iCE40 Hardware Checklist

Technical Note

FPGA-TN-02006-2.1

October 2023

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Acronyms in This Document

A list of acronyms used in this document.

Acronym	Definition
CRAM	Configuration RAM
PLL	Phase-Locked Loop
POR	Power-on-Reset
NVCM	Non-volatile Configuration Memory
SPI	Serial Peripheral Interface

1. Introduction

When designing complex hardware using the iCE40™ device family (iCE40 LP/HX, iCE40LM, iCE40 Ultra™, iCE40 UltraLite™, iCE40 UltraPlus™), you must pay special attention to critical hardware configuration requirements. This technical note steps through these critical hardware requirements related to the iCE40 device. This document does not provide detailed step-by-step instructions but gives a high-level summary checklist to assist in the design process.

The iCE40 ultra-low power, non-volatile devices are available in four versions – LP series for low power applications, HX series for high-performance applications, LM and Ultra/UltraLite/UltraPlus series for ultra-low power for mobile applications.

This technical note assumes that you are familiar with the iCE40 device features as described in the following documents:

- iCE40LP/HX Family Data Sheet (FPGA-DS-02029)
- iCE40LM Family Data Sheet (FPGA-DS-02043)
- iCE40 Ultra Family Data Sheet (FPGA-DS-02028)
- iCE40 UltraLite Family Data Sheet (FPGA-DS-02027)
- iCE40 UltraPlus Family Data Sheet (FPGA-DS-02008)

This technical note covers the following critical hardware areas:

- Power supplies as they relate to the supply rails and how to connect them to the PCB and the associated system
- Configuration and how to connect the configuration mode selection
- Device I/O interface and critical signals

2. Power Supply

The VCC (core supply voltage) VCCIO_2, SPI_VCC and VPP_2V5 determine the iCE40 device's stable condition. These supplies need to be at a valid and stable level before the device can become operational. Refer to the family data sheets for voltage requirements.

To evenly balance the stress in the solder joints, Lattice recommends that PCB solder pads match the corresponding package solder pad type and dimensions. If a different PCB solder pad type is used, the recommended pad dimension is based on an equivalent surface contact area.

Table 2.1. Power Supply Description and Voltage Levels

Supply[3, 4]	Voltage (Nominal Value)	Description
VCC	1.2 V	Core supply voltage
VCCIOx	1.8 V to 3.3 V	Power supply for I/O banks
VPP_2V5	1.8[6] V to 3.3 V	Target serial peripheral interface (SPI) configuration
	2.5 V to 3.3 V	Controller SPI configuration
	2.5 V to 3.3 V	Configuration from NVCM
	2.5 V to 3.0 V	NVCM programming
VPP_FAST	1.8 V to 3.3 V, Leave unconnected[5]	Optional fast NVCM programming supply
SPI_VCC	1.8 V to 3.3 V	SPI supply voltage
VCCPLL[1, 2]	1.2 V	Analog voltage supply to phase-locked loop (PLL)

Notes:

1. VCCPLL must be tied to VCC when PLL is not used.
2. External power supply filter required for VCCPLL and GNDPLL.
3. iCE40LM device family do not have VPP_2V5 and VPP_FAST supplies.
4. iCE40 Ultra/iCE40 UltraLite/iCE40 UltraPlus device families do not have VPP_FAST.
5. VPP_FAST, used only for fast production programming, must be left floating or unconnected in applications, except CM36 and CM49 packages MUST have the VPP_FAST ball connected to VCCIO_0_1 ball externally.
6. VPP_2V5 can optionally be connected to a 1.8 V (+/–5%) power supply in Target SPI configuration modes subject to the condition that none of the HFOSC/LFOSC and RGB LED driver features are used. Otherwise, VPP_2V5 must be connected to a power supply with a minimum 2.3 V level.

2.1. Recommended Power Filtering Groups and Components

It is recommended to add filters to every power rail of iCE40 devices. Reliable filters enhance the overall performance of the system. Table 2.2 shows the recommended filter group.

Table 2.2. Recommended Power Filtering Groups and Components

Power Input	Recommended Filter	Notes
VCC	4.7 µF + 100 nF per pin	Core logic. 1.2 V
VCCIOx	4.7 µF + 100 nF per pin	I/O banks power supply pin VCCIOx Banks 0, 1, 2 1.8 V, 3.3 V
VPP_2V5	4.7 µF + 100 nF per pin	NVCM programming and operating supply voltage 2.5 V
SPI_VCC	4.7 µF + 100 nF per pin	SPI supply voltage 1.8 V, 3.3 V
VCCPLL1, 2	100 Ω + 4.7 µF + 100 nF per pin	PLL analog supply voltage 1.2 V

