GILDER TECHNOLOGY REPORT

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The Death of the EDFA?

At OFC, the all-optical network emerged at last from the vapors and assumed the imperious reality of thousands of arduously designed and manufactured systems

"Seven *Watts* of power from a single microchip laser?" Enough to send some 500 separate bitstreams down 3000 kilometers of fiber. Enough to power a palmtop or a floating Coleman lantern. Enough to light a Christmas tree of ideas at an optical conference.

Charlie Burger, our doughty optical analyst, has seen (or read about) almost everything in the current world of optics. He survived kidnapping by **BlueArc** (*GTR*, Feb. 2001), power lasers from SDL (now **JDS Uniphase**-JDSU), and mind-bending adulterations of English in conference technical sessions with more acronyms than words. But he was aghast at the claims uttered seconds earlier by Chunie Ghosh, CEO of **Princeton Optronics**.

Talking to Charlie at a well-used table in the press room at OFC 2001, Chunie limned out his power trip as a 25-year veteran of radio frequency (RF) and optoelectronic engineering, including a stint as lab director at Sarnoff Labs. He knows his stuff and confirmed the seven watts. Then he added a further whopper. Chunie claimed to have achieved these seven watts from the exquisitely marshaled micromirrors of a vertical cavity surface emitting laser (a VCSEL or "vixel" for short). Though cooler to run and easier to make and use than the established edge emitters, VCSELs are inherently low power devices. They offer fractions of milliwatts, as in **Bandwidth9**'s 0.45 mW tunable VCSEL, barely enough photons to transmit in the LAN (local area network), and a dint far too dim to light up a stock during mud season.

Speechless for the moment, Charlie continued to stare at Chunie. Our man was trying to hold his own in the closing hour of the IEEE's yearly optics gala. But after three days of probing the mysteries of photons while buffeted by 38,000 conference gawkers (double last year's record total), Charlie's batteries were running down. Perhaps this guy from Princeton Optronics was missing a decimal point in his arithmetic processor or **Agilent** (A) Time Domain Reflectometer.

Charlie reasoned that it has taken **CoreTek** (**Nortel** -NT) five years to push the power envelope in its tunable VCSEL to 20 milliwatts (enough to transmit one lambda wavelength bitstream) using an external optical pump. Princeton was claiming to emit a non-tunable seven watts without outside pumps of any kind. Then, evoking a flicker of life in his brain, Charlie recalled CoreTek guru Parviz Tayebati declaring to him only two days earlier, "Power is going to be a commodity in the Telecosm."

In This Issue:

Who are these guys? What do they mean? The Telecosm is supposed to be an era when power becomes scarce again and power budgets constrain the solutions of technology.

Charlie's mind spins. If you know Charlie, this is a perilously high torque event. You want to get out of the way of rapidly rotating sharp synaptic cutlery, fast lifted heavy weights, and other steel trappings. He slaps his forehead with the palm of his hand, as if the steel trap had caught some furry or efflorescent object. Could **Novalux**, another company making startling power claims for VCSELs, be more than the Sand Hill hot air he originally thought? As Charlie makes a quick note to read their postdeadline paper, he begins to contemplate the huge implications for the Telecosm. *Power glut,* anyone?

Conjure a glut, and you're in vogue. Bandwidth glut … fiber glut … inventory glut …zag and streak through the Telecosm like storms on the Weather Channel. Dare we at the *GTR* join the peddlers of polyglut? How about *innovation glut?*

Companies that excel at multiplying lambdas and moving tunability to the network edges, at the expense of bandwidth, will reap large rewards

Such a perverse idea enticed us as we concluded three days of trolling the exhibit floor of OFC 2001, embedded in Anaheim's Disney moonscape. Winding our way from booth to booth, each succeeding display seemed more promising, answering the challenges of the previous solution while producing another set of challenges—which were duly solved at the next booth. The resulting "information glut" could have drowned even the stoutest analyst in a sea of technology detail.

Stark was the contrast with OFC 2000, when MEMS photonic crossconnects were the rage until one learned that the prototypes were still glued to the laboratory floor, when seemingly exotic photonic components enticed, until they vanished into vaporware. Anaheim may long be remembered as the coming out party for a dense wave of optical innovations, many already in customer test beds and imminently commercial. But how could such intense innovation flourish during the year of The Great Nasdaq Crash? Are we dreaming?

Corning's glass cathedral

The story runs back five years, a typical incubation period for many technical novelties. **Ciena** (CIEN) broke open the paradigm in 1996 by commercializing WDM, and high-stakes venture capital poured in. Only now emerging from stealth, a resulting spate of innovation is rising behind the dams of a dormant economy.

