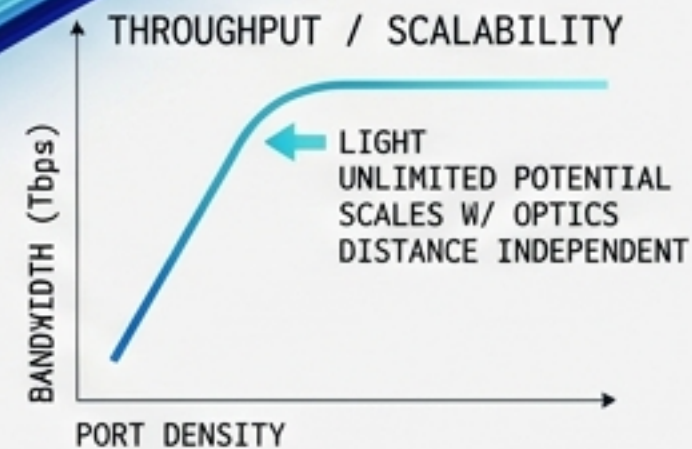
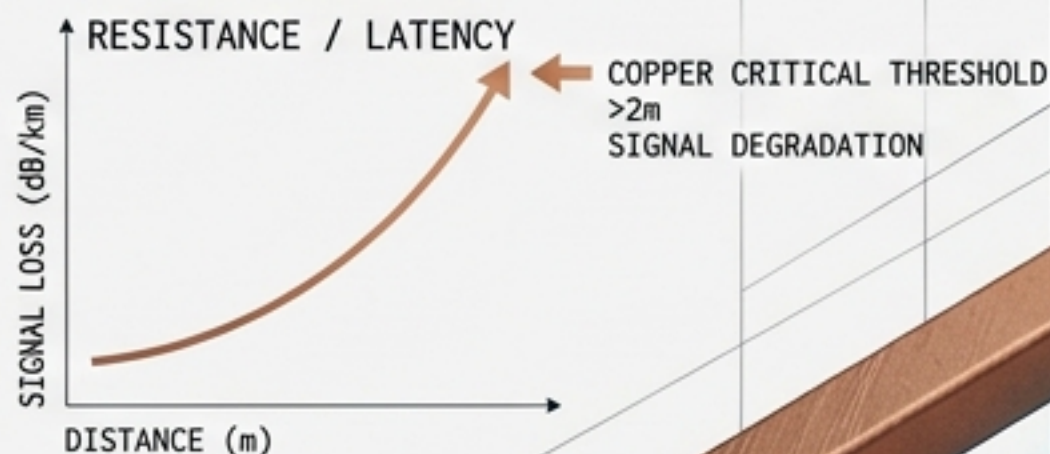