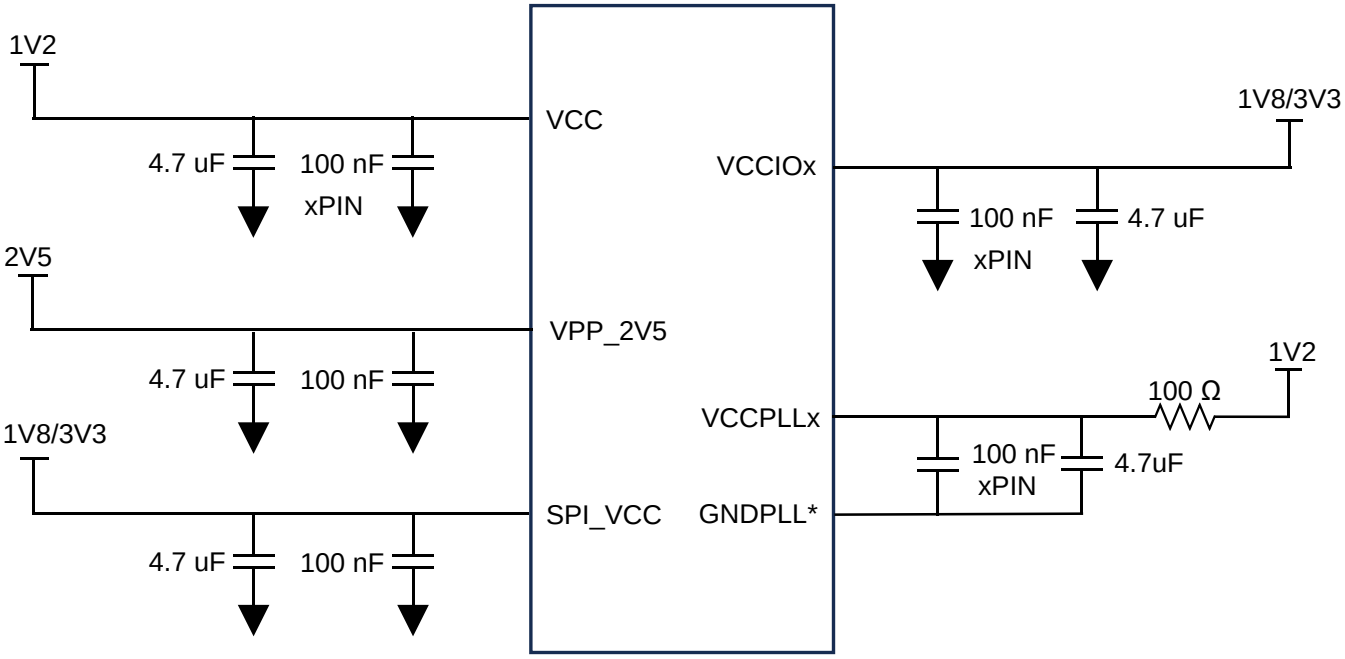

Figure 2.1. Typical Power Supply Filter

Note: GNDPLL should not be connected to the board's system ground except when a particular iCE40 device does not have a dedicated GNDPLL pin. This filter should be applied even if the PLL is not utilized in the design.

2.2. Analog Power Supply Filter for PLL

The iCE40 sysCLOCK™ PLL contains analog blocks so the PLL requires a separate power and ground that is quiet and stable to reduce the output clock jitter of the PLL on device with external VCCPLL supply pins.

Note: PLL is not offered in some device/package combinations without the VCCPLL ball. Refer to the data sheet and the device family Pin List to check the availability of VCCPLL ball.

The sysCLOCK PLL has the DC ground connection made on the FPGA, so the external PLL ground connection (GNDPLL) must NOT be connected to the board's ground except when a particular iCE40 device does not have a dedicated GNDPLL ball.

2.3. Power-Up Sequence

It is recommended to bring up the voltage in the order described in this section. Note that there is no specified timing delay between the power supplies, however, there is a requirement for each supply to reach a level of 0.5 V, or higher, before any subsequent power supplies in the sequence are applied.

To bring up the voltage, follow these steps:

1. Apply the VCC and VCCPLLx rails. These rails can come from the same source and must comply with the power supply filtering requirements. VCC is responsible for powering the core logic while VCCPLLx is responsible for powering internal clock circuitry.
2. Apply the SPI_VCC rail. This rail is responsible for powering SPI logic circuit used for NVCM or external flash.
3. Apply the VPP_2V5 rail. This rail is responsible for powering NVCM.
4. Other supplies (VCCIOx) do not affect device power-up functionality. Apply these supplies any time after VCC and VCCPLLx.

When powering iCE40 device rails with the same potential, it is recommended to use the same regulator to help meet power sequencing.

As an example, VCC and VCCPLL are tied together and should still be the first one to be powered up. Then if VCCIO0, VCCIO2, SPI_VCC are tied, then it should be the next to applied with power since SPI_VCC should be the next from the sequence. Then lastly, VPP_2V5 to be applied with power.

There is no power down sequence required. However, when partial power supplies are powered down, it is required that the above sequence is followed when these supplies are powered up again.

