundary Scan Pins

XC4000 Series devices can be configured through the boundary scan pins. The basic procedure is as follows:

- Power up the FPGA with $\overline{\text{INIT}}$ held Low (or drive the $\overline{\text{PROGRAM}}$ pin Low for more than 300 ns followed by a High while holding $\overline{\text{INIT}}$ Low). Holding $\overline{\text{INIT}}$ Low allows enough time to issue the CONFIG command to the FPGA. The pin can be used as I/O after configuration if a resistor is used to hold $\overline{\text{INIT}}$ Low.
- Issue the CONFIG command to the TMS input
- Wait for $\overline{\text{INIT}}$ to go High
- Sequence the boundary scan Test Access Port to the SHIFT-DR state
- Toggle TCK to clock data into TDI pin.

The user must account for all TCK clock cycles after INIT goes High, as all of these cycles affect the Length Count compare.

For more detailed information, refer to the Xilinx application note XAPP017, "*Boundary Scan in XC4000 Devices*." This application note also applies to XC4000E and XC4000X devices.

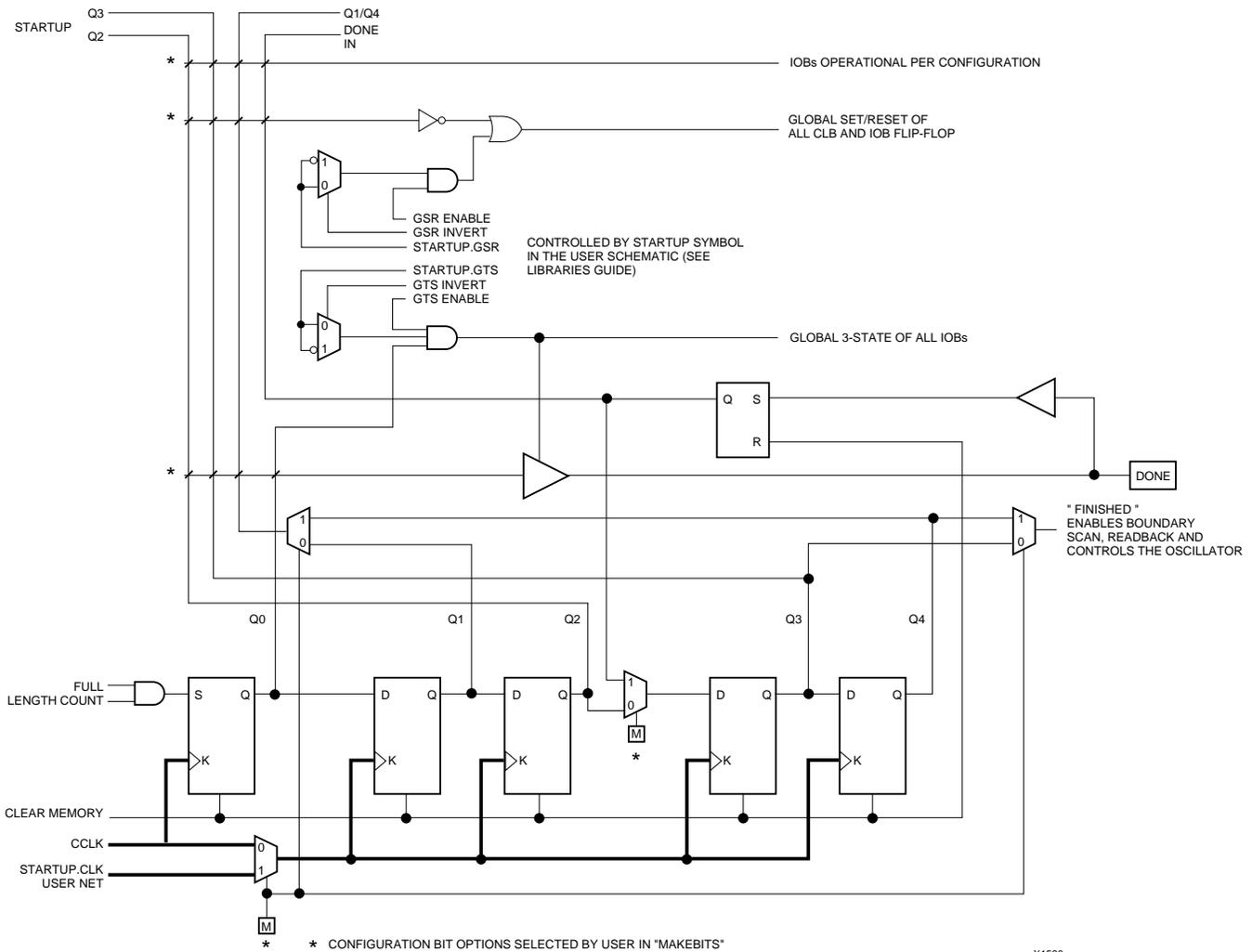


Figure 48: Start-up Logic

Readback

The user can read back the content of configuration memory and the level of certain internal nodes without interfering with the normal operation of the device.

Readback not only reports the downloaded configuration bits, but can also include the present state of the device, represented by the content of all flip-flops and latches in CLBs and IOBs, as well as the content of function generators used as RAMs.

Note that in XC4000 Series devices, configuration data is *not* inverted with respect to configuration as it is in XC2000 and XC3000 families.

XC4000 Series Readback does not use any dedicated pins, but uses four internal nets (RDBK.TRIG, RDBK.DATA, RDBK.RIP and RDBK.CLK) that can be routed to any IOB. To access the internal Readback signals, place the READ-

BACK library symbol and attach the appropriate pad symbols, as shown in Figure 49.

After Readback has been initiated by a High level on RDBK.TRIG after configuration, the RDBK.RIP (Read In Progress) output goes High on the next rising edge of RDBK.CLK. Subsequent rising edges of this clock shift out Readback data on the RDBK.DATA net.

Readback data does not include the preamble, but starts with five dummy bits (all High) followed by the Start bit (Low) of the first frame. The first two data bits of the first frame are always High.

Each frame ends with four error check bits. They are read back as High. The last seven bits of the last frame are also read back as High. An additional Start bit (Low) and an 11-bit Cyclic Redundancy Check (CRC) signature follow, before RDBK.RIP returns Low.