At the end of the long OFC day, marketing sirens begin to beckon like bargirls unless you have the paradigm. Carver Mead taught us to listen to the technology, but in listening to the technology, you cannot master every detail. Paradigms—broad models of change—convey the crucial signals of opportunity.

Each major economic era is marked by key abundances and scarcities. Successful innovators exploit the abundances within a set of constraints defined by the shortages. In fiber optics, the prevailing abundance of the telecosmic era is bandwidth, with 50 THz (trillion Hertz) on a single thread of glass in the transmission window of **Lucent**'s (LU) Allwave fiber or **Corning**'s (GLW) new artfully named 28-SMFe (single mode fiber extended). The prevailing scarcity is connectivity. The tool to redress it is lambdas, the separate wavelengths that can convey information on and off a fiber line. By multiplying lambdas at the expense of possible backbone bit rates, the leaders waste bandwidth, which is in glut, in order to expand broadband connectivity, which is the canonical scarcity of the Internet economy.

In 1949, Claude Shannon, the inventor of information theory, showed us that bandwidth is a replacement for switches. With enough bandwidth, communications engineers can simulate any switched network topology. The enabling all-optical architecture is wavelength division multiplexing (WDM—transmitting multiple signals concurrently through a single fiber strand). Taking more bandwidth per bit than time division multiplexing (TDM—slicing signals into time packets), WDM drives switching and software complexity to the network edge. Software (the 60 millions of lines of code in a telephone central switch) hardens into the glass mirrors of fiber optics at the center. Hardware (the hardwired telephones and PBXs on the edge) softens into digital programmable logic in storewidth computers and adaptable appliances at the edge. As channel counts increase, permanent circuits of WDM wavelengths, or lambdas, will often lie fallow or run below capacity to facilitate connectivity.

Switching WDM channels gets it backward, conserving "scarce" bandwidth at the expense of lambdas. Switching assumes the need to redirect channels as traffic patterns change, efficiently shifting lambdas from low use connections to those undergoing higher use. The Law of the Telecosm tells us otherwise: The companies that excel at multiplying lambdas and moving tunability to the network edges—at the expense of bandwidth—will reap large rewards.

Simon Cao of **Avanex** (AVNX) understood this principle early on. The harvest was Avanex's can-do OFC demo of a hardened WDM metro core network tuned at the edge to fixed lambda circuits. Enabling the system is Avanex's elegant multiplexing technology, the PowerMux, which fuses up to a thousand wavelengths into a single stream on one end and separates them to be sent to their destinations at the other. This device will drive the cost of marginal lambdas to $100 and below. Connecting the signals to the fiber is one of the industry's first dynamic transmitter cards, which locks a tunable laser to the correct lambda for connectivity. Moving wavelengths on and off the fiber network is the PowerExchanger all-optical add-drop multiplexer (OADM), which enables lambda connections by setting up "on-off ramps" of channels between the metro and access network. Keeping all the signals readably clean is the PowerShaper, a critical wave-shaping technology that mitigates fiber distortions.

Corvis, Chorum claim Cao's law

Standing alone, Avanex's demo might have seemed simply an isolated hero stunt. But the paradigm marches on. Initially vindicated by **Chorum Technologies**, Simon's vision seemed to pervade the conference and manifested itself at almost every turn as we crisscrossed OFC. Highlighted in the January *GTR*, Chorum's interleaver (a multiplexer which separates and combines alternate "odd-even" lambdas) uses liquid crystals to manipulate the polarization state of light. Like Avanex's PowerMux, the Chorum interleaver will enable placement of thousands of WDM channels on a single fiber thread.

The alleged showstopper faced by these technologies is dynamic range or power variation. As those thousands of lambdas traverse the Internet, optically amplified and add-dropped at multiple nodes, the power among channels may come to vary markedly with time at any point in the network. Such power variations can create crippling non-linearities and other distortions. At OFC, following the inspiration of Avanex's PowerAttenuator, Chorum introduced a new line of polarization-based optical processors which balance power among WDM channels.

Also on display was Chorum's liquid-crystal (LC) switch, dynamically shuffling up to 80 lambdas from any input fiber to any two output fibers without the aid of a multiplexer. Called PolarWave, the device fulfills the hardened network architecture envisioned by Chorum's J. Y. Liu and Kuangyi Wu, in which multiple wavelengths are banded together based on destination. With no moving parts, these relatively small switches may eventually direct tens of thousands of lambdas at the largest backbone nodes, obviating the massive MEMS cross-connects under development by **Calient** and **Xros** (Nortel).

