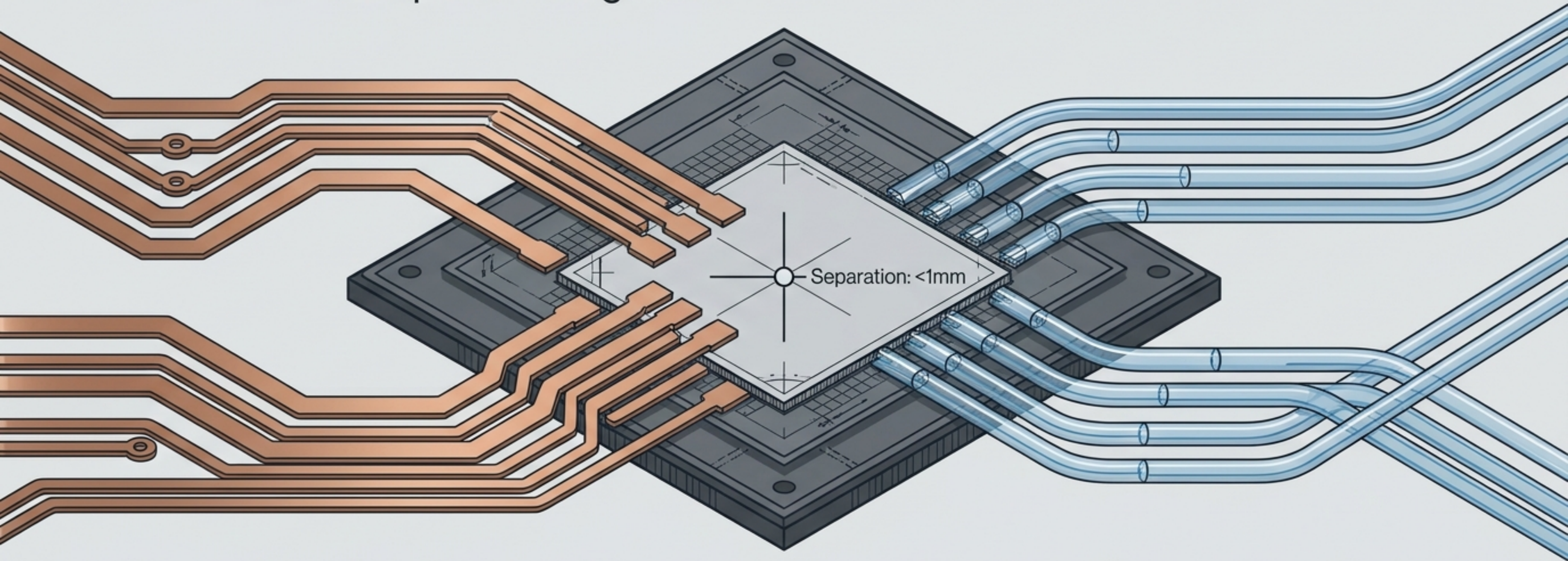


The Packaging War

How Close to the Chip Should Light Go?



OIO

CPO

NPO

LPO

Pluggable

Fiber

Tens of Kilometers

Cost and power barely move with distance.



Copper

20 - 30 centimeters



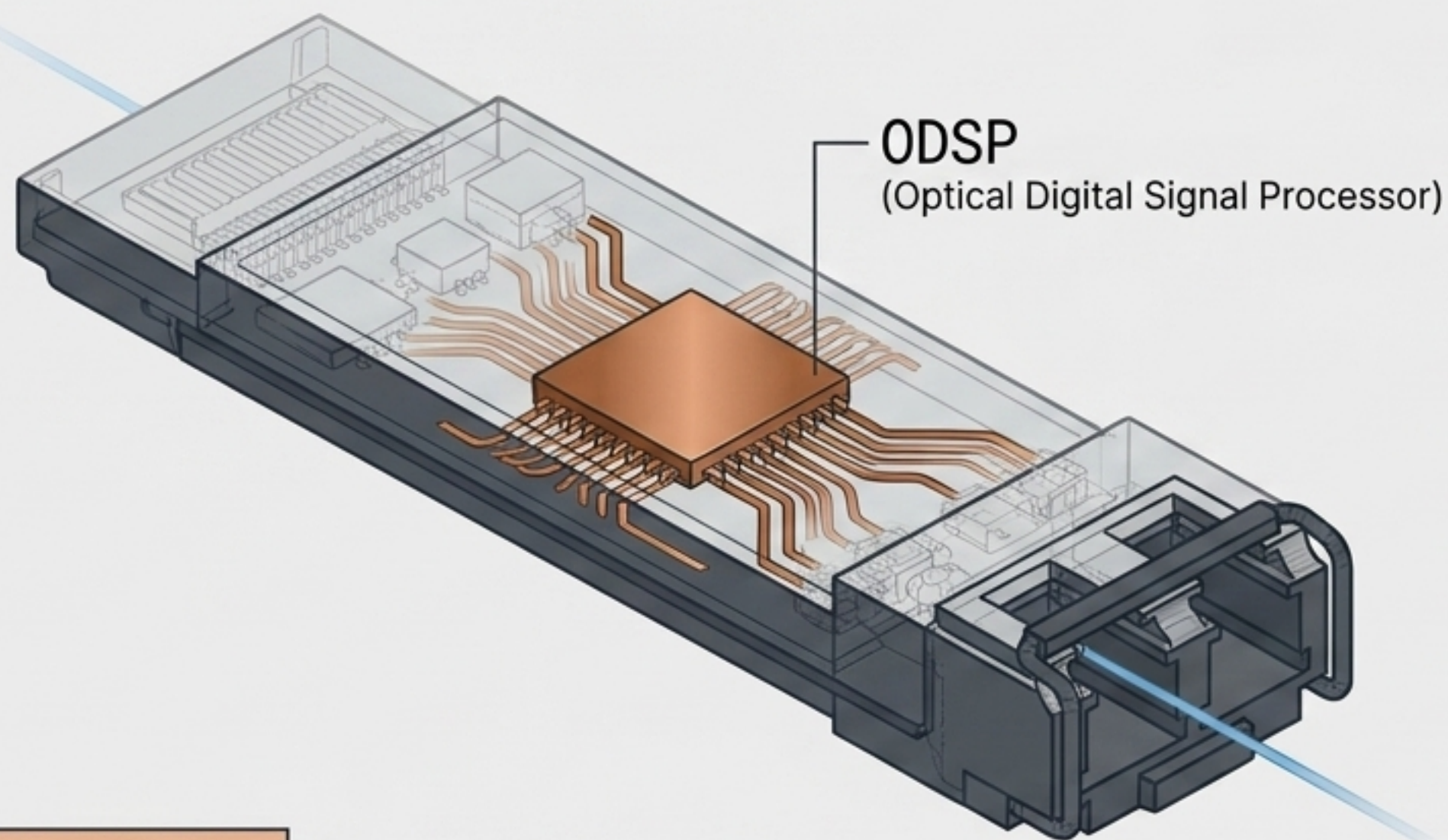
40 dB Signal Loss

The Most Expensive Segment is the Shortest.

- Every packaging innovation is fighting over the same twenty centimeters of copper trace.
- Burned power turns into heat, and heat costs cooling power—doubling the electricity penalty.