Copper Pays by Distance, Light Pays by Port

TECHNICAL BRIEF | PHYSICAL LAYER LIMITATIONS | AI INFRASTRUCTURE

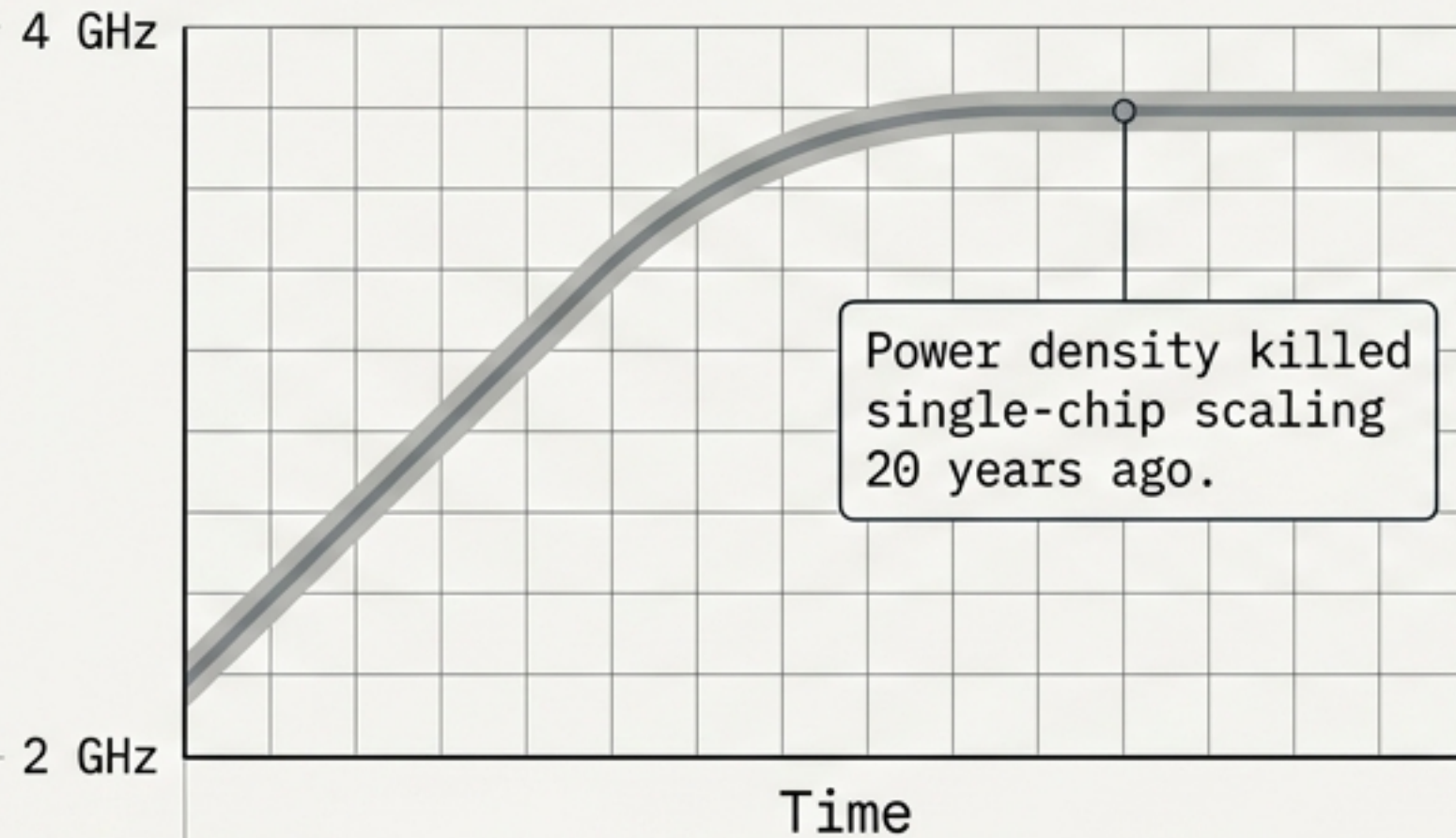


Networking has a Moore's law of its own. As AI's appetite for bandwidth outruns it, the physics of copper is being pushed to its breaking point.

