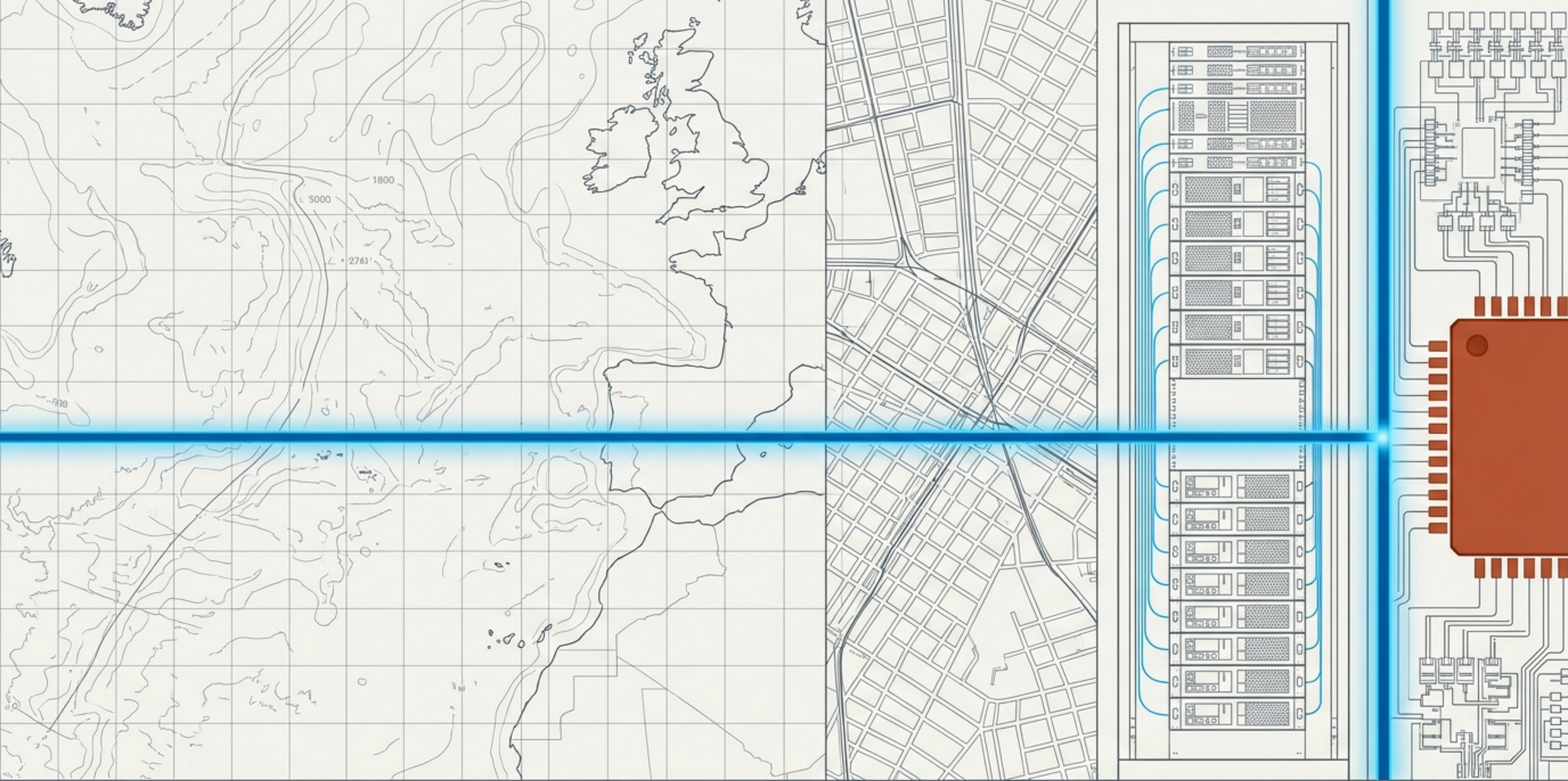
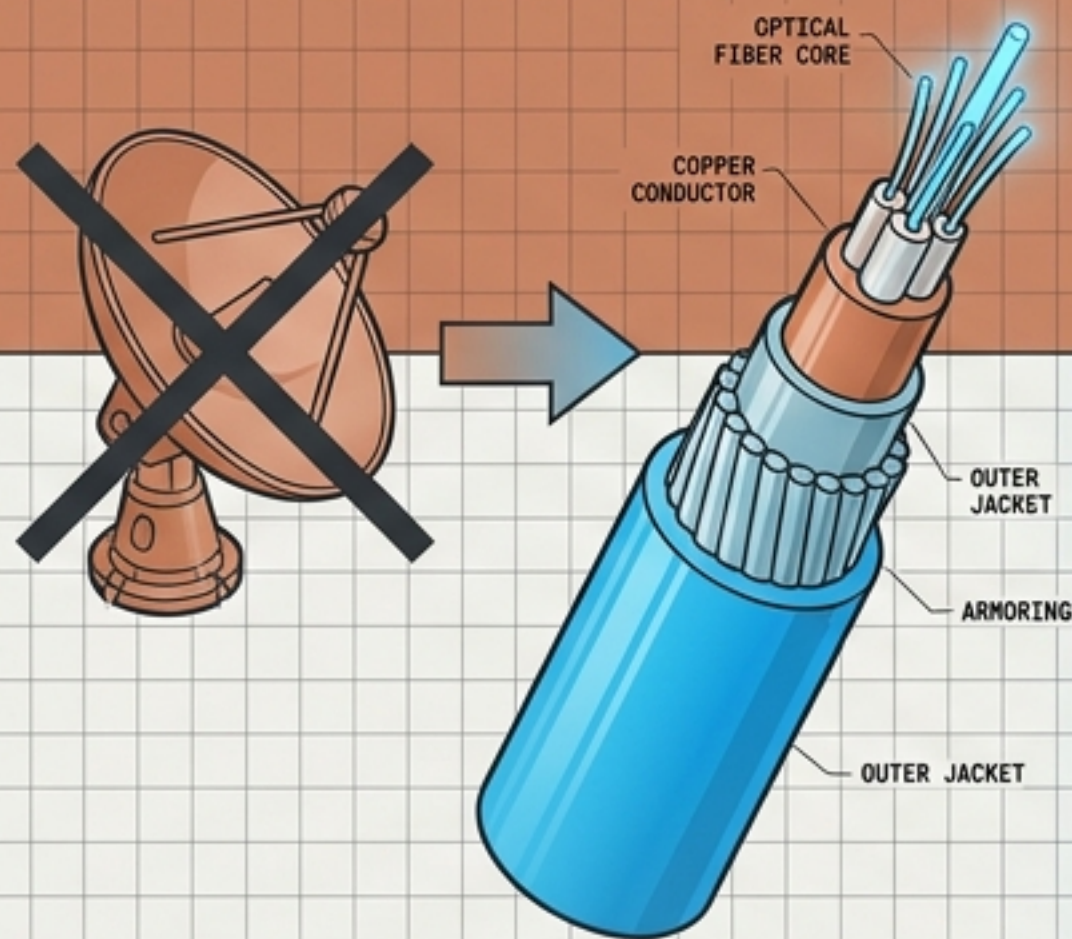




Two centuries of physics and economics have relentlessly squeezed electrical wires out of the network. This is the story of a boundary moving from the floor of the Atlantic to the edge of the server rack.

