GILDER TECHNOLOGY REPORT

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Light Links and Champagne Bubbles

The most impressive optical cross-connect is called "Champagne," and comes from the test and measurement spin-off of Hewlett-Packard

As photonics emerges as the planet's most influential industry, seeping out from the glass into the **TeraBeam** air, the Telecosmic realm grows ever more fraught with the heat of the herd. Sudden buying opportunities tumble into our laps so lambently that butterfingered investors often let them slip away.

Who can blame them? Weirder and weirder becomes the world. Does it make sense, for example, that the most impressive new optical cross-connect switch is called "Champagne" and comes from the test and measurement spin-off of computer company **Hewlett-Packard** (HWP)? No more sense than the early automobile industry when leading entrants came from firms famous for such other products as the Pierce Birdcage and the Buick Bathtub. That's the way it is when an embryonic industry moves to the center of the sphere. With due apologies to all, we imagine the meeting at Hewlett-Packard that launched this strange product:

"The Next Big Thing will be optical switches," says Carly Fiorina, the new CEO, imported from ***Lucent*** *(LU) where they know about such things. "HP has to be there."*

"Gee, that's too bad," says former manufacturing titan and current chairman Richard Hackborn defensively, "we make servers and printers."

"Well, that never fazed the makers of the Buick Bathtub," shoots back Jay Keyworth, the brainy physicist director. "Are we entrepreneurs or what?"

"Don't be silly," interjects the savvy young Walt Hewlett, "you can't make an optical switch from a bathtub."

"No, but we have something better, something Lucent and ***Nortel*** *(NT) and* ***Cisco*** *(CSCO) and* ***Kohler*** *can only dream about," says Hackborn, warming to the subject….*

"A paradigm?" queries Keyworth.

"No! Better! Printers. Billions of them. If ***Texas Instruments*** *(TXN) can turn its silicon mirrors into an optical switch, we can do it with printers."*

"Yesssss!" Carly jumps in, "and they are laser printers. We're halfway there!"

"Yessssss!" shouts Walt Hewlett, suddenly inspired. "They have a laser to send the signals, a processor to handle the paper train, an organic photoconducting drum, and a lot of toner. We could make our money on the paper and the toner."

"No, no, no, Walt," chides lab scientist David Donald, a leading expert on inkjet technology. "Those laser printers are opto-electronic.

In This Issue:

The Next Big Thing is all-optical switches. We need an optical switch that is totally paper free. We have no choice but to use the inkjet printer."

"Huh!!??," says everyone at once.

"The bubbles!" Donald shouts back. We switch with the bubbles. "We could even license the name 'Champagne.' Think of the marketing angles…"

"Surely you're joking," says Carly, with a scornful stare that suggests he better be.

But a resourceful young scientist from HP's Deer Creek Laboratories, Dr. Julie Fouquet, saves the day. Breaking into song like Gigi, she intones:

The night I invented Champagne...
I began with a waveguide matrix plane.
I added fluid of the right refraction
Then I blew bubbles with inkjet action
To switch the signals that way or this
With no mirrors or MEMS to deflect or twist…

"The key," she explains, "is a tiny device to couple the inkjet to the waveguide chip. The inkjet must inject the bubbles into the narrow 15-micron wide crosspoint directly in the path of the signals. I can get Giovanni Barbarossa, just in from Lucent, to help design it. In the presence of a bubble of the right refractive index, the light undergoes total internal reflection. In the absence of a bubble it proceeds on in the same direction. And you know what the beauty of it is?"

All gaze at her with blank expressions. Finally, Hackborn asks with a weary sigh, "No, tell us. What's the beauty of it, Julie?"

"It fails gracefully," she answers.

"Yes," says Walt, "that's what Dad always says, fail gracefully. When I was running the two mile for Harvard…"

*But Fouquet is unstoppable: "Unlike micromirrors, which fail by getting stuck and skewing the entire signal, or losing it, Champagne bubbles are failsafe," she proclaims. "Champagne bubbles don't melt or seize up. The worst thing that happens is that the signal keeps going until it can be switched at some later point. We can put 32 of these waveguides in a one inch square package and they can be organized in Clos multistage arrays that can be scaled and cascaded up to 512 by 512 ports and still be virtually nonblocking. But we've got to act quickly before **Lexmark** (LXK) steals the idea."*

Carly interrupts. "You guys are nuts. The venerable name of HP is not going to be appended to any such folderol! Back to the Garage!"

"Wait!" pleads Waguih Ishak, head of the optical labs. "What about a spin-off? We could call it the Julie Fouquet InkJet Printer and Photonic Thermal Actuator and Planar Lightwave Company."

*"If it's planar, we might even be able to persuade Gerry Grinstein of **Delta Airlines** (DAL) to be our chairman. He recently retired," offers Hewlett, adding, "and he has experience with railroads as well."*

"But that Fouquet name won't work," interjects Keyworth severely. "We have to hire a PR firm and develop a jingly meaningless moniker that sounds paradigmatic. With the right name, Gilder will be a pushover. He'll endorse the company in the GTR, invite Julie to Telecosm, and we'll all get rich."