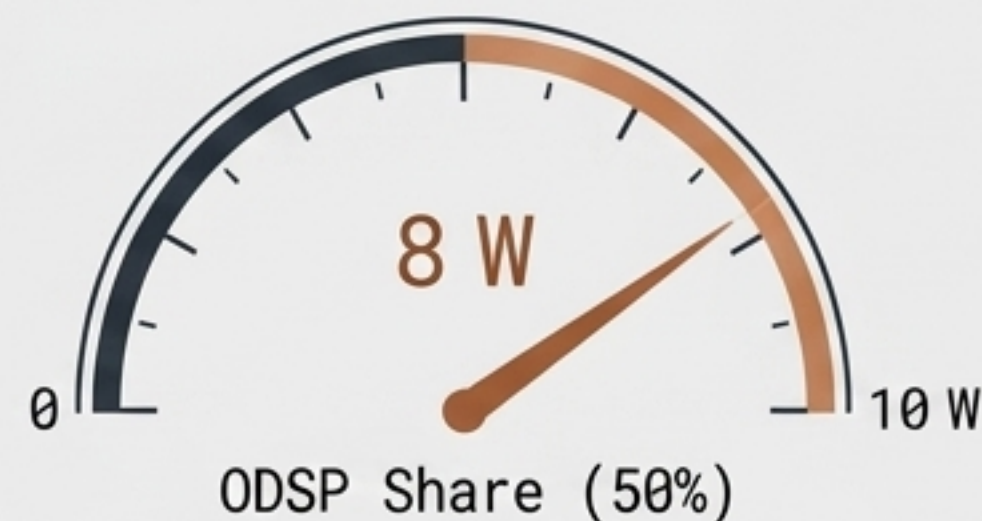
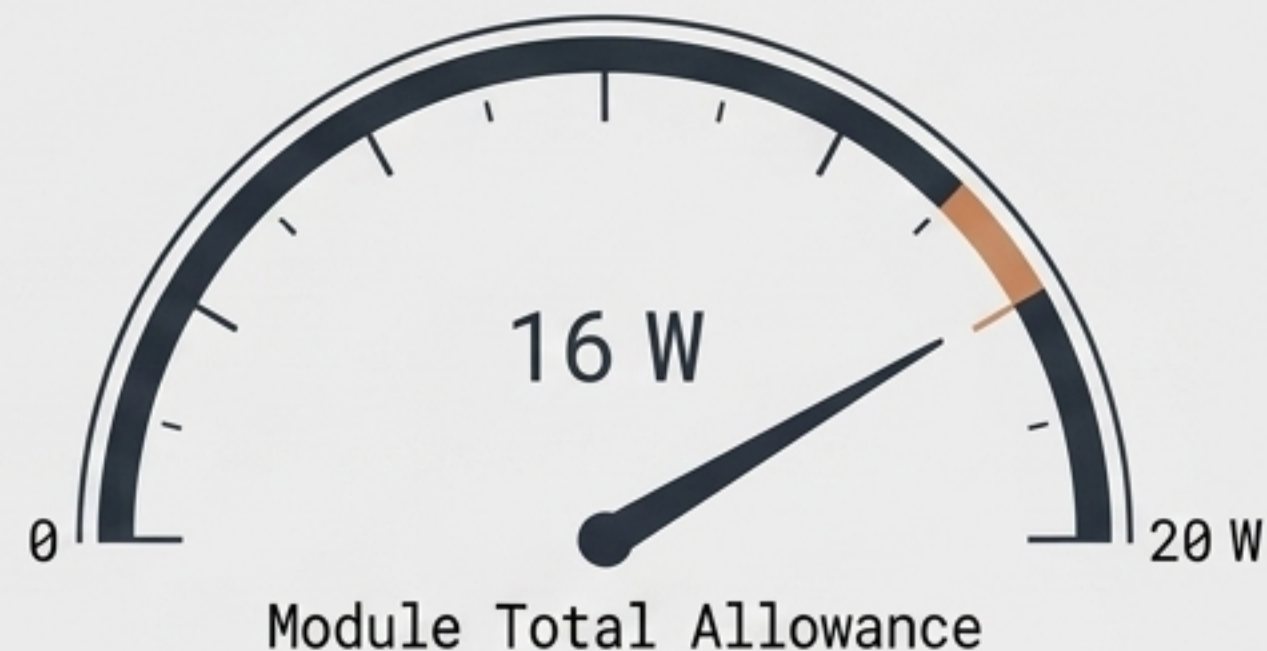
The Brain and the Bottleneck

Roughly half a module's power draw is spent in one chip—the ODSP—working to reconstruct heavily degraded signals.



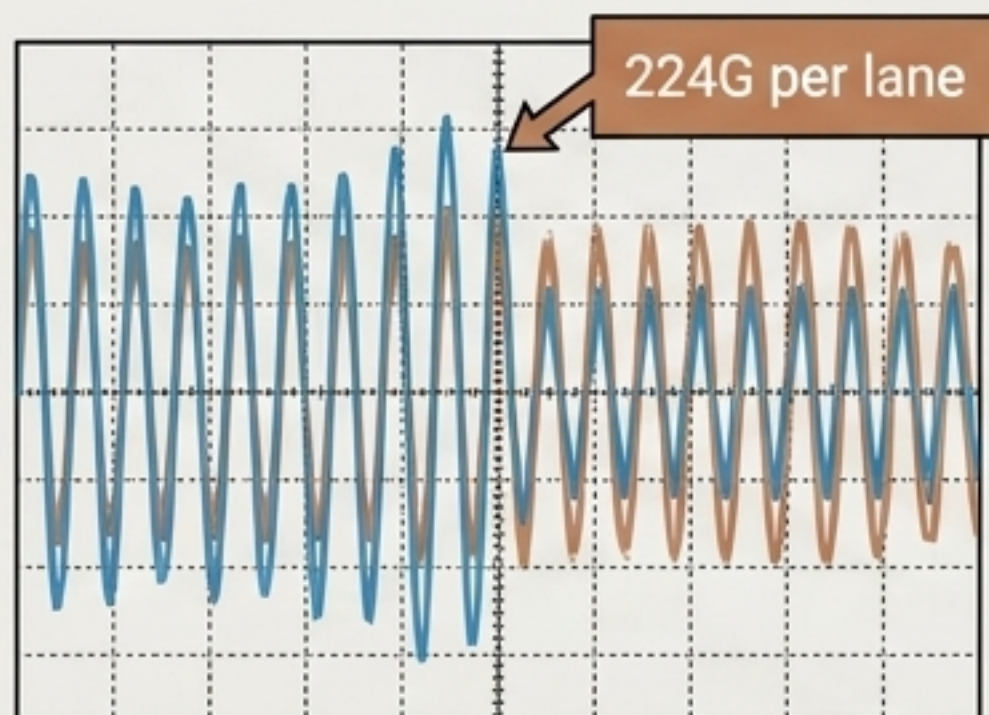
ODSP Duties:

- Equalization: Cleans up the 40dB degraded copper signal.
- Compensation: Corrects optical channel bandwidth limits.
- Error Correction: Runs forward error correction (FEC).



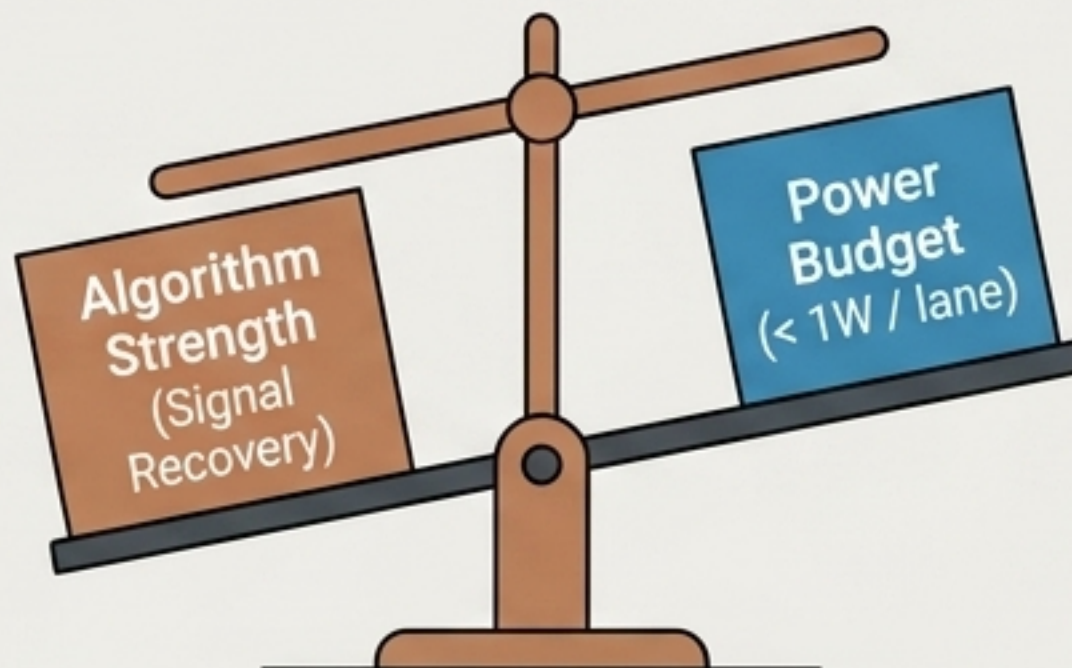
Pushing the Analog Edge

The Physics



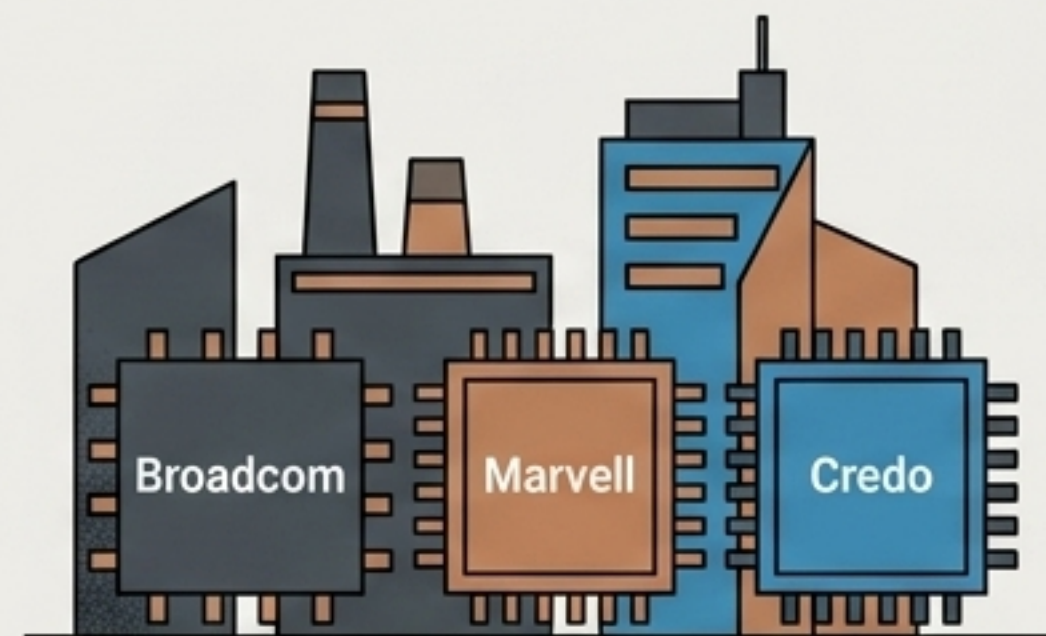
Puts Nyquist frequency at 56 GHz. Demands fast ADCs and sub-100 femtosecond RMS jitter.