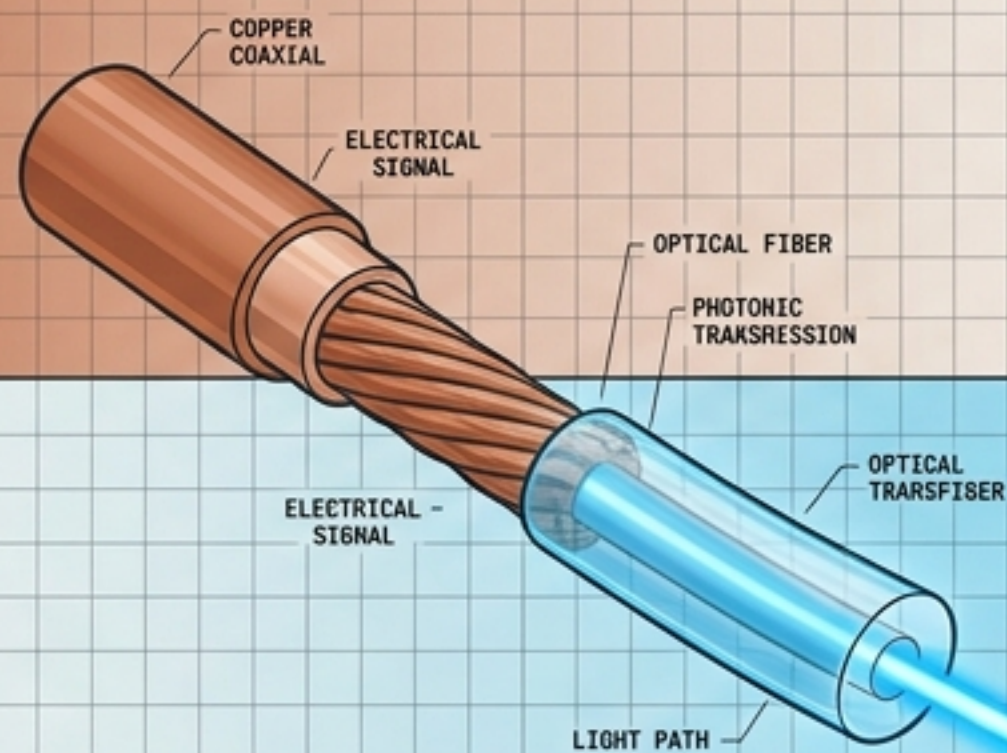
THREE SHIFTS DEFINED THE HISTORY OF THE NETWORK

WIRELESS VS. WIRED



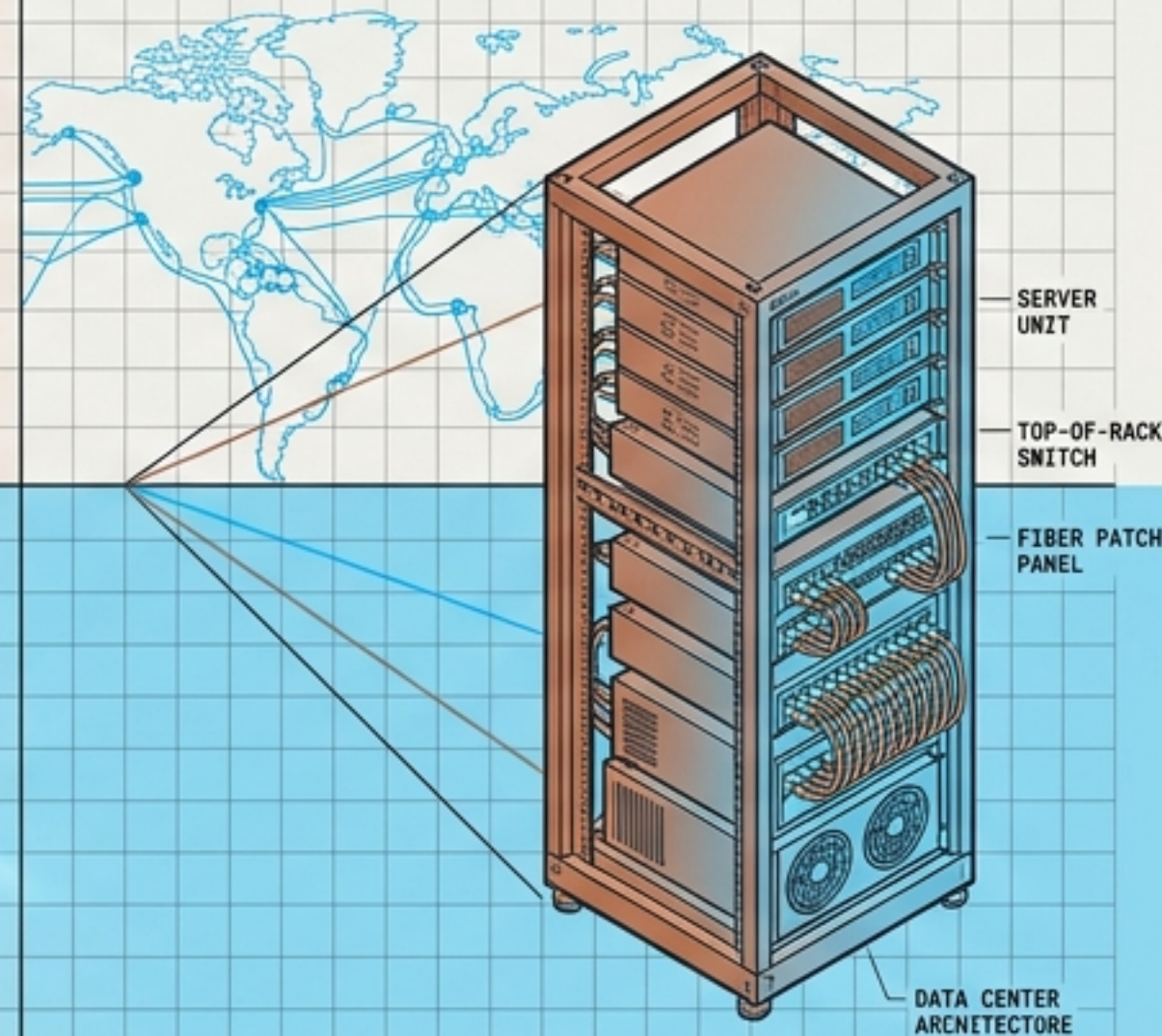
Physics dictates capacity

COPPER VS. GLASS



The Repeater Tax

LONG HAUL VS. SHORT REACH

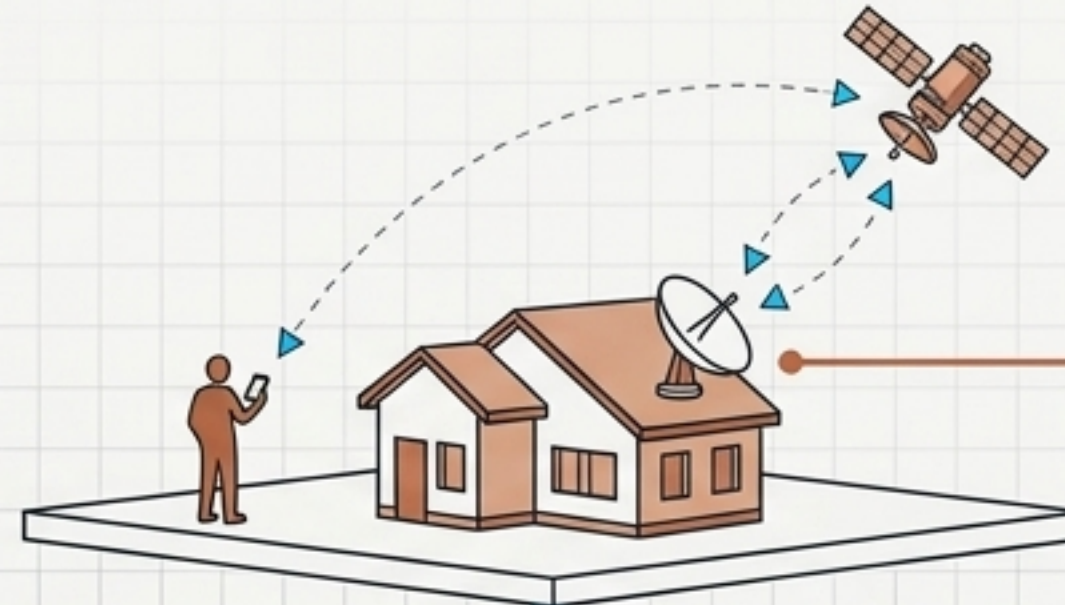


Economic convergence

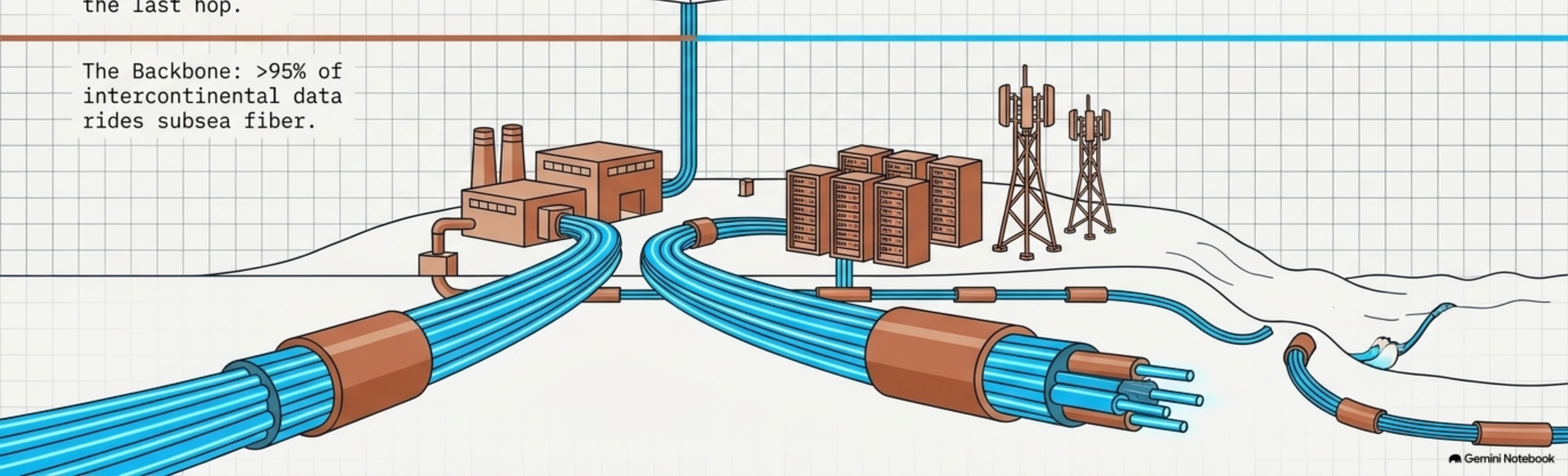
The illusion of a wireless world

The Access Edge:
Wireless covers
the last hop.

