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Back to the Caves II?

There's only one answer to the mobile device display problem and Microvision Corporation has the answer

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Two years ago, in July 2002, in a letter entitled "Back to the Caves?", I introduced my infallible contrarian upside indicator: a proliferation of bears in the Massachusetts Berkshires where I live. I was not referring to a mere market metaphor, nor to the continued ursine infestation of the Internet and the dowdy downside punditry of the media. I was describing great black shaggy mammals, intruding everywhere in my bucolic county, from my favorite running paths on the Appalachian Trail to garbage cans next to Bret Swanson's driveway near Tanglewood in Lenox and up to Yo Yo Ma's melodious mansion in Tyringham and on to the now famous bedroom of film critic Gene Shalit next to the golf course of the Stockbridge Club. Although I believe in the First Amendment, even for Ursa Major Michael Moore and Ursa Minor Alan Abelson, I have little enthusiasm for bears. Capitalism thrives because assets tend to go to those most optimistic about their potential yields, rather than to rebarbative pessimists with huge paws and teeth and an addiction to junk food and with brains the size of golf balls. If the world is going to get its work done, the bears will have to be beaten back and it will go better for you if you are not cowering in their caves at the time.

At the time of that newsletter, two years ago this month, I focused my readers on the new analog paradigm and on my featured company, **National Semiconductor** (NSM). National was at a current equivalent (adjusted for splits) of $7.24. I also pointed to **Synaptics** (SYNA) then at $7.54, **Essex** (KEYW) at $3.40, JDS Uniphase (JDSU) at $2.67, and **Corvis** (CORV) at 64 cents. Our center spread at the time celebrated such further attractions as **Equinix** (EQIX) at around $10 and imperial **Qualcomm** (QCOM) at $27.50. Without even undergoing the onerous task of reading the letter, anyone who had plunged into the companies featured in the front-page outtake would have roughly tripled his money.

Not relying on ursine signals alone, we also trumpeted the findings of Arthur Laffer, the supply-side eponym, who compared U.S. corporate market cap with NIPA (National Income and Product Account) reported taxable earnings. Offering the view that in July 2002, amid recession pangs and war fears, "the economic fundamentals are amazingly bullish," he asserted that the S&P 500 was 40 percent below real discounted earnings. Since then the S&P is up some 40 percent while overall corporate earnings have nearly tripled to a new record of $1.2 trillion.

Today once again the Berkshire bears are back, leaving their caves to prowl on Main Street, hike the Appalachian trail, and probe garbage cans all over the county. Adding to the bearishness are demand-side economists who imagine that a predictable pause in the advance of some economic indicators portends an extended slump. Many point to the misleading series on hourly earnings, which shows a seri-

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ous decline ever since the period in the early 1970s when Nixon's price controls disguised an inflationary blow-off as a huge surge in wages. In political seasons in particular, you find big-government bears constantly comparing that golden age of price controls in the early 1970s to the always-unsatisfactory present. If this sharply declining series captured any significant economic truth, we would indeed be in trouble. But, during that period, the U.S. has moved from one-fifth of global GDP to one-third today. The wage numbers fail to include vast increases in other forms of compensation including health care and retirement benefits, tips, commissions, bonuses, salaries, and all time highs in home ownership (66 percent) and household wealth, which has tripled to a net of some $42 trillion.

Coming back, too, big time, is Laffer. He asserts that measured against real earnings and taxes, stocks are even lower than they were two years ago. More than 80 percent undervalued, he says. Indeed, Laffer's filter of S&P companies, which considers only economic fundamentals and financial performance, finds that among the 50 most desirable stocks to own right now, no fewer than 11 are GTR companies: **Altera** (ALTR), **Xilinx** (XLNX), Qualcomm, **Texas Instruments** (TXN), **Analog Devices** (ADI), National, **Intel** (INTC), **Broadcom** (BRCM), JDSU, and **Advanced Micro Devices** (AMD). Most of the other 50 desirables are either former (or future?) telecosm companies, or competitors.

Another leading supply-side analyst Don Luskin reports that the market is massively undervalued and that tech stocks, despite their cyclical perils, are poised to lead the market back.

Luskin points out that from the bottom on March 11, 2003, the technology sector of the S&P 500 has risen only two percentage points more than the entire index has (39 percent to 37 percent). But during this period, the S&P overall saw only a 19 percent rise in earnings while the tech sector nearly doubled earnings, to just under $60 billion. Although Luskin believes political uncertainty will restrain a full bull run, he concludes: "Our 'yield gap' valuation model (which compares forward earnings yields of equities to the yield of long term Treasuries) shows the Technology Sector now to be more undervalued than it was at the March 2003 bottom…and more relatively undervalued today than at any time since the sector washout in the spring of 2001, which set the stage for a 41 percent rally in just seven weeks."

