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X-Ray Vision

Analogic has mastered the technologies of X-ray physics and engineering for the new security markets

How do you "see" molecules? The molecules in plastic explosives? Or nerve gas? Or cocaine? Or Anthrax DNA? A dog's nose is pretty good at this form of vision, which is why canines are showing up a lot in places like airports these days. Chemical laboratories can work out the molecular composition of anything, if you give them a big enough sample, and enough time to run it through a lot of bulky hardware. But for mass screening, in real time, you have go to power—highly-ordered photon power. You see molecules in much the same way as you see a tomato in the supermarket. You shine the right kind of light, and watch what happens when it hits the target.

The quantity and quality of the light matters a lot—all cats look black in the night, and so does a red tomato under a green light. Only two kinds of power are suitable for getting a quick read on molecular composition—on whether, say, a lump of stuff is packed with huge amounts of nitrogen, meaning that it could be explosive. One is pulsed magnetic power, which lets you probe atomic nuclei, if you happen to have time to spare and a mountain of magnetic-imaging hardware nearby. The other main power option is the X-ray.

After September 11, investors rushed to put their money in a handful of companies that make baggage-screening systems for airports. We like one of them too, American Science & Engineering (ASE), but so does everybody else, apparently. ASE's stock price leapt four-fold following 9/11. And we like Analogic (ALOG),—which was largely ignored in the post-9/11 rush to defense and security technology stocks.

Analogic is the OEM for the airport automatic explosive detection systems (EDS) built by L3 Communications (LLL). More importantly, its business is squarely centered in digital power technologies. Analogic understands the power-centered engineering of *sight*. It builds the hardware and software that projects power, detects it, and makes sense of the torrents of data so generated.

Perfect Vision

The power of sight begins with power itself. So far as the basic physics go, the only way to *see* something is to detect a flow of power from there to here.

Quite primitive forms of power will often suffice. Daylight, for example. Or the heat or noise generated by the target itself. Or its smell. As long as some faint whiff of the explosive, or drug, or landmine drifts the right way through the air, the exquisitely sensitive canine nose can probably pick it up. Many laboratory methods rely on similar chemistry-centered processes to determine molecular composition. Mass spectrometry, for example. Just ionize the molecules in a sample and fire them through a magnetic field: how much they deflect tells you how heavy they are, and how much charge they bear, which generally lets you work out what they are.

A second group of *seeing* systems excites its targets with neutrons or streams of electrons, and infers what's there from how much particle-beam power gets through, or bounces back. Neutron backscatter techniques measure the hydrogen content of a material, for example, and are thus used in the petroleum industry, and for detecting explosives and chemical weapons.

A third group of much bulkier and more exotic detectors aims powerful magnetic and electromagnetic fields at atomic nuclei. Nuclear Magnetic Resonance (NMR) directs a pulsed radio-frequency field, in the megahertz range, at atomic nuclei located within a very strong (and sometimes pulsed) magnetic field. How much energy each nucleus absorbs, in what frequency bands, depends on how many protons it contains. Nuclear Quadrupole Resonance (NQR) is a related but still largely experimental technique; it measures electrical gradients that depend on the chemical structure of molecules, and at its best it can be as specific as chemical spectroscopy.

A fourth group—by far the most important, practically speaking—projects photon power, and looks to see what happens to it. Plain old light will take you a long way in distinguishing shiny aluminum from dull wood.

We discussed *seeing* in the millimeter wave bands in last month's DPR (*The Power of Millimeter Waves, November 2001*). Push the frequency up quite a lot further, through the visible bands and on up into X-rays, and you can see broken bones. "Gamma backscatter" sensors use an external radioactive source to paint targets with high-frequency X-rays; organic materials, drugs, and several other common forms of contraband that tend to absorb and then reemit these high-frequency photons more than most other materials do.

So far as the basic engineering goes, there are only two ways to see things better. Build a better detector—a better eyeball. Or supply better illumination—a better light bulb.

The better ordered the power you project, the more you can see with it. "Black body" radiation, the most chaotic form of all, conveys only the temperature of the object radiating it. Shine a precisely tuned millimeter wave beam or laser or X-ray on a target, and you can find out a whole lot more. Use multiple beams in both bands without mixing them up—"multi-spectral imaging"—and you can see still more, just as a color picture conveys more information than black and white. Order lets us aim the power just where we want it, at just the right frequency, to detect what does interest us, and to punch through the surrounding clutter that doesn't.