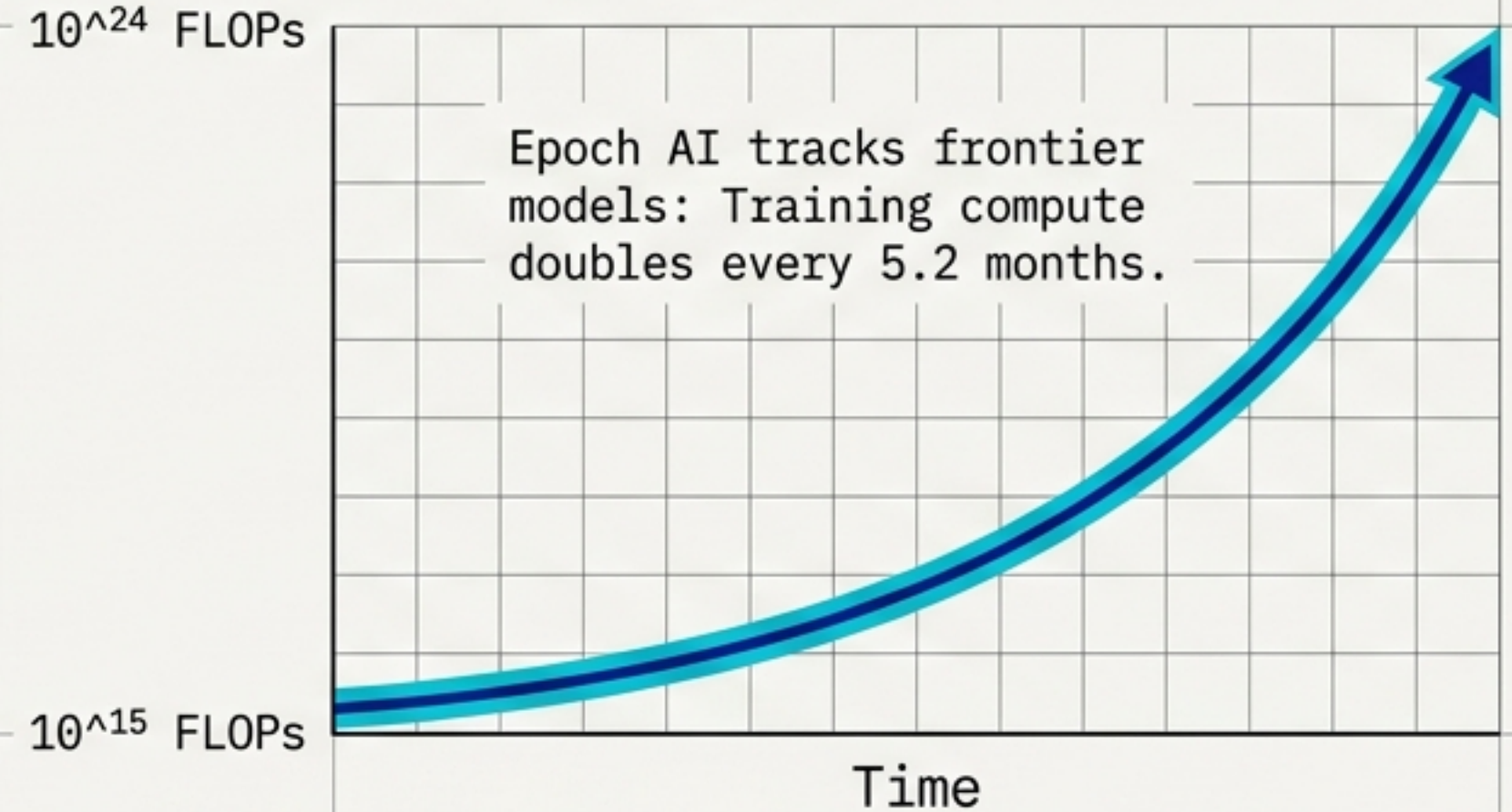
MARKET DYNAMICS | BANDWIDTH DEMAND | 2025-2030 PROJECTION

AI forced the network to become the computer

The Flatline



The Hockey Stick



The Network Wall

- When a single chip can't scale, the only move is to wire up to 100,000 GPUs into a single massive cluster.