Currently spooked by war, terrorism, and Smiley the protectionist bear John Edwards, the market suffers from the erratic earnings reports of a technology sector in transit between paradigms. Readers of the *GTR* are unsurprised to see companies such as **AT&T** (T) and **Nokia** (NOK) report declines in earnings (and in AT&T's case, sales drops 19 quarters in a row), and are unlikely to panic over a semiconductor inventory overhang of some $800 million (compared to $13 billion in Q1 of 2001).

With software hardening in the core and hardware softening on the edge, the telecosm is moving from hardwired terminals such as phones and TV sets to programmable wireless teleputers from Qualcomm and **Samsung** and 3D game machines from **Sony** (SNE) and **Microsoft** (MSFT) that also serve as DVD players, personal video recorders, and Internet browsers. The microcosm is moving from fixed ASICs from **LSI Logic** (LSI) and **Fujitsu** and microprocessors from Intel and AMD to programmable logic from Altera, which as Nick Tredennick points out, is portentously outselling its rival Xilinx five to one at the crucial low end of the market. Headed for its first gigabuck year, Altera is now forty percent below its recent highs and beckons as an obvious buy. The technology scene is also moving from digital complexity to new optical analog from NSM, TI, and Essex. It is moving from mega software from Microsoft to mobile component

The market is massively undervalued and tech stocks, despite their cyclical perils, are poised to lead the market back

software from Qualcomm, **Sun's** (SUNW) Java project, **IBM's** (IBM) Linux and others. Smart investors will recognize the opportunity amid the turmoil.

Meanwhile, Nick Tredennick has been investigating some exciting new developments in Silicon Valley. His report follows.

—George Gilder

For Your Eyes Only

Vision is astounding. It is impossible for me to shake the conviction that what I see is absolutely real. Yet I know that vision is a complex chain of chemical and electrical events triggered by the impact of photons on my retinas. The entirety of what I see is created on a tiny patch of sensors at the back of each eye. Compared to the quality and fidelity of biological imaging systems (eyes), all of our electronic and electromechanical imaging systems are worse than Paleolithic.

In a movie theater, the projector's light shines through the film and onto the screen and then bounces off the screen and into the eyes of the audience. The projector's lamp must provide enough light to create images for all the eyes in the audience, which represent a tiny fraction of possible destinations for the projector's photons. The efficiency of this system is close to zero. A few millionths of a watt (microwatts) worth of photons create the eye's image. Multiply by a few hundred viewing eyes and divide by the 5,000 to 10,000 watts of the projector's xenon-bulb light source. This system's efficiency will be measured in micropercent.

Laptop displays are a little better, but still close to zero. The laptop's display is the system's power hog (did you think it was the microprocessor?), consuming between two and five watts plus half again as much for backlighting. A backlit display can consume one-third of the notebook's power. The laptop's display spends watts to deliver microwatts of image to the eye at a system efficiency gauged in millipercent. Emissive displays offer good contrast in the dark and work poorly in

daylight (because the photons they emit compete with ambient light). Reflective displays require daylight or power-hungry artificial illumination. Miniaturizing the display for mobility shrinks the image it delivers to the eye, but doesn't improve display efficiency.

The transition from tethered systems such as wired desktops to mobile systems changed the design objective from cost performance to cost-performance-per-watt. In electronics, the need for more performance per watt will induce new design methods (reconfigurable systems) and new memory components. In displays, the same constraints apply. The liquid-crystal display, with its near-zero efficiency, is ripe to be displaced by an innovative design.

The cell phone is becoming the universal mobile device, what George calls a teleputer. It began with voice communication, but now includes the functions of a personal digital assistant, text and data transfer, email, and image capture. Soon cell-phone users will want standard web-browser functions. Tiny displays cannot offer browser functions.

There's only one answer to the mobile device's display problem: don't use a conventional display. The industry has gotten stuck on imagers that mimic paper. The efficiency of these systems is limited by their format. **Microvision Corporation** (MVIS) has an answer: write the image directly on the retina. To achieve this feat, it has made a major advance in a technology called microelectronic machines or MEMS. At a time when mostly speculative feats in "nanotechnology" are attracting all the attention, let's briefly tour the pullulating $5 billion plus realm of MEMS before returning to Microvision's spectacular application.

MEMS and nanotechnology

"The Orchestra on the Titanic"(*GTR* April 2004) is one of the best article titles I have seen—it expresses deep insight into how the semiconductor industry works. The orchestra continues to play because, given the circumstances, it doesn't know what else to do. It explains the difficulty in moving from instruction-based microprocessors from Intel and AMD to configurable and reconfigurable implementations from Altera, Xilinx, **Stretch**, **Tensilica,** and others. The orchestra of design engineers knows instruction-based problem solving. But the instruction-based ocean liner is slowly sinking as mobile systems dominate development. A similar analogy exists for the move from arrays of discrete components (such as sensors, actuators, resistors, coils and capacitors that detect, shuttle and shape signals across chips and boards) to MEMS that perform the entire function in a single microelectronic machine sculpted into a chip or built up by a process of layering and etching.