For more information, refer to the *Power-Up Supply Sequence* section of the iCE40 device data sheet.

2.4. Power Source

It is recommended that the voltage regulators are accurate to within 3% of the optimum voltage to allow power noise design margin.

When calculating the voltage regulator total tolerance, include:

- Regulator voltage reference tolerance
- Regulator line tolerance
- Regulator load tolerance
- Tolerances of any resistors connected to regulator's feedback pin that sets the regulator's output voltage

With 3% tolerance allocated to the voltage source, the design has a remaining 2% tolerance for noise and layout related issues. The 1.2 V rail is especially sensitive to noise as every 12 mV is 1% of the rail voltage. For PLLs, target less than 0.25% peak noise.

3. Configuration Considerations

The iCE40 LP/HX/Ultra/UltraLite/UltraPlus devices contain two types of memory, CRAM (Configuration RAM) and NVCM (Non-volatile Configuration Memory). The iCE40LM device contains only the CRAM. CRAM memory contains the active configuration. The NVCM provides on-chip storage of configuration data. It is one-time programmable and is recommended for mass-production.

For more information, refer to iCE40 Programming and Configuration (FPGA-TN-02001).

The configuration and programming of the iCE40 LP/HX/LM/Ultra/UltraLite/UltraPlus devices from external memory uses the SPI port, both in Controller and Target modes. In Controller SPI mode, the device configures its CRAM from an external SPI flash connected to it. In Target mode, the device can be configured or programmed using the Lattice Diamond™ Programmer or embedded processor, and the Lattice Radiant™ Programmer for iCE40 UltraPlus devices.

On the iCE40LP/HX and iCE40 Ultra/UltraLite/UltraPlus device family, the SPI_SS_B determines if the iCE40 CRAM is configured from an external SPI (SPI_SS_B=0) or from the NVCM (SPI_SS_B=1). This pin is sampled after Power-on-Reset (POR) is released or CRESET_B is held low and then goes high.

Table 3.1. Configuration Pins

Pin Name	Function	Direction	External Termination	Notes
CRESET_B	Configuration Reset input, active low.	Input	10 kΩ pull-up to VCCIOx.	A low on CRESET_B delay's configuration.
CDONE	Configuration Done output from iCE40.	Output	Pull-up to VCCIOx. The maximum Rpullup value is calculated as follows: Rpullup=1/(2 X ConfigFrequency X CDONETraceCap)	—
SPI_VCC	SPI supply voltage.	Supply	—	—
SPI_SI	SPI input to the iCE40, in both Controller and Target modes.	Input	—	Released to user I/O after configuration.
SPI_SO	SPI output from the iCE40, in both Controller and Target modes.	Output	—	Released to user I/O after configuration.
SPI_SCK	SPI clock	Input/Output	10 kΩ pull-up to VCC_SPI recommended.	Direction based on Controller or Target modes. Released to user I/O after configuration.
SPI_SS_B	Chip select	Input (Target mode)/Output (Controller mode)	10 kΩ pull-up to VCC_SPI in Controller mode and a 10 kΩ pull-down in Target mode is recommended if not driven by a processor.	Refer to iCE40 Programming and Configuration (FPGA-TN-02001) for more details.

A typical connection from a host programmer to an iCE40 device with external flash is shown in Figure 3.1 and Figure 3.2. When programming the external flash, HOST CS is connected to both CS pins of flash and iCE40 device with 10K pull-up, Drive CRESET_B low while programming the external flash. The Host Programmer will be communicating with the external flash in this configuration, and upon normal operation, the iCE40 device will be fetching data from the external flash for proper bootup and operation.

Programming the iCE40 device in Target mode (CRAM or NVCM) must have modification in connections as shown in Figure 3.2. The HOST CS is only connected to the iCE40 device without 10K pull up and HOST must ensure pin CS is LOW to activate the Target SPI configuration. Notice that connections of MOSI and MISO are interchanged during the configuration at NVCM, revert to original connection including flash CS for normal operation.

Routing for these connections can be done using headers, same as lattice breakout boards for iCE40 devices. In applications, it can be done using multiplexers or jumper resistors. You must consider what is the best routing approach that is needed for the intended applications.