- If the network bottlenecks, multi-million-dollar GPUs sit idle waiting for data. Interconnects are now the choke point of AI.

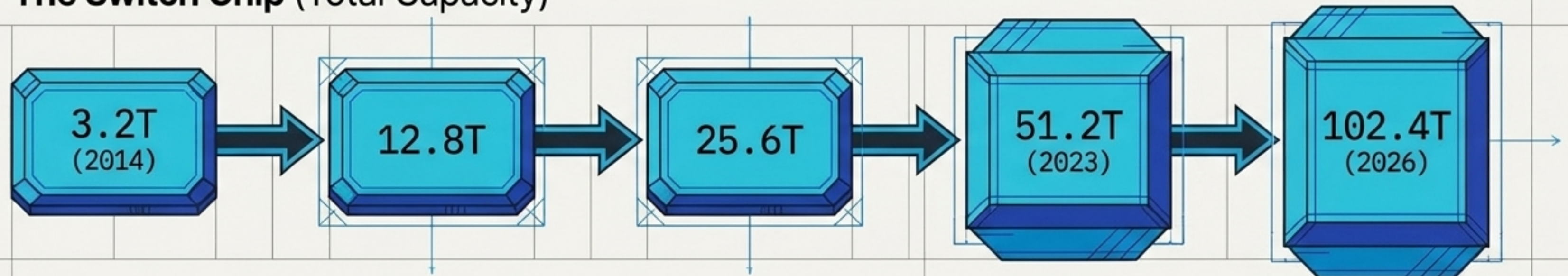
Networking's relentless cadence is compressing

AI compressed the standard 2-to-3-year upgrade cycle by half. The distances in a data center won't shrink, but the data rates won't stop climbing.

The SerDes Lane (Parallel to Serial)

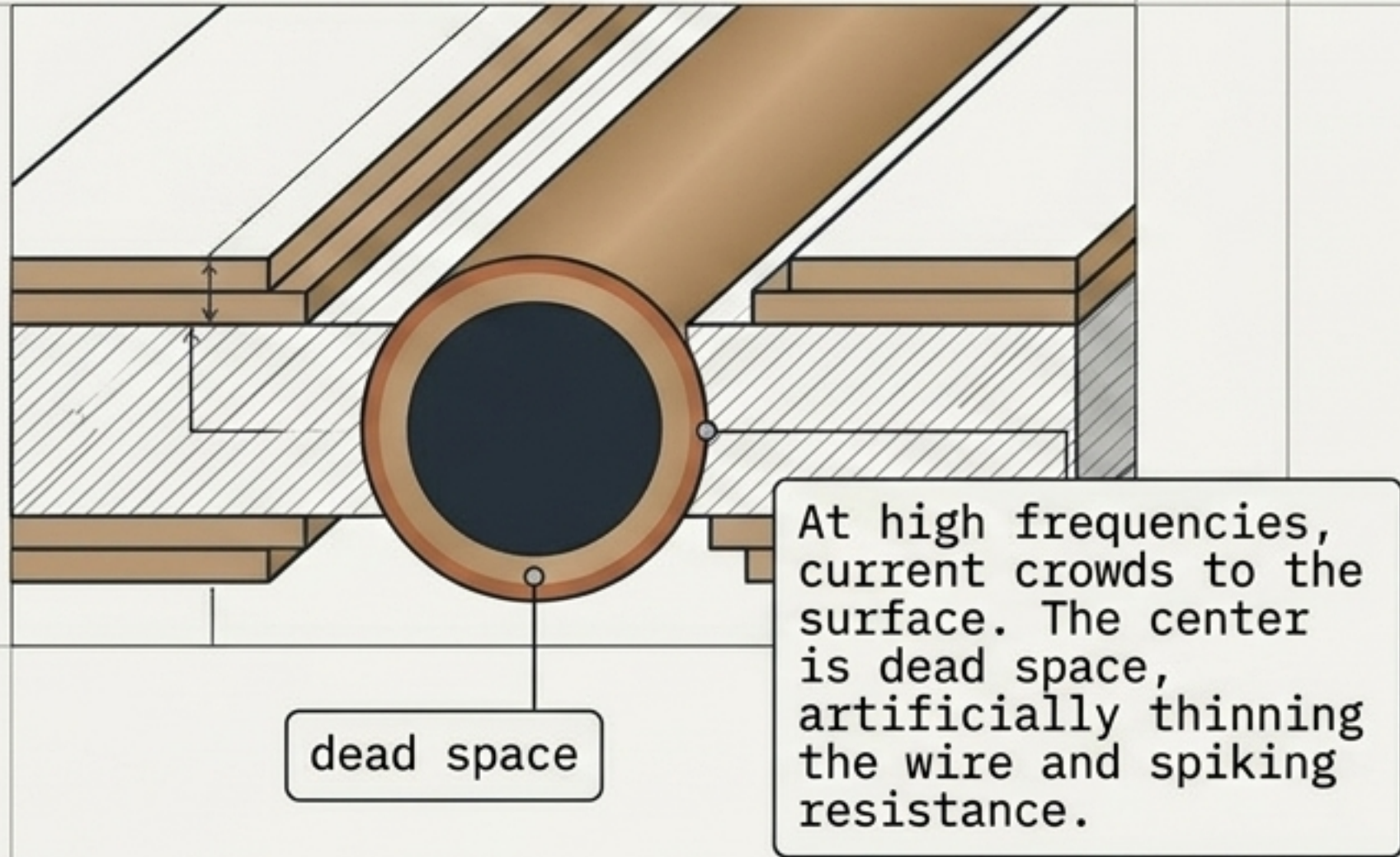


The Switch Chip (Total Capacity)