The difference between MEMS and nanotechnology is scale. MEMS designers scale down things that we are already familiar with, such as gears, latches, pistons, levers, bearings, moving-plate capacitors, and switches. MEMS can be built with trailing-edge semiconductor-processing equipment. The scale is microns, so devices are thousands of atoms across. Nanotechnology, by contrast, is atomic-scale structures—single atoms to tens or hundreds of atoms gauged in the tens of nanometers or below. Some applications, where the materials need only be coarsely controlled, are already emerging. Applications that require building atomic-scale machines are years away and will likely derive from biological systems, where techniques of information storage, protein catalysts, and self-assembly are well developed.

Microelectromechanical systems

Five years ago, MEMS developments were dominated by novelties such as gears, rods, pistons, and mechanical locks. Photos showed mechanical systems with moving parts and featured fleas and ants for scale comparison. Practical applications followed, notably the airbag accelerometers used in millions of automobiles and the nozzles used in inkjet printer cartridges, which together still comprise the bulk of the total some $5 billion plus MEMS market.

From this beginning, enthusiasts, including me, predicted an explosion of MEMS applications. Matching in scale the electronic systems that make use of them, MEMS could be batch fabricated using trailing-edge semiconductor-processing equipment. Batch fabrication meant cheap, mass-manufactured components, economies of scale, and rapid evolution riding the coattails of semiconductor processing. But the explosive growth didn't happen.

With some segments, such as protein microarrays, more than doubling every year, the overall MEMS growth rate is 20 percent a year, faster than the historic rate for the semiconductor market (approximately 15 percent per year). But such highly visible MEMS segments as biosensors and automotive have dollar growth rates below 10 percent (though *unit* volumes for autos are growing twice that fast). Crucially inhibiting the market are lack of standards, lack of uniform production methods, the high costs of a short design history and low-volume manufacturing, and inertia. The semiconductor industry is the orchestra on the Titanic. It knows how to build and how to use discrete macro-scale components, so it will embrace macro-scale components beyond the time when something else (MEMS) is required.

But standards will emerge and enable low-cost production. Companies such as **Coventor**, **MEMScap**, and **IntelliSense** are developing software for MEMS design and simulation. Development software may even offer the one path to dominance in this intrinsically fragmented trade, and Coventor seems to be in the lead. The Titanic-equivalent of discrete-component production will eventually sink.

Compelling applications are already arising across several industries.

Automotive/industrial. There's a revolution underway in the auto industry. Electronic systems, sensors, and actuators are displacing mechanical linkages from the throttle cable to the century-old drive train. Smart electric motors at each wheel—that drive selectively based on conditions and that capture energy on braking—will displace the transmission,

TELECOSM TECHNOLOGIES

Advanced Micro Devices	(AMD)
Agilent	(A)
Altera	(ALTR)
Analog Devices	(ADI)
Avanex	(AVNX)
Broadcom	(BRCM)
Cepheid	(CPHD)
Chartered Semiconductor	(CHRT)
Ciena	(CIEN)
Corvis	(CORV)
Energy Conversion Devices	(ENER)
Equinix	(EQIX)
Essex	(KEYW)
EZchip	(LNOP)
Flextronics	(FLEX)
Intel	(INTC)
JDS Uniphase	(JDSU)
Legend Group Limited	(LGHLY.PK)
McDATA	(MCDTA)
Microvision	(MVIS)
National Semiconductor	(NSM)
Power-One	(PWER)
Proxim	(PROX)
Qualcomm	(QCOM)
Samsung	(SSNLF/SSNHY)
Semiconductor Manufacturing International	(SMI)
Sonic Innovations	(SNCI)
Sprint PCS	(FON)
Synaptics	(SYNA)
Taiwan Semiconductor	(TSM)
Terayon	(TERN)
Texas Instruments	(TXN)
VIA Technologies	(2388.TW)
Wind River Systems	(WIND)
Xilinx	(XLNX)
Zoran	(ZRAN)

Note: The Telecosm Technologies list featured in the *Gilder Technology Report* is not a model portfolio. It is a list of technologies that lead in their respective application. Companies appear on this list based on technical leadership, without consideration of current share price or investment timing. The presence of a company on the list is not a recommendation to buy shares at the current price. George Gilder and *Gilder Technology Report* staff may hold positions in some or all of the stocks listed.