The Backbone: >95% of
intercontinental data
rides subsea fiber.



Starlink is a transceiver. It talks to a satellite, which talks to a ground station, which instantly connects to the fiber backbone. Wireless is a coverage tool, not a volume carrier.



The transatlantic scorecard settles the backbone debate

1927 (Radio)

1 circuit (\$75 for a 3-minute call)

1956
(TAT-1 Copper Cable)

36 channels (35 voice, 1 telegraph)

1962 (Satellites)

Telstar carries first live TV

1988
(TAT-8 Fiber Cable)

280 Mbit/s (40,000 simultaneous calls)

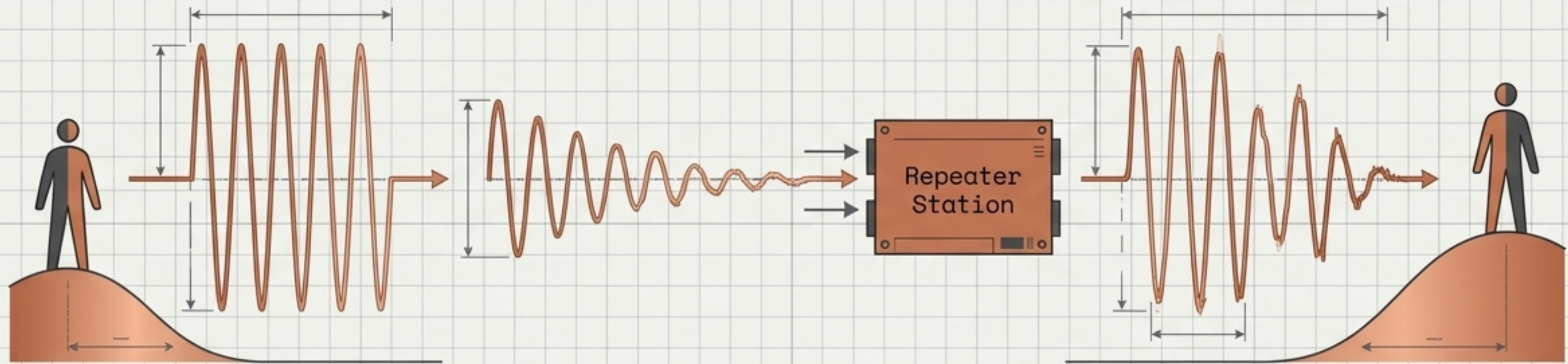
TAT-8 was a 10x capacity jump over the last copper cable (TAT-7). Satellites never took the lead back.

The Backbone vs. The Edge

		Wireless (Satellites/Radio)	Wired (Subsea/Fiber)
	Primary Role	Last-mile access	Global volume carrier
	Core Advantage	Coverage (anywhere on earth)	Capacity (virtually unlimited)
	Limiters	Spectrum scarcity, atmospheric interference	Physical trenching, installation cost
	Primary Tech	Starlink, Wi-Fi, 5G	TAT-8, WDM (Wavelength-Division Multiplexing)

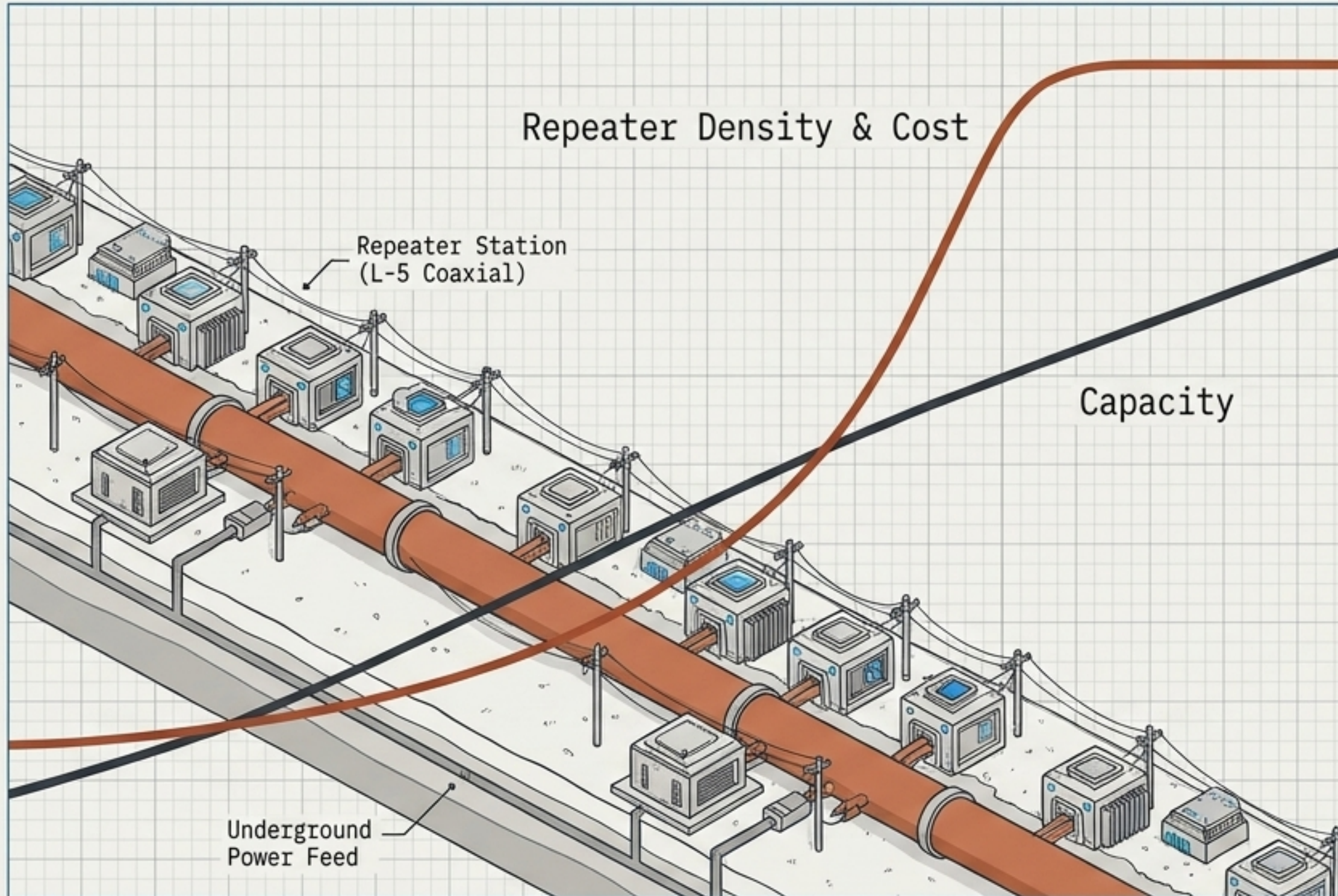
Networks optimize for reach at the edges, but physics demands glass for the heavy lifting.

Copper's disease and the repeater tax



Copper suffers from skin effect and dielectric loss. To increase capacity, you raise the frequency. But higher frequencies degrade faster. The only fix is building active repeater stations to catch, amplify, reshape, and guess the bits. Every station adds cost and error.

The economic wall of repeating electricity



By the 1970s, copper was hitting its physical ceiling.

The L-5 coaxial trunk system of 1974 required a heavily powered, maintained repeater station every 1.6 kilometers just to keep the signal alive.

Pushing more capacity meant packing stations even tighter. The road was ending.