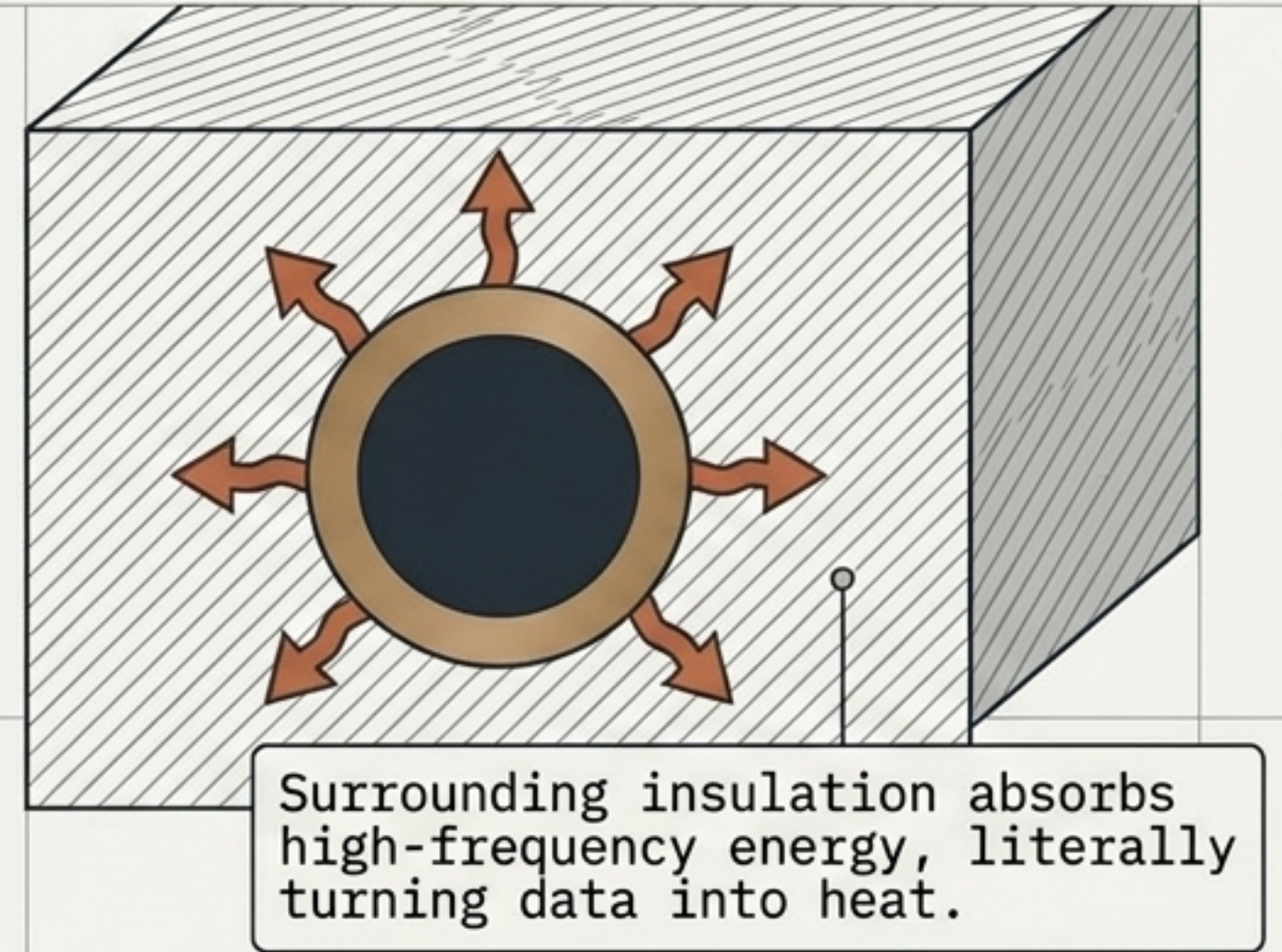


Copper's fundamental enemy is high frequency

Skin Effect



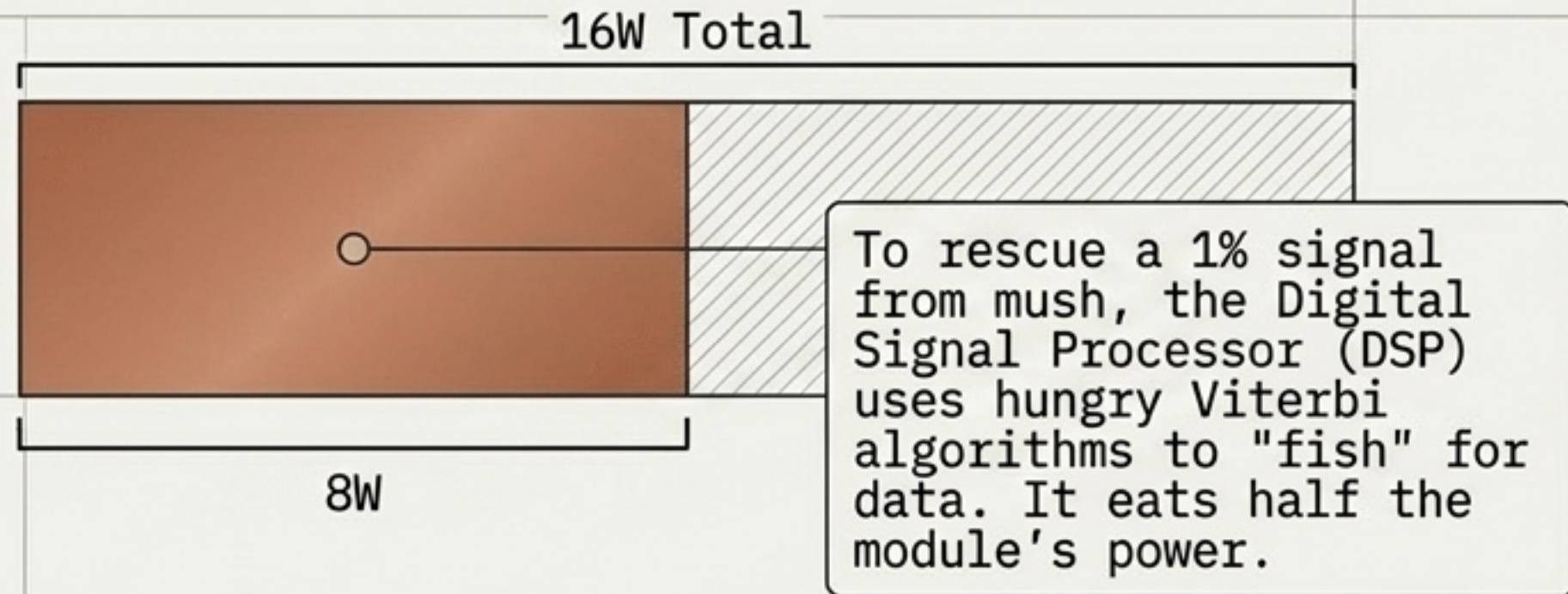
Dielectric Loss



The Brutal Math: At the 224G generation (56 GHz Nyquist frequency), insertion loss hits 40 dB. Only 1% of the original signal amplitude survives the journey.

The compounding tax of fishing for a 1% signal

Power Breakdown



The Triple Penalty

Power

DSPs burn massive wattage just to listen.