The Trade-off



Stronger equalization recovers the signal better, but instantly blows through the strict thermal budget.

The Moat



Tape-outs on 5nm/3nm run tens of millions of dollars. The moat is decades of accumulated SerDes IP.

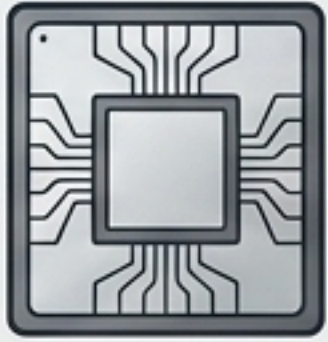
At 1.6T, pluggable modules will push 25W. Data centers cannot afford this heat.

The Siting Problem

As data volume doubles, the “courier fee” on the copper PCB skyrockets.

The packaging war boils down to a single question: How close to the office tower do you build the courier depot?

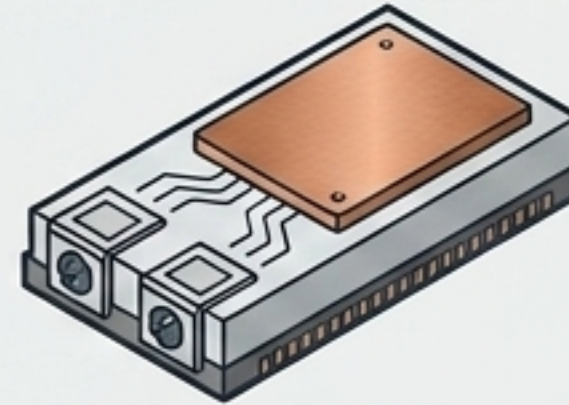
HARDWARE DOMAIN



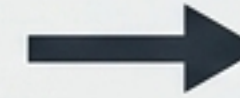
Main Switch Chip



PCB Traces



ODSP / Module

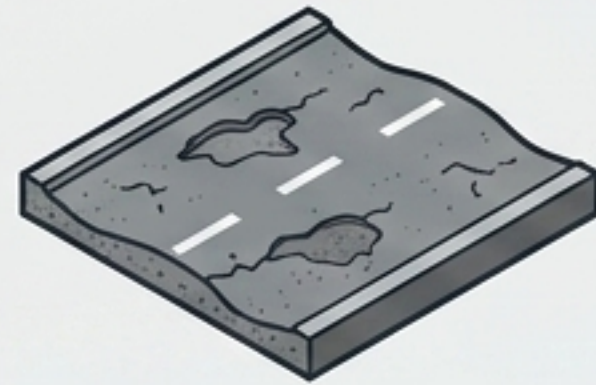


Fiber Optic Cable

LOGISTICS METAPHOR



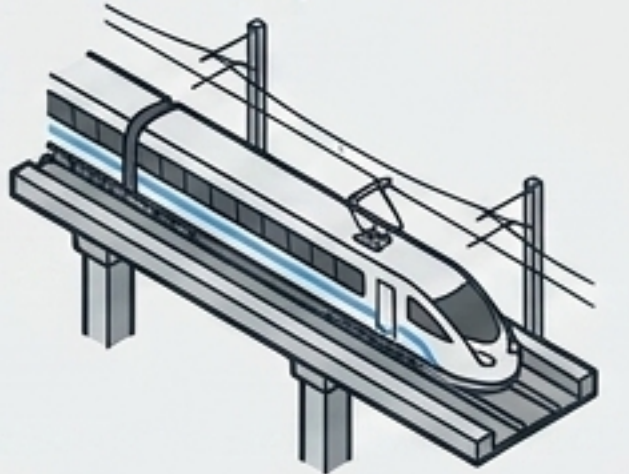
Office Tower



Potholed Street