Altera (ALTR)

SOFTENING HARDWARE, HARDENING SOFTWARE

JULY 26: 19.28, 52-WEEK RANGE: 17.43 – 26.82, MARKET CAP: 7.22B

Down from almost 27 to 19, ALTR is one of the most attractive telecosm buying opportunities. With Xilinx, it is the chief maker of programmable logic devices, general-purpose chips that can be used in a vast array of communications, industrial, and increasingly consumer products. June quarter sales were $269 million, up 11% sequentially and 30% from last year, and net income was $75.3 million. New products, including Stratix II and Cyclone, have earned great reception in the market, and the even newer Cyclone II and MAX II devices expect the same. The dramatically lower-cost Cyclone II follows Tredennick's law by targeting mass markets previously untouchable by programmable logic. Six hundred fifty new customers in the second quarter seem to approve. With gross margins of 70%, Altera has a shot to become a dominant chip company, as its products invade markets for digital signal processors (DSPs), microprocessors, and application specific chips (ASICs and ASSPs).

Broadcom (BCRM)

LEADING FABLESS BROADBAND DESIGNS

JULY 26: 33.19, 52-WEEK RANGE: 19.81 – 47.05, MARKET CAP: 10.43B

June quarter sales were $641.3 million, a record, increasing 12% sequentially and 70% from last year. Using pro forma numbers, which the company thinks are meaningful because of frequent past acquisitions, net income was $122 million. Broadcom extended its lead in set-top boxes and digital video recorders, continued to gain in Wi-Fi, was confirmed the top market share supplier of ubiquitous Ethernet chips, and made serious gains against Terayon in the DOCSIS 2.0 cable-head-end chip market. The company for the first time also entered the CDMA wirless market with its acquisition of WCDMA design house Zyray. WCDMA is a competitive market—Qualcomm has quickly taken the lead—but its fast growth should at the very least provide second-source opportunities for Broadcom.

With a stock price that has fallen from 47 to just 33, a great company that just a few months ago appeared well- or over-valued, has now come back to earth and trades at a forward P/E of just 21.

Corvis (CORV)

THE PARAMOUNT ALL-OPTICAL COMPANY

JJULY 26: 1.12, 52-WEEK RANGE: 1.04 – 3.07, MARKET CAP: 543.54M

If you purchase shares of Corvis common today, you are investing in an integrated Corvis Equipment + Focal + Broadwing entity about to be born. The company is transitioning from a horizontal system-sales-only business model to a vertically integrated systems vendor with its own national fiber-optic network from access to backbone.

Through its Broadwing subsidiary, Corvis launched the first national communications system that transmits its contents entirely on wings of light, avoiding the optoelectronic bottlenecks of its less nimble rivals. The acquisition of Focal Communications is still scheduled for later this summer despite some surmountable legal snarls. With Focal, a CLEC provider of voice and data services to 4,000 enterprise customers with networks in 23 tier-one markets, Corvis will not only lower its access costs (which come mainly from local network leasing charges at the network edge). It will also gain ready access to Focal's market while enabling Broadwing to bundle services. In turn, Broadwing helps Focal with transport costs—profit margins on the Corvis-built backbone approach 90%.

In optical networking, the market is focusing on a "distressed industry" rather than the causes of the distresses. To Wall Street, MCI's and ATT's weaknesses are Corvis's weaknesses. MCI and ATT are renewing many 60-month contracts far below 1999 rates and with networks that are less reliable, more costly to run, and have

Sonic Sneezes –

Sonic Innovations (SNCI)

FRUITFUL INTERPLAY OF ANALOG, DIGITAL & BIONICS

JULY 26: 4.41, 52-WEEK RANGE: 3.80 – 12.54, MARKET CAP: 90.65M

Hearing aids reach only 20% of the nearly 30 million Americans who can benefit from them. Among that 20%, most are dissatisfied with their devices. However, selling hearing aids suggests the proverbial problem of selling shoes in the jungle. The hearing-impaired think like the fabled tribal folk who don't buy shoes because—well, no one else wears those ugly things … and because they "do just fine" without them … and, most importantly for the hearing impaired, because their meager cash goes for such other items as costly prescription drugs, eyeglasses, or medical insurance. Tougher still is the plight of the newcomer hearing-aid firm that must break through the old-boy network of audiologist suppliers and high-margin resellers.

Our shoes-in-the-jungle company is Sonic Innovations.