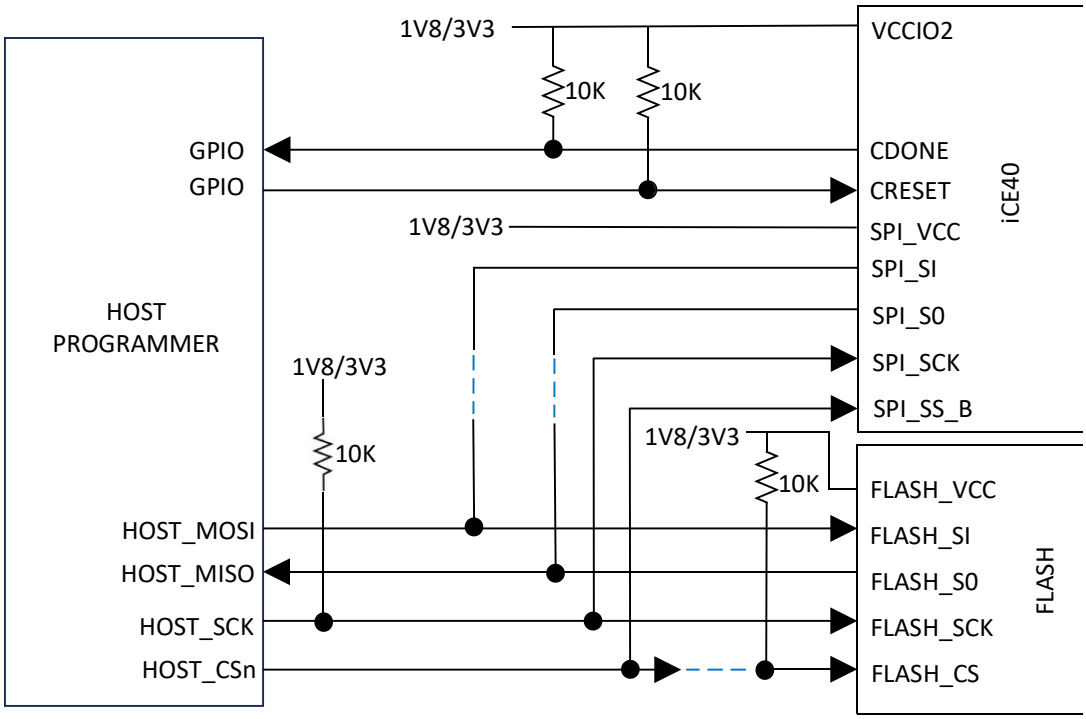

Figure 3.1. Typical Connection for External Flash Programming

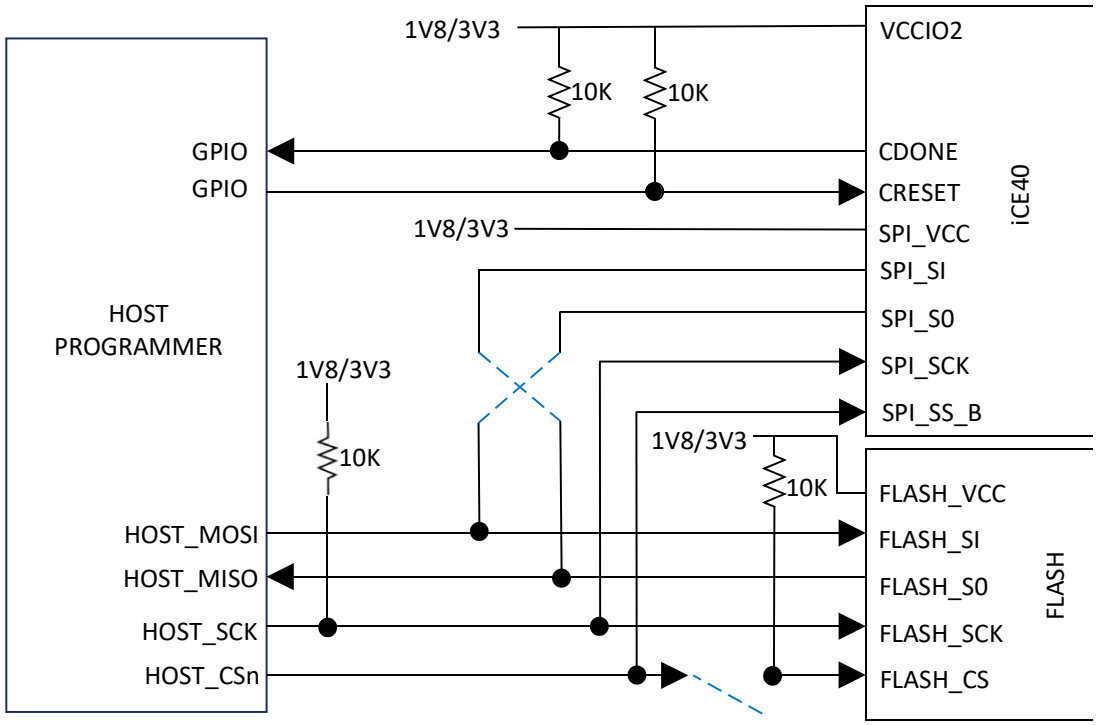

Figure 3.2. Typical Connection for iCE40 Device Target or NVCM Programming

3.1. SPI Flash Requirement in Controller SPI Mode

You are free to select any industry standard SPI flash. The SPI flash must support the 0x0B Fast Read command, using a 24-bit start address with eight dummy bits before the PROM provides first data. For more information, refer to iCE40 Programming and Configuration (FPGA-TN-02001).