A theory in 1966, an engineering project by 1970

1966

Dielectric-fibre surface waveguides for optical frequencies

C.K. Kao and G.A. Hockham

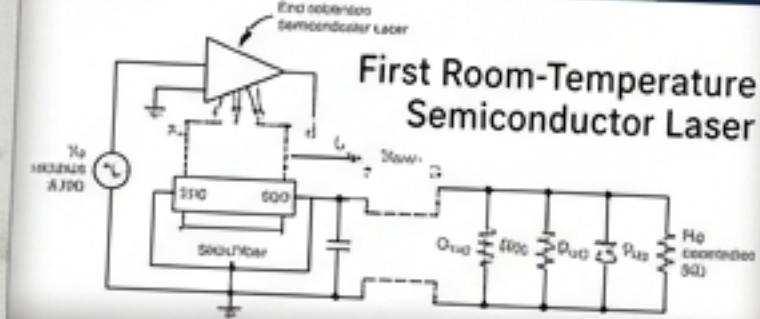
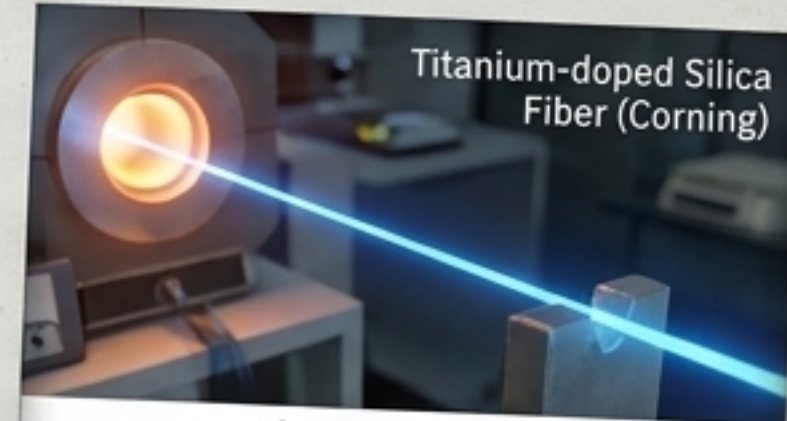
¹Department of Technology, for film optical frequencies.
Optical, University, Zaria, November 1962

A technical pleroments cover is
proposed that loss of pene
be reduced to outdoor
< 20 dB per kilometer. The r
remotaty of abarru for reduc
the glass npei the resonond

1,000 dB/km



1970

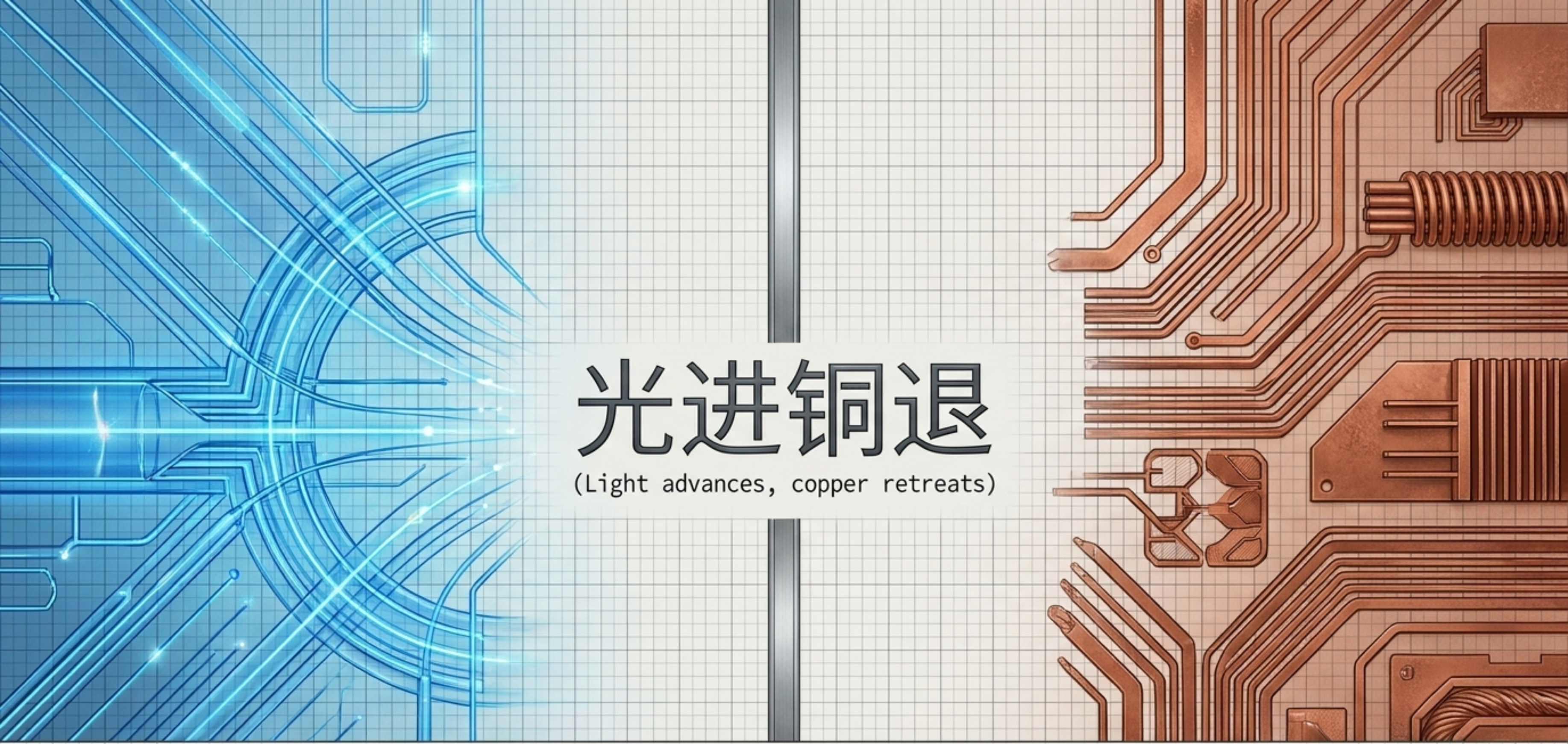


Kao's claim was filed as science fiction—glass was fifty times too lossy. Four years later, the glass thread and the lamp to shine into it arrived within months of each other. Science fiction became an engineering project.

Why light wins the long game

	Copper	Light
Metric 1: Degradation Cause	Skin effect, dielectric loss.	Virtually none.
Metric 2: Attenuation	~40 dB loss over just a few meters (224G chip-to-chip).	~20 dB loss over 100 kilometers (0.18-0.20 dB/km).
Metric 3: Bandwidth	Maxes out at 1.6T per cable over short racks.	Exponentially higher via Wavelength-Division Multiplexing (WDM).

Because decibels are logarithmic, 40 dB of loss means a hundred times less power reaches the far end compared to 20 dB. Physics wrote the outcome: no amount of manufacturing skill can make copper beat glass.