"Sounds like a plan."

Whether it is a promising plan or not depends on the all-optical paradigm. **Agilent** (A) (the name of the HP spin-off) combines some $8.3 billion of revenues from test and measurement equipment, much of it optical, semiconductors, healthcare products, and other businesses. It is coming from outside the industry and therefore can think out of the box that the telcos have created with their SONET opto-electronics. And it indeed has Delta's Grinstein as chairman….

The Lambda imperium

When the WDM (Wavelength Division Multiplexed) network was first commercially introduced in 1996, the feat of sending several wavelengths down a single fiber strand was welcome as a proof that optical bandwidth would be as bountiful as its enthusiasts claimed. But as the number of wavelengths on a fiber soared past 8, 16, and 32 to 800 already in lab tests of the **Avanex** (AVNX) PowerMux—with 3300 or more feasible in Lucent's new AllWave fiber—WDM no longer merely enhances the network. It consumes it. One of Lucent's 864-strand cables could hold 2.86 million lambdas, separately addressable in space and frequency. At 10 gigabits per second per lambda, that Lucent cable could hold 28.6 petabits—or more than 3 petabytes—per second, which is near the total Internet traffic *per month* just a couple years ago.

WDM now appears as the basis for a network that differs radically from all its opto-electronic precursors. Rendering the bandwidth-conserving economies of packet switching unnecessary, the thousands and ultimately millions of lambdas could each serve as a potential end-to-end circuit at the sole disposal of its current users. But unlike the physical wire links of the old copper cage—finite, fixed in position, essentially static in capacity, with all their flexibility provided by the switches between them—in the WDM/PowerMuxed network the links themselves are hardly material at all. They are ribbons of light appearing and disappearing on command, changing size and speed at need, perhaps, in Simon Cao's ultimate vision, hardly needing switches at all as we now understand them. The trinity of link, switch, and circuit dissolves into one substance, a fusion of logic and light, with potentials as unexpected as the new creation itself.

"Listening to the technology," the primary rule of the network becomes: *multiply lambdas*. All other apparent imperatives, especially those that seem to require electronics in the core, will inexorably yield. We will have an all-optical network not simply because we can nor because every function of the network can best be performed optically (for that is still not true) but because a WDM network cannot tolerate electronics. Electronics fatally obstruct the free proliferation of lambdas.

To put it another way, WDM is not a function in the all-optical network; rather, the requirement that the network be all-optical is a function of WDM.

For electronic devices, WDM is not a harbinger of abundance but a death sentence. In the electronic domain, every multiplied wavelength demands not merely one more waveguide or micromirror to steer it on its way. It entails another set of electronic boxes across the extent of the network, laboriously and expensively processing, converting, transponding, regenerating, reading, or routing bits, boxes whose collective cost is counted in the billions.

Nothing indicates the impending wipeout of another electronic node quite so powerfully as the chorus of proclamations that this particular electronic box finally is indispensable. For example, the SONET ring architecture that seemed imperative for network protection and restoration—and is still being extended at a cost racing toward $10 billion annually—is effectively dead because the cost of adding an entire ring of SONET boxes for every new lambda creates a choice between SONET and WDM.

Other apparent imperatives have seemed to bar the replacement of large-scale electronic switch and regenerator nodes with all-optical devices: The electronics provide apparently indispensable control and monitoring functions that cannot be duplicated optically, and the regenerators are needed anyway every few hundred miles because of the physics of dispersion and noise. But regenerators that must separately and expensively convert, clock, filter, and retransmit each lambda are doomed by a WDM regime totaling millions of lambdas. And if the regenerators fall away, the electronic switches—presently tolerated because the regenerators require a conversion to electronics anyway—are revealed as an intolerable bottleneck.

Crucial to this transforming imperium of WDM, therefore, is the emergence of Raman scattering—long dismissed as a marginally troublesome nonlinear effect—as the basis of a new, low-noise form of optical amplification over thousands of miles.

The Raman redemption

Before the invention of the Erbium Doped Fiber Amplifier (EDFA), power loss alone required the placement of electronic regenerators at intervals of less than 100 km. EDFAs, boosting signal power across much of the usable bandwidth of a fiber without electronic intervention, stretched that distance to the current 400 to 600 km, without which WDM would have been infeasible. But EDFAs have a crucial defect; boosting power in bursts at discrete locations, they not only add some noise to the signal, they also amplify the noise picked up by the transmission along the length of the fiber. Eventually the accumulated noise makes electronic regeneration unavoidable.

The trinity of link, switch, and circuit dissolves into one substance, a fusion of logic and light

Raman amplification dramatically eases the problem. A Raman amplifier, instead of pumping up the power at a discrete point in the fiber, adds power along a length of the fiber up to 60 km, with virtually no buildup of noise.