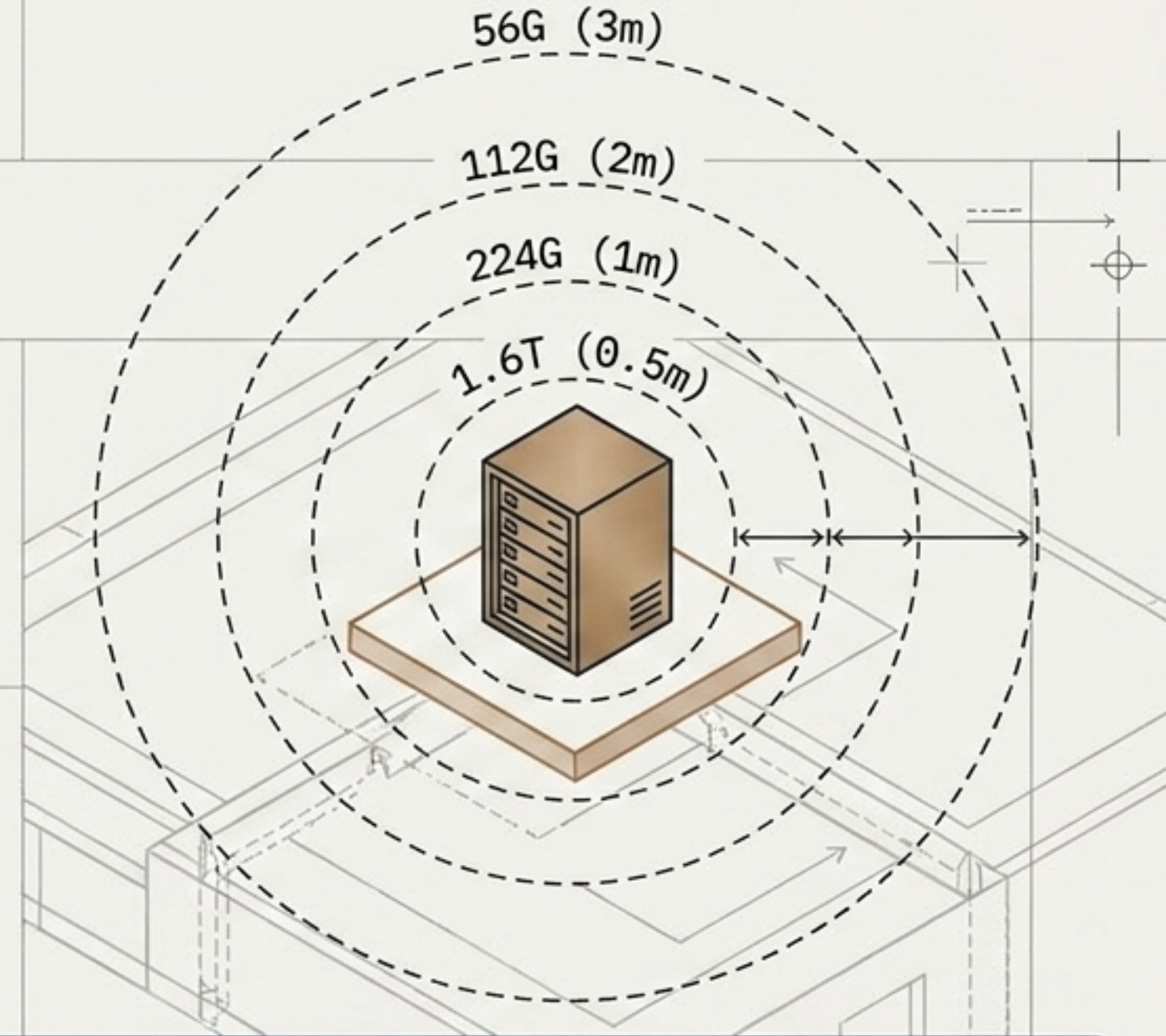
Distance

Every generation cuts copper's reach in half.

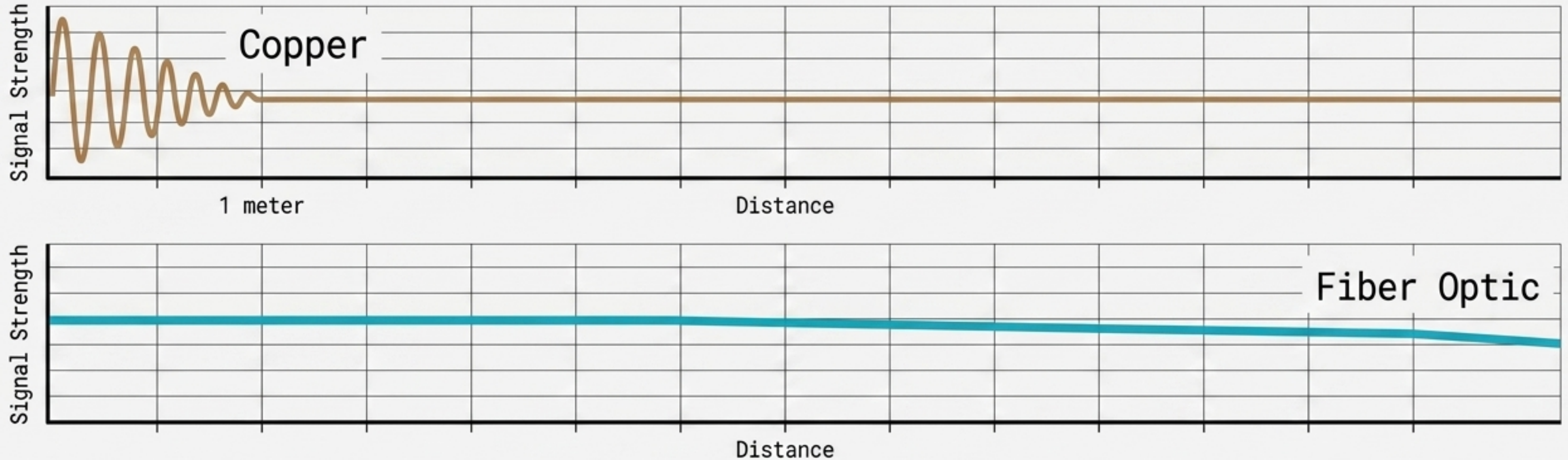
Errors

Zero margin for error. Raw bit error rates of 2×10^{-4} must be corrected to 10^{-13} using strict Forward Error Correction (FEC).

Shrinking Radius



Fiber optics completely ignore the speed limit



0.2 dB per kilometer

Loss in single-mode 1550 nm glass is dictated by material absorption, not signal speed. Doubling data rates changes nothing.

100 Kilometers

After 100km, light loses 20 dB (1-2% remains). It takes fiber 100 kilometers to reach the same amplitude loss that copper hits before leaving a single server board.