Table 23: Pin Functions During Configuration

| CONFIGURATION MODE <M2:M1:M0> | | | | | | |
|-------------------------------|--------------------------|------------------------------|-------------------------------|---------------------------------|-------------------------------|----------------|
| SLAVE SERIAL <1:1:1> | MASTER SERIAL <0:0:0> | SYNCH. PERIPHERAL <0:1:1> | ASYNCH. PERIPHERAL <1:0:1> | MASTER PARALLEL DOWN <1:1:0> | MASTER PARALLEL UP <1:0:0> | USER OPERATION |
| M2(HIGH) (I) | M2(LOW) (I) | M2(LOW) (I) | M2(HIGH) (I) | M2(HIGH) (I) | M2(HIGH) (I) | (I) |
| M1(HIGH) (I) | M1(LOW) (I) | M1(HIGH) (I) | M1(LOW) (I) | M1(HIGH) (I) | M1(LOW) (I) | (O) |
| M0(HIGH) (I) | M0(LOW) (I) | M0(HIGH) (I) | M0(HIGH) (I) | M0(LOW) (I) | M0(LOW) (I) | (I) |
| HDC (HIGH) | HDC (HIGH) | HDC (HIGH) | HDC (HIGH) | HDC (HIGH) | HDC (HIGH) | I/O |
| LDC (LOW) | LDC (LOW) | LDC (LOW) | LDC (LOW) | LDC (LOW) | LDC (LOW) | I/O |
| INIT | INIT | INIT | INIT | INIT | INIT | I/O |
| DONE | DONE | DONE | DONE | DONE | DONE | DONE |
| PROGRAM (I) | PROGRAM (I) | PROGRAM (I) | PROGRAM (I) | PROGRAM (I) | PROGRAM (I) | PROGRAM |
| CCLK (I) | CCLK (O) | CCLK (I) | CCLK (O) | CCLK (O) | CCLK (O) | CCLK (I) |
| | | RDY/BUSY (O) | RDY/BUSY (O) | RCLK (O) | RCLK (O) | I/O |
| | | | RS (I) | | | I/O |
| | | | CS0 (I) | | | I/O |
| | | DATA 7 (I) | DATA 7 (I) | DATA 7 (I) | DATA 7 (I) | I/O |
| | | DATA 6 (I) | DATA 6 (I) | DATA 6 (I) | DATA 6 (I) | I/O |
| | | DATA 5 (I) | DATA 5 (I) | DATA 5 (I) | DATA 5 (I) | I/O |
| | | DATA 4 (I) | DATA 4 (I) | DATA 4 (I) | DATA 4 (I) | I/O |
| | | DATA 3 (I) | DATA 3 (I) | DATA 3 (I) | DATA 3 (I) | I/O |
| | | DATA 2 (I) | DATA 2 (I) | DATA 2 (I) | DATA 2 (I) | I/O |
| | | DATA 1 (I) | DATA 1 (I) | DATA 1 (I) | DATA 1 (I) | I/O |
| DIN (I) | DIN (I) | DATA 0 (I) | DATA 0 (I) | DATA 0 (I) | DATA 0 (I) | I/O |
| DOUT | DOUT | DOUT | DOUT | DOUT | DOUT | SGCK4-GCK6-I/O |
| TDI | TDI | TDI | TDI | TDI | TDI | TDI-I/O |
| TCK | TCK | TCK | TCK | TCK | TCK | TCK-I/O |
| TMS | TMS | TMS | TMS | TMS | TMS | TMS-I/O |
| TDO | TDO | TDO | TDO | TDO | TDO | TDO-(O) |
| | | | WS (I) | A0 | A0 | I/O |
| | | | | A1 | A1 | PGCK4-GCK7-I/O |
| | | | CS1 | A2 | A2 | I/O |
| | | | | A3 | A3 | I/O |
| | | | | A4 | A4 | I/O |
| | | | | A5 | A5 | I/O |
| | | | | A6 | A6 | I/O |
| | | | | A7 | A7 | I/O |
| | | | | A8 | A8 | I/O |
| | | | | A9 | A9 | I/O |
| | | | | A10 | A10 | I/O |
| | | | | A11 | A11 | I/O |
| | | | | A12 | A12 | I/O |
| | | | | A13 | A13 | I/O |
| | | | | A14 | A14 | I/O |
| | | | | A15 | A15 | SGCK1-GCK8-I/O |
| | | | | A16 | A16 | PGCK1-GCK1-I/O |
| | | | | A17 | A17 | I/O |
| | | | | A18* | A18* | I/O |
| | | | | A19* | A19* | I/O |
| | | | | A20* | A20* | I/O |
| | | | | A21* | A21* | I/O |
| | | | | | | ALL OTHERS |

* XC4000X only

- Notes
1. A shaded table cell represents a 50 kΩ - 100 kΩ pull-up before and during configuration.
 2. (I) represents an input; (O) represents an output.
 3. INIT is an open-drain output during configuration.

Configuration Timing

The seven configuration modes are discussed in detail in this section. Timing specifications are included.

Slave Serial Mode

In Slave Serial mode, an external signal drives the CCLK input of the FPGA. The serial configuration bitstream must be available at the DIN input of the lead FPGA a short setup time before each rising CCLK edge.

The lead FPGA then presents the preamble data—and all data that overflows the lead device—on its DOUT pin.

There is an internal delay of 0.5 CCLK periods, which means that DOUT changes on the falling CCLK edge, and the next FPGA in the daisy chain accepts data on the subsequent rising CCLK edge.

Figure 51 shows a full master/slave system. An XC4000 Series device in Slave Serial mode should be connected as shown in the third device from the left.

Slave Serial mode is selected by a <111> on the mode pins (M2, M1, M0). Slave Serial is the default mode if the mode pins are left unconnected, as they have weak pull-up resistors during configuration.