4. Clock Inputs

The iCE40 device provides certain pins for use as clock inputs as describe in Figure 4.1. These shared pins can be used alternately for general purpose I/O. For the global clock requirements, refer to the *External Switching Characteristics* section of the iCE40 device family data sheet.

When these pins are used for clocking purposes, you need to pay attention to minimize signal noise on these pins. For more information, refer to iCE40 sysCLOCK PLL Design User Guide (FPGA-TN-02052).

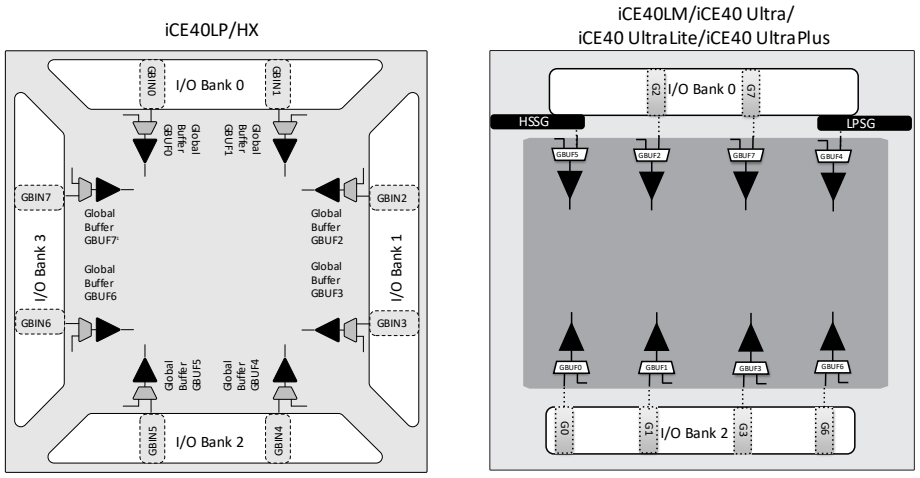

Figure 4.1. High-Fanout Global Buffer Routing Resources for Clocks

5. sysI/O

The iCE40 device provides certain configuration for each I/O. These pins can be configured as input, output, and tri-state. Additionally, an internal pull-up resistor can be enabled from the configuration. For more information, refer to the iCE40 device data sheet.

For the value of the pull-up resistor, the implementation on the iCE40 device is through the use of a pull-up current. The values are shown in Table 5.1.

Table 5.1. Weak Pull-Up Current Specifications

Condition	Min	Max	Unit
VCCIO = 1.8 V, 0 ≤ VIN ≤ 0.65 VCCIO	–3	–31	µA
VCCIO = 2.5 V, 0 ≤ VIN ≤ 0.65 VCCIO	–8	–72	µA
VCCIO = 3.3 V, 0 ≤ VIN ≤ 0.65 VCCIO	–11	–128	µA