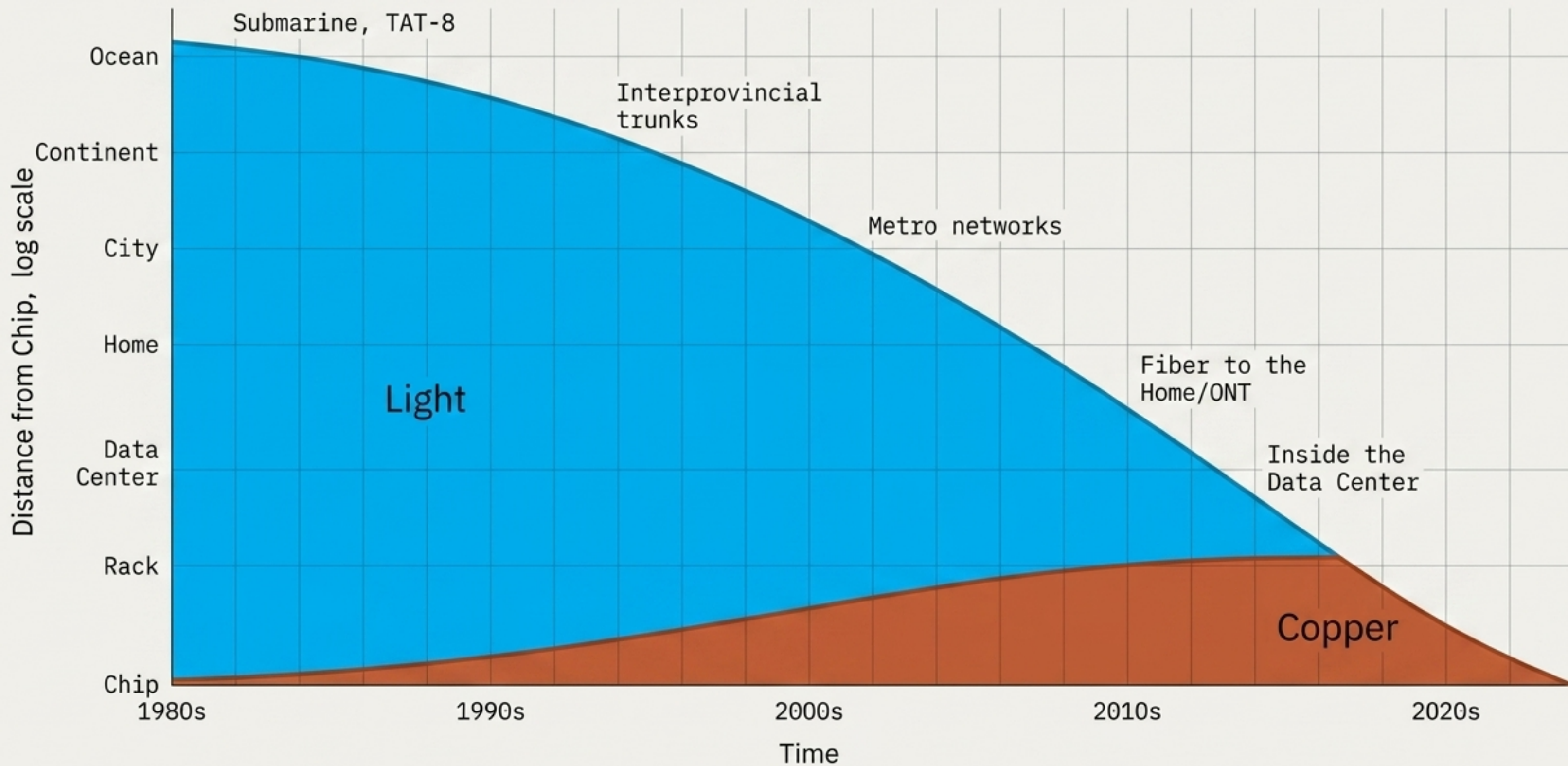


光进铜退

(Light advances, copper retreats)

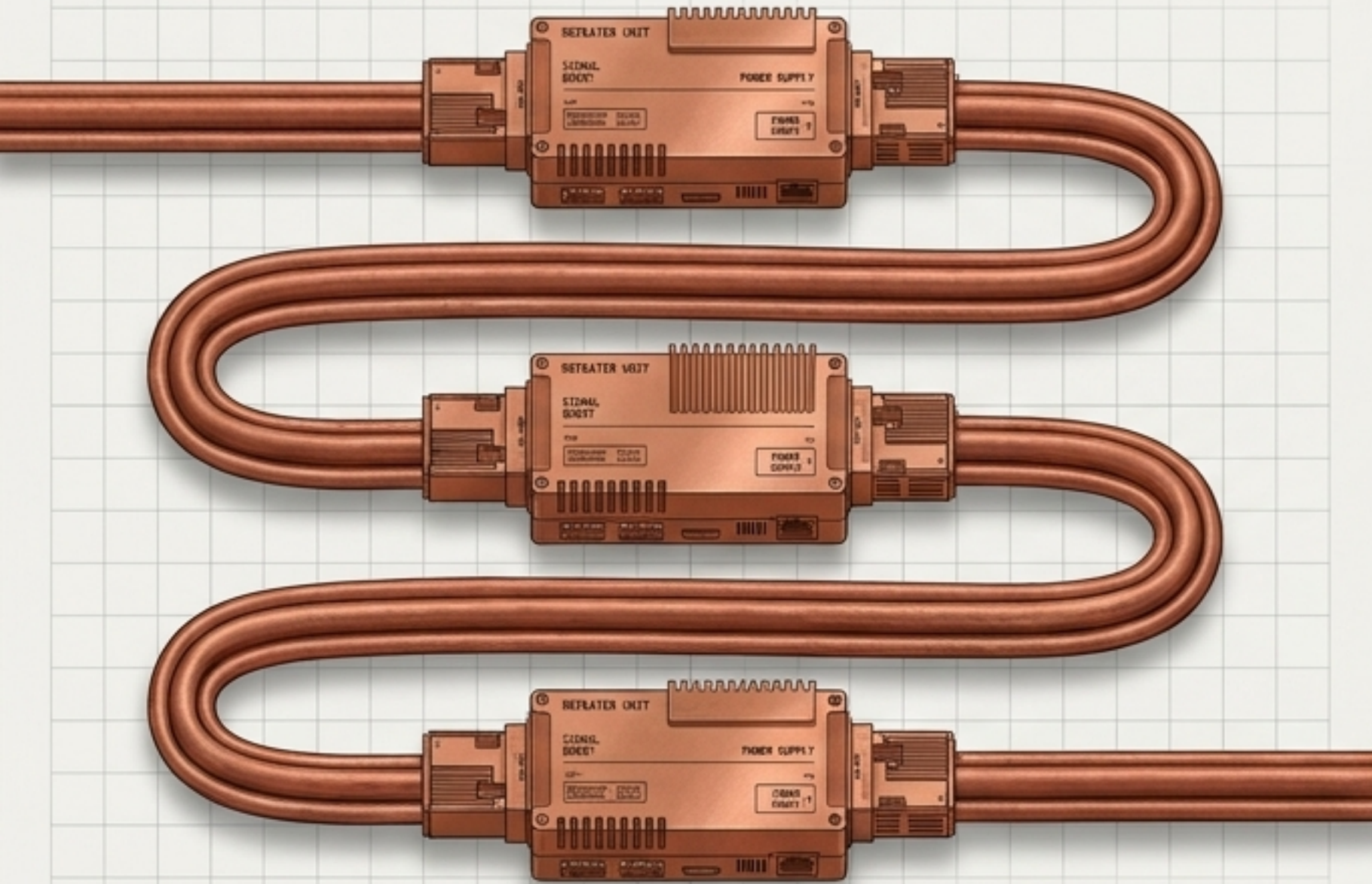
The final shift didn't swap one technology for another; it just changed their territory. Light stayed what it was, and the boundary between glass and copper relentlessly slid from the macro world toward the microscopic.