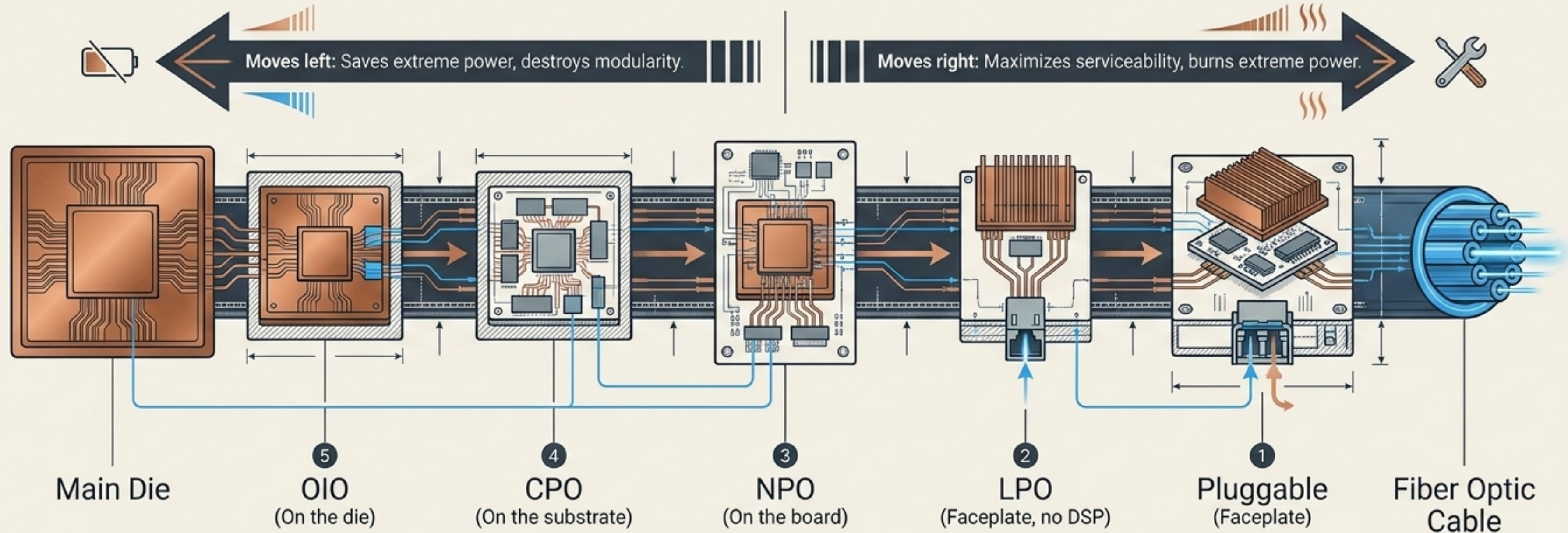


Courier Depot

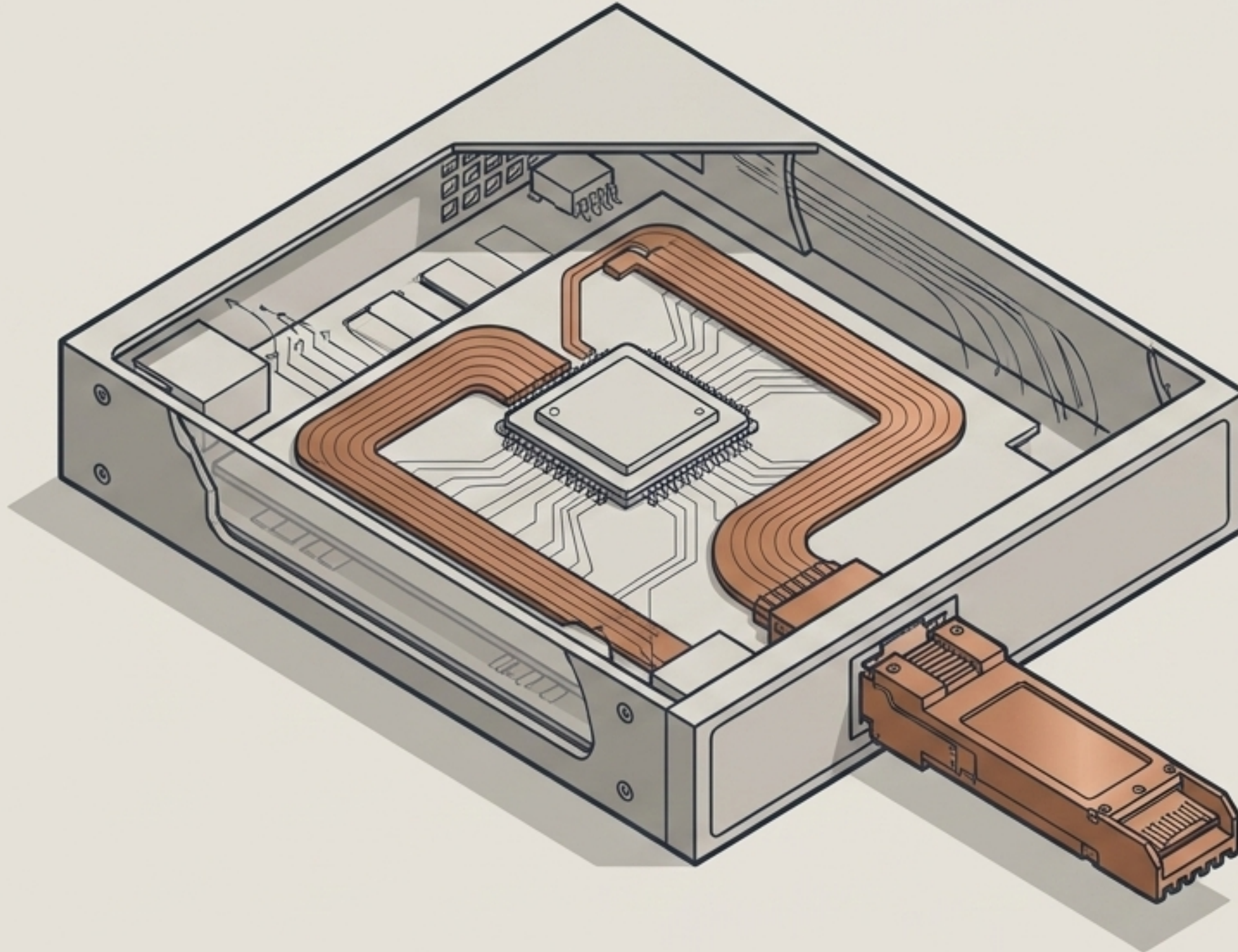


Trunk Railway

Five Depots, One Highway



Pluggable Optics: The Standard Locker



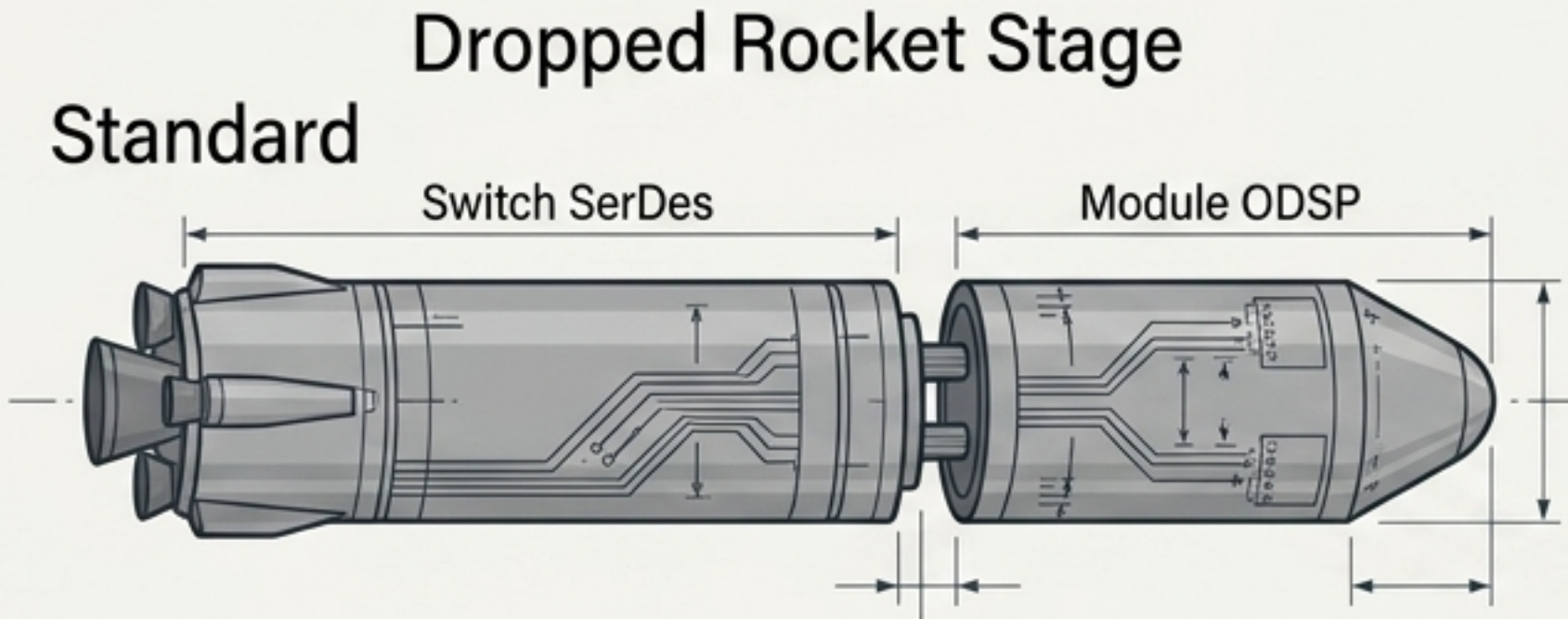
Power:	14 – 16 W
SerDes:	Long-reach (4.5 – 6 pJ/bit)

The depot is outside the building. The street is long, requiring the switch chip to use its strongest, most power-hungry long-reach SerDes. The signal arrives heavily damaged and must be completely scrubbed by the ODSP.

Advantage:

Standardized dimensions. Any vendor's locker fits perfectly and can be hot-swapped instantly.

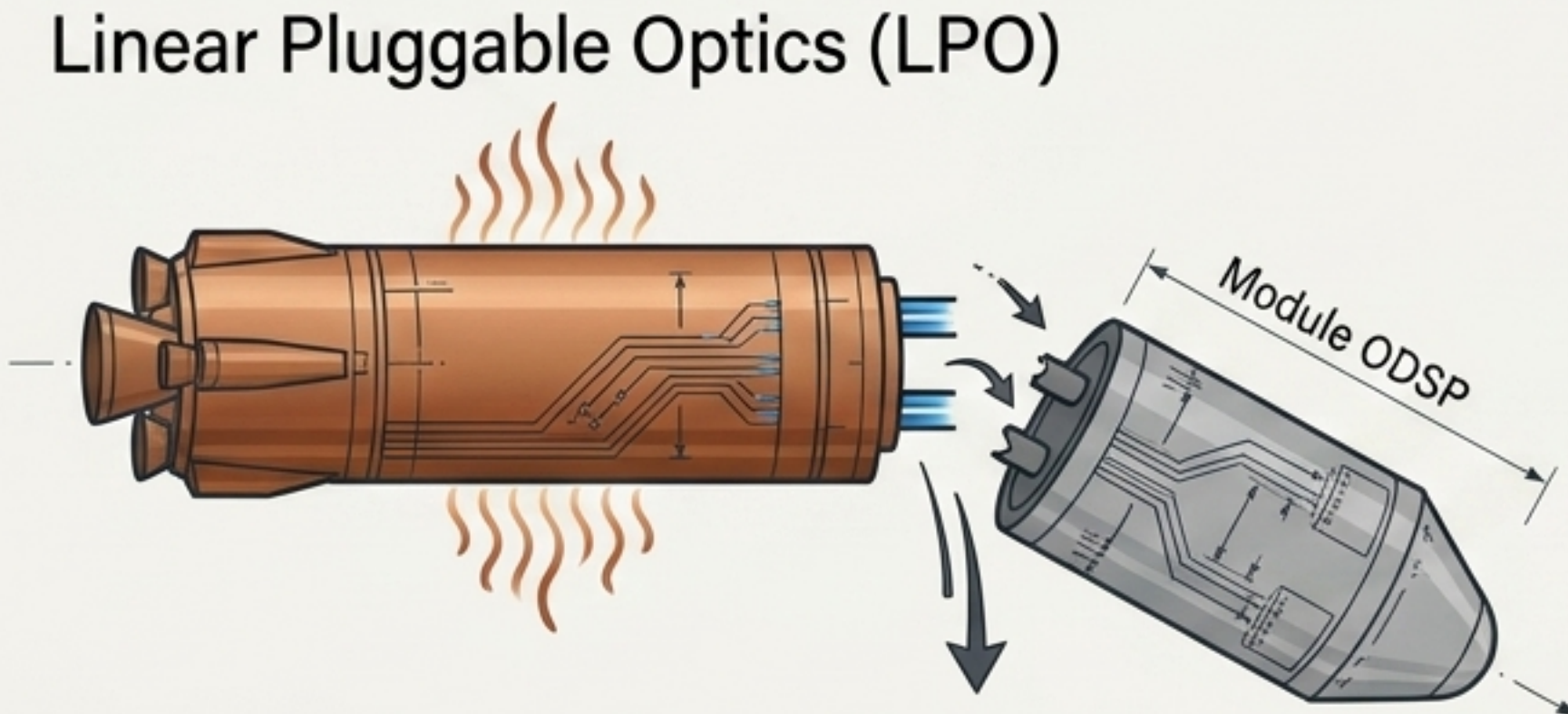
LPO: Dropping the Stage



Module Power:
Drops 40-50% (7.5 - 9 W)

The ODSP is removed in favor of a linear driver. Power plummets.

But the switch chip must now **drive the whole path itself**, upgrading 512 SerDes lanes to hotter drivers.