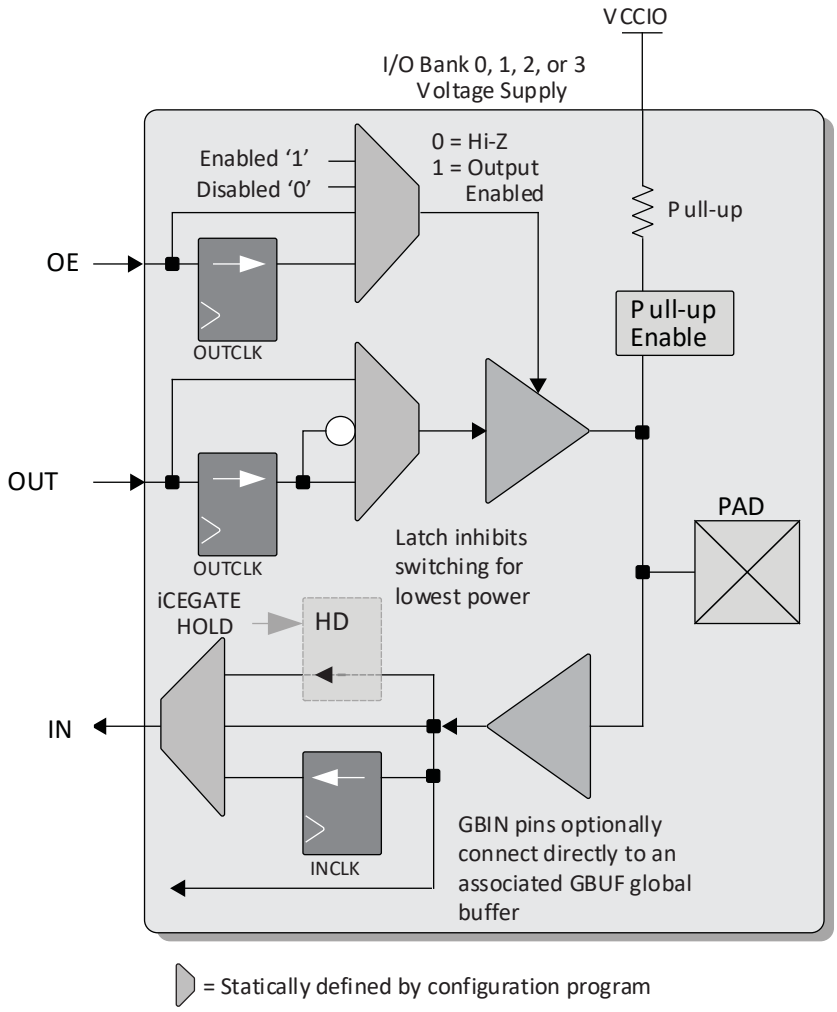

Figure 5.1. Programmable Input/Output

6. LVDS Pin Assignments (For iCE40LP/HX Devices Only)

Refer to the Pinout files for differential input pins. Differential outputs are supported in all banks. The maximum differential pair input for each iCE40 device is shown in Table 6.1.

Table 6.1. Maximum Differential Pair Inputs

iCE40HX1K	iCE40LP1K	iCE40HX4K	iCE40LP4K	iCE40LP8K	iCE40HX8K
11	12	12	20	23	26

LVDS and Sub-LVDS inputs require external termination resistors for proper operation, as shown in Figure 6.1. A termination resistor (RT) between the positive and negative inputs at the receiver forms a current loop. The current across this resistor generates the voltage detected by the receiver's differential input comparator.

LVDS and Sub-VLDS outputs require an external resistor network consisting of two series resistors (RS), and a parallel resistor (RP). This resistor network adjusts the FPGA's output driver to provide the necessary current and voltage characteristics required by the specification.

For more information on the computation for RS and RP, refer to the *LVDS and Sub-LVDS Termination* section of Using Differential I/O (LVDS, Sub-LVDS) in iCE40 LP/HX Devices (FPGA-TN-02213).

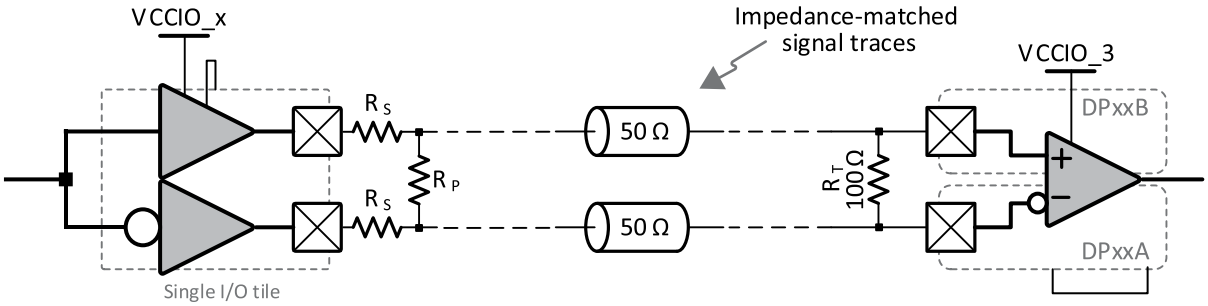

Figure 6.1. LVDS Termination

7. Layout Recommendations

A good schematic design should translate into a good layout to work without any issues on noise and power distribution. The following lists some general recommendations for layouts:

- All power should come from power planes to ensure good power delivery and thermal stability.
- Each power pin has its own decoupling capacitor, typically 100 nF, that should be placed as close as possible to each other.
- Placement of analog circuits must be away from digital circuits or high switching components.
- High-speed signals should have a clearance of five times trace width from other signals.
- High-speed signals that transition from one layer to another should have a corresponding transition ground via if both reference planes are ground. If the reference on the other layer is a VCC plane, then a stitching capacitor should be used (ground to VCC). Refer to Figure 7.1.