Corning's own 80-channel liquid crystal switch was thought to be a natural for the smaller metro networks, as optical communications president Wendell Weeks pointed out to us in one of Corning's many meeting rooms at the company's imposing OFC booth complex. Then he smiled as he told us that almost all sales to date have been to backbone networks. The result would not have surprised **Corvis** (CORV), whose own relatively small all-optical switch handles **Broadwing**'s (BRW) ultra-long-haul network at 160 channels per fiber, upgradeable to 320 channels.

"Why do we need large crossconnects?" Corvis asks us in Anaheim. Bandwidth is advancing in cost effectiveness 40 times faster than software, a key component of any large switch. When we transmit from San Francisco to the Northeast, we know that a large group of channels will always connect to Washington, another group to New York, and still another to Boston. In the face of increasing lambda counts, such traffic patterns will require little switching.

After surveying OFC for a day and a half, **ONI**'s (ONIS) sage Rohit Sharma had already picked up on the trend—ever smaller switches along with all-optical add-drops and ubiquitous amplification. Also gaining hold, he tells us, is the waveband technology touted by Chorum and incorporated by Corvis. **LightChip** is onto it.

Though not scalable to very high channel counts due to the need for an on-chip fiber connection for every channel. LightChip's proprietary diffraction grating technology today multiplexes up to 40 coarse WDM channels per fiber. Based on robust free-space optics natural to manipulating photons, LightChip's all-optical add-drop multiplexer stands to make significant inroads into smaller capital-conscious networks. Its *manual* configurability, which results in a very simple and therefore low-cost architecture, becomes a benefit in a hardened core that requires only slow switching, chiefly for circuit provisioning.

With Lucent selling off its paradigmatic technologies and gushing talent, Nortel's old product line may prosper for awhile

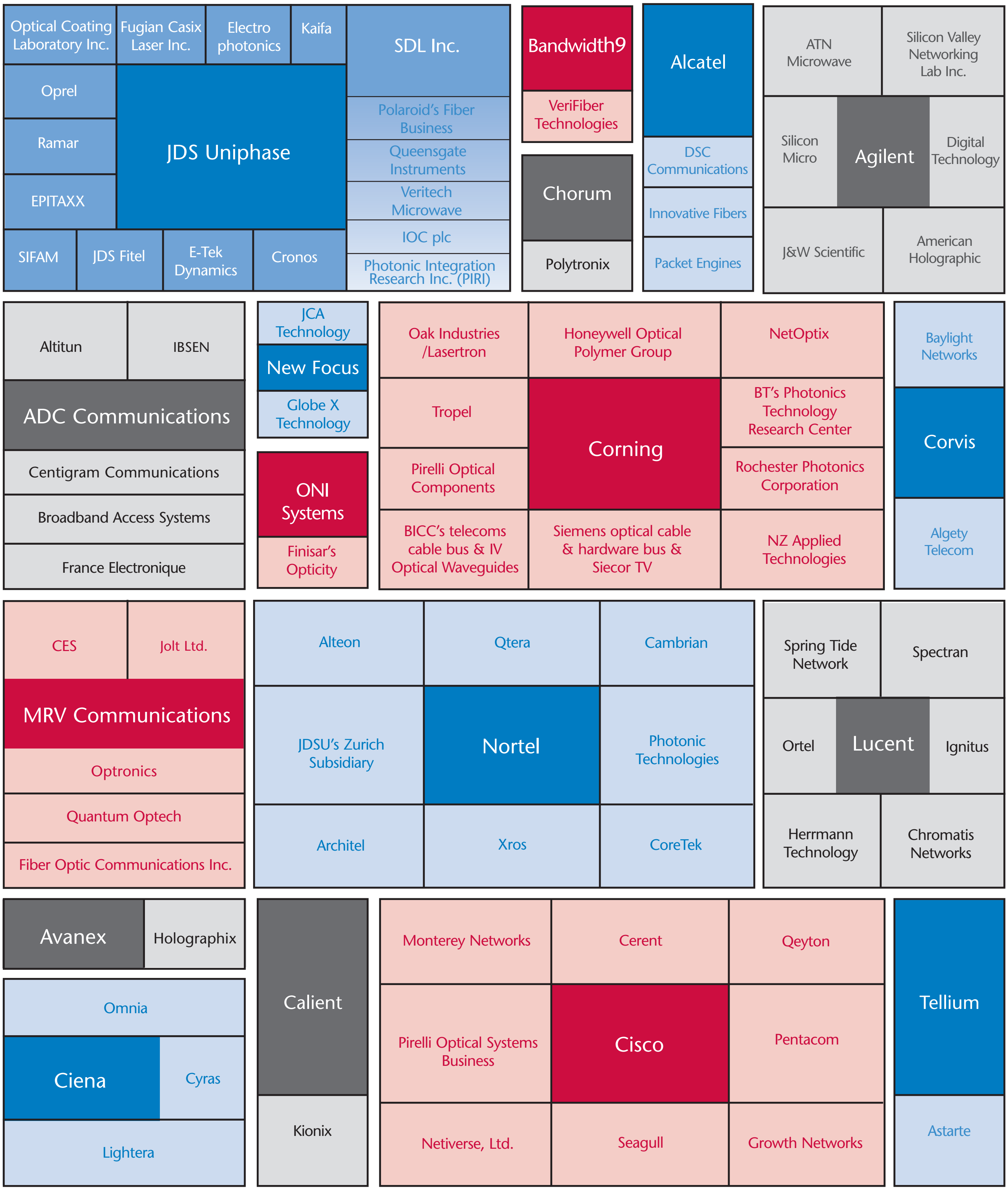
Corning's own configurable add-drop, which mixes and matches up to 80 channels, gave **Marconi** (MONI) the winning edge in a deal with **British Telecom** (**BTY**). That was last May. Since that early success, the liquid-crystal device has been slow to catch on until now. The networks were too dull for Corning's cutting edge. Today, however, the all optical philosophy is catching on across the fibersphere.