Using our Silicon Valley guide and guru Carver Mead's electronic models of the cochlea, Sonic has leapfrogged its digital rivals in functionality and size. Modern hearing aids address the frequency-dependence of hearing loss with multi-banded devices that amplify high and low sounds differentially according to the particular problem of customers. With smaller

MEAD'S ANALOG REVOLUTION

NATIONAL SEMICONDUCTOR (NSM)
SYNAPTICS (SYNA)
SONIC INNOVATIONS (SNCI)
FOVEON
IMPINJ
AUDIENCE INC.
DIGITALPERSONA

COMPANIES TO WATCH

ATHEROS
ATI TECHNOLOGIES (ATYT)
BLUEARC
COX (COX)
CYRANO SCIENCES
ENDWAVE (ENWV)
ESS TECHNOLOGIES (ESST)
ISILON
MEMORYLOGIX
NARAD NETWORKS
POWERWAVE (PWAV)
QUICKSILVER TECHNOLOGY
RF MICRO DEVICES (RFMD)
SEMITOOL (SMTL)
SIRF
SOMA NETWORKS
SYNOPSYS (SNPS)
TENSILICA
XANOPTIX

higher latency than Broadwing's. By contrast, Corvis is renewing 24- and some 36-month contracts at or only slightly below original prices. And Corvis reports that they are being invited to more big bids than ever before. Over the past three quarters (the first ones to include figures from the Broadwing network), gross margins for communications services have increased from 23.4% to 31% and GAAP losses have decreased from $113.5 million to $29.4 million while Broadwing sales have remained steady. New enterprise customers have offset lost consumer long-distance accounts.

Corvis's recent share price of $1.12 yields a post-Focal acquisition enterprise value of $500 million or only 0.58x Corvis's estimated pro forma consolidated sales. Yet Corvis's enterprise value has been as high as 1.85x sales since the first full Broadwing quarter but prior to the Focal announcement, when operating losses were 3x today's pro forma estimate. A enterprise value to sales ratio of 1.85 translates to a post-acquisition price per share of $3.00.

Fretting about the next quarter, the market is looking for downside surprises, but Corvis is an Upside Story. Wealth creation is not a linear process. Corvis is undergoing resource conversion, meaning its immediate earnings outlook will be uncertain. So why fret over today's market slump? Instead, take advantage of it. If Corvis succeeds over the next two years, its stock today is cheap.

Qualcomm (QCOM)

AIR KING—WORLD'S BEST TECHNOLOGY COMPANY

JULY 26: 70.50, 52-WEEK RANGE: 35.13 – 73.50, MARKET CAP: 57.38B

Last month we said, "Buy on any dips." And we hope you did. Shares jumped more than 6% on the June quarter earnings report, which revealed sales of $1.3 billion, up 10% sequentially and 50% over last year. Powered by operating margins of 37%, net income was $486 million, for earnings of $.58 per share, 5 cents ahead of Street estimates. The company cash hoard stands at $7 billion.

Although wireless giant Nokia has six times Qualcomm's sales, on July 22 Qualcomm for the first time ever surpassed its arch-rival's market cap of more than $57 billion. We think over the next five years QCOM will continue to surprise the market. It's predictable.

Sprint PCS (FON)

WIRELESS PARADIGM PIONEER

JULY 26: 18.84, 52-WEEK RANGE: 13.55 – 19.99, MARKET CAP: 26.87B

Sprint added 505,000 direct wireless customers and another 392,000 through its wholesale affiliates in the June quarter. Sales of $3.6 billion improved 17% from last year, and 5% sequentially, on impressive ARPU (average revenue per user) of $62 and slightly lower churn of 2.3%. PCS wireless sales ($3.6 billion) are now 52% of total FON revenue ($6.9 billion). Five million subscribers to Sprint's "Vision" advanced data service and nearly two million entry-level data customers now yield 7% of wireless sales.

Wall Street Calls an Ambulance

chips, Sonic not only performs better multi-banding than its rivals, but also discerns when a new word is coming and then increases the volume for the relevant split-second, capturing the often elusive sounds at the beginnings of words. The result is the first and only hearing aids ever to meet the FDA's standard for superior performance under noisy conditions. Further, in 2002, Sonic introduced the first non-fitted, completely-in-the-canal (CIC) hearing aid incorporating the company's top-of-the-line electronics. Instead of a laboriously custom-fitted tip, it has a sponge tip that conforms to the ear canal and wholesales for less than half the cost of its rivals' retro-fitted CICs.

Facing the control of U.S. audiologist channels by established hearing aid companies, Sonic has been marketing to physicians, who respond to quality, and has been expanding aggressively overseas. Unlike the US, most European countries offer insured coverage of hearing aid costs, making consumers less price conscious and facilitating Sonic's high-end strategy.

Hence the company's latest sneeze. Germany's national health bureaucracy has lowered reimbursements on premium hearing aids by about 8 percent. Instead of saying "gesundheit," the Street promptly confined SNCI to the intensive care ward, collapsing its enterprise value (EV = market cap + long-term debt – net current assets) from $187 million on June 14, the day SNCI caught cold, to $81 million last week as the stock dipped a shade under $4.50 per share.