The Interoperability Problem:

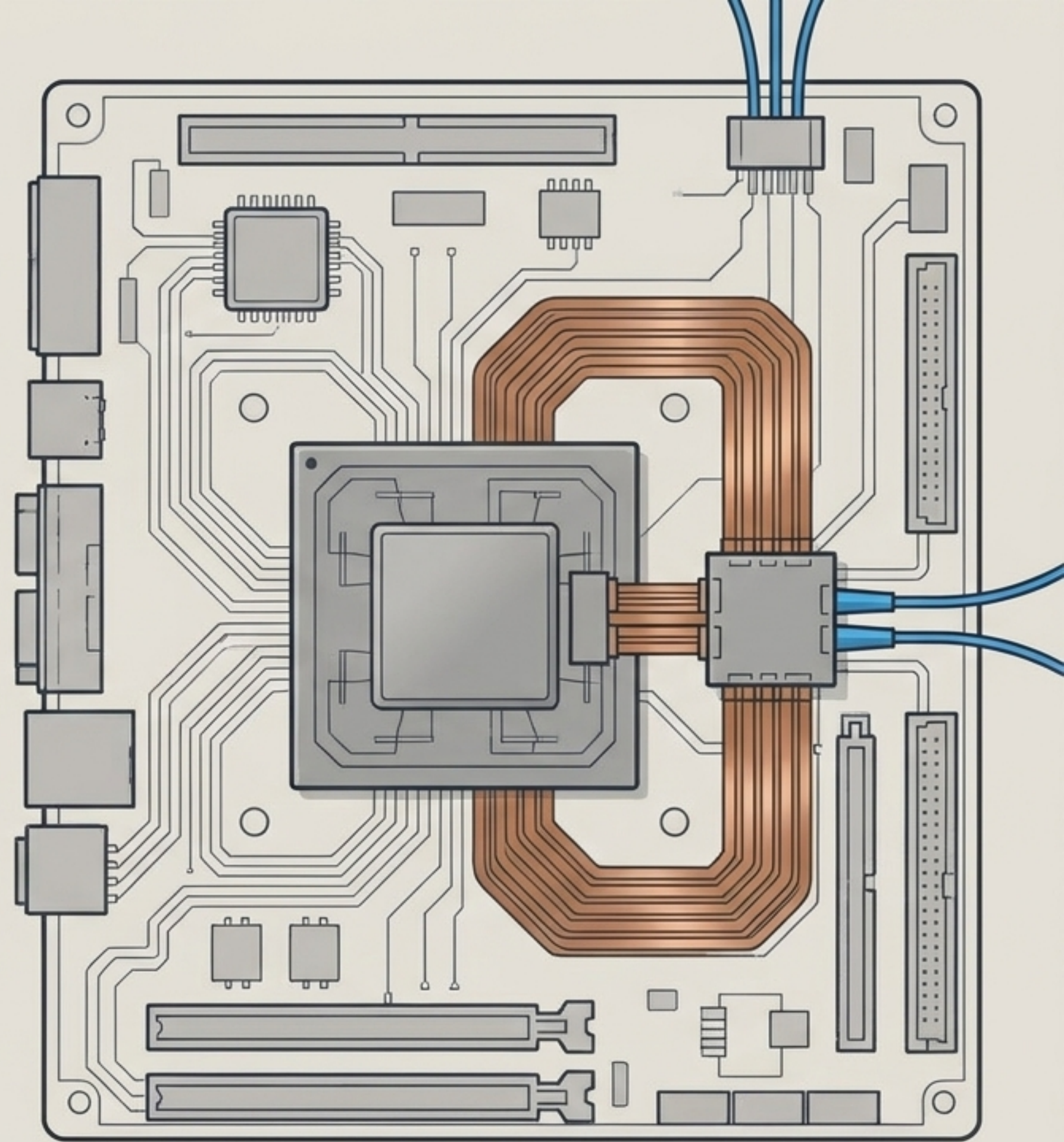
If a signal arrives damaged, there is no ODSP to clean it up. Vendors point fingers at each other's hardware, breaking the plug-and-play ecosystem.

NPO: The Middle Rung

SerDes:	XSR-class (Short-reach)
Energy:	1 - 2 pJ/bit (Several times cheaper than long-reach)

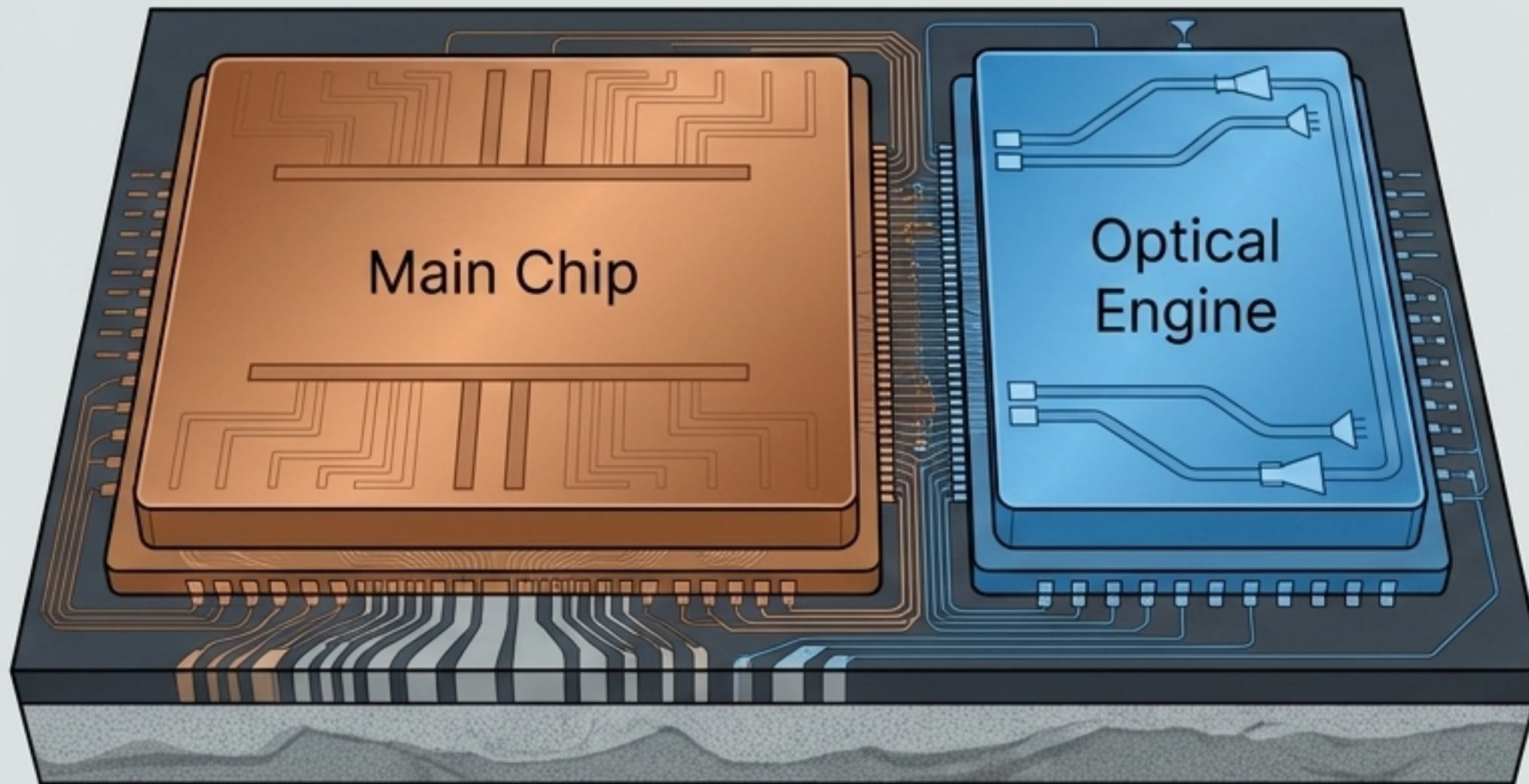
Near-Packaged Optics shrinks the “street” from a kilometer to a few dozen meters. The optical engine moves off the faceplate and directly onto the PCB, severing the distance to the main chip.

- The engine is semi-custom but remains replaceable as a unit. Widely viewed by the industry as a transition architecture.