Raman amplifiers employ high-powered pump lasers to create Stimulated Raman Scattering (SRS). The Raman beam issues from a high-powered backward-facing pump source at the receive terminal that is tuned to a lower frequency than the transmission beam. Lower frequencies lose power to higher frequencies, and the pump beam gives up its power to the transmission wavelengths above it. Proportional to the pump intensity, the transferred energy from the pump field provides gains of 10 to 20 dB with up to 30 dB considered possible. Typically an optical signal can undergo a loss of about 20–30 dB before it needs to be amplified. So Raman provides significant gains.

Corning, Nortel go long

More important, because they introduce gain without adding noise, Raman amps help obviate regenerators over long stretches of the network. **Corning**'s (GLW) new composite amplifier integrates its new Lasertron Raman pump module (via its acquisition of **Oak Industries**) with its PureGain EDFA. Demonstrated at OFC as part of a system pumping a 10 Gbps signal 1800 km without regenerators, Corning believes it can stretch that distance to 3000 km. **Qtera** (Nortel) introduced its own ULTRA long-haul system at the same time. Incorporating a unique blend of Raman amplification and a form of soliton transmission, the ULTRA pumped fifty-six, 10 Gbps channels an astounding 3,600 km on the convention floor (the fiber sheaths were wrapped tightly into spools) without electronic intervention. As we go to press, **Qwest** (Q) has announced a multimillion dollar agreement with Nortel to deploy the Qtera ULTRA this quarter.

Either system could potentially save tens of millions of dollars in cost for unneeded regenerators on a single 160-channel coast-to-coast fiber link.

Also pursuing Raman is Lucent, which has not yet announced any products but demonstrated last October in Geneva a system featuring a Raman amplifier providing 23 dB of gain at 1550 nm despite using a mere 520 mW of output power. **JDS Uniphase** (JDSU), **Spectra Physics** (SPLI), **OptoCom**, **MPC**, and **Coherent** (COHR) among others are asserting their future Raman roles. **Corvis** may be using Raman in its ultra-long-haul system. But as David Huber's stealth company, with its IPO in the works, pro-

STANDARD OR NOT, TERAYON SURGES

In a crucial U.S. breakthrough for Terayon's (TERN) S-CDMA technology, Adelphia Communications, the sixth largest cable TV operator in the U.S., has announced it is deploying both Terayon's proprietary S-CDMA cable modems and its TeraJet DOCSIS standard compliant modems. Adelphia is by far the largest U.S. company to deploy S-CDMA modems.

Adelphia is using the noise defeating S-CDMA system in the Los Angeles area where it anticipates the greatest strains on its network from strong customer demand, an electronically noisy environment, and the pressure to upgrade to broadband quickly because of competition from DSL. Elsewhere the DOCSIS compliant TeraJet will serve for now.

The lesson is clear: Standards are convenient, but they won't trump customer demand if a not-yet-standard technology can meet that demand.

The S-CDMA advantage is showing in Terayon's surging revenues (Chart 1), modem shipments (Chart 2), and headend shipments (Chart 3) as the company has jumped from fourth place in cable modem market share to second (Charts 4 & 5).

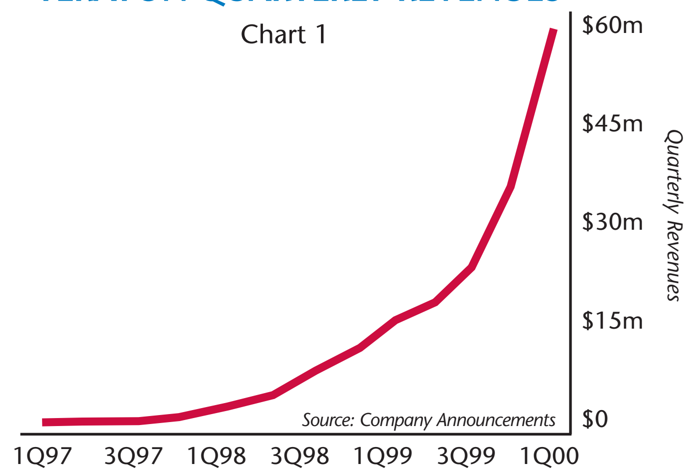
Driving Terayon's growth is the success of its network customers, who are using S-CDMA to speed and simplify the upgrade to broadband at lower cost and turning that advantage into a higher percentage of broadband subscribers among homes passed. Shaw and Rogers, Terayon's number one and two customers in 1999, have extraordinary penetration percentages, Shaw's more than doubling @Home's (Chart 6).

Ultimately, however, it may be in the crowded cities of Asia, where tightly packed apartment buildings resound with electronic noise, that Terayon has its greatest triumphs.

