

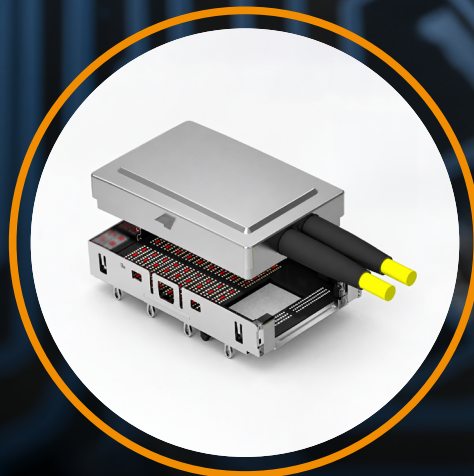
EVERY CONNECTION COUNTS



NEAR-PACKAGED OPTICS (NPO) SOCKET DESIGN GUIDE

*Selecting and Implementing
Sockets for 224G-448G
High-Density Near
Package Interconnects*

By Chad W. Morgan and Rui Yuan



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ABOUT THE AUTHORS



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1. INTRODUCTION

1.1 Technology Trends

Modern communications and AI architecture are pushing signal rates and packaging densities to physical limits. To achieve data transmission at 224 Gbps to 448 Gbps, high-speed twinaxial copper cables and/or optical fibers are progressively replacing PCB traces to improve transmission distance and signal integrity. As a result, NPO and CPO are emerging as key architectures supporting next-generation AI and high-performance computing systems. NPO represents a practical near-term approach, enabling shorter electrical channels while maintaining flexibility in manufacturing, serviceability, and system integration, whereas CPO represents a longer-term evolution toward higher levels of integration.

1.2 Purpose of this Guide

This guide provides practical recommendations for selecting and implementing socket interconnect solutions for NPO applications. Building upon TE Connectivity’s (TE) validated simulation, measurement, and reliability data, it outlines key design considerations and implementation guidelines covering mechanical performance, signal integrity, compression mechanisms, alignment tolerances, assembly, and system integration.

2. WHY SOCKET INTERCONNECT FOR NPO?

NPO architecture reduces electrical channel length by bringing optical engines closer to the compute package, creating new requirements for high-density, high-performance electrical interconnects. Socket interconnects provide a practical solution by enabling high-speed electrical performance, field serviceability without permanent soldered connections.

This guide focuses on dual-compression xLGA socket interconnects, such as MicroLGA and NanoLGA, which are designed to support the electrical and mechanical requirements of NPO systems, and also serve as interface for TE’s NPC and CPC architectures.

3. DUAL-COMPRESSION SOCKET INTERCONNECT ARCHITECTURE

Dual-compression socket interconnects provide a compact, solderless electrical interface for **224G–448G NPO applications**. The socket is compressed between upper and lower substrates (substrate/PCB) to establish reliable electrical contact while enabling high-density packaging and field replaceability.

Compared with traditional plug-in connectors, dual-compression sockets offer the following key design advantages:

Design Advantage	Description
Minimized Stub Design	Eliminates exposed contact cantilever stubs, avoiding unacceptable signal degradation at 448 G PAM-6 (~100 GHz) where even a 0.5 mm stub is detrimental
Ultra-Thin Compression Height	Compression thickness can be as low as 0.56–0.70 mm, keeping the design resonance-free
360° Ground Shielding	Full peripheral ground enclosure around each differential pair, providing excellent crosstalk control
Field Replaceability	Solderless, allowing system repair without replacing expensive copper cables or optical module assemblies

4. MECHANICAL PERFORMANCE AND RELIABILITY

Reliable electrical performance depends on maintaining consistent mechanical contact throughout the product lifecycle. This section outlines the key mechanical characteristics of dual-compression socket interconnects, including vertical working range, compression force, and long-term reliability.

4.1 Vertical Working Range

The vertical working range ($\Delta\delta$) of a socket is the difference between the maximum and minimum compression displacement that the contact terminals can tolerate while maintaining reliable electrical contact.