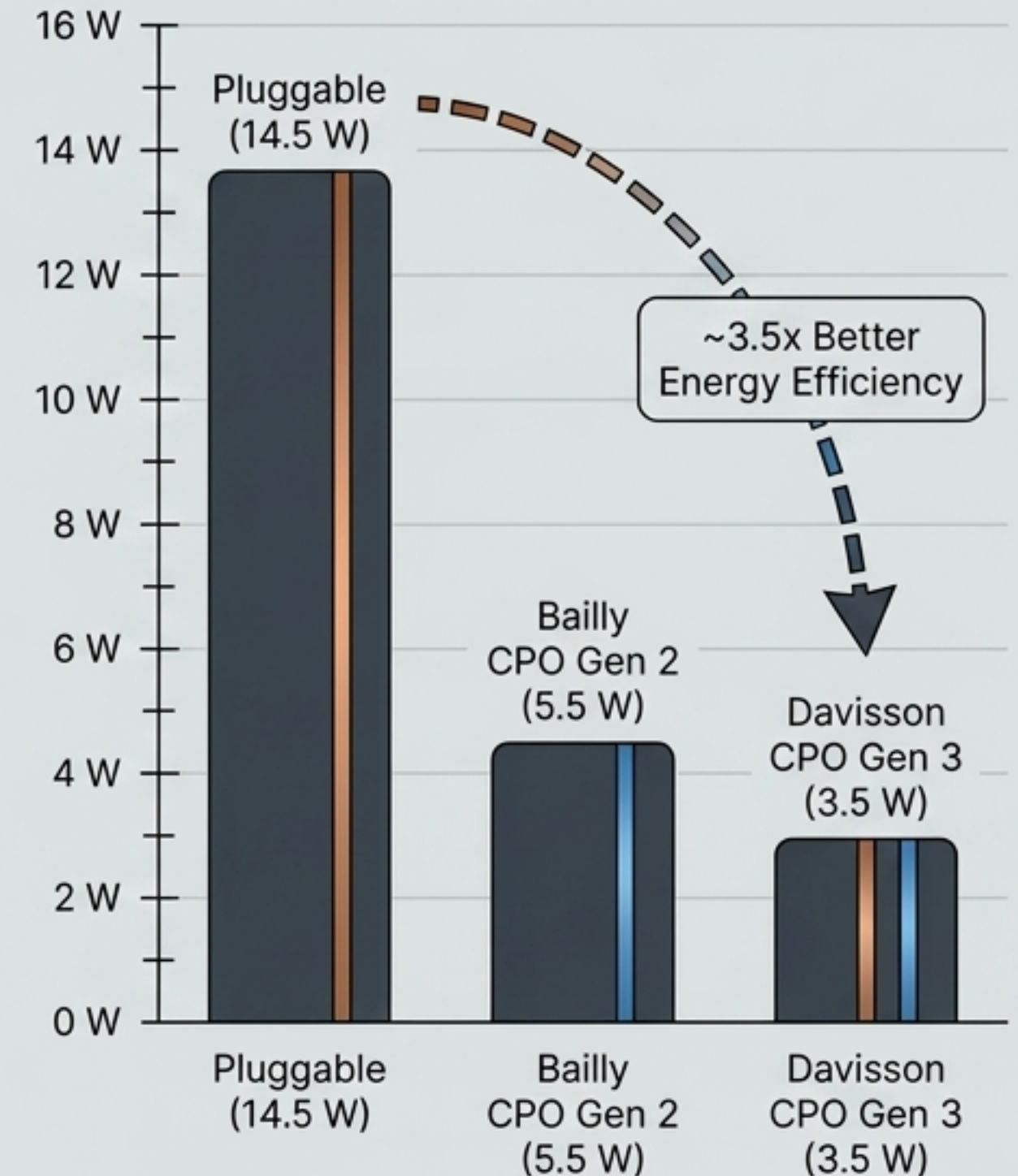


CPO: Inside the Building

The parcel locker goes away. The depot moves to the same floor as the recipient. The ODSP and long-reach SerDes are entirely eliminated.



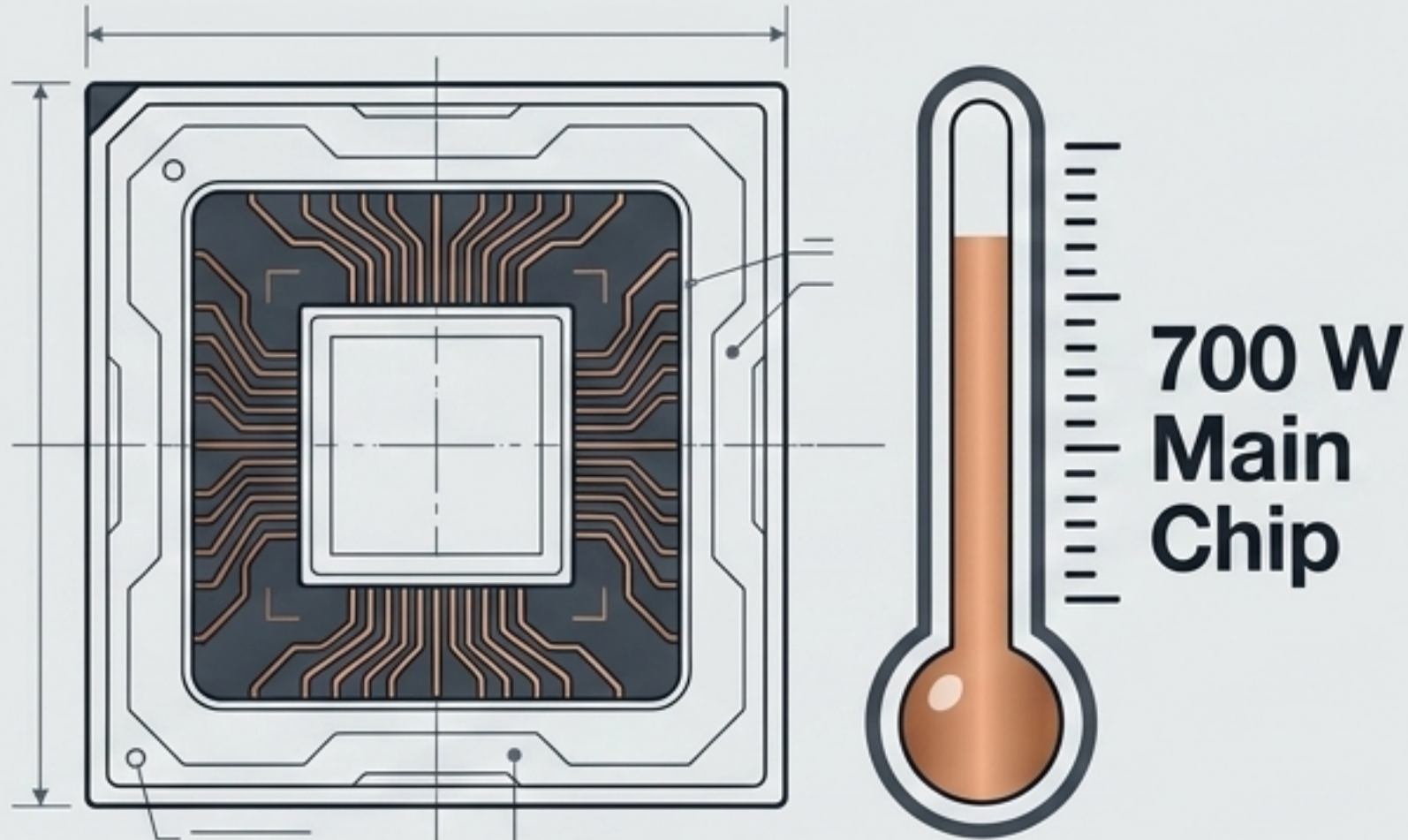
Power per 800G Link



The CPO Penalty

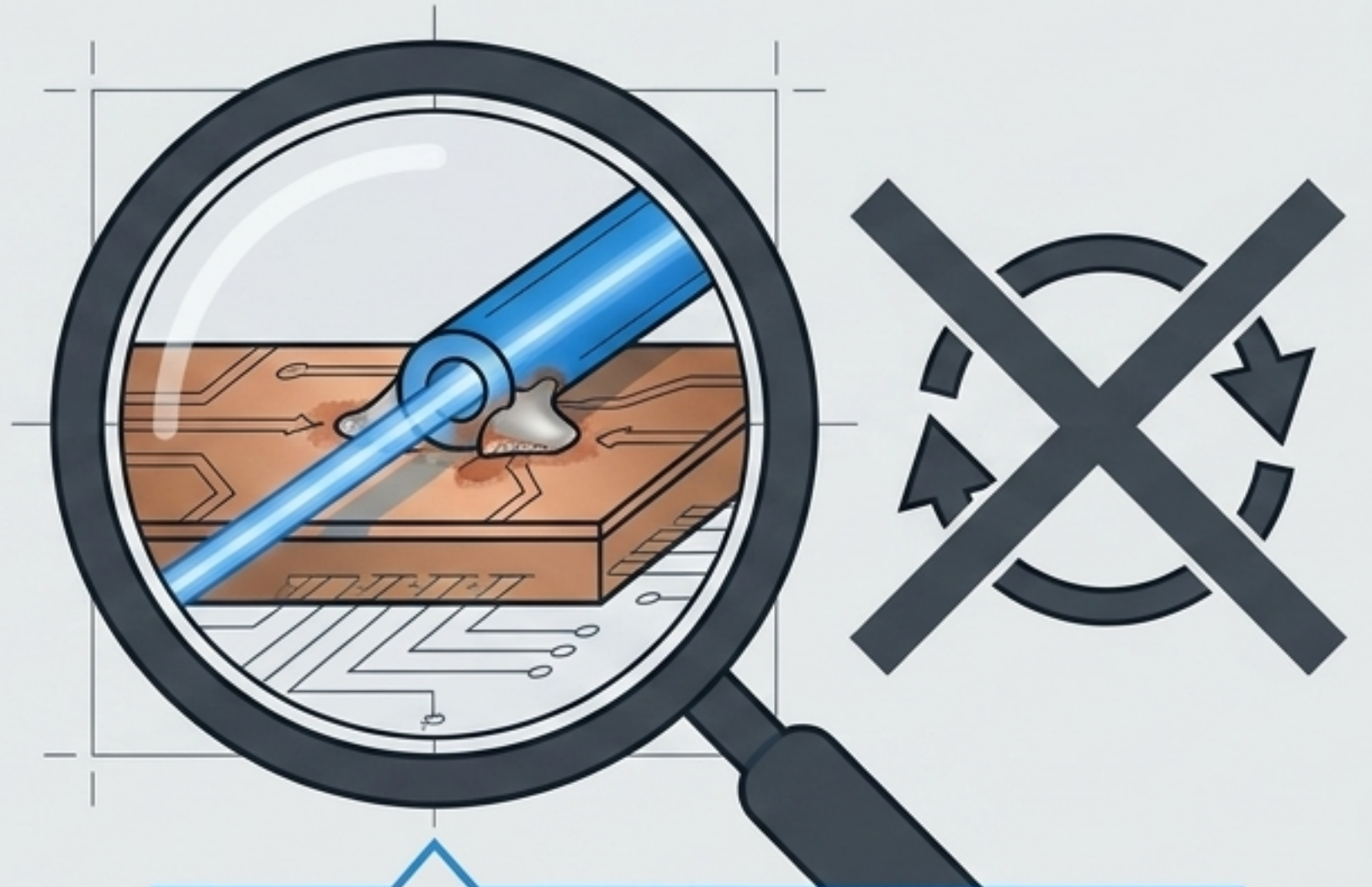
Extreme proximity brings extreme system costs. Maintenance now requires surgical repair by the original designers.

