Designing with One-Shot Auto-Direction Level Translators

System Considerations for Using the onsemi NL3X5004 and NL5X4002

AND90453/D

An auto-direction level translator moves logic between two supply domains with no direction-control pin. That convenience costs something: the steady-state output must stay weak enough for the device on the far side to overdrive it, otherwise direction could never be inferred. A one-shot — a monostable pulse generator triggered by an input edge — restores the missing speed by briefly switching in a much lower-impedance drive path. Almost every board-level limit of these parts follows from the gap between those two states. This note uses the **onsemi** NL3X5004 and NL5X4002 as reference devices.

The Weak-driver Bargain

Because either port must be able to take control, the translator can never behave like a conventional line driver. In steady state the NL3X5004 presents a buffered path through 1 kΩ series resistors, and the NL5X4002 presents 10 kΩ pull-ups behind a bidirectional pass FET. Neither can move a large capacitive load quickly on its own. On a qualifying edge the one-shot enables a strong pull-up, a strong pull-down, or both, for a short interval, then releases the line back to the weak sustaining path (Figure 1).

Two consequences dominate everything that follows. The assist is transient, so the charge it can deliver is finite; and the source impedance the board sees changes part-way through every transition. Treat these devices as weak steady-state drivers with a temporary edge assist, not as continuously strong buffers.

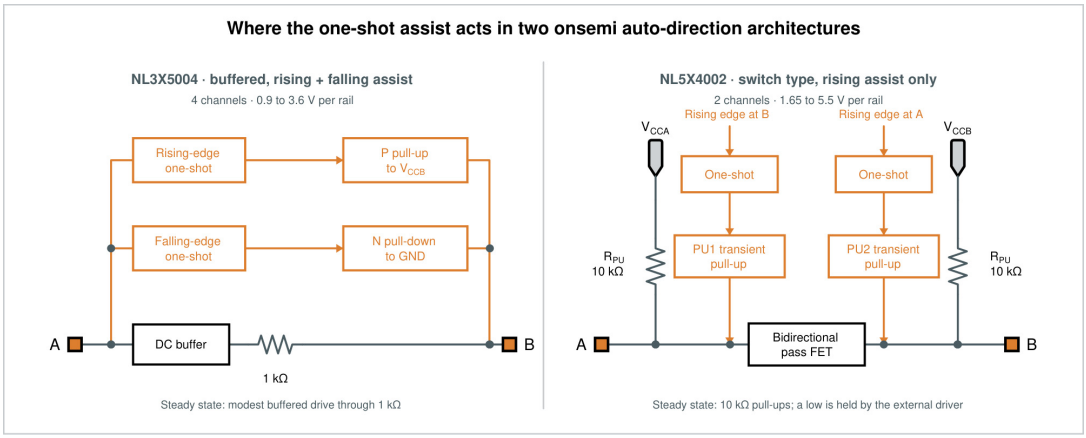


Figure 1. Simplified Functional View of One Bidirectional Channel in Each Device.
Orange Marks the Transient Assist; Slate Marks the Steady-state Signal Path. For the NL3X5004 only the A-to-B Direction is Drawn; a Mirrored Set of One-shots Serves B to A. Enable Circuitry and Internal Inversions are Omitted

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Two Assist Profiles in One Portfolio

The two reference devices are not interchangeable, and the difference is architectural rather than cosmetic. Which edge gets help, and how the opposite edge is produced, is the first thing to settle.

Table 1. ARCHITECTURAL COMPARISON OF THE TWO REFERENCE DEVICES
Values are from the NL3X5004 and NL5X4002 data sheets; consult the current revision for guaranteed limits and their test conditions.

Attribute	NL3X5004	NL5X4002
Channels	Four bidirectional	Two bidirectional
Supply range, each rail ($V_{cc}A$, $V_{cc}B$)	0.9 V to 3.6 V	1.65 V to 5.5 V
Steady-state path	Buffered drive through 1 kΩ series resistors	Bidirectional pass FET with a 10 kΩ pull-up per port
Assisted edges	Rising and falling	Rising only
Assist elements	P-Channel pull-up and N-Channel pull-down one-shots per direction	PU1/PU2 transient pull-ups, each triggered by a rising edge on the opposite port
Natural fit	Push-pull links on short, lightly loaded nets	Open-drain links where the low level is driven externally

On the NL5X4002 there is no falling-edge one-shot, so the low level is established by whichever external endpoint pulls the line down through the pass path. That is exactly right for an open-drain bus and exactly wrong for a push-pull link needing symmetric help. Note also that a finished pulse disables only the auxiliary assistance; it does not place the port in high impedance. EN is the separate control that disables the I/O ports.