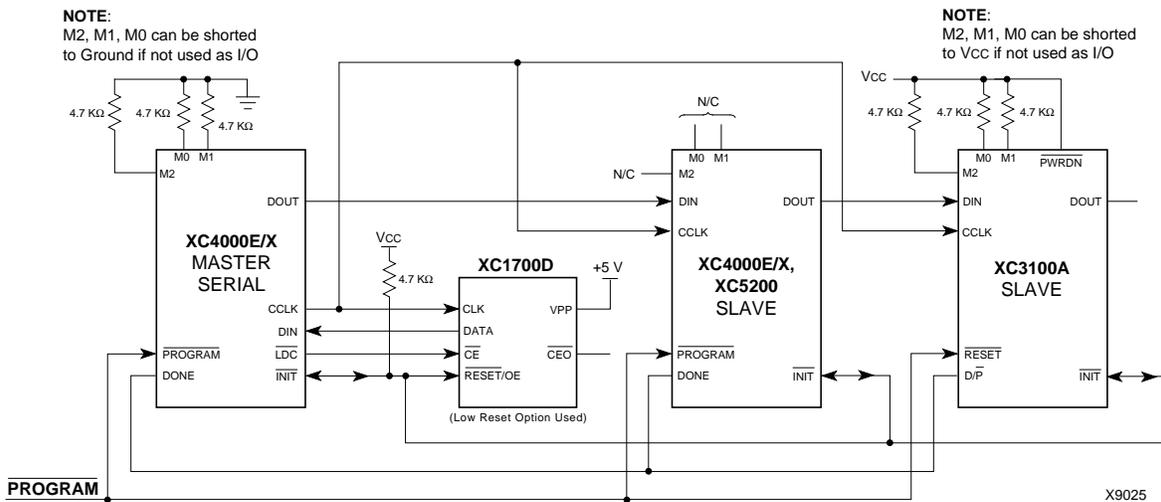
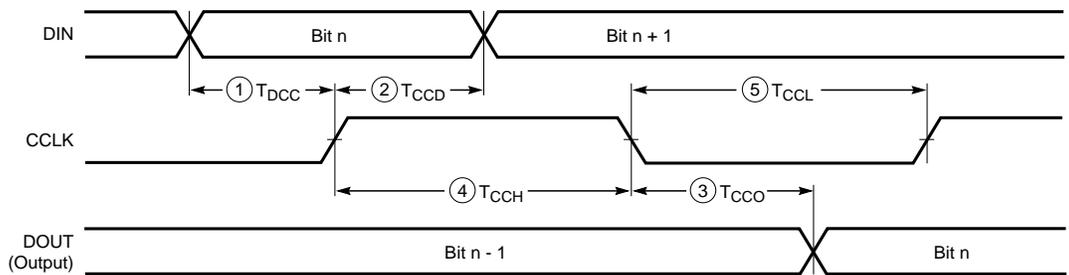


Figure 51: Master/Slave Serial Mode Circuit Diagram



X5379

| | Description | Symbol | Min | Max | Units |
|------|-------------|-------------|----------|-----|-------|
| CCLK | DIN setup | 1 T_{DCC} | 20 | | ns |
| | DIN hold | 2 T_{CCD} | 0 | | ns |
| | DIN to DOUT | 3 T_{CCO} | | 30 | ns |
| | High time | 4 T_{CCH} | 45 | | ns |
| | Low time | 5 T_{CCL} | 45 | | ns |
| | Frequency | | F_{CC} | | 10 |

Note: Configuration must be delayed until the INIT pins of all daisy-chained FPGAs are High.

Figure 52: Slave Serial Mode Programming Switching Characteristics

Asynchronous Peripheral Mode

Write to FPGA

Asynchronous Peripheral mode uses the trailing edge of the logic AND condition of \overline{WS} and $\overline{CS0}$ being Low and \overline{RS} and $CS1$ being High to accept byte-wide data from a microprocessor bus. In the lead FPGA, this data is loaded into a double-buffered UART-like parallel-to-serial converter and is serially shifted into the internal logic.

The lead FPGA presents the preamble data (and all data that overflows the lead device) on its DOUT pin. The RDY/BUSY output from the lead FPGA acts as a handshake signal to the microprocessor. RDY/BUSY goes Low when a byte has been received, and goes High again when the byte-wide input buffer has transferred its information into the shift register, and the buffer is ready to receive new data. A new write may be started immediately, as soon as the RDY/BUSY output has gone Low, acknowledging receipt of the previous data. Write may not be terminated until RDY/BUSY is High again for one CCLK period. Note that RDY/BUSY is pulled High with a high-impedance pull-up prior to \overline{INIT} going High.

The length of the \overline{BUSY} signal depends on the activity in the UART. If the shift register was empty when the new byte was received, the \overline{BUSY} signal lasts for only two CCLK periods. If the shift register was still full when the new byte was received, the \overline{BUSY} signal can be as long as nine CCLK periods.