TE's xLGA sockets utilize a preconditioning process in which the terminals are first pressed past their elastic limit, aligning all terminal tips to the same plane. All subsequent insertions and removals occur within the linear elastic range, ensuring repeatability.

Taking a 0.6 mm × 0.6 mm pitch socket as an example, the typical vertical working range is approximately 70 μm (35 μm per side).

4.2 Contact Force and Total Compression Load

Although the force applied by each individual contact is relatively small, the total compression load increases significantly in high-density scenarios:

Scenario	Contact Force per Terminal	Total Terminals	Total Compression Force
64-Pair Connector	15 gf	768 (12×64)	~11.5 kg-f (>25 lbs)
16 Connectors Surrounding ASIC	15 gf	12,288	>184.3 kg-f (>406 lbs)

In high-density NPO applications, reliable spring-loaded compression hardware is required to maintain adequate compression force across the socket footprint.

4.3 Long-Term Reliability: Thermal Aging and Stress Relaxation

Thermally induced contact creep in xLGA sockets can be effectively controlled through optimized material selection and has been field-validated over many years. Contact load relaxation, corrosion resistance, durability, and other tests are performed in accordance with EIA-364 standards. Current xLGA products have passed TE 501 reliability testing.

5. XY/Z TOLERANCE AND ALIGNMENT REQUIREMENTS

Proper alignment is critical to achieving reliable electrical and mechanical performance in NPO applications. This section summarizes the key alignment and compression requirements for TE's xLGA socket interconnects, supported by simulation and validation results.

5.1 XY Direction Misalignment Tolerance

To address the inevitable XY-direction offset during NPO module assembly, TE has completed dedicated simulation validation:

- When XY offset exists within tolerance limits: insertion loss variation remains limited; crosstalk continues to meet system requirements
- Conclusion: The validated XY-direction tolerance supports practical NPO application requirements

5.2 Z-Direction Compression and Flatness

The Z-direction is the primary control dimension for NPO socket applications:

Key Parameter	xLGA Socket
Fully Compressed Thickness	0.56 mm (NanoLGA+)
	0.70 mm (NanoLGA)
Vertical Working Range per Side	~35 μ m
Uncompressed Impedance Sensitivity	-1 Ω / 10 μ m
*Target Impedance Setting	89 Ω

***Note:** The target impedance is set to 89 Ω , with the metal beam design contributing a tolerance of ± 3 Ω .

To ensure reliable electrical contact, the flatness and tilt of mating PCBs, substrates, and the connector itself should be less than 40 μ m per side.

6. SIGNAL INTEGRITY (SI) PERFORMANCE

Signal integrity should be evaluated early in the NPO design process to ensure adequate margin at 224G–448G data rates. This section summarizes the key signal integrity characteristics of TE’s xLGA socket interconnects supported by simulation and measured performance data.

6.1 Insertion Loss and Return Loss

MicroLGA and NanoLGA socket interconnects support 224 Gbps PAM-4 applications.
NanoLGA+ achieves a first resonant frequency of approximately 100 GHz, supporting 448 Gbps PAM-6 applications (Fmax $\approx$ 100 GHz).