Yet Sonic is worth more than twice that price based on financials after the German sneeze, ample cash in the till to cover all liabilities, improving gross margins, and an enterprise value to sales ratio of just 0.8 (compared 3.5 to 4 for its rivals). Despite CEO Andrew Raguskus' estimate of $24.5 million for June quarterly revenues (a $1.8 million shortfall from March), trailing-twelve-month revenues have risen for two years and GAAP net income has been positive for three consecutive quarters.

Why did Wall Street call the ambulance for a cold that Raguskus warned us might be coming back in April? Living in the shadow of Sarbanes-Oxley, Raguskus might be partly to blame with this (typically) dour comment in the June 14 press release: "The unfortunate timing of this change just as we are reaching the critical mass that helps us generate stronger profitability magnifies the short-term effect of this issue." Translated: operations were about to benefit significantly from economies of scale and now we'll just have to wait a little longer. Not so bad if you see Sonic's currently healthy finances in light of it long-term technological superiority. If you don't, however, then words like "unfortunate … critical … magnifies … issue" suggest cancer.

With Europe accounting for a third of Sonic's sales in 2003, the German policy might spread to other socialist countries on the continent. In the US, with 46 percent of Sonic's sales, customers continue to go for cheap analog devices. Based on past history, the stock could even slip further in the near-term. SNCI's bottom EV/sales ratio during the past year was 0.67 (July 03), which today would yield an equity price of $3.88 per share.

Nonetheless, the company's future remains highly promising. Sonic has just enhanced the ability of its aids to perceive directionality of sounds. And the usually somber Raguskus is promising a further technological breakthrough in January. Commercially, Sonic has yet to enter Japan, the third largest market. Down the road, the baby-boomer majority is getting older and deafer. (Do you hear us?) There was nothing in the June profit warning that changes SNCI's promise of an expanding technological edge.

The bottom line for SNCI: Electronics customers have been trained by the computer industry to expect better performance for lower prices. If Sonic eschews its medical-device heritage and begins behaving like the fabless microchip company it is—lowering prices, expanding market share, delivering upside surprises in cost-performance, as it rides Moore's law into supremacy—it can become a monster. To a real electronics company with a technical edge, an 8% gouge in Germany should be hardly audible amid the rush down the learning curve.

—Charles Burger

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driveshaft, and differential. To do this, hundreds of sensors and actuators will monitor, report, and control conditions inside and outside the automobile. MEMS sensors and associated systems can, for example, detect a rollover and report the car's condition and location to emergency services.

More than fifty million automobiles are sold every year. In 2002, led by the now-ubiquitous airbag accelerometer, the average automobile carried five MEMS sensors. By 2007 there will be more than nine. Automotive applications for MEMS include tire-pressure monitoring, suspension and stability monitoring, engine monitoring, cockpit environment measurement, security systems, and navigation and entertainment systems.

The technology scene is moving from digital complexity to new optical analog from NSM, TI, and Essex

Two-axis accelerometers from Analog Devices and **Motorola** (MOT) sell for as little as $2.50. A new three-axis accelerometer from **STMicroelectronics** (STM), the LIS3L02D, offers digital output. One intended application for this accelerometer is in handheld devices. The three-axis accelerometer enables motion-based user interfaces for one-handed operation—just tilt the device to slide through menu items. It is shock resistant to 3,000 g, making it suitable for cell phones. It is also suitable for any automotive, industrial, or consumer application for which sensing motion, acceleration, or inclination is important.

Gyroscopes measure relative motion by measuring acceleration in pitch, roll, and yaw. With a gyroscope, something to measure speed, and a known starting point, a system can navigate by "dead reckoning." The system calculates the heading by measuring the acceleration of turning and the time in the turn and adding or subtracting the resulting angle from the last heading. It computes distance using time and speed. In these days of geo-location by GPS, dead reckoning may seem a "dead" art. Soon, even our handheld devices will know where they are because integrated GPS receivers, from companies such as **Garmin** (GRMN) and **SiRF** (SIRF), will be cheap enough for every system to have one. But GPS by itself isn't good enough. GPS signals are weak and they are subject to interference from a host of sources, including microwave ovens, and to attenuation by buildings, trees, and other obstacles. Dead reckoning always works. If the GPS is working, the system can use GPS to improve its dead-reckoning calculations; if GPS is unavailable, dead reckoning can take over to maintain geo-location. According to Marlene Bourne of InStat/MDR, ten of the top twelve companies making inertial measurement units (IMUs, systems that do dead reckoning) are building units based on MEMS gyros.

Analog Devices introduced two MEMS gyroscopes late last year, the iMEMS ADXRS150 and ADXRS130. These gyros measure Coriolis acceleration and put out an electrical signal that is proportional to the rate of rotation. Able to withstand shocks to 1,000 g, they are a hundredth the size of macro-scale gyros with equivalent performance. The first applications are likely to be in military systems and in automobiles for rollover detection and for stability-control systems.