Nortel and Lucent, paradigm pared

In the midst of this paradigm party, Avanex still holds the winning technology for multiplying, manipulating, and shaping lambdas and light pulses. But the field is growing. Chorum, **Southampton Photonics**, and **WaveSplitter** can duplicate Avanex's winning channel shape, which accommodates dense lambda spacings. With free-space optics, however, Simon Cao's technology scales more easily and cost-effectively, a major advantage. Simon not only understood the paradigm ahead of the field, but he also understood that classical optics manipulates light best. The result is that Avanex now leads in product as well as in vision.

Pared by the paradigm are the purveyors of bit rate. No doubt the move to 40 Gbps and eventually to 80 Gbps is technologically feasible. But at 40 gigs channels must be spaced 50 GHz apart on the electromagnetic spectrum. At 80 gigs the minimum spacing increases to 100 GHz, holding maximum channel-count to the low hundreds, thereby limiting lambdas while conserving abundant bandwidth by crowding more bits per second into each channel. The bitrate model bets on Moore's Law over Cao's Law while facing daunting connectivity, switching, and transmission challenges.

OPTICS ACQUISITIONS



Yet this is the model that Nortel hopes will turn its faltering company around. The strategy will fail. As the world leader in SONET equipment sales, Nortel has spent its most productive years learning how to better conserve bandwidth. For them, TDM is a sustaining technology, WDM disruptive. To Nortel, in the grip of the old paradigm, the new one seems delusory. History teaches us, however, that with the advent of a new paradigm, the old one eventually shrinks into triviality. With Lucent selling off its paradigmatic technologies and gushing talent, Nortel's old product line may prosper for awhile. But both companies leave the list.

Nortel's one continuing paradigm play is CoreTek's tunable VCSEL technology. But even there, the light may be dimming, which brings us back to perhaps the biggest story at OFC and the fount of the Telecosm—power. Intrinsically scarce in long distance optics, more available power can enhance connectivity and obviate expensive amplifiers and regenerators.

JDSU banks on the EDFA

Although fiber attenuation over long distances is one thousand times less than copper's, electronic signals can "fan out" on a chip through virtually loss-less voltage dividers. Split light, by contrast, is inherently lossy. Beginning with signal launch power—which determines how far lightwaves can traverse fiber before they become too weak to read—light pulses lose photons every time they are split, tapped, reflected, coupled, shifted, until no photons remain. The erbium-doped fiber amplifier (EDFA) solves this problem. First conceived at American Optical by Elias Snitzer in 1971, it was elaborated for British Telecom at Southampton University in England by David Payne and Simon Poole in 1986, and prototyped successfully by Randy Giles and Emmanuel Desurvire at Bell Labs in 1991. By infusing a 10 centimeter stretch of the fiber signal path with rare earth ions, and pumping it with an attached laser on the side, the doped glass amplifies all the signals in two wavelength bands totaling approximately 10 THz of normal fiber's 44 THz bandwidth.

By absorbing energy from a 980 nm pump laser, and now commonly from a 1480 nm pump as well, erbium ions in an EDFA's doped fiber span are excited to a higher energy level. Two kinds of emission follow: one good (*stimulated*), one noisy (*spontaneous*). In stimulated emission, signals transmitted in one of the erbium bands (1528–1565 nanometers for the C-band and 1570–1620 nanometers for the L-band) pass through the doped fiber, and collide with erbium ions. Dropping from their excited states, the erbium ions emit photons at the same wavelength as the transmission photons, thus amplifying the signal. In time, non-signal ions also emit photons spontaneously in the band, adding an undercurrent of noise that is amplified at each successive EDFA. Scientists call this *amplified spontaneous emission* (ASE).