Power density matters too: higher-power density, which means higher frequency, which means shorter wavelength, is better than lower. A kilometer-length radio wave can't resolve things much smaller than a few kilometers across. Lunar craters, maybe—but not cracks in a jet engine's turbine blade. Shorter wavelengths pick up more detail. They also tend to penetrate better (though the physics isn't quite that simple; very long wavelength signals tend to get through things effectively, too). Magnetic fields won't penetrate medical containers, so nuclear magnetic imaging systems are useless for uncooperative targets. Boost their power and frequency, by contrast, and X-rays will punch through metal quite easily.

Beyond the basic physics of order and wavelength, the art of seeing clearly comes down to a wide range of engineering trade-offs and strictly practical considerations. Chemistry-centered approaches to detection can be extremely sensitive and precise—but also cumbersome and slow. And they depend on getting a physical sample into the detector somehow or other, if only by the wafting of an odor from the suitcase to the dog's nose. Radioactive cobalt and the electron beams used to produce high-energy X-rays are quite dangerous, as are the X-rays themselves, so detectors often require elaborate shielding and containment. Some wavelengths (e.g. visible light) can be projected from extremely compact semiconductor chips; others require large antennas, or electron guns and bulky cathode ray tubes. Technologies that can detect tiny traces have the virtue of being extremely sensitive, but for that very reason often cannot distinguish between a forest and a single twig. In the seeing of explosives, for example, the goal is to detect a mass large enough to cause real harm, rather than the residue of a campfire match or a firecracker. Mass screening systems, like those that airports use for suitcases, have to have a fast throughput; the loading of the luggage can't take so long that it would be faster to drive.

A perfect vision system would penetrate effortlessly, through all uninteresting forms of clutter. It would provide complete molecular character recognition—a chemical fingerprint of the target, and a finely focused one too, fine enough to distinguish the Sarin gas from the glass vial that contains it. But it would also provide a higher perspective, distant enough to discern shape and volume. If obtaining a perfect molecular signature is impractical—and it usually is—then one asks for secondary indicators, like density, and the average atomic "Z factor"—a composite profile of the average number of protons in the atoms that occupy a given space.

What does it take to get all this? Far more than anyone now has, at least outside a fully equipped laboratory, with unlimited time to look. To see as perfectly as that, one must project power across a very wide band of frequencies, and from every possible angle. The seeing must happen in three dimensions, and at multiple frequencies, each perfectly tuned and kept separate from the rest. Finally, the analysis of the huge amounts of data generated from this multi-spectral stream of power requires remarkable processing analysis and software systems, built around a deep understanding of power itself, and the physics of digital sight.

X-Rays

Most of the photon technologies widely used today still begin with electrons moving through metal wires—"filaments" or "antennas." Edison bridged the electron-photon divide by using electricity to make heat in a filament; Marconi's radio bridged it by pumping oscillatory currents through a metal antenna.

The millimeter-wave devices we discussed last month define the current pinnacle of photon power produced Marconi's way, by driving an oscillating current through an antenna. It takes extraordinary amplifiers to control currents at the 30 to 300 GHz frequencies that produce millimeter-wavelength emissions. And for reasons we described last month, the frequencies of tuned-circuit radios aren't going to get pushed a lot higher than that, at least not using

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ordinary metal wires. It would be physically impossible to get a "radio" of Marconi's basic design to emit visible light, still less X-rays—all the power would pour out as heat and radio waves long before it got to the atomic-scale "antenna" that was supposed to emit the beam.

So X-ray machines don't use Marconi's technology at all—they use, basically, Edison's. A 110-volt current supplied from a wall outlet gives way to a beam of electrons fired from a 100,000-volt "electron gun." The bulb's tungsten filament gives way to a tungsten target, against which the electron beam collides. The beam's energy intensity is high enough to trigger the emission of X-rays, rather than mere light. Marconi's first practical radio started with kilometer-wavelength photons. X-rays typically run thirteen orders of magnitude shorter, with wavelengths comparable to the diameter of a single atom.

There isn't much likelihood that the projection of X-rays will soon make the transition that visible light and lasers have made, from "gas lamp" to solid-state, semiconductor-based, light-emitting diode, or laser diode. As we discussed in the May and June 2001 DPRs, the highest frequency LEDs are just now moving into the ultra-violet bands, and still at quite low powers. And laser diodes have yet to get beyond green light (although with crystal frequency doublers, their output can be pushed into the deep UV). Perhaps work on solid-state X-ray sources for X-ray lithography will yield advances, someday. But for now, X-ray projectors remain locked in Edison's world.

So the basic business of generating X-rays remains nasty, brutish, and hot. Relatively modest amounts of heat can excite atoms enough to make them emit light. But you have to accelerate an electron beam down a 100,000-volt hill to get them to kick X-ray-frequency photons out of the metal target into which they slam. Most of the century-long history of X-ray technology has centered on how to slam them that hard, without melting, incinerating, or killing everything else in sight.