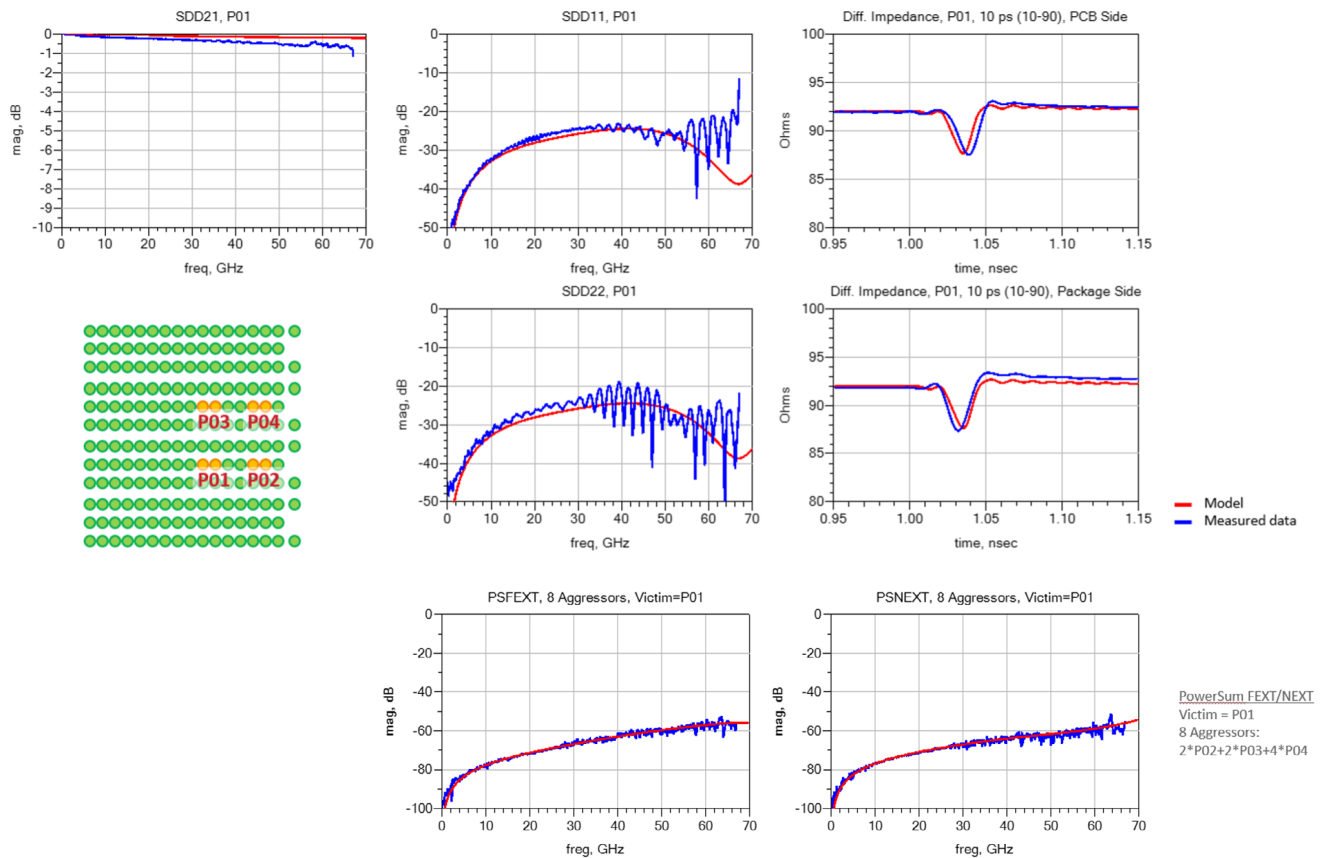
6.2 Crosstalk Performance

Through optimized differential-pair layout and ground shielding:

	PSNEXT/PSFEXT (8 Aggressors)	SNR Margin at 30 dB Insertion Loss
xLGA Socket	< -55 dB	PAM-4: 16 dB; PAM-6: 11 dB

Note: xLGA sockets can convert all crosstalk into far-end crosstalk (PSFEXT) by grouping TX and RX layouts, leveraging the attenuation characteristic along the signal path to further improve margin.

At 67 Gbps class: both simulation and measurement demonstrate adequate design margin.



7. COMPRESSION HARDWARE DESIGN

Reliable compression hardware is essential to achieving consistent mechanical performance with xLGA socket interconnects in high-density NPO applications. This section outlines recommended compression hardware design practices and supporting validation results.