Since total output power is divided over the channels, the EDFA gain per channel depends on the number of lambdas. To keep pace with increases in WDM channel-count and power-robbing passive components such as multiplexers and add-drops, EDFA designs have added multiple pumps, couplers, erbium fiber strands, filters, and C- and L-band hybrids that tend to be very complicated and messy. EDFA pioneer David Payne of Southampton Photonics uses a proprietary architecture to couple each of four pump lasers to eight fibers, thereby amplifying eight fibers in a hybrid device to save dramatically on cost and space.

As pump lasers continue their ascent in power and descent in cost per watt of output, Raman clearly becomes the amplifier of choice.

With the advent of ultra-long-haul networks and denser and denser WDM, optical amplification is clearly an "undershoot" technology. As defined in Clayton Christensen's *Innovator's Dilemma*, undershoot markets give the customer less than he needs, offering protection to high-margin, leading-edge suppliers who maximize performance of a challenged product. Indeed, banking on the pivotal pump lasers for the EDFA is JDSU, which by acquiring SDL gained an 80 percent share of the 980 nanometer pump market. But in undershoot, performance is key, and the EDFA will soon be running for its life against an amplifier of superior ability.

Raman amplification isn't new. In fact, it predates EDFA technology and JDSU supplies pumps for Raman also. But Ramans require much higher pump power than EDFAs do. Hence, power efficient erbium amplifiers were commercialized very quickly in the mid-1990s and Raman was forgotten.

Ironically, WDM sealed the fate of its own benefactor. EDFAs enabled WDM, which hones a voracious hunger for power as channel counts, passive components, and fiber spans mount. Higher output power and wider bandwidth (with the addition of the L-band) became necessary. Now EDFAs require pump power of 250 mW and more, high enough for Raman amplification. As OFC showed—and Chunie Ghosh signaled with his seven watt VCSEL—the cost of pumps plummets, while power ramps steeply.

Telecosm Ramanesque

Raman amplification ingeniously transforms a fiber nonlinearity—stimulated Raman scattering—from a problem into a solution. In Raman, photons transfer part of their energy to other photons approximately 110 nm down spectrum, thereby transferring energy from the shorter to the longer wavelength. Broadband WDM uses this effect almost magically to transfer distortion from the signal band to the amplification band while increasing signal power. Taking the Raman shift into account, pump lasers in the 14xx nm band can amplify the entire erbium C- and L-bands (1528–1620 nm).

Currently, most Raman amplification takes the form of Raman/EDFA hybrids. Rather than amplifying the signal at launch in a discrete device like an EDFA, Raman lasers pump backward down the fiber and pervasively amplify the signal from the other end, tens of kilometers before it reaches the EDFA. This lowers the gain demanded of the discrete EDFA and thus lowers the accumulated noise. The noise abating magic of Ramans stems from their slow and distributed impact. Rather than amplifying all at once in a concentrated small loop of erbium-doped glass, they amplify pervasively in the fiber's transmission path itself.

Genoa's LOA is good enough for metro networks, cheaper than EDFA amplification, its chip is classically disruptive

Historically, networkers have had to play trade-off between amplifier hut spacings best for performance, and much greater spacings best for cost. The usual outcome was around 80 to 100 km. CIBC tells us and Corvis confirms that Raman can radically improve the tradeoff. In a 160 channel, 10 Gbps network, six electronic regeneration sites worth a total of $75 million are replaced by 40 Raman amplifiers totaling $1 million. As pump lasers continue their astounding ascent in power and rapid descent in cost per watt of output, Raman clearly becomes the amplifier of choice.

The need for additional amplification at standard 80-100 km hut spacings is the only reason today to couple a Raman amp with an EDFA. Distributed Raman can't do it all, and so needs an EDFA boost. But the EDFA is going away, even as we write. At the 20 dB (100x) gain already achieved by Corvis Raman amplifiers, the unusually close 40-50 km hut spacings in the Broadwing and **Williams (WCG)** networks allow them to eliminate EDFAs altogether at bitrates up to 10 Gbps.

Princeton power grab

Meanwhile, at OFC two companies from Princeton electrified the crowds with high powered pumps. Ten-month old **Princeton Lightwave** said it is ready to sample one watt 14xx nm pump laser diodes for Raman amplifiers. At that output power, Princeton Lightwave stands to blow out current 300 milliwatt commercial diodes from JDSU. Princeton Optronics' Chunie Ghosh, who jolted Charlie to life in the final hour of OFC, tells an even more compelling story. Much like CoreTek (Nortel), Chunie has been trying to squeeze power out of tricky vertical cavity surface emitting lasers (VCSELs) for five years. Thermally sensitive, VCSELs were thought to be forever banished to the bottom of the power curve.