The fifty-year retreat of copper

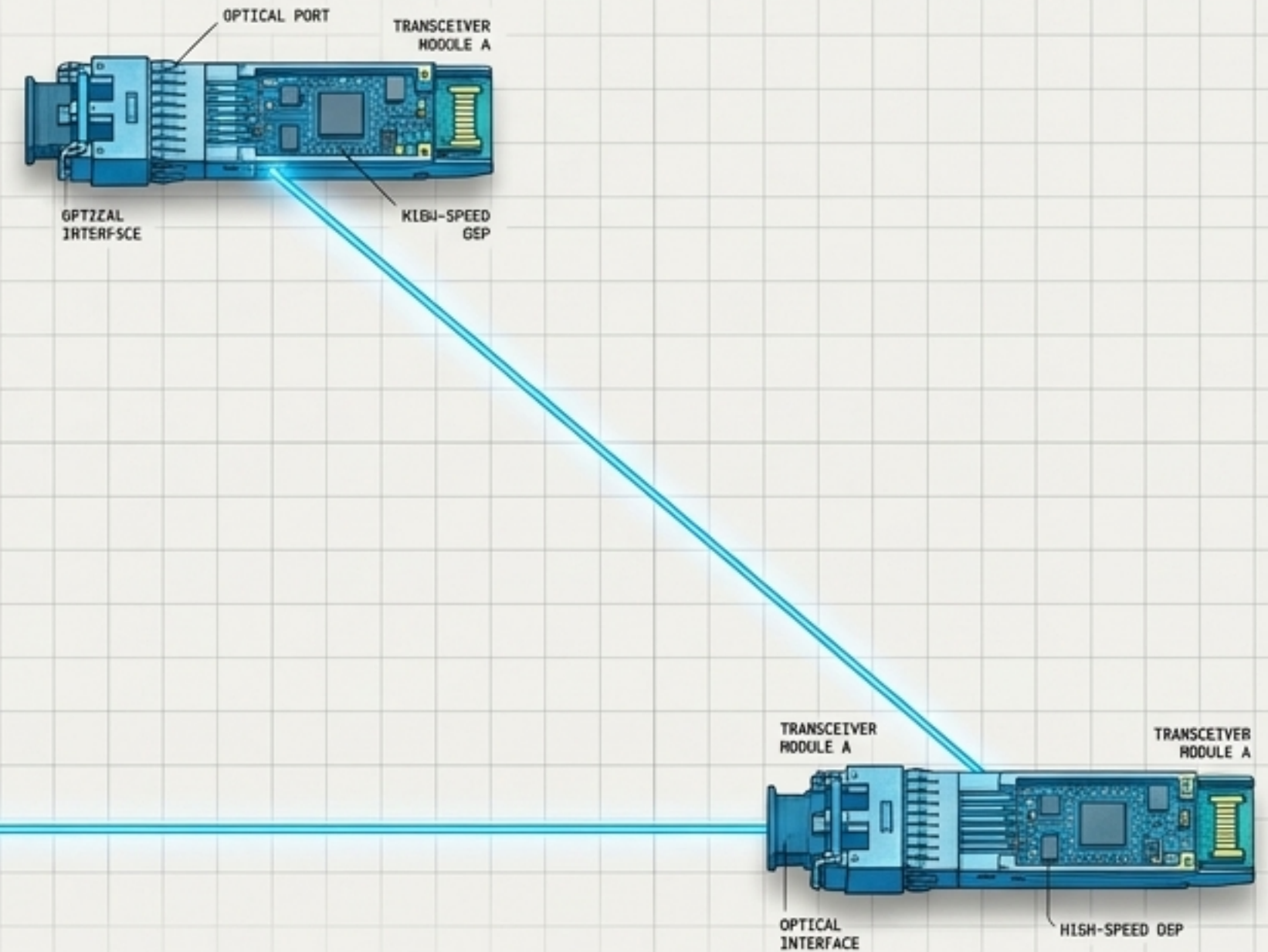


The economics of the sliding boundary

Copper pays by distance.



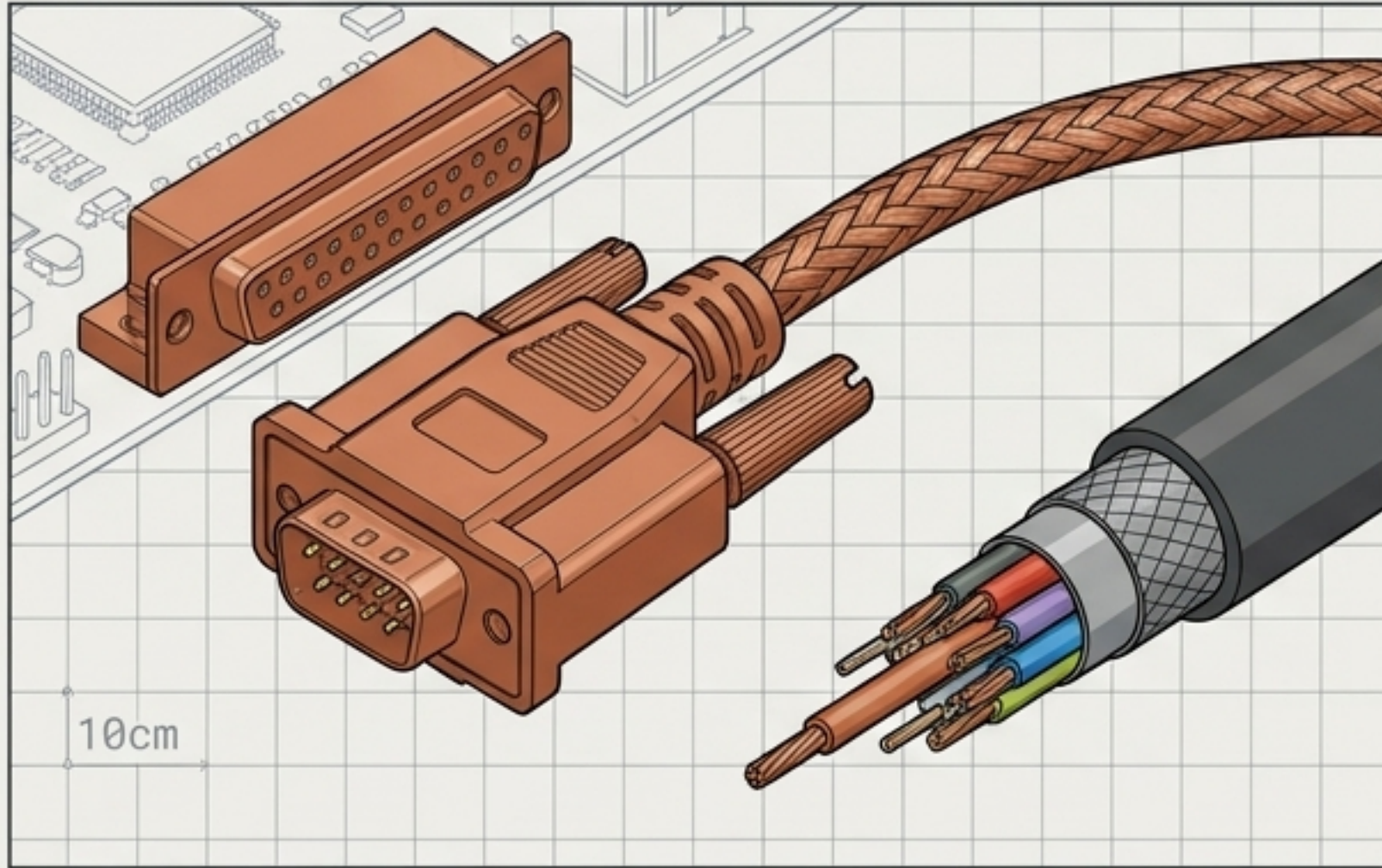
Light pays by port.



Light naturally replaces copper from the farthest links inward. As line rates double with every technology generation, copper's maximum physical reach is cut in half, forcing light to take another step inward to close the gap.

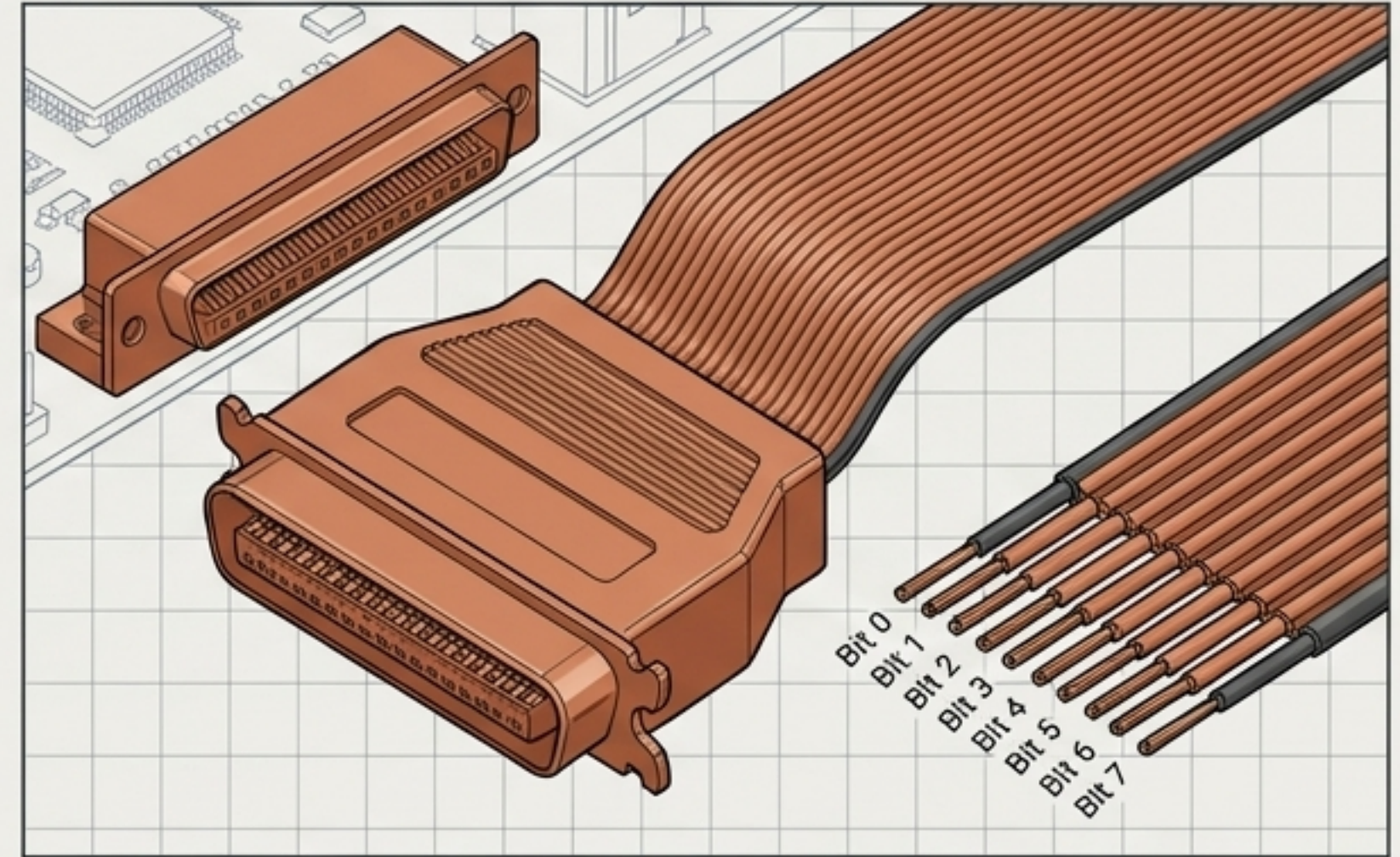
Meanwhile, computers walked the exact same road

1960s - RS-232 serial port



Single file bits, one wire.
~115 kb/s (minutes to send a photo).