The first X-ray tubes were of very low power by modern standards. Several-minute exposures were required to generate a usable image. Power levels couldn't be boosted too high, because the metal targets melted. An important innovation was the introduction of a rapidly rotating target, which supplied a more effective area to conduct away heat. A modern diagnostic X-ray unit will now have a power rating of fifty kilowatts or so, and can take pictures with fraction-of-a-second exposures. But the tubes still have to be enclosed in earthed metal housings, to protect the operator from electric shock, and the housings incorporate a layer of lead, to provide shielding from stray radiation. Lead aprons abound.

The next engineering challenge is to get the X-ray photons where you do want them. One approach, extensively used in medical and some industrial applications, is to put a molecular-sized X-ray light bulb—a radionucleotide, like Cobalt 60, whose emissions are called (by pure historical convention) "gamma rays"—somewhere near the target. But these "bulbs" aren't easy to aim, and disposal is a problem too. Go with the electron gun, and the challenge then is to form and aim a fine beam from one side of the target, and detect what comes through on the other. If you can't get to the other side—which is quite often a problem with things like jet turbine blades—you try backscatter imaging instead. In principle, it can supply the same information; the engineering practicalities, however, are a lot more difficult.

To form 3-D images of a target, you need to fire beams from multiple angles. Geoffrey Hounsfield began working out the concept and the mathematics in 1967, then waited for image-analyzing computers to catch up with the gargantuan number-crunching requirements that his scheme demanded, and was awarded a Nobel Prize for his work in 1979. Computer-assisted tomography, (as in CT or "CAT" scan), begins with a large metal doughnut that spins one or more electron-gun X-ray sources around a target, with detectors mounted on the diametrically opposite side of the doughnut. About 1,000 pulses are dispatched and picked up for each rotation of the doughnut, and then it's up to the computer. If the target advances horizontally through the middle of the ring as the doughnut rotates, you get a helical scan that can yield a complete 3-D map. The state of the art of the technology today is probably the "dynamic spatial reconstructor" research prototype at the Mayo Clinic. It consists of 14 X-ray tubes, scintillation screens, and video cameras. It can produce 3-D CT images in as little as 10 milliseconds.

Density and Z Number

But the fact remains: to get the X-ray where you want it today, you either have to mess with radioactive materials, and all the regulatory and environmental overhead they entail, or with the bulk and weight of electron-beam thermionic hardware.

Why bother with all this cumbersome, near-19th-century hardware? Why not just stay a bit lower down the rainbow, with visible light, say, or millimeter waves? Power density has qualities all its own. A typical X-ray beam—generated by a 1 mA flow of electrons propelled across a 100-kV gap—conveys about 100 Watts, little more than an ordinary light bulb. But light bulb Watts don't require a lead apron. X-ray Watts do.

Wilhelm Roentgen grasped the possibilities almost before he named the new "rays" he discovered in 1895. In one of his first experiments, he placed his hand in front of his X-ray source, to image his own bones. Within a year, Belgium became the first country to put X-rays into hospitals throughout the country. Today, medical applications of X-ray-frequency photons are ubiquitous. X-rays are also widely used in industrial imaging—to check for flaws in jet engines, steel-belted tires, gas and water valves, castings, pipeline welds, ski-lift cables, beams in bridges, and road surfaces. They are used to gauge steel quality, and to measure the thickness of materials like tin and aluminum. They spot impurities in vegetables moving down a food processing line and check for the mouse in the beer bottle before it becomes a lawsuit. Museums use X-rays to examine underlying brushstrokes in paintings. Astronomers pick up X-ray emissions from the heavens, to study "black holes," among other things, which turn out to be not quite as black as one might suppose.

Roughly speaking, the denser a material, the better it absorbs X-rays. But very few materials stop X-rays completely. Fire enough X-ray beams from enough different angles (or, alternatively, fire from fewer angles but detect "backscatter" too), and you can generate a complete and very fine three-dimensional map of the target's density. Any target will also tend to "backscatter" some fraction of the incoming photons. The fewer protons an atom has in its nucleus—i.e. the lower its atomic number "Z"—the better it tends to do so. Together, these two phenomena can provide a profile of both density and Z factor. And the ratio of those two quantities provides a molecular signature of sorts—not a perfect one, but specific enough to be very useful. Many explosives, for example, are quite dense, but are also packed with relatively low Z-number atoms, like nitrogen.

Use more of the rainbow within the broad range of X-ray frequencies, or track both backscatter as well as transmission, and you get more information. A pure transmission system, with only a single gun, or multiple guns all producing X-rays of the same frequency, can create a 3-D map of density. Use two or more beams of different frequency and a Z-number map can be formed, too. Backscatter systems are better, however, for Z-number mapping. Combine a density map with a Z-number map, and you move an additional big step forward toward specific chemical signatures and a complete, internal map of the target's chemistry.