In the end, standards, like history, are written by the victors. GTR

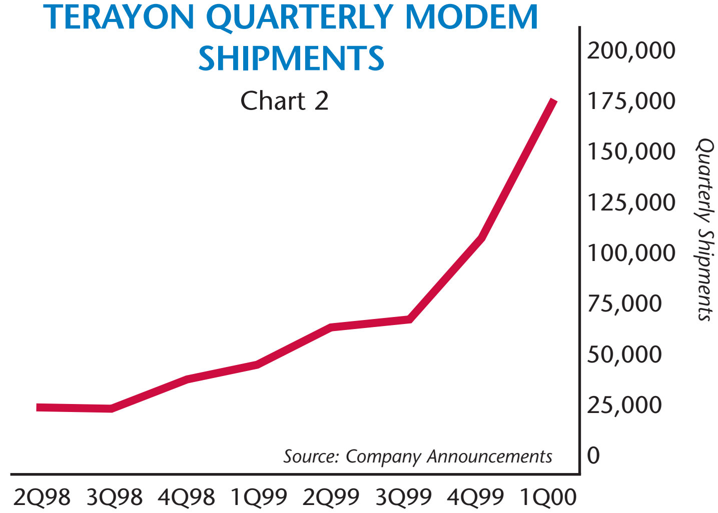
TERAYON QUARTERLY REVENUES

Chart 1



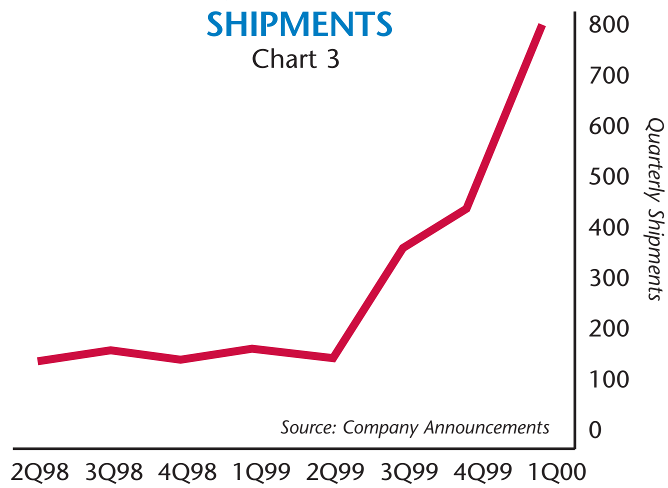
TERAYON QUARTERLY MODEM SHIPMENTS

Chart 2



TERAYON QUARTERLY HEADEND SHIPMENTS

Chart 3



TERAYON PULLS INTO 2ND PLACE

Chart 4

4Q98 CABLE MODEM MARKET SHARE

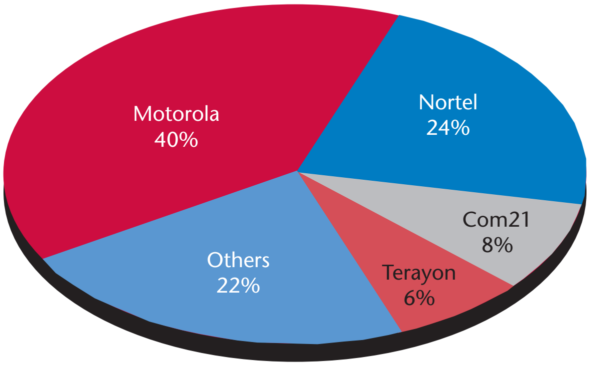
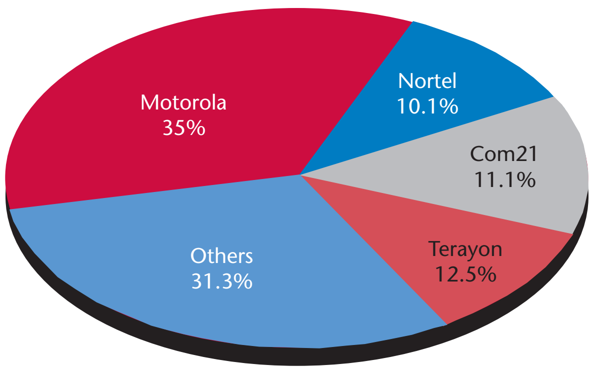