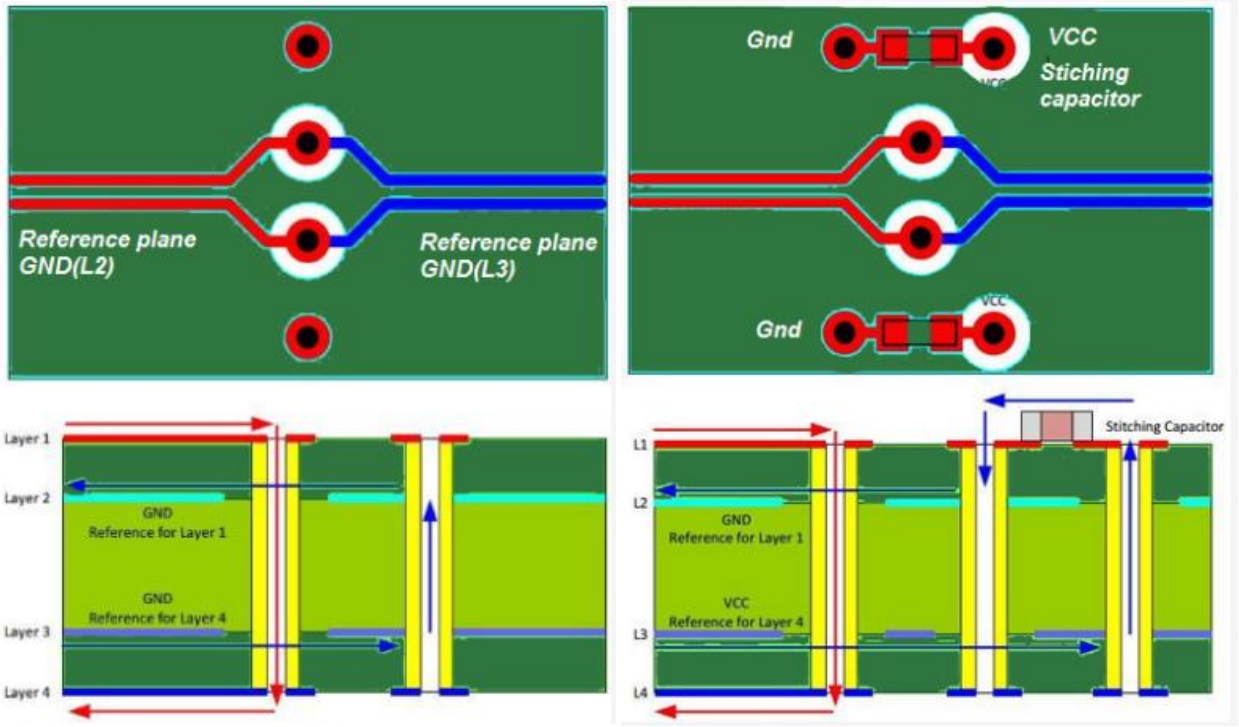

Figure 7.1. Layout Recommendations

- High-speed signals have a corresponding impedance requirement, calculate the necessary trace width and trace gap (differential gap) according to the desired stack-up. Verify trace dimensions with the PCB vendor.
- For differential pairs, match the length as close as possible. A good rule of thumb is to match up to +/ –5 mils.

For more information on layout recommendations, refer to the following documents:

- PCB Layout Recommendations for BGA Packages (FPGA-TN-02024)
- PCB Layout Recommendations for Leaded Packages (FPGA-TN-02160)

8. Checklist

Table 8.1. iCE40 Hardware Checklist

	iCE40 Hardware Checklist Item	OK	N/A
1	**Power Supply**		
1.1	Core supply VCC at 1.2 V		
1.2	I/O power supply VCCIO 0-3 at 1.8 V to 3.3 V		
1.3	SPI_VCC at 1.8 V to 3.3 V		
1.4	VCCPLL uses 1.2 V connected 100 Ω series resistor and 4.7uF bypass capacitor (even if PLL is not used).		
1.5	GNDPLL must NOT be connected to the board[1]		
1.6	Power-up supply sequence and Ramp Rate requirements are met[2]		
1.7	VPP_2V5 should not exceed 3.0V during NVCM programming		
2	**Power-on-Reset (POR) inputs**		
2.1	VCC		
2.2	SPI_VCC		
2.3	VCCIO_0-3		
2.4	VPP_2V5		
	VPP_FAST		
3	**Configuration**		
3.1	Configuration mode based on SPI_SS_B level when CRESET_B transitions high, or POR completes		
3.2	Pull-up on CRESET_B, CDONE pin		
3.3	TRST_B is kept low for normal operation		
4	**I/O pin assignment**		
4.1	LVDS pin assignment considerations		

Notes:

1. An exception is when a particular iCE40 device does not have a dedicated GNDPLL ball.
2. Refer to the iCE40 device family data sheet for the ramp rates under the *Power Supply Ramp Rates* section.

References

For more information, refer to the following resources:

- iCE40 LP/HX Family Data Sheet (FPGA-DS-02029)
- iCE40LM Family Data Sheet (FPGA-DS-02043)
- iCE40 Ultra Family Data Sheet (FPGA-DS-02028)
- iCE40 UltraLite Family Data Sheet (FPGA-DS-02027)
- iCE40 UltraPlus Family Data Sheet (FPGA-DS-02008)
- iCE40 Programming and Configuration (FPGA-TN-02001)
- iCE40 sysCLOCK PLL Design User Guide (FPGA-TN-02052)
- PCB Layout Recommendations for BGA Packages (FPGA-TN-02024)
- PCB Layout Recommendations for Leaded Packages (FPGA-TN-02160)
- iCE40 LP/HX device family web page
- iCE40 Ultra/Ultra Lite device family web page
- iCE40 UltraPlus device family web page
- Lattice Insights web page Lattice Semiconductor training courses and learning plans

Technical Support Assistance

Submit a technical support case through www.latticesemi.com/techsupport.