7.1 NPO Compression Architecture Design Recommendations

To accommodate the pressure sensitivity of NPO optical engine modules, the following compression hardware design practices are recommended:

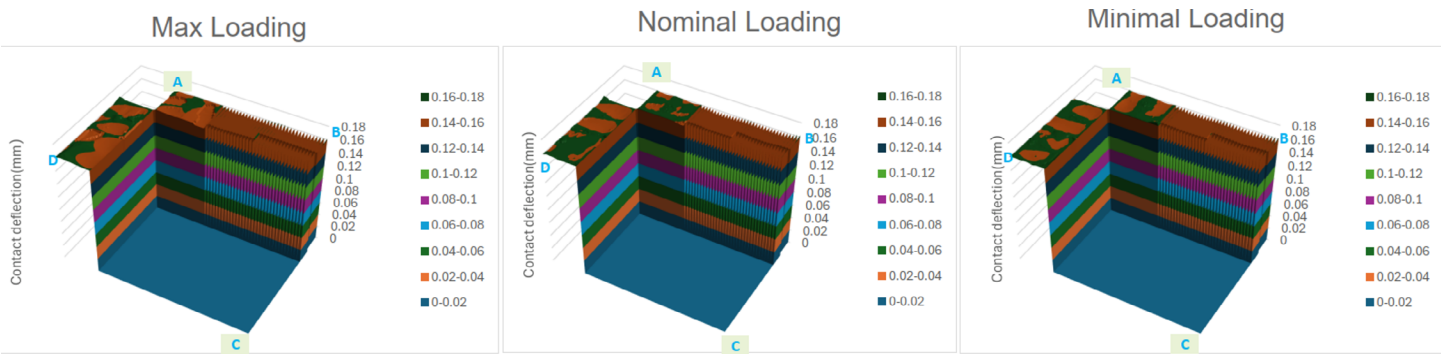
- **Back Plate (BP) Support:** Install a rigid back plate on the rear side of the PCB to prevent local warpage
- **Elastic Compression Mechanism:** Adopt disc spring or leaf spring designs to provide continuous, uniform loading force
- **Force-Loaded rather than Displacement-Loaded:** Ensure stable pressure throughout the product lifecycle

7.2 Pressure Uniformity Validation

The cloud plots and accompanying data show that contact deflection remains highly uniform across the entire socket footprint under all loading conditions. The small variation between the minimum and maximum contact deflections indicates consistent force transfer to the socket terminals, resulting in a uniform pressure distribution across the entire contact array.

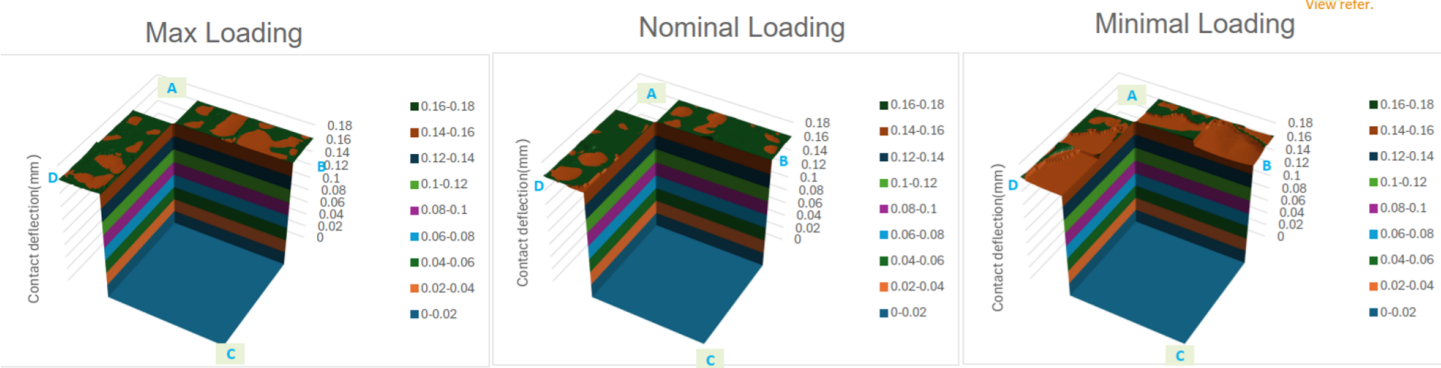
Contacts Deflection Distribution (Top Row)