Chart 5

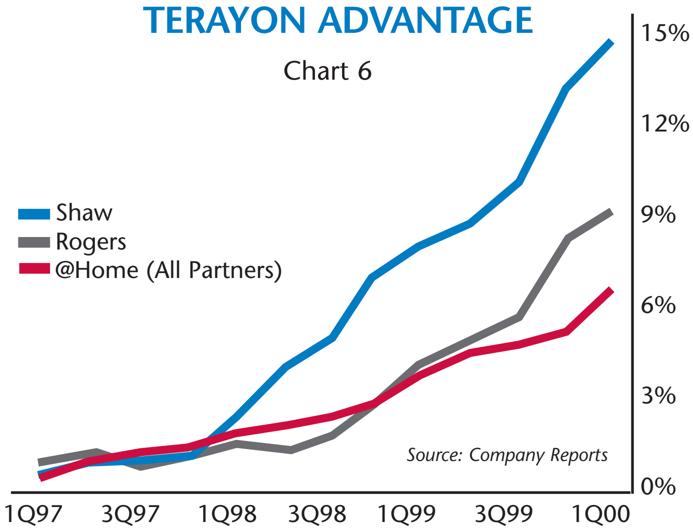
4Q99 CABLE MODEM MARKET SHARE



Source: Cahners In-Stat Group

SUPERIOR PENETRATION FIGURES FOR SHAW AND ROGERS SUGGEST TERAYON ADVANTAGE

Chart 6



gresses from merely uncommunicative to autistic it becomes harder than ever to assess with confidence.

Raman systems can be tuned to amplify any band in the transmission spectrum of optical fiber from the 1310 nanometer region up through the L-band (1560-1620 nm), including the previously unusable 1400 nm region opened up by Lucent's AllWave. By contrast, EDFAs function only in the C- (circa 1550 nm) and L-bands. Thus the entire spectrum of usable fiber frequencies, eventually comprising thousands of channels or more, can be covered by as few as four or five differently tuned Raman amplifiers.

IPG pumps power

Entailing pump lasers far more powerful than the 200-300 mW lasers used in most EDFAs today, Raman systems are coming from the same **IPG Photonics** that is providing the 5 W lasers powering TeraBeam free-space optical transmission. (See GTR, March 2000.) Using a proprietary Ytterbium-doped fiber laser, IPG founder Dr. Valentin Gapontsev has invented a complex side-pumped device with a power range from 600 mW to a fantastic 10 W and a gain of some 30 dB. Along with **SDL** (SDLI) first to market with a Raman amp, IPG is one of only two companies currently offering Telecordia (Bellcore)-rated Raman products. IPG has also introduced a commercial line of EDFAs with power output ranging up to 5 W, a nearly 10-fold increase over the previous power leader, SDL. Customers for the 40 dB gain device include **Alcatel** (ALA), **Siemens**, **NTT**, **Marconi**, Corvis, **NEC** (NIPNY), **TYCO** (TYC) Submarine, and **British Telecom** (BTY).

Like the Avanex PowerMux, the Raman revolution gains its momentum not from any uses in existing networks but from its alignment with the WDM circuit-switched paradigm. WDM is no longer *in* the network; it *is* the network. Bit rate is yesterday. Lambda count is now the defining standard. Any opto-electronic contrivance, any architectural conception that would compromise lambda creation, will be swept away.

Astarte, Xros, Lucent connect

With signals crossing the country without opto-electronic regeneration, opto-electronic switches give way. At OFC 2000 the first true all-optical cross-connects were being announced by Lucent and **Xros** (Nortel), **Astarte** and Agilent. (*Cross-connect* simply means a large switch, one that can switch many lines at once at a major intersection.) Their readiness and functionality were furiously debated by opto-electronic holdouts such as **Monterey**, **Tellium**, and **Ciena** (CIEN), each introducing new "hybrid" switches demanded by their retarded customers. But the progress of WDM, now reborn in the PowerMux, renders the debate absurd. The opto-electronic switch necessarily treats message streams as bits rather than lambdas, laboriously processing what should simply be steered, as if rivers worked not by banking the flow of the stream but by checking and sorting each H_2O molecule for its appropriate destination.

The proudest boasts of the opto-electronic enterprise betray its futility. Consider the mythical terabit router, still over the rainbow no matter how many times Cisco, **Juniper** (JNPR), or **Nexabit** (Lucent) double count the throughputs. The thousand-port version of the Xros optical cross-connect previewed at the Optical Fiber Communication Conference in March would be a 10 terabit switch even if each mirror were switching only one lambda at current 10 gig speeds. Switching 100 lambdas per mirror—its current theoretical limit before heat becomes a factor—would make it a petabit switch.

Either the Corning or Qtera system could save tens of millions on a single 160-channel fiber link

Triumphal as a petabit switch sounds, in reality, once the optical cross-connect is in place no one will quote throughput numbers anymore. Practically speaking throughput will always be 100 percent of line speed times port count. Port count will rule, which is how it should be in a network of lambda circuits.

Essentially mirrors, all-optical switches are insensitive to bit rate. Consider the mirror in your bathroom. Performing the essential task of any optical switch, it redirects an information-bearing beam of light so that you can detect nonlinearities, smears, and other interference in your otherwise immaculate countenance.

How fast does it work? Measured, say, in photons per second it always switches exactly as fast as it needs to—at line speed if you will. It sends back to you, practically speaking, as many photons as you send to it. In full darkness the line speed is zero—no photons per second—and no information is transmitted. Switch on a nightlight and our switch pokes along just enough to switch what you are transmitting, the broad outlines of your countenance, shedding detail. In daylight it is a high-speed switch, but you can pump the bit rate even higher by switching on a makeup light, risking a perhaps demoralizing information overload.