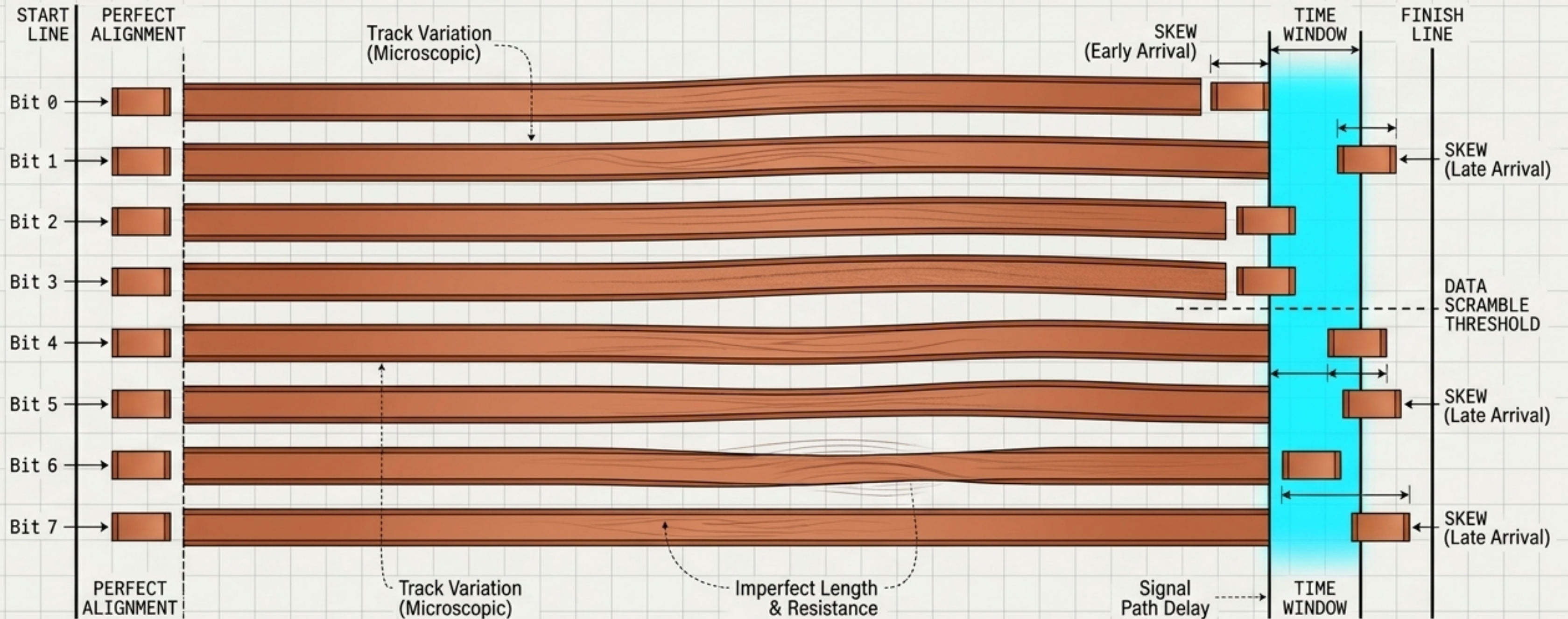
1970s - Centronics parallel printer



Parallel communication.
8 wires, 8 bits simultaneously. ~1-2 MB/s.

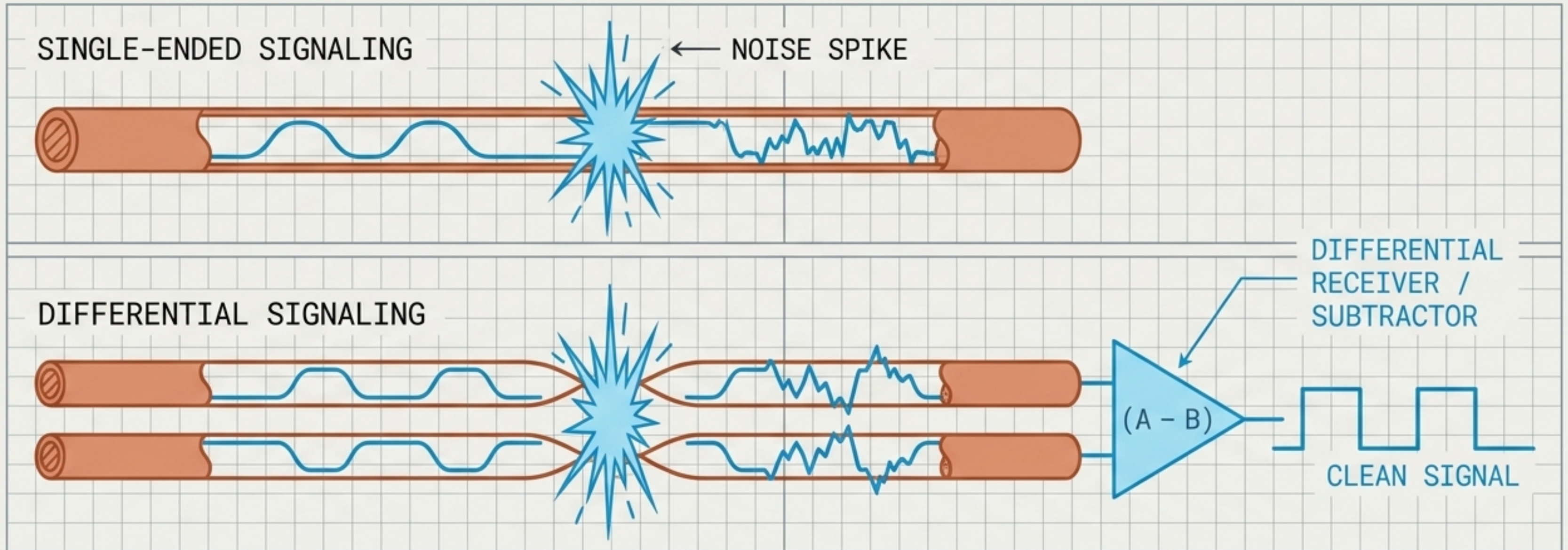
While telecom was crossing oceans, computing was connecting chips and peripherals.
The early logic was intuitive: to go faster, add more wires and send bits in parallel.

Why parallel speed broke: The Skew Problem



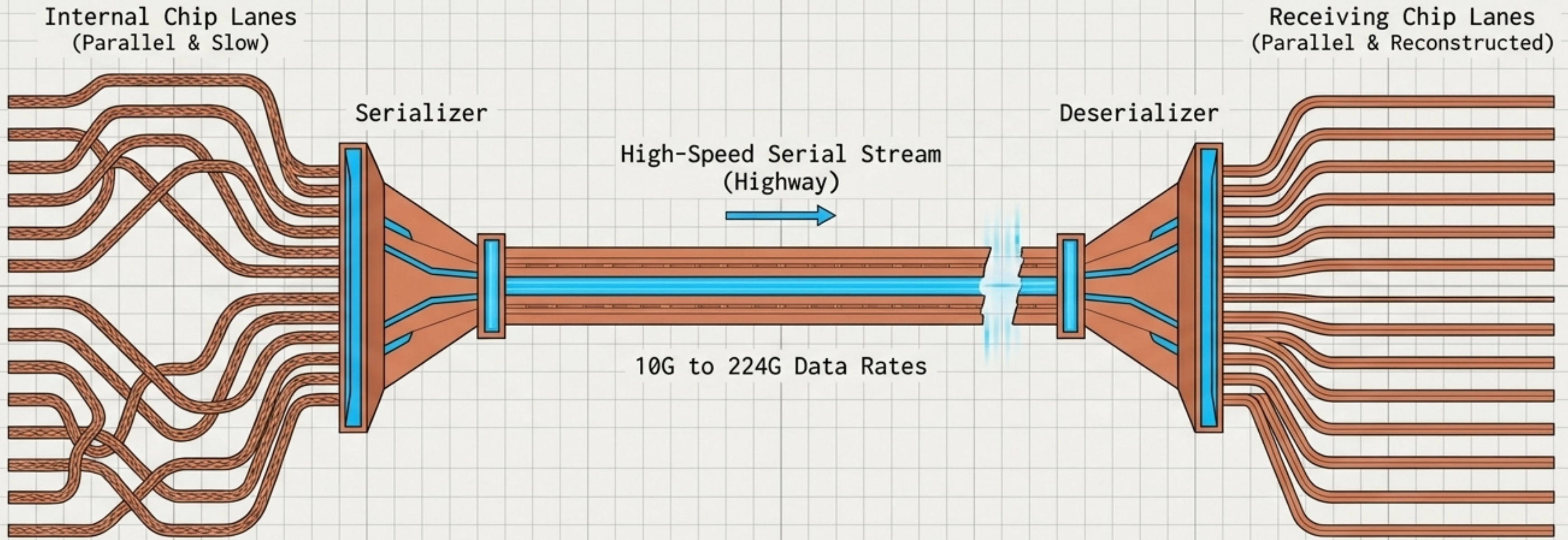
No manufacturing process can make 8 wires perfectly identical. At low speeds, the arrival difference (skew) doesn't matter. But as speeds push higher, the "time window" to read a bit becomes shorter than the lane-to-lane delay. The data word scrambles.