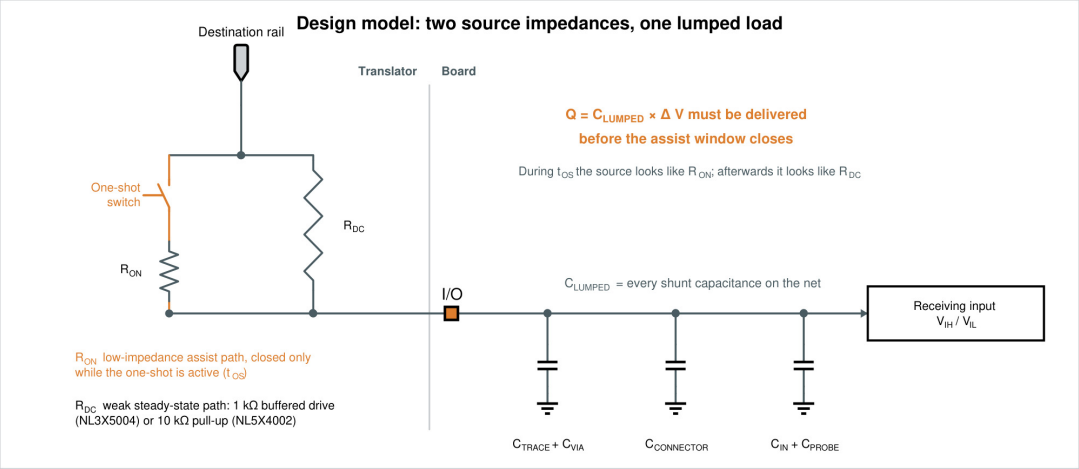


Figure 2. The Design Model Used Throughout This Note:
The One-shot Closes a Low-impedance Path for a Bounded Interval, after Which only the Weak Steady-state Path Remains. Everything Right of the Dashed Line is Under the Board Designer's Control

Budget the Charge, not Just the Capacitance

Moving a node takes charge: $Q = C \times \Delta V$. The capacitance is the total lumped shunt capacitance on the net — receiver input capacitance, trace, vias, connectors, cable, any external RC components, and any oscilloscope probe that may be attached. Every picofarad added anywhere on the net draws from the same finite charge budget.

The impedance ratio explains why. Industry information for this device class contrast a roughly 10 kΩ sustaining path driving 15 pF, giving a transition on the order of 330 ns, against a roughly 50 Ω assisted path covering the same load in a few nanoseconds — illustrative device class-level not from any specific **onsemi** specifications, the ratio is the point of illustration. Figure 3 shows the three outcomes.

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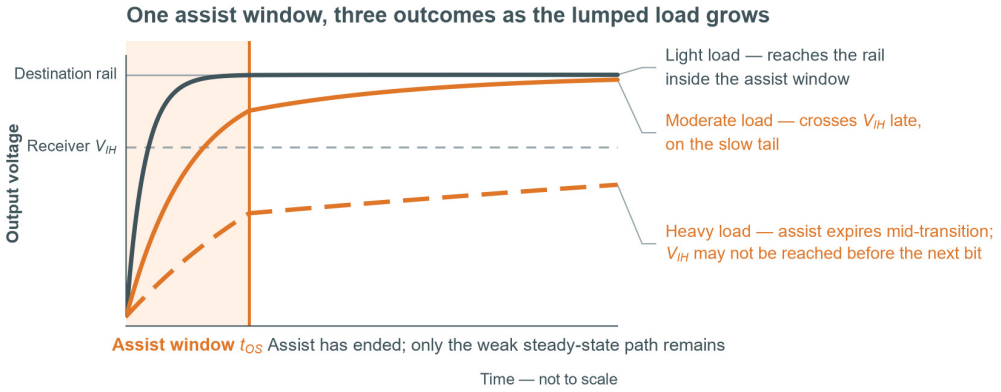


Figure 3. Qualitative Rising Edges for Three Lumped Loads Sharing one Assist Window.
Not to Scale and not Simulated; the End of the Assist is no Guarantee that the Receiver has Reached a Valid Level

Neither the NL3X5004 nor the NL5X4002 data sheet specifies a one-shot pulse duration or a retrigger interval, so there is no number to budget against directly. Use the published switching limits with their stated load and supply test conditions, and treat your own measured load as the variable you control. Literature for auto-direction devices of this class commonly suggests keeping lumped capacitance below roughly 70 pF unless a specific data sheet says otherwise; take that as a planning heuristic and verify it.

Keep the Interconnect Inside the Assist Window

Trace length hurts twice, and the two mechanisms are easy to conflate. Longer routing adds capacitance, which consumes assist charge. Separately, once a route is electrically long, it stops behaving like a lumped capacitor and starts behaving like a transmission line, and impedance discontinuities send energy back toward the source.

Timing decides whether that reflection is harmless. If the round-trip delay is shorter than the assist window, the returning wave meets a still-low source impedance and is damped. If it returns afterwards it meets the weak sustaining path, and the ringing can cross the receiver threshold repeatedly. Because the one-shot is edge-triggered, those crossings can retrigger it, producing double clocking, pulse bursts, or sustained oscillation (Figure 4).