Thermal Threat



Lasers hate heat, but are now permanently trapped next to a 700W furnace.

Maintenance Threat



The light path is sealed. Dead channels cannot be hot-swapped.

OIO: Direct to the Die

Optical I/O eliminates even the substrate. Light enters the package directly against the compute die. This architecture is built for GPU-to-GPU scale-up, distinct from CPO's switch-side network focus.



1

TSMC COUPE
(Volume production April)

2

Ayar Labs

3

Marvell

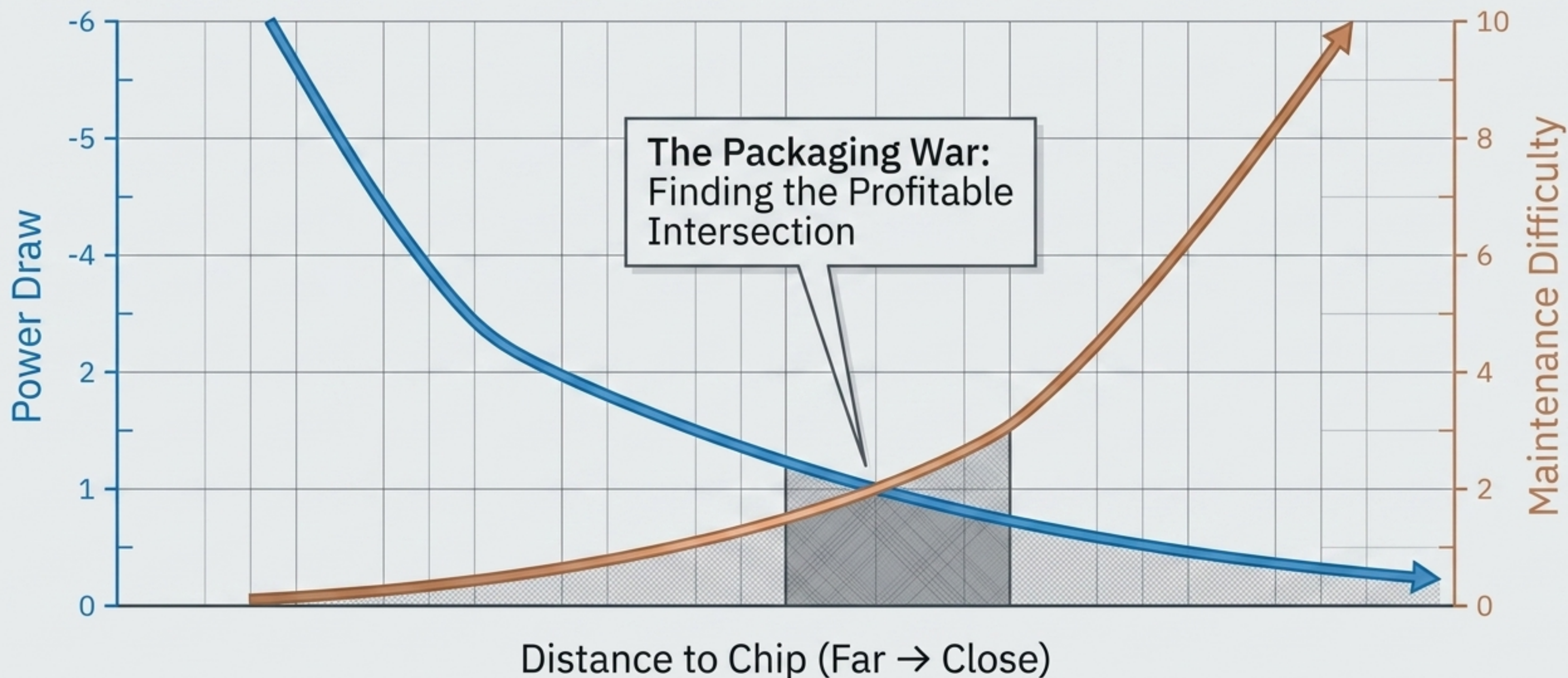
The Architecture Matrix

	Pluggable	LPO	NPO	CPO	OIO
Distance to Chip	 Faceplate	 Faceplate	 PCB	 Substrate	 Die
SerDes Requirement	 Long-Reach	 Strong Linear	 XSR	 None	 None
Power per Link	 High (15W)	 Medium (8W)	 Low	 Ultra-low (3.5W)	 Lowest
Serviceability	 Hot-Swap	 Hot-Swap	 Replaceable	 Soldered	 Soldered
Ecosystem	 Standard	 Fragmented	 Semi-Custom	 Vendor-Locked	 Vendor-Locked

The closer light gets to silicon, the more power efficiency you gain, and the more modular flexibility you lose.

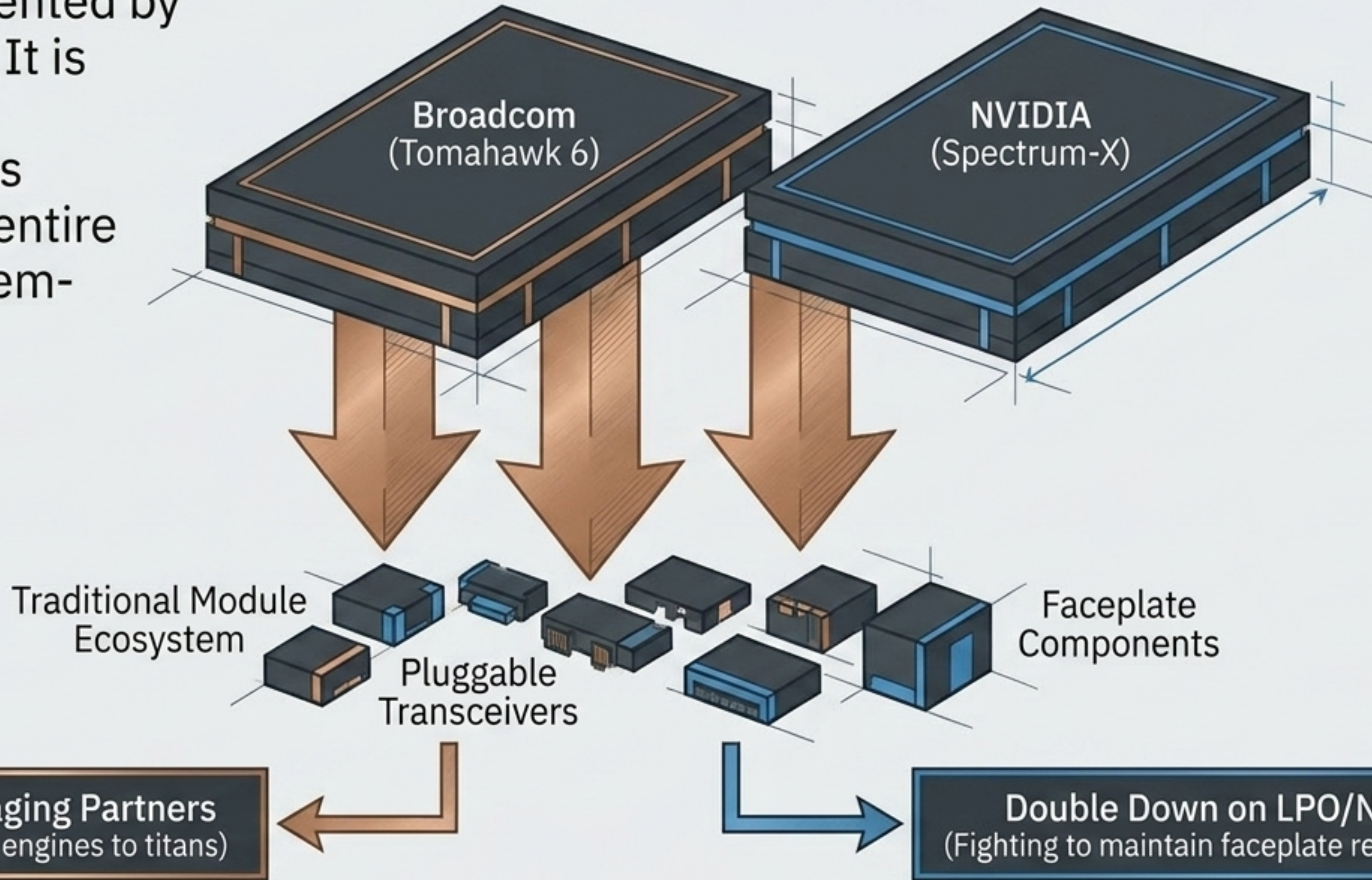
The Trade-off Curve

There is no perfect solution, only a choice of which penalty a data center is willing to pay.