For frequently asked questions, refer to the Lattice Answer Database at www.latticesemi.com/Support/AnswerDatabase.

Revision History

Revision 2.1, October 2023

Section	Change Summary
Disclaimers	Updated the disclaimer.
Introduction	Fixed a broken link for the iCE40 UltraPlus Family Data Sheet.

Power Supply	• The following changes were made to Table 2.1. Power Supply Description and Voltage Levels:
	  • Changed supply name from VCCIO_X to VCCIOx and corrected the voltage value.
	  • Added voltage values for VPP_2V5.
	  • Added footnote 6.
	• Added the following subsections:
	  • Recommended Power Filtering Groups and Components
	  • Power-Up Sequence
	  • Power Source
	• Moved Analog Power Supply Filter for PLL from the main section to the subsection.
	• Removed the Isolating PLL Supplies figure.

Configuration Considerations	• Moved this subsection to the main section.
	• Removed a note from Table 3.1. Configuration Pins.
	• Added the following figures and described the routing connections:
	  • Figure 3.1. Typical Connection for External Flash Programming
	  • Figure 3.2. Typical Connection for iCE40 Device Target or NVCM Programming

Clock Inputs	Added this section.
sysI/O	Added this section.
LVDS Pin Assignments (For iCE40LP/HX Devices Only)	Added contents including Figure 6.1. LVDS Termination.
Layout Recommendations	Added this section.
Checklist	The following changes were made to Table 8.1. iCE40 Hardware Checklist: • Updated checklist items 1.4 and 3.1. • Added footnote 2.
References	Added this section.
Technical Support Assistance	Added a reference to the Lattice Answer Database on the Lattice website.
All	• Minor changes in formatting and styles. • Replaced “Master” and “Slave” terms with “Controller” and “Target” to adhere to Lattice’s Inclusive Language Guidelines.

Revision 2.0, January 2022

Section	Change Summary
Power Supply	Updated footnote 5 in Table 2.1 Power Supply Description and Voltage Levels.

Revision 1.9, July 2021

Section	Change Summary
Analog Power Supply Filter for PLL	Updated the footnote in Figure 3.1.
Checklist	Updated Table 5.1 iCE40 Hardware Checklist to add 1.7, 1.8 and footnote.

Revision 1.8, April 2020

Section	Change Summary
Disclaimers	Added this section.
Acronyms in This Document	Added this section.
Power Supply	Updated Table 3.1 Configuration Pins. Changed *VCCIO_2* to *VCCIO_X* and added footnote.
All	• Updated document IDs of referenced data sheets and technical notes. • Minor changes in formatting and styles.

Revision 1.7, December 2016

Section	Change Summary
All	• Changed document number from TN1252 to FPGA-TN-02006. • Updated document template.

Revision 1.6, June 2016

Section	Change Summary
All	Added support for iCE40 UltraPlus device family.
Introduction	Updated Introduction section. Added reference to FPGA-DS-02008, iCE40 UltraPlus Family Data Sheet.
Power Supply	Updated Power Supply section. Revised Table 2.1, Power Supply Description and Voltage Levels. Added footnote 5 to VPP_FAST.
Analog Power Supply Filter for PLL	Updated Analog Power Supply Filter for PLL section. Revised Figure 3.1, Isolating PLL Supplies. Changed 100 W to 100 Ohms.
Configuration Considerations	Updated Configuration Considerations section. Revised Table 3.1, Configuration Pins. Updated SPI_SS_B External Termination.
Technical Support Assistance	Updated Technical Support Assistance section.

Revision 1.5, January 2015

Section	Change Summary
All	Added support for iCE40 UltraLite device family.

Revision 1.4, June 2014

Section	Change Summary
All	Added support for iCE40 Ultra device family.
Analog Power Supply Filter for PLL	Updated Analog Power Supply Filter for PLL section.
Configuration Considerations	Updated Configuration Considerations section. Updated Table 3.1, Configuration Pins. Changed VCCIO_2 to VCC_SPI in SPI_SCK and SPI_SS_B.

Revision 1.3, October 2013

Section	Change Summary
Configuration Considerations	Updated Configuration Considerations section. Updated Table 3.1, Configuration Pins.
Technical Support Assistance	Updated Technical Support Assistance information.

Revision 1.2, December 2012

Section	Change Summary
Power Supply	Updated Power Supply section. Revised Table 2.1, Power Supply Description and Voltage Levels. Corrected VCC nominal voltage.

Revision 1.1, September 2012

Section	Change Summary
LVDS Pin Assignments (For iCE40LP/HX Devices Only)	Updated LVDS Pin Assignments (For iCE40LP/HX Devices Only) text section. Corrected description of differential input and output support.

Revision 1.0, September 2012

Section	Change Summary
All	Initial release.

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