Why work so hard on VCSEL technology when gains are achieved much easier with edge-emitting diodes? Because VCSELs can be tested thousands at a time at the wafer level and therefore offer lower costs and higher yields. As a result, Chunie claims a near four to one materials cost advantage, a better beam shape, and power applicable over the entire transmission window of the fiber. After the 500 mW pump diode, he will introduce a cascaded Raman pump (5–7 diodes) later this year with 1.5 W of power (compared to today's 800 mW commercial standard).

Also solving the VCSEL power problem, Novalux has finally condensed its long-awaited pump laser from vapor into product. By coupling a second, extended cavity to the traditional VCSEL design, Novalux increases the reservoir of current in the laser. But Novalux has chosen to pump its 360 milliwatt at 980 nanometers and it remains to be seen if they can move it to the more strategic 14xx nanometer band.

At the standard 80–100 km hut spacing, Lucent's TrueWave long-haul fiber requires 400–500 mW of pump power for EDFA-free operation. Raman opens the paradigm world. Truly broadband, it will amplify across Lucent AllWave and Corning's 28-SMFe's entire 1280–1625 nm transmission window, almost a fivefold increase in bandwidth over the EDFA bands. Raman achieves a much flatter and more manageable gain than EDFAs without gain flattening filters, which add to cost and loss.

EDFAs won't fall off a cliff—they'll continue to see use in applications where discrete amplifiers make sense, and may hang on for a while undersea because of the higher electrical power required for Raman pumping. But the Raman powerdigm certainly calls into question Nortel's purchase of JDSU's Swiss 980 pump facility. Worse yet for Nortel (and perhaps JDSU, whose metro EDFA sales helped save them in 2000's fourth quarter), EDFAs may be in for squeeze from below as well as from above.

Genoa chips away at EDFAs

Merely lower performance versions of their high-end brothers, metro EDFAs are likely in overshoot according to Christensen's model. **Genoa** CEO Rick Gold envisions a disruptive day when amplification becomes ubiquitous in the metro, sprinkled liberally throughout these networks wherever desired—not just where absolutely necessary. Instead of large, expensive, 30 dB power gains fueled by EDFAs, we will thrive with smaller, less expensive amps that consume less power.

Rick Gold's dream product resembles a semiconductor optical amplifier (SOAs). Though lower powered than EDFAs, SOAs can amplify broadband over the entire AllWave transmission window. But crosstalk between multiple wavelengths was a showstopper for SOAs until Genoa solved it with its breakthrough linear optical amplifier (LOA), which optically pumps the semiconductor with a VCSEL built into the chip itself.

Using a unique process invented by Genoa's founders, the amplifier and the so-called "ballast" laser are manufactured simultaneously as one monolithic structure in indium phosphide. In operation, multiple wavelengths pass horizontally across the chip, directly through the amplifying beam of the vertically emitting laser. With characteristics suitable for MAN and LAN, Genoa's ingenious device produces 13 dB of gain compared to 30 dB typical in EDFA and can amplify 20 channels at a total transmission power of 10 mW before saturation and crosstalk begin.

Unlike EDFAs, these amplifiers can be integrated into numerous network devices. "Good enough" for metro networks but radically cheaper than EDFA amplification, the Genoa chip is classically disruptive.

Fiber will fuse two tiers of light, a message stream, and a continuous power source. Raman can reach across continents and tiny Genoa chips can fill every network nook in between.

Corvis concretes, Ciena softens

If the hardware innovations at OFC offered widespread confirmation of the PowerMux powerdigm, the intellectual case made a leap as well. Unexpectedly, it was the enigmatic Corvis who advanced the new paradigm in optics most eloquently and clearly. Speaking on a panel with Calient's Tim Dixon, Ciena's Steve Chaddick, Chorum's Scott Grout, and representatives from MEMS makers OMM and IMM, Corvis' chief hardware engineer Dave Smith issued a challenge to the conventional wisdom of optics.

The discussion focused on the software needed to control all the lambdas and datapaths. With perhaps the leading all-optical cross-connect, Calient shifted field ominously and now claims its real value is in network management and software. Uh, oh. At the forefront of developing a wavelength analog to multiprotocol label switching (MPLS), Calient's Dixon reminded us that 50 percent of his company's engineers are in software, as all future hires will be.