Information systems. Perhaps the most obvious computer-based MEMS application is in storage systems. The macro-scale electromechanical hard disk benefits from MEMS sensors and actuators. Acceleration sensors from Analog Devices and from STMicroelectronics, for example, detect the movement of a laptop computer and either park the disk heads in a safe area or shut down the disk to prevent damage to the disk surface. MEMS actuators, also available from STMicroelectronics, aid the moving disk arm in acquiring and in maintaining track alignment.

MEMS-based storage might displace the hard disk itself someday. Solid-state and MEMS-based storage come from companies such as IBM, with its Millipede, or from others such as **Hewlett-Packard** (HPQ), **Hitachi** (HIT), **Nanochip**, **Nanomagnetics**, **Nanosys**, **Nantero**, Samsung, and **Zettacore**. Advances in Millipede, according to reports, were what prompted IBM to sell its venerable hard drive division to Hitachi.

Today's hard disk has a single read/write head floating over a thin magnetic coating on a rotating surface. In a MEMS-based storage system, the read/write heads are batch fabricated, so it isn't much more expensive to build thousands than to build one. Increasing the number of read/write heads reduces the number of storage bits assigned to each head, which means shorter seek time (shorter distance to move to find a particular bit). More read/write heads means massive read/write parallelism, which increases data throughput. In the extreme, a read/write head could be manufactured for each storage bit. The result is a disk with short access time, high transfer bandwidth, and no moving parts!

Wireless. The number of components in a cell phone has been dropping. Two years ago it was 185 components. This year, it's about 25. All of the digital stuff has long-ago been integrated into one or two chips. What remains outside these integrated chips to dominate component count are the discrete capacitors, crystals, inductors, switches, surface acoustic wave (SAW) filters, and tuning capacitors, which are difficult to integrate because they have special characteristics or moving parts. Even if some of these components could be integrated, MEMS costs are still often too high to displace very-high-volume, very-cheap discrete equivalents.

Intel offers an RF module for cell phones that integrates forty discrete passive components, reducing circuit-board space requirements by two-thirds, lowering assembly cost and boosting system reliability. But integrating the cell phone's last two-dozen discrete components, as important and as compelling as it is, isn't the primary strength of MEMS for wireless applications. Their primary strength lies in opening wireless design to fundamentally new approaches.

MEMS microphones could find wide application in consumer appliances. Startup **Akustica** makes a microphone-amplifier chip for hearing aids and cell phones. Akustica's chip, which is built in a standard CMOS foundry process, has an on-chip amplifier and an array of sixty-four microphones etched in silicon. Counting hearing aids, automotive applications, mobile communications devices, and consumer electronics, Akustica thinks the addressable market is about $10 billion. Recently, MEMS microphones from **Knowles Acoustics** entered the market in **Neonode's** N1 cell phone.

Analog Devices, Intel, **Philips** (PHG), Samsung, STMicroelectronics, and Texas Instruments are among the companies that build RF MEMS for wireless applications.

Biomedical. Once semiconductor processing reached the scale of biological systems 15 years ago, it became possible to co-opt solutions from Nature, leveraging millions of years of evolutionary development. Leaders in this industry include our own **Agilent** (A) and **Cepheid** (CPHD). Covered in the September 2001 *Dynamic Silicon* (back issues available to subscribers at www.gildertech.com), I will be revisiting this sector in a future *GTR*. For pointers to more than a hundred companies involved in silicon-based biological diagnostics, visit www.gene-chips.com.

Back to Microvision

Optical applications are a great match for MEMS because manipulating light involves movement and scale down to something on the order of a quarter of the wavelength of the light being manipulated. Light in optical systems is close to the visible range at wavelengths of 400 to 1,600 nanometers. Physical features of MEMS built on old semiconductor processing equipment can be built with features on the order of 100 to 400 nanometers. MEMS optical components include switches, variable optical attenuators, and tunable filters and lasers. Texas Instruments' DLP (digital light processor) chip implements 1.3 million moving MEMS mirrors on a single chip. These chips are appearing in a wide range of display systems, from simple office presentation projectors to theater projection systems. The next large market looks as if it will be in DLP-based home theater systems and in DLP-based TVs.

Microvision performs the same essential display function of TI's millions of mirrors using just one moving mirror and light source. Photons from the light source bounce off the mirror and impact the retina. Moving the mirror with small x and y deflections paints an area of the retina with a source-modulated stream of photons to create an image. Light-source power is measured in milliwatts, making Microvision's system orders of magnitude more efficient than any conventional display system. Further, the image that's created isn't the postage-stamp image of today's cell-phone LCD. It appears to the viewer as a full-color image with all the resolution of a giant desktop display, but with better contrast. Microvision's display has a contrast ratio of 5,000 compared with 500 for a typical laptop LCD.