Note that after the last byte has been entered, only seven of its bits are shifted out. CCLK remains High with DOUT equal to bit 6 (the next-to-last bit) of the last byte entered.

The RDY/ \overline{BUSY} handshake can be ignored if the delay from any one Write to the end of the next Write is guaranteed to be longer than 10 CCLK periods.

Status Read

The logic AND condition of the $\overline{CS0}$, $CS1$ and \overline{RS} inputs puts the device status on the Data bus.

- D7 High indicates Ready
- D7 Low indicates Busy
- D0 through D6 go unconditionally High

It is mandatory that the whole start-up sequence be started and completed by one byte-wide input. Otherwise, the pins used as Write Strobe or Chip Enable might become active outputs and interfere with the final byte transfer. If this transfer does not occur, the start-up sequence is not completed all the way to the finish (point F in [Figure 47 on page 53](#)).

In this case, at worst, the internal reset is not released. At best, Readback and Boundary Scan are inhibited. The length-count value, as generated by the XACTstep software, ensures that these problems never occur.

Although RDY/ \overline{BUSY} is brought out as a separate signal, microprocessors can more easily read this information on one of the data lines. For this purpose, D7 represents the RDY/ \overline{BUSY} status when \overline{RS} is Low, \overline{WS} is High, and the two chip select lines are both active.

Asynchronous Peripheral mode is selected by a <101> on the mode pins (M2, M1, M0).

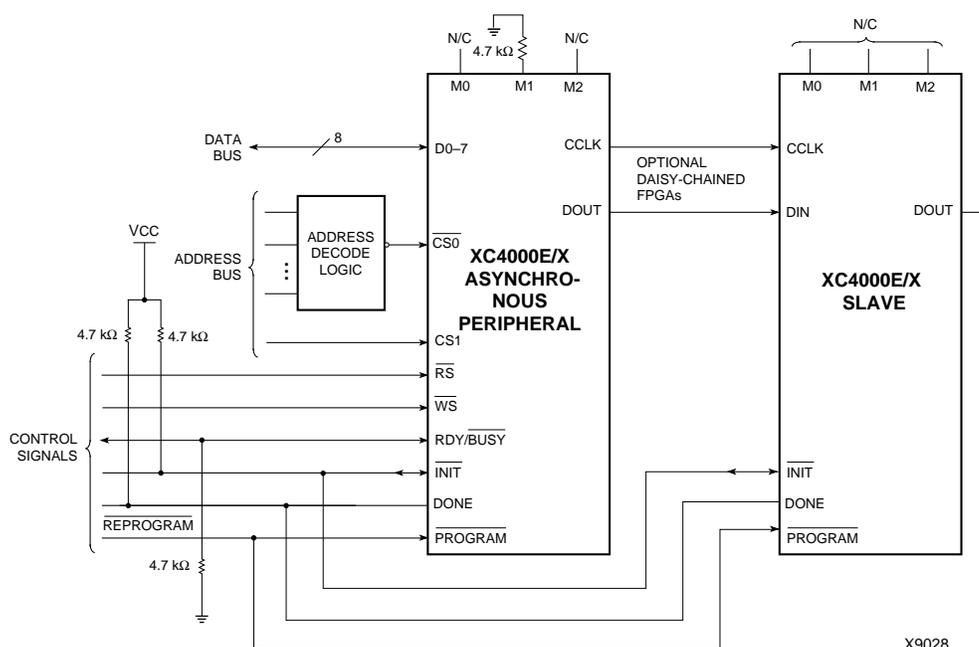
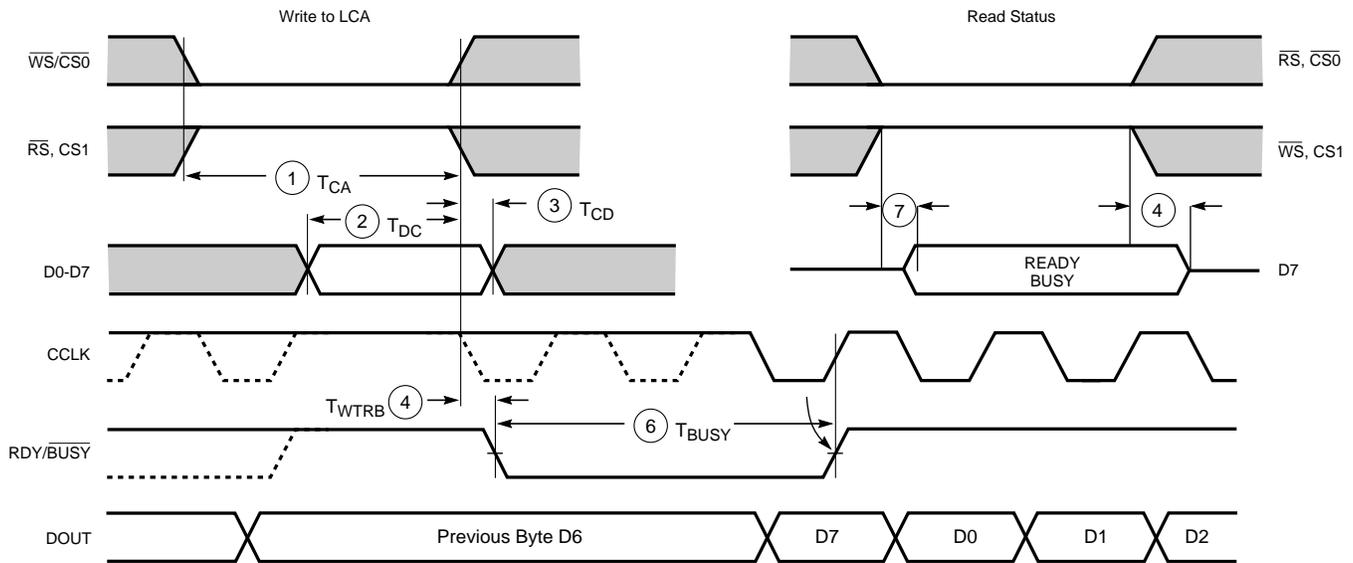