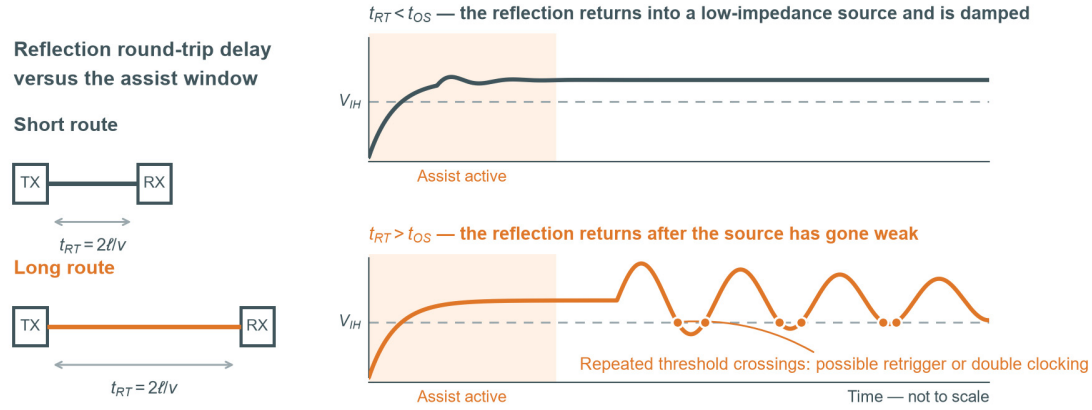


Figure 4. Qualitative Comparison of a Short and a Long Route.
The Waveforms are Illustrative, not Measured. Signal-integrity Behavior Depends on the Actual Stack-up, Terminations, and Discontinuities

The layout rules that follow are unglamorous but effective. Place the translator beside the most heavily loaded or most timing-critical domain. Keep each translated net short enough that it remains effectively lumped at the operating bandwidth. Minimize stubs, connector trees, and via transitions, since each adds capacitance and an impedance discontinuity. Provide a solid, uninterrupted return path and bypass both supply rails close to the device, because supply bounce moves the very thresholds the edge detector compares against.

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External Networks, Slow Edges, and Corners

Adding a resistor to a translated net is rarely neutral. An external pull-up in parallel with the NL5X4002 internal 10 kΩ gives an effective resistance of the two in parallel: the line charges faster passively, but every low-driving endpoint must sink more current, so recheck the low-level voltage and sink-current budget on both domains. Series resistance and RC filters cut the other way — they slow the stimulus arriving at the translator input, which is precisely what the edge detector is watching.

That is the most common way a working design drifts into trouble: a nominally fast source becomes a slow-edge source once enough distributed capacitance, connectors, weak pull-ups, or filtering sit ahead of the translator. Slow transitions can trigger the one-shot unreliably, or let it expire long before the output completes. If a net has been "fixed" for ringing by adding resistance, re-verify the input edge rate afterwards rather than assuming the symptom and the cause were the same thing.

Output impedance and one-shot timing also vary with process, supply, and temperature; higher temperature generally raises output impedance, effectively releasing the line earlier relative to what the load still needs. A board that is comfortable at room temperature can be marginal at a corner with nothing on the schematic changed, so repeat the critical measurements at the supply and temperature extremes.

Choosing the Right Translator

One-shot auto-direction translators are a specialized solution optimized around convenience and moderate loading, not a universal replacement for a direction-controlled translator or a true line driver.

Table 2. ARCHITECTURE SELECTION GUIDE

The deciding variables are the lumped load, the electrical length of the interconnect, and the drive type at the far end.

System Condition	Preferred Approach
Genuinely bidirectional bus, moderate speed, short traces, modest lumped capacitance	A one-shot auto-direction translator is a good fit
Open-drain bus with externally defined pull-ups	Switch-type autosense architecture such as the NL5X4002
Push-pull interface with long traces, connectors, or heavy capacitive loading	Direction-controlled or fixed-direction buffer with sustained drive strength
Cable, backplane, or heavily connectorised run	Re-partition so the translator sits on the short, lightly loaded side

What to Check on the Bench

Measure at the receiving pin, not at the translator, and use low-capacitance probes — the probe itself is part of the load budget. Check rise and fall times, valid logic levels, propagation delay, and settling in both directions at the intended supply and load extremes. For open-drain links, exercise line release and turnaround. For push-pull links, confirm the previous driver is released before the next is enabled: one-shot assistance is edge acceleration, not bus arbitration.

Table 3. BENCH SYMPTOMS AND THE DESIGN VARIABLE EACH ONE USUALLY POINTS TO

Symptom	Likely Cause	What to Change
Rounded Shoulder Part-way Up the Edge	Assist expired before the load settled	Reduce lumped capacitance; shorten the route; move the translator closer to the load
Ringing with Repeated Threshold Crossings	Reflection returning after the assist ended	Shorten the route, remove stubs, control impedance
Extra or Doubled Pulses	One-shot retriggering on reflected or slow edges	Improve edge quality at the translator input; re-examine external RC
Contention or a Stuck Bus	Two push-pull drivers active at once	Enforce turnaround in firmware; the one-shot does not arbitrate
Fine at 25 °C, Marginal at a Corner	Output impedance and assist timing shift with temperature	Re-test at supply and temperature extremes

For more information on **onsemi** voltage level translation devices please visit **onsemi**'s level translation landing page on onsemi.com.

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REVISION HISTORY

Revision	Description of Changes	Date
0	Initial document release.	11/19/2026

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