Chaddick stressed the difficulty of the software problems Ciena's Core Director has overcome and insisted Calient's purely photonic cross-connect wouldn't meet the needs of carriers. "Forty percent of our customers' interfaces are still STS-1s (52 Mbps), another 40 percent are STS-3s (155 Mbps), and only the remaining 20 percent are split between OC-192s (10 Gbps), OC-48s (2.5 Gbps), and OC-12s (622 Mbps)…If you don't have a hybrid switch with electronic interfaces, you don't get to sweep the Nortel gear out of the network." Challenging Dixon's claims of software expertise, Chaddick added, "Anyone that doesn't have a switch through trials with a carrier doesn't know how big the software problem is….There is this monstrous control plane issue to deal with."

Confidently, if subtly, Dave Smith suggested a very different approach. "There are many ways to build an all-optical network, but it's not a given that you have to have a tremendously dynamic core. What we need are architectures that give control at the edge," he asserted. With the continued doubling or tripling of data traffic every year, electronic switches will not suffice.

Soft on the outside, hard on the inside, the new network will put intelligence on the edge where the people are and hardware where the photons are

"Who says we are going to have some arbitrary limit on the number of wavelengths in a network? The number of wavelengths we want is not determined by the capacity requirements. Even in a tiered network where we have, for example, just 16 nodes, you need enough channels to connect all the nodes….Architecture drives the number of channels to fully connect your network." Smith wants to waste bandwidth to multiply scarce connections. Methodically, Smith finished his dissection of the Soft Network advocated so often by Ciena, **Sycamore** (SCMR), Calient, and even **Cisco** (CSCO). "I would focus a word of caution on software. Some of the biggest crashes in telecom history have been the results of software failures….look at your PC and see how often if crashes….I do not trust handing a multi-terabit network over to software engineers."

Paul Green said years ago that with fiber optics the quality of service (QOS) issues so dear to electronic switch and software makers would go away. Light would be 10 orders of magnitude more reliable and 10 orders of magnitude faster. The network would harden. Whether in the BlueArc Silicon Server or in a Corvis or Avanex network, software complexities rooted in the scarce processing power and memory of the microchip can be driven out by wasting the abundant gates of FPGAs or the copious bandwidth of optical fiber.

Today the network remains largely hard on the outside, with TVs and telephones and appliances, and soft on the inside with code rich routers and switches and protocol converters and add-drop mazes.

Soft on the outside, hard on the inside, the new network will put the intelligence on the edge where the people are and the hardware where the photons are. It will put electronics where memory and processing is needed and glass where the speed of light is the only constraint. Thus, the network will conform to the physics of light and electrons and to the needs of its users on the Net. This is the promise of an inspiring OFC, where the all-optical network emerged at last from the vapors and assumed the imperious reality of thousands of arduously designed and manufactured systems. While the market still is saying no to the new network topology, OFC issued a resounding yes.