The mapping requires, however, enormous amounts of raw computing power, and advanced software painstakingly tailored to X-ray physics and the engineering particulars of the imaging device. So much, indeed, that a new type of computing—"stream computing"—has emerged to handle the back end of sonar, radar, X-ray sources, and certain broadband applications such as voice-over-Internet and digital TV. Multiple processors, together with high-performance RISC architectures and custom high-speed communications buses, speed the flow of data among multiple processors within a chassis, and multiple chassis within a system on-board and intra-board. The software layers are equally critical, and they depend on a deep understanding of the basic physics and engineering of sight, in the frequency bands and engineering configurations at hand. You don't just hurl a 200+Mb data stream at gigaflop DSPs and CPUs, and hope for a crystalline picture to emerge.

From Hospital to Airport

Accounting for some $4 billion a year in U.S. equipment sales, medical markets remain by far the dominant outlet for X-ray technology. Familiar corporate nameplates dominate here: GE, Philips, and Siemens. A typical medical CT company may sell 1,000 machines per year to probe human bodies in hospitals.

Why don't these same companies just sell to the airports too? They haven't so far. About seven companies serve the global X-ray security-system market. Only three of them are publicly traded in the United States. And while many of them can trace their origins back to the medical side of the market, those corporate links have not been maintained.

Why not? The security-system technology is designed for very rapid—and thus, by necessity, highly automated - screening. The human body and its ills, by contrast, present a very well defined and correspondingly limited family of structures and pathologies; and both diagnosis and treatment still center on the individual physician's judgment and discretion. Suitcases by the millions stream through the catacombs of an airport, and their contents are overwhelmingly innocuous. A medical CAT scan, by contrast, doesn't happen at all until a doctor suspects there's something important to look for, and the highly trained physician has the time and attention span to look at the picture carefully. Airport machines have to run round the clock, in messy environments; medical CTs are used much less intensively, and they're coddled. You don't hear the AMA calling on equipment vendors to automate the physician out of the medical CAT-scan loop. But the FAA insists on precisely that for airports.

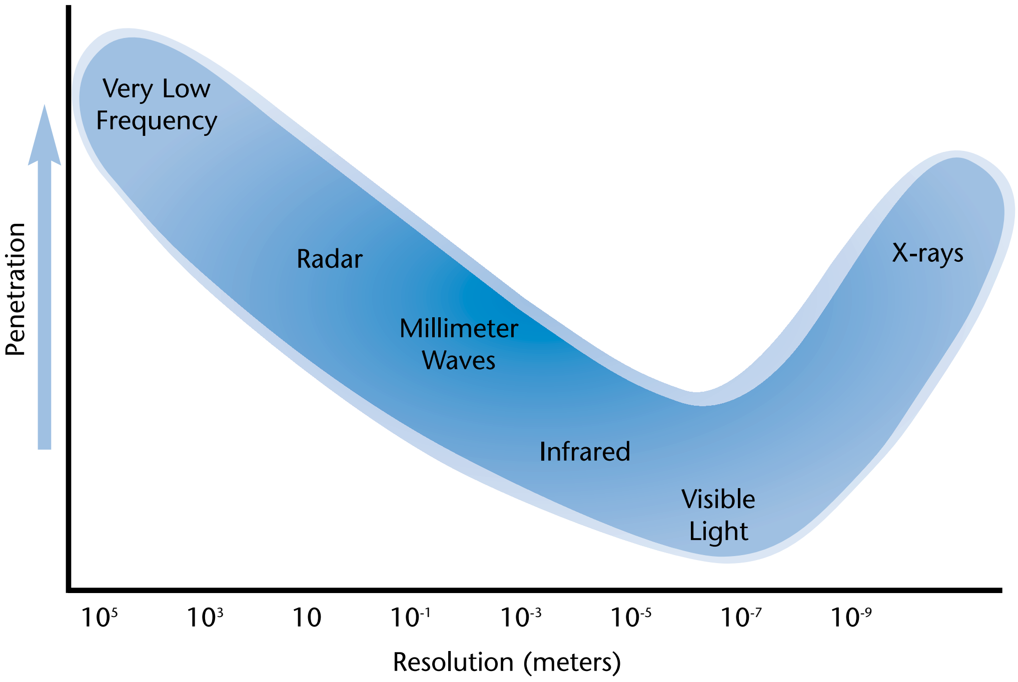
Only two players currently put their nameplates on an EDS that the FAA certifies as meeting its (classified) performance criteria for high-speed automatic (operator-free) detection. A third player will almost certainly get certified early next year. Our pick: None of the above. We have found only one company that is fundamentally advancing X-ray technology in the dimension that we consider most important—*highly ordered power*. Not just mechanical engineering. Not pure software. But rather, technology that projects or receives power itself, in new ways, that fundamentally improves the high-frequency photon power train.