The point is, the mirror doesn't care. Short of its melting point—which varies from milliwatts for the smaller micromirrors from Lucent and Xros to many watts for Astarte and Agilent—no matter how many photons you fire at it, you get essentially all of them back. Caring not what message the photons bear, the mirror reflecting your plain white shower curtain does not have to work any harder if Laetitia Casta emerges from behind it. By contrast, a burst of Laetitia would swamp the buffers of bit-rated electronics.

Electronic switches lag in the same way. With OC-192 (10 Gbps) increasingly common in the backbone, 10 Gig Ethernet emerging, and Nortel offering the rare 80 Gbps long-haul lambda, there is still no available electronic switch that can handle more than 2.5 Gbps per channel. When a10 Gbps optical stream slams into an electronic switch fabric, not only does it have to be converted to electronics, it must be demuxed into component streams of 2.5 Gbps or even less, switched, and then remuxed at the other end. Ciena's OFC announcement that it would upgrade its CoreDirector to handle 10 Gbps later this year only drove home the point: the gap between electronic switches and optical transmission speeds is actually growing.

In a PowerMuxed world, however, speed becomes only the second biggest showstopper for opto-electronic switches. The all-optical circuit-switched network will depend on dynamically variable PowerMuxed lambdas, with customized channel sizes and line speeds. Mirrors won't care, but electronic switches are not only bit rate retarded they are bit rate specific. For opto-electronic switches, changing line speeds means swapping out every switch along the path, at massive expense, or every line card, at massive inconvenience. In a PowerMuxed, dynamic lambda, PowerShaped, Raman amplified, ultra-long haul, circuit-switched world, if you have to wait to swap out a line card before you can change bit rates, you might as well take up semaphore or smoke signals.

From mirrors to bubbles

The all-optical cross-connects previewed at OFC fell into two broad classes—mirrors and bubbles.

The new Astarte switch, developed with TI and using MEMS (Micro Electro Mechanical Systems), will be released at 576x576 ports. Gold-coated, single-crystal silicon micromirrors (6x9 mm) on a gimbal suspension are directed electromagnetically, which Astarte prefers for its linearity and precision. As in the other micromirror devices, two facing arrays of mirrors instantly direct light waves from each input fiber to any output fiber. Single stage and modular, the Astarte switch should scale to thousands of ports. **AT&T** (T) and **KDD** have done field trials with smaller versions, and Astarte expects to have the 576x576 version in commercial release by the end of the year.

Xros, founded in late 1996 to exploit MEMS technology, is likely to be the first to market with a 1000-port switch, its 1152x1152 device. Each 2x2 mm mirror can be tilted to a precision of one five-millionth of a degree. The OFC prototype displayed only a 32x32 mirror array partially loaded with 24 active ports. But, as Xros savant Rajiv Ramaswami points out, the electronic control systems for the full switch occupy only three bays, with full redundancy and one third the power compared to some fifteen bays of gear for an allegedly comparable electronic switch.

The first of the three to be announced was the Lucent LambdaRouter. Using its "MicroStar" MEMS technology, Lucent's mirrors have 500 micron diameters, truly tiny compared to their Xros or Astarte rivals. Lucent offers a 256x256 configuration in principle scalable to a thousand and beyond.

But as pumped as we were watching the three companies incite a MEMS all-optical revolution, Julie Fouquet's Champagne switch, built on two older technologies, is the real surprise. Like its micromirror counterparts, the Agilent switch is wonderfully transparent to bit rate and color, but it is built on the solid ground of inkjet and planar lightwave circuitry (PLC) technologies.

The Agilent advantage

These well-understood processes will give Agilent crucial manufacturing advantages, and speed time to market while the MEMS switches are still in the craft-guild stage. No dynamically aligned mirrors, control systems, or cleanroom boxes—just passive waveguides and mass-produced IC actuators. In addition, the elegantly simple architecture fails gracefully, passing the beam straight on to the next switching point if the bubble pops. Using a noncorrosive fluid, Agilent can switch dependably even after sitting idle for long periods.

A mesh of intersecting silica waveguides, several of the compact 32x32 switching matrices fit on a single wafer. At each intersection a trench is etched into the waveguide. The trenches are filled with a fluid of higher refractive index than free space, allowing the unguided light to pass straight through the narrow (15 micron) trench. To redirect or switch the light, the fluid is displaced by a small bubble, which is generated at the crosspoint by an inkjet technology-based thermal actuator fabricated on a separate chip bonded to the waveguide. The bubble acts like a mirror, causing light to undergo total internal reflection. A bubble can be formed and removed hundreds of times every second.