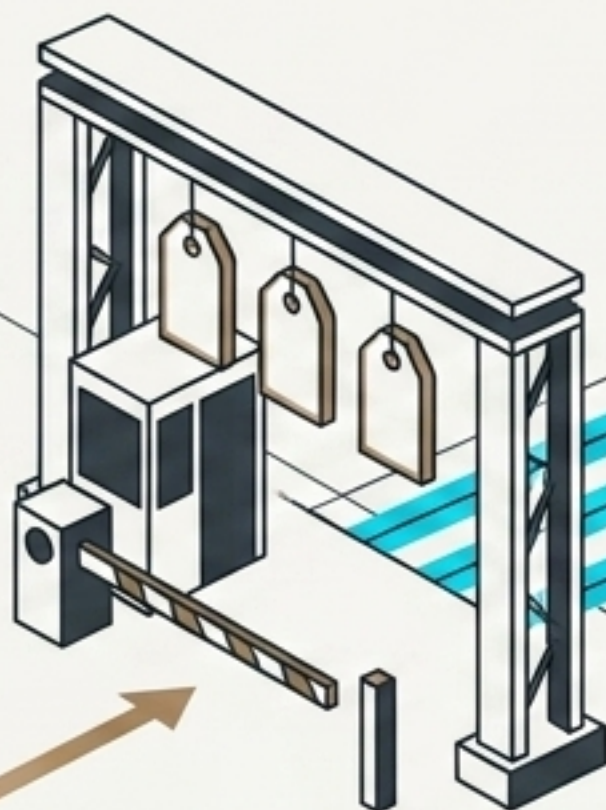
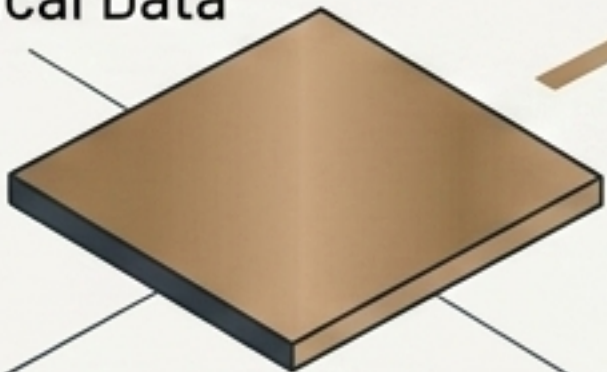
8 to 10 THz

The massive usable spectrum of C+L bands allows tens of Tb/s on a single fiber.

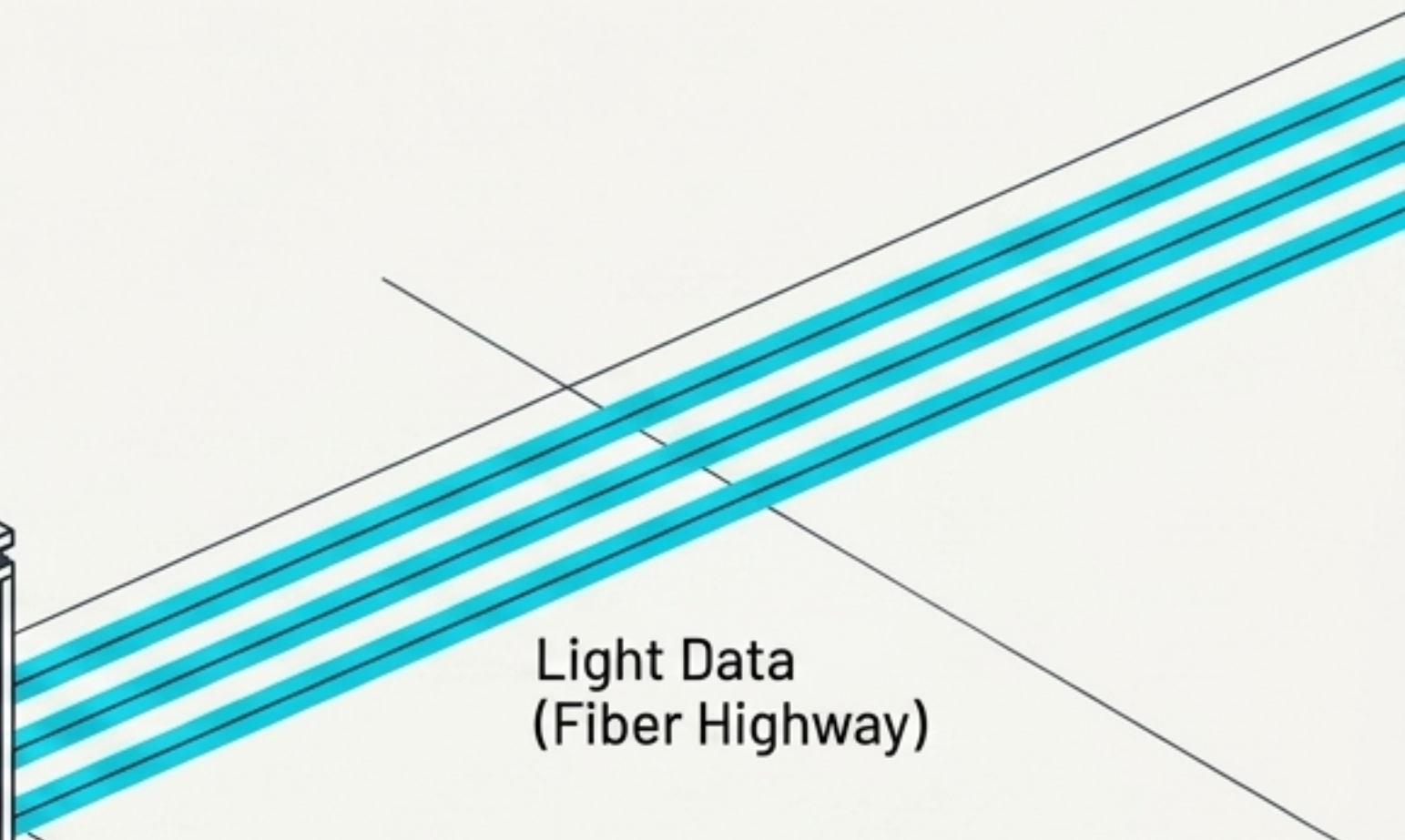
The fixed port toll of optical conversion

Inside a chip, data is electrical. To travel on fiber, it must be converted. Whether data travels 1 meter or 10 kilometers, you pay this fixed fee upfront:

Electrical Data



The Optical Module



Light Data
(Fiber Highway)

Cost Toll:

Lasers, drivers, TIAs, and precision optics cost an order of magnitude more than passive copper DACs.