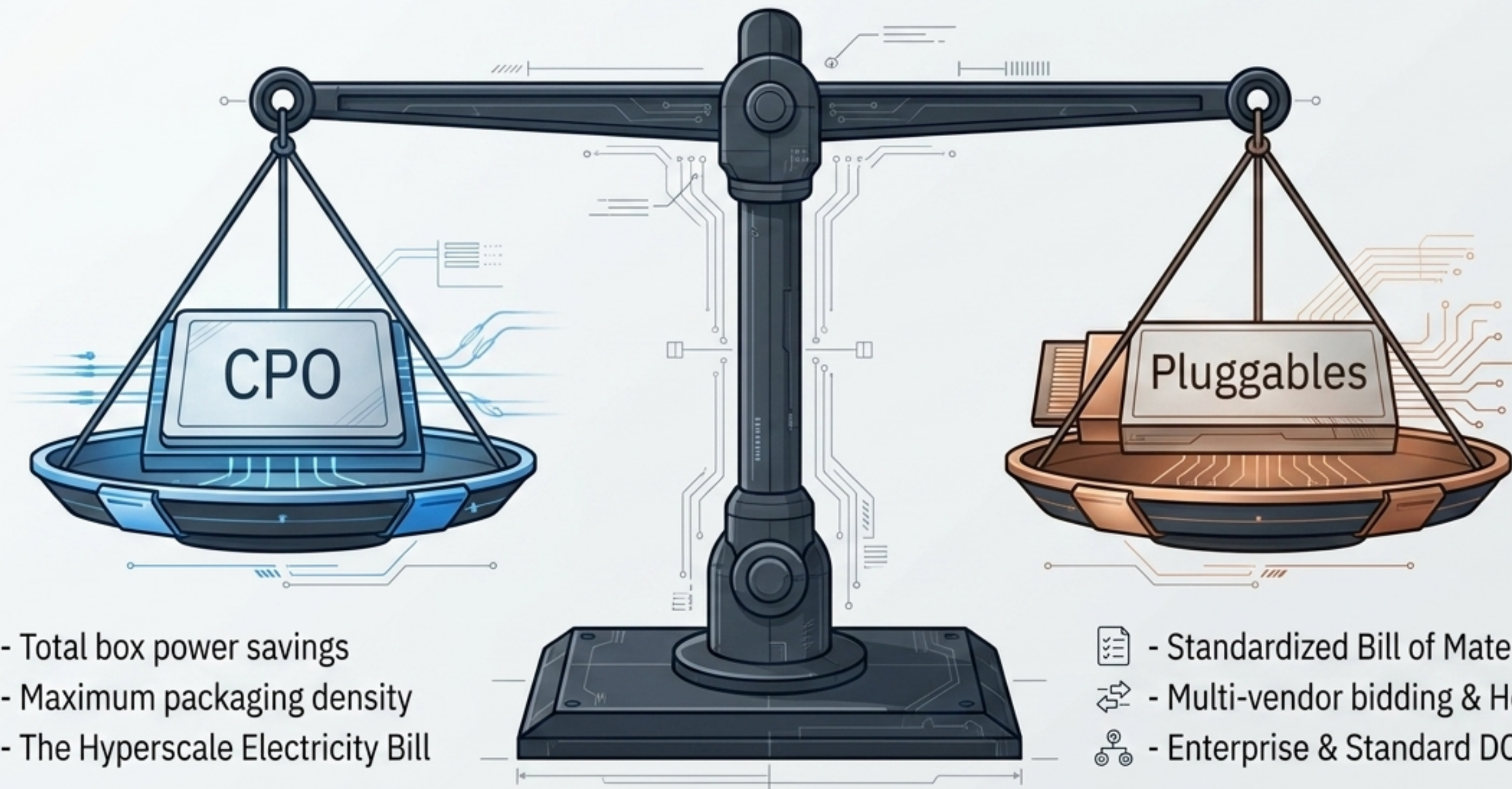
A Top-Down Revolution

CPO was not invented by module makers. It is being forced by switch chip titans redesigning the entire box to save system-level power.



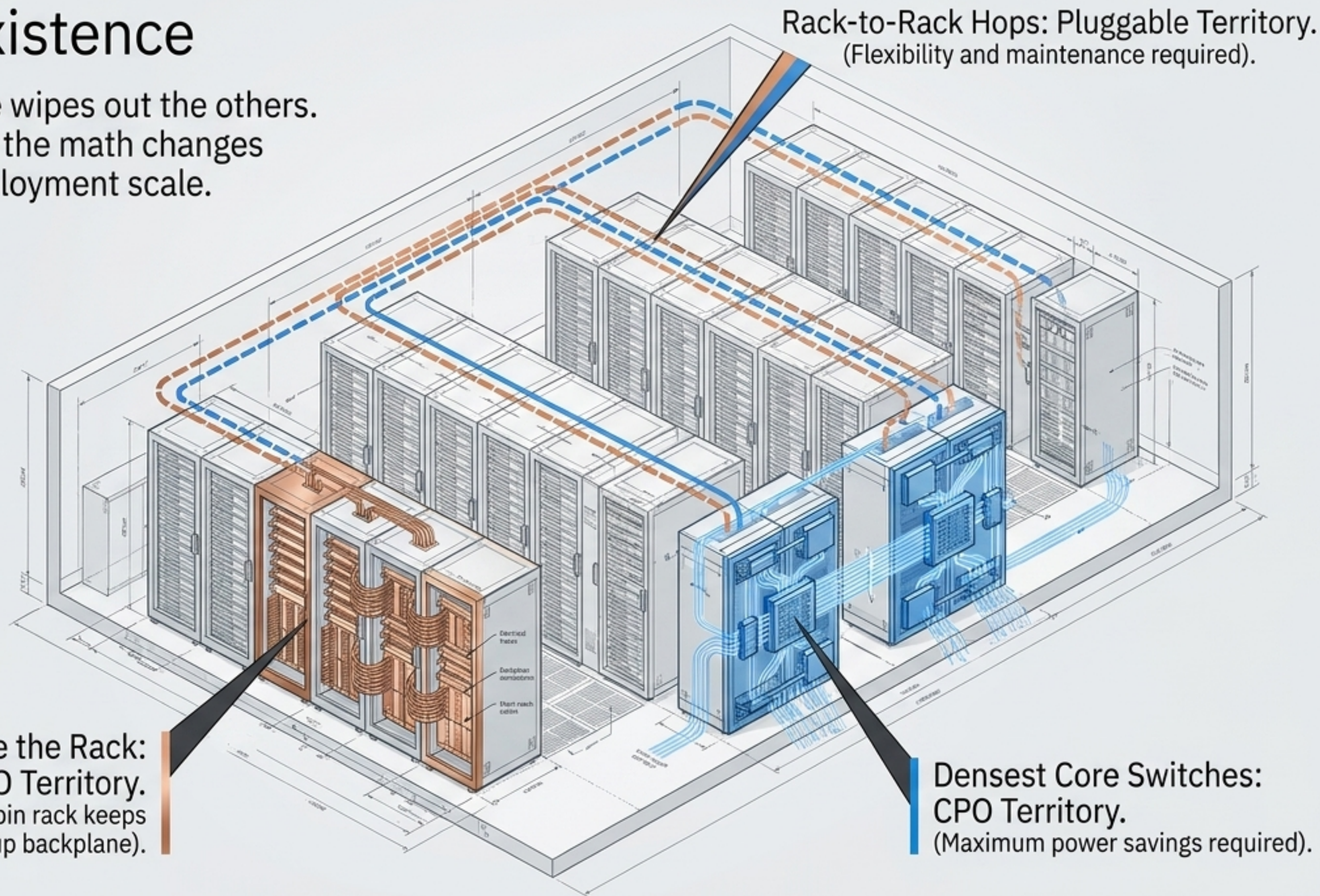
Physics vs. Economics

The cloud buyer weighs module replacement cost against lifetime system electricity cost



No single architecture wipes out the others.
They coexist because the math changes
depending on the deployment scale.

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THE WAR FOR THE DEPOT