Because of the add/drop capabilities inherent in its mesh architecture, Champagne is a natural for protection switching and real-time lambda provisioning. Recognizing this advantage, Agilent has already built add/drop ports into its basic switching unit, adding 32 add and 32 drop ports, for a total of 128 ports on its 32x32 configuration.

Still the Agilent switch's modest size does present a significant if surmountable hurdle in the contest for the optical cross-connect market. Where large port counts are required, small switches must be cascaded; at each juncture signal loss accumulates. Even within a single 32x32 switch the average 5 dB (7 dB maximum) fiber-to-fiber loss of the Agilent device, though manageable, exceeds that of a 1000-port MEMS switch, roughly 2.5 dB. After cascading to a 512x512 platform, lab tests show Agilent with a maximum loss headache of 15 dB.

Agilent's customers, such as Altcatel, who are currently testing the switch, aren't worried. Preferring the simple silicon waveguide architecture to the complexity of MEMS, they assume that typical cross-connect nodes will incorporate amplifiers anyway, more than compensating for any loss from the switch itself.

Even before popping the Champagne cork, the Agilent spin-off was playing in the Telecosm as a leading manufacturer of optical test and measurement devices. The test and measure division of the company, out of which the Champagne is bubbling along with other photonic advances, accounts for 49 percent of revenues. It's semiconductor division, accounting for 21 percent, is focused on gigabit Ethernet and CDMA RF chipsets (These are FY1999 figures.) With the ingenious contrivance of the bubble switch, a solid contributor to the Telecosm becomes an exciting one as well, and we add Agilent to the Telecosm Table this issue.

Edging Cisco

Between the Avanex PowerMux, the optical cross-connect, and the continuing dramatic extension of ultra-long haul transmission without electronic regeneration, the year 2000 will be recorded as Year 1 of the true WDM network. The opto-electronic holding action, as embodied for instance in Cisco's $500 million investment in Monterey, is suddenly irrelevant and will never be a significant factor in the network. Speaking of Cisco, its SONET hardware investment, $7 billion for Cerent, may be even more fruitful than anticipated in the short term as network growth continues to outpace all expectations. But it faces an even shorter life expectancy. With the PowerMux pushing toward 3000 lambdas and beyond, all of which want to be switched all-optically, all the time, the prospect of installing a new set of half a dozen or more Cerent boxes for every new color in the rainbow, along every ring of the network, is more intolerable than ever.

Electronics must be liberated from the stultifying futility of keeping pace with the speed of light. If there are places in the network where we need 40 or 80 gig streams and beyond, the optical switch will handle them serenely. But as we waste bandwidth to multiply lambdas, bit rates may actually decrease. Where needed, we will send relatively modest message streams end to end along their own lambdas rather than cramming multiple messages on one lambda to be expensively sorted out at the other end.

Cisco's opto-electronic holding action is suddenly irrelevant

Lambda circuits are the product that customers will pay for, and "terabit" routers and switches will become classic targets of Clay Christensen's disruptive technologies model. The router market will continue to boom but be thrust to the edge, and not the cutting edge either. The lower-end machines optimized for the edge will herald not the contraction of the router market but a huge expansion of it. Built and sold in far greater numbers than today, they will be needed at the edge to handle the very flood of optical traffic that will drive them from the core of the network.

Thanks, Ken

Ken Ehrhart, our sapient research director, serene ruler of the center spread, master of the microchip market, and the most senior staffer of the GTR, present at the creation and before, is leaving us to pursue an opportunity on the Telecosm frontier. Though we are sad to see him go, the work he is pursuing is deeply exciting. We look forward to the day when we can report on its fulfillment as happily as we record our thanks for his help over the past four years.