Analogic was founded in 1969, by Bernard Gordon, an MIT graduate who is still Chairman today. Gordon can fairly be described as the "father of high-speed analog-to-digital conversion" (*A Sense of Power*, *August 2001*). The long list of devices he has invented includes digital Doppler radar, digital algorithms for music and video, the first fetal monitors, both mobile and instant-imaging computed tomography CT systems, beam phased-array ultrasound systems, and the first solid-state X-ray generator. He has also kept the $360 million (annual revenues) Analogic profitable every quarter from its inception. The current CEO is Thomas Miller, another engineer, who came to the company two years ago after executive stints with Carl Zeiss and Siemens Medical Systems.

Analogic is an OEM technology company. It designs, builds, and sells key components to imaging manufacturers across the board: medical, security, industrial, and others. The company divides its operations by technology, rather than market segments: X-ray Technology, Computed

Tomography, High-Speed Multi-Computer Processing, Digital Imaging, Software Development, Magnetic Resonance, Ultrasonography, and Test and Measurement Instruments. Which, as a matter of basic corporate strategy, is just the right approach. Digital power technologies are cross-cutting technologies. They slice across traditional market lines. They fundamentally advance what is very often the most technology-intensive and rapidly advancing heart of things that see, move, communicate, or think: the power train.

Power to Penetrate and See



Over the vast span of electromagnetic frequencies, there is a complex, often competing relationship between the power to penetrate obstructions and the power to resolve detail. What you "see," and how well, depends on both metrics. Visible light punches through the atmosphere, but reflects off almost everything else—so it provides high-resolution information about the shape of things all around us. Radar travels even further through the air, and penetrates clouds too—but at wavelengths too long to resolve things much smaller than aircraft, tanks, or ships. Millimeter waves don't penetrate quite as well, but can resolve much smaller objects. X-rays penetrate most everything, and can resolve the molecular signature of explosives.

With that said, Analogic does maintain front-end appearances, preserving business units by creating or acquiring subsidiaries that remain nominally organized around the specialized markets they ultimately serve. Its Anatel Communications subsidiary was created in 2000 to focus on voice-over-Internet capabilities—Analogic designed the first known commercially available DSP resource card. Its B-K Medical unit (acquired in 1992) is a world leader in medical ultrasound. Its Camtronics Medical Systems leads in cardiology imaging (founded in 1986). Its SKY Computers (formed in 1980) produces near teraflop-level image processing computers. Its Anrad subsidiary produces breakthrough solid-state X-ray detectors. And in March 1998, Analogic created a subsidiary, International Security Systems, to focus on security markets.

Analogic built up its imaging skills over the course of 30 years, in the one civilian market that was intensely interested in high-resolution 3-D imaging all along—the medical market. Analogic has pioneered medical data acquisition, as well as detector and image processing hardware and software. It is the world's leading supplier of CT Data Acquisition Systems; its products show up in three-quarters of all CT systems in use. Analogic power systems are in one-third of all medical MRI units. The company's SKY Computers has been in medical imaging since its inception, and also serves markets for signal intelligence, industrial inspection, radar, and sonar. Analogic's 15-year-old Camtronics subsidiary pioneered digital solutions for cardiac procedures. Its B-K Medical subsidiary was founded 25 years ago and has established a leadership position in ultrasonic frequencies. Two years ago, Analogic formed a strategic alliance with Eastman Kodak to develop next-generation digital radiography, built around an amorphous selenium technology from Analogic's Anrad subsidiary.

Anrad adds an important dimension to Analogic's X-ray imaging businesses. In the seeing business, better eyes substitute, at the margin, for brighter light. The alternative to more X-rays: build a better X-ray detector. Traditional X-ray imaging is a three-stage process. The X-ray photon creates an initial flash of light on a fluorescent coating on the tube (scintillation, typically from a layer of sodium iodide producing multiple optical photons). The gas then acts as an optical-photon amplifier, or "photomultiplier." The light is then recorded on photographic film (or a TV screen). To get a digital image, place a scintillation layer—for example a cadmium tungstate film—directly on a high-sensitivity equivalent of a digital camera, in which a CCD or CMOS chip is the optical-to-electron converter.

All the other vendors of solid-state digital X-ray detectors still use that two-stage approach. So does Analogic, for higher-energy X-rays that are needed for baggage scanning, for example. But an important new alternative has emerged for lower-energy X-rays, and here, Analogic's Anrad is the clear leader. Rather than go from X-ray to visible-light photon to electron, Anrad's technology goes straight from X-ray photon to electron. The only other player in direct X-ray imaging, Hologic (HOLX), buys its selenium detectors from Anrad.