George Gilder and Charles Burger
April 5, 2001

TELECOSM TECHNOLOGIES

ASCENDANT TECHNOLOGY	COMPANY (SYMBOL)	REFERENCE DATE	/ PRICE	MAR '01: MONTH END	52 WEEK RANGE	MARKET CAP
FIBER OPTICS						
Optical Fiber, Photonic Components	Corning (GLW)	5/1/98	13.64	20.69	18.19 - 113.33	20.7B
Wave Division Multiplexing (WDM) Components	JDS Uniphase (JDSU)	6/27/97	3.63	18.44	13.88 - 140.50	24.1B
Adaptive Photonic Processors	Avanex (AVNX)	3/31/00	151.75	10.57	8.11 - 174.50	693.7M
All-Optical Cross-Connects, Test Equipment	Agilent (A)	4/28/00	88.63	30.73	28.00 - 125.00	14.0B
Tunable Sources and WDM Components	New Focus (NUFO)	11/30/00	20.31	12.51	10.08 - 165.13	799.6M
Crystal-Based WDM and Optical Switching	Chorum (private)	12/29/00	–	–	–	–
WDM Metro Systems	ONI (ONIS)	12/29/00	39.56	19.50	15.75 - 142.00	2.7B
WDM Systems, Raman	Corvis (CORV)	3/30/01	7.03	7.03	4.69 - 114.75	2.6B
Metro Semiconductor Optical Amplifiers	Genoa (private)	3/30/01	–	–	–	–
LAST MILE						
Cable Modem Chipsets, Broadband ICs	Broadcom (BRCM)	4/17/98	6*	28.90	23.06 - 274.75	6.8B
S-CDMA Cable Modems	Terayon (TERN)	12/3/98	15.81	4.56	3.13 - 100.00	300.5M
Linear Power Amplifiers, Broadband Modems	Conexant (CNXT)	3/31/99	13.84	8.94	7.00 - 79.00	2.2B
Broadband Wireless Access, Network Software	Soma Networks (private)	2/28/01	–	–	–	–
WIRELESS						
Satellite Technology	Loral (LOR)	7/30/99	18.88	2.19	1.14 - 10.50	651.1M
Low Earth Orbit Satellite (LEOS) Wireless Transmission	Globalstar (GSTRF)	8/29/96	11.88	0.58	0.33 - 15.75	61.7M
Code Division Multiple Access (CDMA) Chips, Phones	Qualcomm (QCOM)	7/19/96	4.75	56.63	45.69 - 152.75	42.7B
Nationwide CDMA Wireless Network	Sprint (PCS)	12/3/98	7.19 *	19.00	15.72 - 66.00	17.8B
CDMA Handsets and Broadband Innovation	Motorola (MOT)	2/29/00	56.83	14.26	13.57 - 52.65	31.3B
Wireless System Construction and Management	Wireless Facilities (WFII)	7/31/00	63.63	4.13	3.31 - 99.94	181.1M
Internet Backbone and Broadband Wireless Access	WorldCom (WCOM)	8/29/97	19.95	18.69	13.50 - 49.94	54.9B
GLOBAL NETWORK						
Metropolitan Fiber Optic Networks	Metromedia (MFNX)	9/30/99	12.25	5.48	3.37 - 48.19	3.3B
Global Submarine Fiber Optic Network	Global Crossing (GX)	10/30/98	14.81	13.49	9.25 - 42.00	11.9B
Regional Broadband Fiber Optic Network	NEON (NOPT)	6/30/99	15.06	5.00	3.50 - 85.50	93.8M
Global Submarine Fiber Optic Network	360networks (TSIX)	10/31/00	18.13	3.56	2.31 - 24.19	2.9B
STOREWIDTH						
Directory, Network Storage	Novell (NOVL)	11/30/99	19.50	5.00	4.38 - 29.06	1.6B
Java Programming Language, Internet Servers	Sun Microsystems (SUNW)	8/13/96	6.88	15.37	13.74 - 64.69	50.1B
Network Storage and Caching Solutions	Mirror Image (XLA)	1/31/00	29	4.25	2.81 - 82.03	450.9M
Disruptive Storewidth Appliances	Procom (PRCM)	5/31/00	25	8.63	6.13 - 74.00	104.6M
Remote Storewidth Services	StorageNetworks (STOR)	5/31/00	27*	11.00	8.00 - 154.25	1.0B
Complex Hosting and Storewidth Solutions	Exodus (EXDS)	9/29/00	49.38	10.75	6.63 - 73.19	5.9B
Hardware-centric Networked Storage	BlueArc (private)	1/31/01	–	–	–	–
Virtual Private Networks, Encrypted Internet File Sharing	Mangosoft (MNGX.OB)	1/31/01	1.00	1.28	0.75 - 19.25	34.6M
MICROCOSM						
Analog, Digital, and Mixed Signal Processors	Analog Devices (ADI)	7/31/97	11.19	36.24	30.85 - 103.00	13.0B
Silicon Germanium (SiGe) Based Photonic Devices	Applied Micro Circuits (AMCC)	7/31/98	5.67	16.50	12.13 - 109.75	4.9B
Programming Logic, SiGe, Single-Chip Systems	Atmel (ATML)	4/3/98	4.42	9.81	8.13 - 29.44	4.5B
Single-Chip ASIC Systems, CDMA Chip Sets	LSI Logic (LSI)	7/31/97	15.75	15.73	14.00 - 76.25	5.1B
Single-Chip Systems, Silicon Germanium (SiGe) Chips	National Semiconductor (NSM)	7/31/97	31.50	26.75	17.13 - 73.88	4.7B
Analog, Digital, and Mixed Signal Processors, Micromirrors	Texas Instruments (TXN)	11/7/96	5.94	30.98	26.40 - 90.00	53.7B
Field Programmable Gate Arrays (FPGAs)	Xilinx (XLNX)	10/25/96	8.22	35.13	31.00 - 98.31	11.6B
Seven Layer Network Processors	EZchip (LNOP)	8/31/00	16.75	6.19	0.75 - 38.44	39.8M
Network Chips and Lightwave MEMS	Cypress Semiconductor (CY)	9/29/00	41.56	17.73	14.00 - 58.00	2.2B
Field Programmable Gate Arrays (FPGAs)	Altera (ALTR)	1/31/01	30.25	21.44	19.63 - 67.13	8.3B

ADDED TO THE TABLE: CORVIS AND GENOA **DELETED FROM THE TABLE: LUCENT AND NORTEL** * INITIAL PUBLIC OFFERING

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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