Figure 58: Asynchronous Peripheral Mode Circuit Diagram



X6097

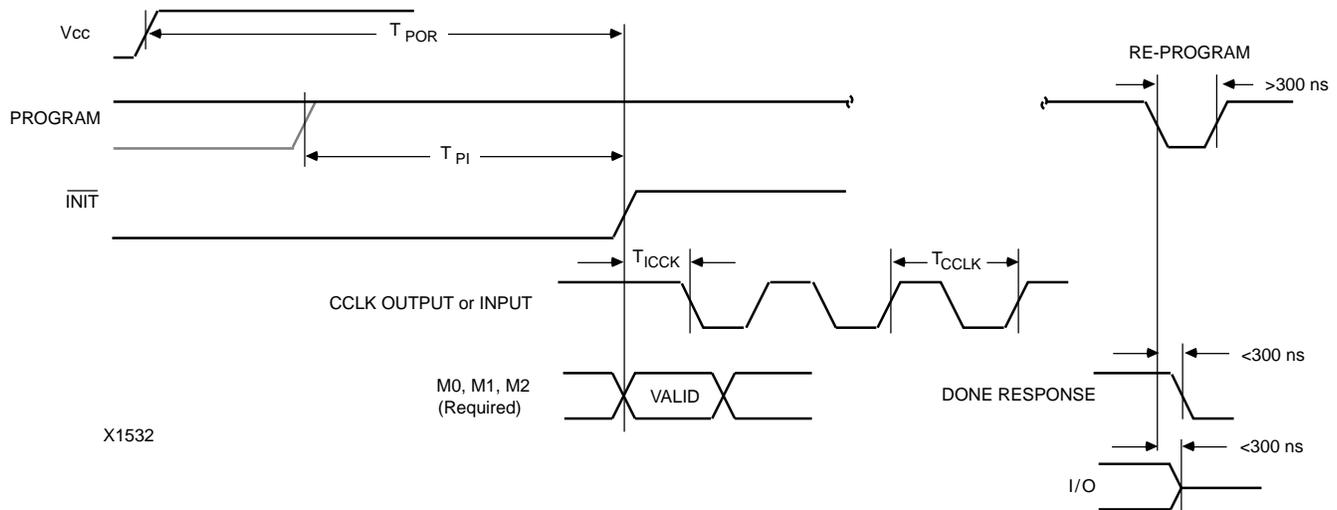
| | | Description | Symbol | Min | Max | Units |
|-------|---|--|------------|-----|-----|--------------|
| Write | 1 | Effective Write time (CS0, WS=Low; RS, CS1=High) | T_{CA} | 100 | | ns |
| | 2 | DIN setup time | T_{DC} | 60 | | ns |
| | 3 | DIN hold time | T_{CD} | 0 | | ns |
| RDY | 4 | RDY/BUSY delay after end of Write or Read | T_{WTRB} | | 60 | ns |
| | 7 | RDY/BUSY active after beginning of Read | | | 60 | ns |
| | 6 | RDY/BUSY Low output (Note 4) | T_{BUSY} | 2 | 9 | CCLK periods |