Renamed after it was acquired from Noranda Advanced Materials in 1999, Anrad builds direct-conversion selenium-based X-ray detectors. Selenium is very good at stopping relatively low-power X-rays, and in converting them directly to electrical impulses—like a solar cell. The electrons are picked up by a TFT array—a transistor architecture developed by the manufacturers of flat-panel displays. Anrad is now perfectly positioned to push costs down, and performance up, on the detection side of X-ray imaging. Which is where the most important action must remain, so long as electron guns continue to rule on the projection side of the X-ray.

Analogic puts in more solid-state detectors than any other

Analogic's low-cost solid-state X-ray detectors anchor the world's most sophisticated automatic airport EDS. Analogic makes the heavily patented eXaminer 3DX 6000 under exclusive contract with Lockheed spinout L-3 Communications. The unit is the first 360° dual-energy, helical, multi-slice CT. It is also the first single-unit, second-generation CT system certified by the FAA. "Second generation" means it can gather complete data on every object in a bag in a single pass. Previously, many high threat airports required checked bags to undergo three levels of interrogation—dual-energy, followed by CT, followed by chemical trace analysis.

Analogic puts in more solid-state detectors than any other security CT—6,048 arrayed in 24 rows of 252. It's able to do so, quite simply, because it knows how to make better detectors cheaper. With two energy beams, a single bag is actually scanned about 720 times in the six seconds it's being probed, gathering ten times more data than any previous system. The massive 200 Mb/s data stream is processed by SKY Computer cards packing six Sharc DSPs from Analog Devices and six custom DSPs. Each card produces roughly 15 gigaflops of DSP image processing power—approaching traditional supercomputer territory.

With the technology assets already in hand, Analogic ranks as one of the two leading providers of stream computing—the specialized, gigaflop capabilities noted earlier, which are essential for real-time imaging analysis. And Analogic announced last month a major investment in Toronto-based Cedara (CDSW), an OEM independent medical-imaging software developer that supplies the likes of GE, Hitachi, Philips, Siemens, and Toshiba. Analogic's principal competitor in the software/computing end of imaging is its neighbor in Chelmsford, MA, the $180 million (annual revenues) Mercury Computer Systems (MRCY). Mercury's market orientation is roughly the inverse of Analogic's, with 70 percent of MRCY revenues coming from defense, with medical and industrial accounting for the balance. We like Mercury too as a pure play in streaming computing for "see" applications in digital power. But Analogic is better positioned to understand and put together the very complex interactions of power physics and engineering hardware that the software must address.

OEMs and Others

Like Intel, Analogic can sell its power-imaging technology into any market, existing and yet to emerge, by selling it through other vendors. The company's pathbreaking X-ray detectors are already sold in medical and security markets, and will in due course land in many industrial markets too, far beyond the hospital and airport applications that are attracting the most notice today. Its imaging software and high-speed number crunching cards likewise cut across markets. These technologies don't analyze "human bodies" or "suitcases." They analyze vast streams of data generated by electron guns and tungsten targets and selenium detectors. The company's A-D and D-A converters—which accounted for 12 percent of the company's total revenues last year—are used in other companies' CT scanners and radar systems. Its ultrasonic "engines" are provided as OEM systems to medical-imaging firms. Its specialty RF amplifiers go into vendors' MRI equipment. Its high-speed signal electronics form the core of test equipment used in the semiconductor (and similar) industries. Last July, Analogic formed a venture with Britain's equivalent to our DARPA for radar and electro-optics.

Others—most notably one significant Analogic customer—have headed in the opposite direction, attempting to consolidate technology and end-user sales. Wall Street duly noted the hit Analogic took in July when Philips announced its $1.1 billion acquisition of Cleveland-based Marconi Medical Systems. Philips accounted for some 22 percent of Analogic's revenues last year. (GE at 11 percent and Toshiba, 7 percent of revenue generated, are their next two biggest customers.) The Dutch (Philips) and British (Marconi) are unreformed advocates of consolidation—still much like the old AT&T, or the old IBM. We think that's exactly the wrong approach for digital power today as it shuts technology out of all the markets the consolidator doesn't serve directly. The important markets aren't just the ones that companies already know and serve, they're the wide range of new markets that coalesce around new digital-power capabilities. (Indeed, Analogic will continue to supply Philips with many subcomponents, notwithstanding the Marconi deal.)