George Gilder and Richard Vigilante
May 12, 2000

TELECOSM TECHNOLOGIES

ASCENDANT TECHNOLOGY	COMPANY (SYMBOL)	REFERENCE DATE	/ PRICE	APR '00: MONTH END	52 WEEK RANGE	MARKET CAP
WINGS OF LIGHT						
Wireless, Fiber Optic Telecom Chips, Equipment, Systems	Lucent (LU)	11/7/96	11 25/32	62 3/16	49 13/16 - 84 3/16	203.0B
Wave Division Multiplexing (WDM) Systems, Components	Ciena (CIEN)	10/9/98	8 9/16	123 5/8	22 11/16 - 189	19.3B
Wireless, Fiber Optic, Cable Equipment, Systems	Nortel (NT)	11/3/97	23	112	33 1/4 - 144 3/16	159.3B
Optical Fiber, Photonic Components	Corning (GLW)	5/1/98	40 15/16	197 1/2	47 11/16 - 226 7/16	54.9B
Wave Division Multiplexing (WDM) Components	JDS Uniphase (JDSU)	6/27/97	3 5/8	103 11/16	14 7/8 - 153 3/8	75.9B
Adaptive Photonic Processors	Avanex (AVNX)	3/31/00	151 3/4	121 7/8	47 3/8 - 273 1/2	7.6B
All-Optical Cross-Connects	Agilent (A)	4/28/00	88 5/8	88 5/8	39 13/16 - 162	40.1B
THE LONGEST MILE						
Cable Modem Chipsets	Broadcom (BRCM)	4/17/98	6 *	172 3/8	37 5/16 - 253	38.1B
S-CDMA Cable Modems	Terayon (TERN)	12/3/98	31 5/8	93	26 3/8 - 285 1/4	3.2B
Linear CDMA Power Amplifiers, Cable Modems	Conexant (CNXT)	3/31/99	13 27/32	59 7/8	17 - 132 1/2	12.5B
THE TETHERLESS TELECOSM						
Satellite Technology	Loral (LOR)	7/30/99	18 7/8	9 13/16	7 9/16 - 25 3/4	2.5B
Low Earth Orbit Satellite (LEOS) Wireless Transmission	Globalstar (GSTRF)	8/29/96	11 7/8	11 3/4	7 7/8 - 53 3/4	1.4B
Code Division Multiple Access (CDMA) Chips, Phones	Qualcomm (QCOM)	7/19/96	4 3/4	108 7/16	21 1/2 - 200	82.0B
Nationwide CDMA Wireless Network	Sprint (PCS)	12/3/98	7 3/16	55	20 3/4 - 66 15/16	50.5B
CDMA Handsets and Broadband Innovations	Motorola (MOT)	2/29/00	172	119	76 3/16 - 184 5/8	88.2B
THE GLOBAL NETWORK						
Broadband Fiber Network	Level 3 (LVLT)	4/3/98	31 1/4	89	45 1/4 - 132 1/4	32.9B
Broadband Fiber Network	Metromedia (MFNX)	9/30/99	12 1/4 †	30 7/8	10 9/16 - 51 7/8	17.1B
Submarine Fiber Optic Network	Global Crossing (GBLX)	10/30/98	14 13/16	31 1/2	20 1/4 - 64 1/4	26.3B
Broadband Fiber Network	Northeast Optic (NOPT)	6/30/99	15 1/16	56	14 - 159	945M
Telecommunications Networks, Internet Access	WorldCom (WCOM)	8/29/97	19 61/64	45 7/16	37 3/4 - 64 1/2	133.3B
CACHE AND CARRY						
Directory, Network Storage	Novell (NOVL)	11/30/99	19 1/2	19 5/8	16 1/16 - 44 9/16	6.4B
Java Programming Language, Internet Servers	Sun Microsystems (SUNW)	8/13/96	13 3/4	91 15/16	26 15/16 - 106 3/4	160.7B
Network Storage and Caching Solutions	Mirror Image (XLA)	1/31/00	29 †	87 1/2	3/4 - 112 1/2	2.6B
THE MICROCOSM						
Analog, Digital, and Mixed Signal Processors	Analog Devices (ADI)	7/31/97	11 3/16	76 13/16	17 1/2 - 94 11/16	28.1B
Silicon Germanium (SiGe) Based Photonic Devices	Applied Micro Circuits (AMCC)	7/31/98	5 43/64	128 7/8	12 3/16 - 158 7/8	15.9B
Programming Logic, SiGe, Single-Chip Systems	Atmel (ATML)	4/3/98	8 27/32	48 15/16	8 1/2 - 61 3/8	11.2B
Digital Video Codes	C-Cube (CUBE)	4/25/97	23	64 1/4	22 1/8 - 106 1/4	2.7B
Single-Chip ASIC Systems, CDMA Chip Sets	LSI Logic (LSI)	7/31/97	31 1/2	61 7/8	16 11/16 - 90 3/8	19.5B
Single-Chip Systems, Silicon Germanium (SiGe) Chips	National Semiconductor (NSM)	7/31/97	31 1/2	60 1/2	12 1/4 - 85 15/16	11.0B
Analog, Digital, and Mixed Signal Processors, Micromirrors	Texas Instruments (TXN)	11/7/96	11 7/8	162 7/8	50 1/8 - 199 9/16	133.3B
Field Programmable Gate Arrays (FPGAs)	Xilinx (XLNX)	10/25/96	8 7/32	73 1/4	19 1/2 - 88 7/16	23.6B

Added to the Table: Agilent (A)

* INITIAL PUBLIC OFFERING
† SPLIT ADJUSTED THIS ISSUE

NOTE: The Telecosm Table is not a model portfolio. It is a list of technologies in the Gilder Paradigm and of companies that lead in their application. Companies appear on this list only for their technology leadership, without consideration of their current share price or the appropriate timing of an investment decision. The presence of a company on the list is not a recommendation to buy shares at the current price. Reference Price is the company's closing share price on the Reference Date, the day the company was added to the table, typically the last trading day of the month prior to publication. Mr. Gilder and other GTR staff may hold positions in some or all of the stocks listed.

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