- Notes:
1. Configuration must be delayed until the \overline{INIT} pins of all daisy-chained FPGAs are High.
 2. The time from the end of \overline{WS} to CCLK cycle for the new byte of data depends on the completion of previous byte processing and the phase of the internal timing generator for CCLK.
 3. CCLK and DOUT timing is tested in slave mode.
 4. T_{BUSY} indicates that the double-buffered parallel-to-serial converter is not yet ready to receive new data. The shortest T_{BUSY} occurs when a byte is loaded into an empty parallel-to-serial converter. The longest T_{BUSY} occurs when a new word is loaded into the input register before the second-level buffer has started shifting out data.

This timing diagram shows very relaxed requirements. Data need not be held beyond the rising edge of \overline{WS} . RDY/BUSY will go active within 60 ns after the end of \overline{WS} . A new write may be asserted immediately after RDY/BUSY goes Low, but write may not be terminated until RDY/BUSY has been High for one CCLK period.

Figure 59: Asynchronous Peripheral Mode Programming Switching Characteristics

Configuration Switching Characteristics



Master Modes (XC4000E/EX)

| Description | | Symbol | Min | Max | Units |
|----------------------------|-----------|------------|-----|------|------------------------|
| Power-On Reset | M0 = High | T_{POR} | 10 | 40 | ms |
| | M0 = Low | T_{POR} | 40 | 130 | ms |
| Program Latency | | T_{PI} | 30 | 200 | μ s per CLB column |
| CCLK (output) Delay | | T_{ICCK} | 40 | 250 | μ s |
| CCLK (output) Period, slow | | T_{CCLK} | 640 | 2000 | ns |
| CCLK (output) Period, fast | | T_{CCLK} | 80 | 250 | ns |

Master Modes (XC4000XL)

| Description | | Symbol | Min | Max | Units |
|----------------------------|-----------|------------|-----|------|------------------------|
| Power-On Reset | M0 = High | T_{POR} | 10 | 40 | ms |
| | M0 = Low | T_{POR} | 40 | 130 | ms |
| Program Latency | | T_{PI} | 30 | 200 | μ s per CLB column |
| CCLK (output) Delay | | T_{ICCK} | 40 | 250 | μ s |
| CCLK (output) Period, slow | | T_{CCLK} | 540 | 1600 | ns |
| CCLK (output) Period, fast | | T_{CCLK} | 67 | 200 | ns |

Slave and Peripheral Modes (All)

| Description | | Symbol | Min | Max | Units |
|--------------------------------|--|------------|-----|-----|------------------------|
| Power-On Reset | | T_{POR} | 10 | 33 | ms |
| Program Latency | | T_{PI} | 30 | 200 | μ s per CLB column |
| CCLK (input) Delay (required) | | T_{ICCK} | 4 | | μ s |
| CCLK (input) Period (required) | | T_{CCLK} | 100 | | ns |