Power Toll:

Conversion burns electricity. Furthermore, cooling those watts doubles the data center's ultimate power bill.

Reliability Toll:

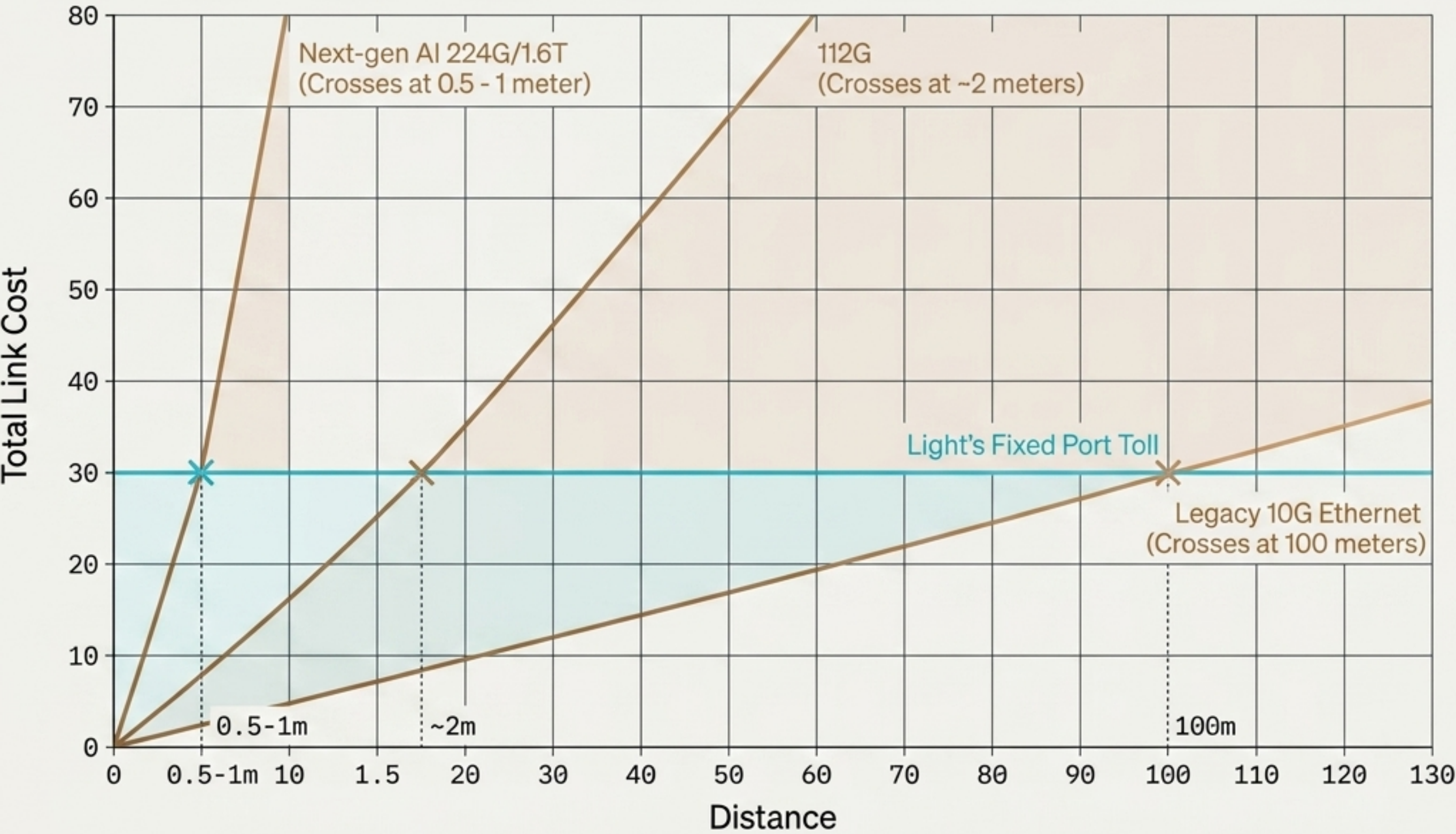
Lasers eventually age and die. Copper wire essentially never fails.

The Diagnostic Matrix: Direct-Drive Copper vs. Optical Fiber

	Direct-Drive Copper	Optical Fiber
Signal Loss	Exponentially scales with speed	Negligible, ignores speed
Distance Limit	0.5 to 3 meters	100+ kilometers
Power Tax	Near zero passive power, pays by distance	High fixed conversion power, pays by port
Component Cost	Pennies, highly commoditized	Premium, complex optical stack
Reliability	Practically indestructible	Subject to laser aging and thermal wear

The **Copper Fortress**: Within a single rack, Copper remains undisputed king. NVIDIA's NVL72 rack utilizes 5,184 direct-drive copper cables (3.2km total) to network GPUs, deliberately avoiding the optical toll to save a massive 20 kW of power.

The crossover point slides left every generation



Copper pays by distance. Light pays by port. Every time bandwidth doubles to feed AI, copper's physical resistance steepens its cost curve.

What used to be a kilometers-wide domain for copper has violently compressed. Today, the moment data leaves the server rack, it must turn to light.