Microvision's image generator is a perfect match for Foveon's sensor in camera applications. Today's electronic viewfinder offers a low-contrast-ratio, postage-stamp caricature of the image to be captured. Microvision's viewfinder can show the image the Foveon chip is seeing at multimegapixel resolution.

Microvision's magic is in its MEMS mirror and in the idea of writing the image directly in the eye. The mirror is batch fabricated at a chip foundry, so it benefits from Moore's-law improvements. As the mirror shrinks and as the wafers it is made on get larger, the MEMS mirror gets cheaper and more efficient. As it gets cheaper and more efficient, it becomes economically suitable for more and more applications. As applications proliferate, production volumes increase, lowering costs.

Early systems produced monochromatic images for military applications. Later systems reached profitable volumes in the Nomad head-mounted system for automotive and aircraft maintenance applications. Third-generation mirrors and optics are in Microvision's current products. Breakthrough volumes will come with fourth-generation improvements in mirrors and in optics that make Microvision's image generators suitable for consumer applications in cell phones and in digital-camera viewfinders. A dual-display system could produce realistic 3D images for gaming, flight simulation, microsurgery, and other applications.

The Microvision MEMS mirror isn't just an image generator, it's a mirror—photons can go both ways. It can read a retina for authentication as easily as it can write to it. Imagers that write directly to the retina and read its unique attributes achieve levels of privacy and security unattainable by other means. Such a system could tag each file with a list of the eyes that are authorized to view or that have viewed the file.

Microvision's MEMS mirror enables building mobile readers for difficult-to-read 2D bar codes. In text, image, and document scanning, Microvision imaging systems can offer scalable resolution and performance. In printers, for example, a system with a Microvision mirror might feed back image information for real-time color control. It is a major advance for imaging that epitomizes the power of MEMS.

Industries in transition

Microvision: the low-power, last link

Battered technology investors might wonder how Microvision's (MVIS) 2003 sales of just $15 million, combined with $14 million in cash, support a market cap of $137 million. Quite a sum considering the recent tech tumble that clipped MVIS shares by 40 percent. The answer is that in the short-term Microvision expects "significantly" higher sales in the second quarter due to the first shipments of its Nomad expert auto technician display system. Nomad projects a virtual overlay of engine parts and repair instructions, for example, onto the retina of an auto technician, who no longer must refer to schematics and written instructions in books or computer screens. A special version of Nomad is also being used by the vehicle commanders in a brigade of the Army's new Stryker light-armor combat trucks.

Until recently Microvision achieved half or more of its sales from U.S. government contracts. That number has fallen to one-third in the most recent quarter, though the U.S. just re-upped for an additional $3.85 million in R&D on a new heads-up-display cockpit helmet. Microvision's low-cost, low-power Flic barcode scanners are its other main source of current revenue, with shipments beginning last winter. Despite potentially large markets for Nomad displays (there are 850,000 auto technicians in the U.S. alone) and Flic scanners, Microvision's valuation is mostly supported by the seemingly limitless future applications of its optical expertise. The company's R&D efforts have even sprouted a nanotechnology subsidiary called Lumera (LMRA), which itself began trading on July 23.

Majority owned by MVIS, Lumera makes (nano)polymers that can be used across a range of communications and biotech applications, including Wi-Fi antennas, laser modulators (replacing inorganic materials like lithium niobate, gallium arsenide, and indium phosphide), and as coatings on "MicroArray" (darn) gene chips. Lumera is valued at $95 million.

With the markets for Microvision's chief retina-scanning technology limited only by the imagination—mobile phones, digital cameras, omnipresent TV, printers, security, medical surgery, military, entertainment, books, and virtual reality made real—the company's potential seems bounded only by its ability to execute and innovate. In a world of non-stop media and imagery overload, Microvision can be the most direct route, the low-power, last link—and give rich new meaning—to those cherished customer eye balls.

—Bret Swanson

The automotive industry is in transition from analog to digital, from mechanical to electrical, and from isolated to connected. The film and video industry is in transition from analog to digital and from isolated to connected. The consumer-products industry is in transition from analog to digital, from tethered to untethered, and from isolated to connected. (The consumer-products industry also offers high-growth opportunities in supplying standard appliances to emerging economies.) The biomedical industry is in transition from analog to digital and from wet laboratories to bioinformatics. The telecom industry is in transition from copper to untethered, from copper to fiber, and from electrical to optical. The computer industry is in transition from desktop to embedded. These transitions will completely transform these industries. Transitions in these industries will create large markets for MEMS, for electrical and electronics components, and for computers and software over the next few years.

—Nick Tredennick with Brion Shimamoto
July 26, 2004

Got Questions?

Visit our subscriber-only discussion forum, the Telecosm Lounge, with George Gilder and Nick Tredennick, on www.gildertech.com

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