InVision Technologies is another player with a different corporate strategy: Focus on a single market defined, largely, by a single regulatory agency. InVision is the only other manufacturer of a CT luggage screener that is currently FAA certified for automatic EDS. And it's certainly Wall Street's darling at the moment. But it's defined more by regulation than by technology. Founded in the aftermath of the PanAm Lockerbie terrorist bombing, InVision was the first company to get FAA certification for its EDS. It has the most CT-based automatic EDS units installed—some 250+ worldwide. But its huge spinning doughnuts do only transmission, not backscatter, and not dual energy. The company's primary focus is on building to FAA specifications. Whatever the FAA's virtues, few government offices have great track records in seeing over the technology horizon.

InVision was spun out of Imatron a decade ago leaving behind a technology that interests us and apparently General Electric too. GE is acquiring Imatron for its *steerable electron beam*, which makes possible the world's fastest medical CT. Steer the beam, and you don't have to spin the doughnut. Magnetic control displaces mechanical, exactly the kind of shift we like. InVision retains exclusive rights to use the beam technology for non-medical applications (perhaps it will do so, eventually). But for now, that clever asset is headed to GE. For its part, GE dominates medical imaging, but has no presence yet in security markets. The logic of all this eludes us. The same physics, the same technologies are in play across these and other markets, and will be in many additional X-ray vision markets yet to emerge.

What both InVision and L3 have to worry about most is a player yet to be named—whoever acquires PerkinElmer Detection Systems, a deeply impressive unit that is in the process of being auctioned out of its $1.6 billion parent, PerkinElmer (PKI). The company's next-generation automatic EDS product will likely get FAA certification within a few months. PKI has an installed base of 16,000 "conventional" X-ray security systems, and capabilities across all key metrics (dual energy, backscatter, software). PerkinElmer machines, used extensively in Europe, rank second (in volume) to European Heinmann's X-ray systems.

If we had to pick a public company among the crop of specialists at this particular level of the X-ray market, we'd go with none of the above; we'd go with American Science & Engineering. But as we noted, we aren't the only ones who noticed ASE post-9/11. The company sells to the less-regulated screening pack, for trade interdictions, border crossings, Customs, State, Defense, and the FBI. It makes units that can scan trucks, for example, and even people. But it lacks FAA certification, and isn't likely to get it any time soon, though it does sell airport scanners abroad.

So what's right about ASE? It acquired in 1998 a leading edge maker of high-power X-ray generators themselves—the power-centered starting point for the whole business. The ASE security scanners generate a pencil beam—a rough X-ray equivalent of the laser pointer, though not a coherent beam, using a wheel to create and aim the beam with quarter-inch precision (in cargo systems). There's no huge mechanical doughnut, and ASE has no interest in building one. It prefers to move the X-ray beam, rather than the whole hardware store. Just a "flying pencil beam" of X-ray photons, probing the target as it moves along a conveyor belt (or as a truck drives through).

And ASE's systems detect both the transmitted energy and the backscatter—which means they can come a lot closer to specific molecular character recognition. Indeed, ASE claims to have largely "founded" backscatter X-ray imaging; it has been awarded 40-plus patents, half of them for backscatter technology, some dating back to the 1970s. To pick up the weak, backscattered signal, ASE uses a large area detector.

A few other companies round out the X-ray security field. Rapiscan is a division of OSI Systems (OSIS), a $110 million conglomerate. Rapiscan's main claim to fame is that it supplies most of the airport gate checking systems. These are dual-energy systems, but quite primitive nonetheless; their main function is to produce a good enough image for an operator to make some judgment, and initiate a trace chemical analysis or physical search. Germany's Heinmann is owned by the German industrial conglomerate, Rheinmetall Group. Heinmann offers EDS capability in many European airports and non-aviation markets, but isn't FAA certified, and probably won't be. Finally, the private European based Yxlon was formed in 1998 through the acquisition of the Philips' industrial X-ray group, Andrex of Denmark and LumenX (Ohio).

X-Ray Vision

That 80 percent of Analogic's business is still anchored in medical technologies may explain Wall Street's relative lack of interest. Hospitals aren't airports.

But X-rays are X-rays. Power technologies are emerging as generic building blocks—the same ones land in computer power supplies and UPS systems and cars and factories, just like microprocessors and RAM chips do. The same ordered power, the same power sensors, the same physics, let you see a tumor or a terrorist's explosives. The core hardware is common across the platforms; to the extent there are differences, they are differences of old-fashioned mechanical and electrical engineering design: how to mount and spin X-ray sources and sensors; how to power and cool them; how to shield operators and ensure safety. Of the three companies now developing next-generation EDS machines for the FAA, two use Analogic as a major OEM (L3 and PerkinElmer).

There's nothing very pretty happening on the generation side of X-rays. Aiming systems that depend on spinning steel doughnuts don't interest us much either. The real action is on the other side of the gun (and the doughnut) in the detectors, the digital imaging computers, and the software. X-ray sight is going to move far beyond the hermetic worlds of hospitals and airports. Analogic is building the stuff that's really changing, and that's advancing fast. That puts it squarely at the center of this important photon-power space.