Pushing one pair as fast as physics allows



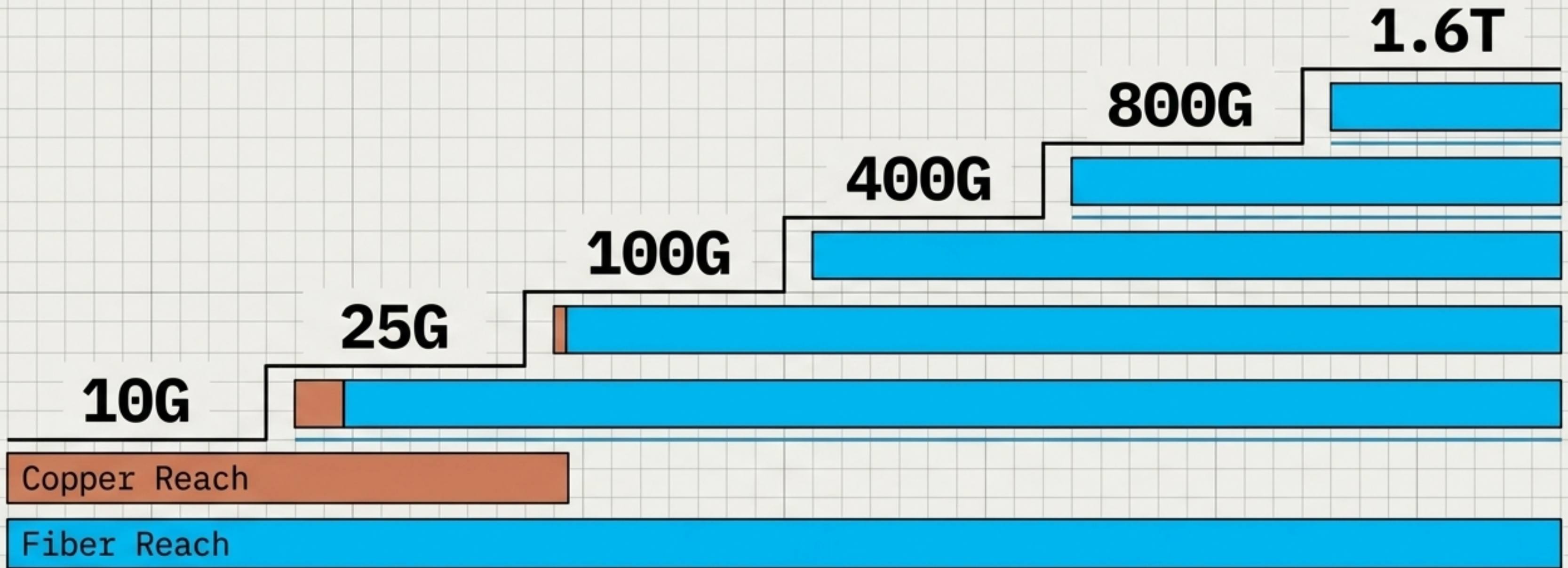
Around 2000, the industry abandoned parallel. PCIe, USB, and SATA all shifted to serial lanes using differential signaling—reading the 0 or 1 from the difference between two wires to eliminate interference. PCIe climbed from 2.5 GT/s in 2003 to 128 GT/s today on a single lane.

The SerDes Funnel



SerDes (Serializer/Deserializer) is the engine of modern speed. It packs wide parallel words into one high-speed serial stream for transmission, then unpacks it at the destination. The 10G to 224G progression is the speed of that single highway.

Ethernet bows to the same physics



10GBASE-T was the last time copper could reliably run 100 meters. From 25G upward, or past 100 meters, fiber is essentially the only medium left. The exact same physics governing printer cables and PCIe dictate the data center architecture.

The Grand Confluence

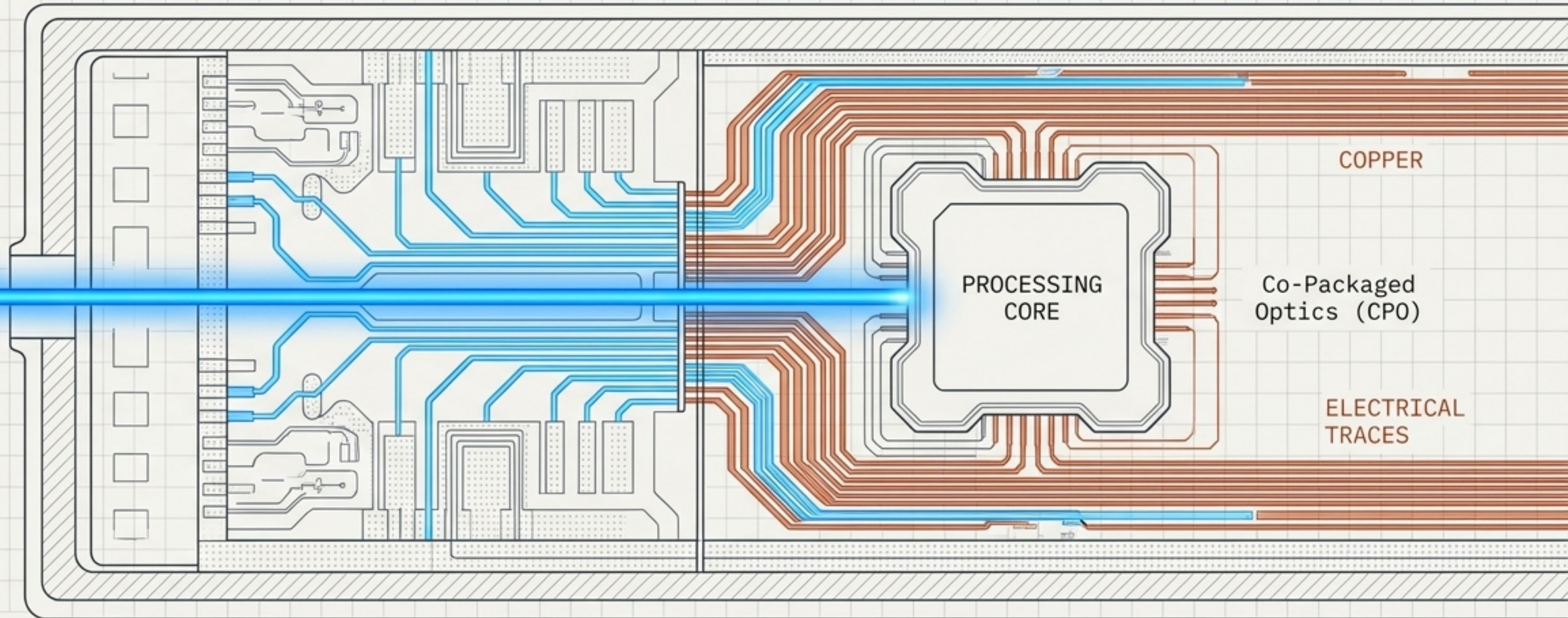
The Optical Module

Telecom's Light
(TAT-8, WDM, long-haul)

Computing's Electricity
(PCIe, SerDes, differential signaling)

Two separate rivers—one scaling down from the ocean floor, one scaling up from the motherboard—meet in the data center. The device translating between them is the optical module.

The final meter



Fifty years squeezed copper from the ocean floor to the last few meters of a rack. The next boundary isn't a cable at all—it's routing light directly into the silicon package itself. The retreat continues.