	Maximum (3401.6N)	Nominal (2792.ON)	Minimal (2243.2N)
Min Contact Deflection [mm]	0.158	0.157	0.154
Max Contact Deflection [mm]	0.160	0.160	0.160



Contacts Deflection Distribution (Bottom Row)

	Maximum (3401.6N)	Nominal (2792.ON)	Minimal (2243.2N)
Min Contact Deflection [mm]	0.159	0.158	0.150
Max Contact Deflection [mm]	0.160	0.160	0.160



7.3 Objective Comparison with Mezzanine Solutions

The following table provides an objective comparison between socket and mezzanine connector solutions:

Dimension	Socket Solution	Mezzanine Solution
SI Performance	Excellent	Ok
	448G scalable under same footprint	
Density	Good	Good
Mounting Method	Solderless	Reflow required on Optics Engine and PCB/Substrate
Field Maintainability	Sockets can be replaced individually	Requires specialized tooling; module removal reliability presents challenges

8. ASSEMBLY GUIDELINES

Proper handling and assembly are essential to maintaining the mechanical and electrical performance of xLGA socket interconnects. This section outlines recommended cleanliness requirements and assembly procedures for installation, replacement, and field service.

8.1 Cleanliness Requirements

Foreign Object Debris (FOD) Control: Prevent contamination from dust, flux residue, and metal debris entering the socket cavity, as FOD may affect contact performance and long-term reliability.

8.2 Assembly Guidelines

The following assembly procedures are recommended:

1. Socket (with cage) installation process
2. Socket-only replacement process
3. Cage replacement process

Refer to the applicable **TE application specifications** for detailed assembly procedures.

9. DESIGN RECOMMENDATIONS AND BEST PRACTICES

The following recommendations summarize the key design considerations for implementing xLGA socket interconnects in **224G–448G NPO applications**.

9.1 PCB/Substrate Design

- **Flatness Control:** Ensure mating PCB or optical engine substrate flatness < 40 µm per side
- **Pad/Anti-Pad Coordination:** Confirm surface pad and anti-pad dimensions with TE to optimize impedance matching
- **Stack-Up Design:** Compatible with standard PCB or HDI materials, Evaluate routing layers and impedance continuity early

9.2 Compression Hardware Design

- Prioritize **force-loaded mechanisms** (load cell or disc spring) to ensure stable pressure throughout the product lifecycle
- For layouts with 16 connectors surrounding an ASIC, calculate total compression force and design sufficiently rigid retention mechanisms

9.3 Signal Layout Optimization

- **TX/RX Grouping:** Concentrate transmit and receive signals separately to convert crosstalk into far-end crosstalk (FEXT), leveraging path attenuation to improve signal-to-noise ratio (SNR)
- **Grounding Strategy:** Open-pin-field design ensuring ample ground around each differential pair

9.4 Thermal Co-Design

- Compression hardware materials and socket housing temperature ratings should support continuous operation at 105 °C
- Cold plates and compression mechanisms may be integrated into a single assembly for simplified installation

10. CONCLUSION

1. This guide demonstrates that xLGA socket interconnects provide a practical and scalable solution for **224G-448G NPO applications**. The following key recommendations summarize the design considerations discussed throughout this guide: **Socket solutions demonstrate full feasibility in NPO applications**.
2. **Pressure sensitivity concerns can be systematically resolved through structural design and compression solutions**. Through BP support, elastic compression mechanisms, and force-loaded design, uniform pressure distribution and long-term stability can be achieved.
3. **Validated XY-direction alignment and Z-direction compression requirements support reliable NPO assembly**. When the recommended flatness and alignment requirements are met, consistent electrical contact can be achieved.
4. **TE's xLGA socket interconnects support 224G-448G NPO applications**. With proper system design, they provide the signal integrity performance required for next-generation NPO architectures.

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