Table 25: Component Availability Chart for XC4000E FPGAs

| | PINS | 84 | 100 | 100 | 120 | 144 | 156 | 160 | 191 | 208 | 208 | 223 | 225 | 240 | 240 | 299 | 304 | |
|---------|------|------|-------------|-------------|-------------|------------|-------------|------------|-------------|------------|----------------|-------------|------------|------------|----------------|-------------|------------|---------------|
| | | TYPE | Plast. PLCC | Plast. PQFP | Plast. VQFP | Ceram. PGA | Plast. TQFP | Ceram. PGA | Plast. PQFP | Ceram. PGA | High-Perf. QFP | Plast. PQFP | Ceram. PGA | Plast. BGA | High-Perf. QFP | Plast. PQFP | Ceram. PGA | High-Perf. QF |
| | | CODE | PC84 | PQ100 | VQ100 | PG120 | TQ144 | PG156 | PQ160 | PG191 | HQ208 | PQ208 | PG223 | BG225 | HQ240 | PQ240 | PG299 | HQ304 |
| XC4003E | -4 | C I | C I | C I | C I | | | | | | | | | | | | | |
| | -3 | C I | C I | C I | C I | | | | | | | | | | | | | |
| | -2 | C I | C I | C I | C I | | | | | | | | | | | | | |
| | -1 | C | C | C | C | | | | | | | | | | | | | |
| XC4005E | -4 | C I | C I | | | C I | C I | C I | | | C I | | | | | | | |
| | -3 | C I | C I | | | C I | C I | C I | | | C I | | | | | | | |
| | -2 | C I | C I | | | C I | C I | C I | | | C I | | | | | | | |
| | -1 | C | C | | | C | C | C | | | C | | | | | | | |
| XC4006E | -4 | C I | | | | C I | C I | C I | | | C I | | | | | | | |
| | -3 | C I | | | | C I | C I | C I | | | C I | | | | | | | |
| | -2 | C I | | | | C I | C I | C I | | | C I | | | | | | | |
| | -1 | C | | | | C | C | C | | | C | | | | | | | |
| XC4008E | -4 | C I | | | | | | C I | C I | | C I | | | | | | | |
| | -3 | C I | | | | | | C I | C I | | C I | | | | | | | |
| | -2 | C I | | | | | | C I | C I | | C I | | | | | | | |
| | -1 | C | | | | | | C | C | | C | | | | | | | |
| XC4010E | -4 | C I | | | | | | C I | C I | C I | C I | | C I | | | | | |
| | -3 | C I | | | | | | C I | C I | C I | C I | | C I | | | | | |
| | -2 | C I | | | | | | C I | C I | C I | C I | | C I | | | | | |
| | -1 | C | | | | | | C | C | C | C | | C | | | | | |
| XC4013E | -4 | | | | | | | C I | | C I | C I | C I | C I | C I | C I | | | |
| | -3 | | | | | | | C I | | C I | C I | C I | C I | C I | C I | | | |
| | -2 | | | | | | | C I | | C I | C I | C I | C I | C I | C I | | | |
| | -1 | | | | | | | C | | C | C | C | C | C | C | | | |
| XC4020E | -4 | | | | | | | | | C I | | C I | | C I | | | | |
| | -3 | | | | | | | | | C I | | C I | | C I | | | | |
| | -2 | | | | | | | | | C I | | C I | | C I | | | | |
| | -1 | | | | | | | | | C | | C | | C | | | | |
| XC4025E | -4 | | | | | | | | | | | C I | | C I | | C I | C I | |
| | -3 | | | | | | | | | | | C I | | C I | | C I | C I | |
| | -2 | | | | | | | | | | | C | | C | | C | C | |

1/29/99

C = Commercial $T_J = 0^\circ$ to $+85^\circ\text{C}$

I = Industrial $T_J = -40^\circ\text{C}$ to $+100^\circ\text{C}$

Table 26: Component Availability Chart for XC4000EX FPGAs

| | PINS | 208 | 240 | 299 | 304 | 352 | 411 | 432 | |
|----------|------|------|----------------|----------------|------------|----------------|------------|------------|------------|
| | | TYPE | High-Perf. QFP | High-Perf. QFP | Ceram. PGA | High-Perf. QFP | Plast. BGA | Ceram. PGA | Plast. BGA |
| | | CODE | HQ208 | HQ240 | PG299 | HQ304 | BG352 | PG411 | BG432 |
| XC4028EX | -4 | C I | C I | C I | C I | C I | | | |
| | -3 | C I | C I | C I | C I | C I | | | |
| | -2 | C | C | C | C | C | | | |
| XC4036EX | -4 | | C I | | C I | C I | C I | C I | |
| | -3 | | C I | | C I | C I | C I | C I | |
| | -2 | | C | | C | C | C | C | |

1/29/99

C = Commercial $T_J = 0^\circ$ to $+85^\circ\text{C}$

I = Industrial $T_J = -40^\circ\text{C}$ to $+100^\circ\text{C}$