Peter Huber and Mark Mills
November 30, 2001

The Power Panel

Ascendant Technology	Company (Symbol)	Reference Date	Reference Price	11/30/01 Price	52wk Range	Market Cap
Project, Sense, and Control	Analogic (ALOG)	11/30/01	36.88	36.88	33.40 - 50.00	487.7m
	TRW Inc. (TRW)	10/24/01	33.21	39.02	27.43 - 45.45	4.9b
	Raytheon Co. (RTN)	9/16/01***	24.85	32.77	23.95 - 37.44	11.9b
	Rockwell Automation (ROK)	8/29/01	16.22	16.50	11.78 - 49.45	3.0b
	Analog Devices (ADI)	7/27/01	47.00	42.50	29.00 - 64.00	15.4b
	Coherent (COHR)	5/31/01	35.50	30.50	25.05 - 53.75	863.0m
Electron Storage & Ride-Through	C&D Technologies (CHP)	6/29/01	31.00	20.60	16.35 - 57.06	539.2m
	Maxwell Technologies (MXWL)	2/23/01	16.72	10.46	5.81 - 22.56	106.3m
	Beacon Power (BCON)	11/16/00	6.00*	0.89	0.75 - 10.75	38.0m
	Proton Energy Systems (PRTN)	9/29/00	17.00*	6.43	4.00 - 16.50	213.6m
	Active Power (ACPW)	8/8/00	17.00*	5.96	3.56 - 31.50	241.6m
Powerchips	Cree Inc. (CREE)	4/30/01	21.53	24.86	12.21 - 47.06	1.8b
	Microsemi (MSCC)	3/30/01	14.00	31.10	9.47 - 40.10	874.2m
	Fairchild Semiconductor (FCS)	1/22/01	17.69	24.50	11.19 - 25.35	2.4b
	Infineon (IFX)	11/27/00	43.75	19.55	10.71 - 46.94	12.2b
	Advanced Power (APTI)	8/7/00	15.00	10.45	6.50 - 29.50	91.1m
	IXYS (SYXI)	3/31/00	6.78	6.08	4.27 - 27.75	162.8m
	International Rectifier (IRF)	3/31/00	38.13	33.46	24.05 - 69.50	2.1b
Network Transmission	ABB (ABB)	9/29/00	24.24**	10.60	6.10 - 18.95	12.5b
	American Superconductor (AMSC)	9/30/99	15.38	13.62	8.35 - 36.00	278.7m
Power: Heavy-Iron-Lite	General Electric (GE)	9/29/00	57.81	38.50	28.50 - 56.19	382.2b
	Catalytica Energy Systems (CESI)	9/29/00	12.38	4.45	4.56 - 24.00	76.6m
Distributed Power Generation	FuelCell Energy (FCEL)	8/25/00	24.94	15.72	10.48 - 46.72	612.9m
	Capstone Turbine Corp. (CPST)	6/29/00	16.00*	4.68	3.20 - 47.38	360.5m
Silicon Power Plants	Emerson (EMR)	5/31/00	59.00	54.06	44.04 - 79.75	23.1b
	Power-One (PWER)	(see below)				
Motherboard Power	Power-One (PWER)	4/28/00	22.75	9.98	5.32 - 70.50	786.9m

Note: This table lists technologies in the Powercosm Paradigm, and representative companies that possess the ascendant technologies. But by no means are the technologies exclusive to these companies. In keeping with our objective of providing a technology strategy report, companies appear on this list only for the core competencies, without any judgment of market price or timing. Reference Price is a company's closing stock price on the Reference Date, the date on which the Power Panel was generated for the Digital Power Report in which the company was added to the Table. All "current" stock prices and new Reference Prices/Dates are based on the closing price for the last trading day prior to publication. IPO reference dates, however, are the day of the IPO. Though the Reference Price/Date is of necessity prior to final editorial, printing and distribution of the Digital Power Report, no notice of company changes is given prior to publication. Huber and Mills may hold positions in companies discussed in this newsletter or listed on the panel, and may provide technology assessment services for firms that have interests in the companies.

** Offering price at the time of IPO.*

*** Effective April 6, 2001, ABB was listed on the NYSE. The reference price has been adjusted to reflect this change. The 52-week range covers the period from April 6, 2001 only.*

**** The October 2001 issue closed on September 16, 2001 and was posted at 8 a.m. on September 17, 2001. Due to the markets' close in the week after September 11, our reference price reflects Raytheon's closing price on September 10, 2001.*

More information about the Powercosm and its technologies
is available on www.digitalpowerreport.com