The Air Force is edging toward the photonic future along three parallel paths.

Beyond Electronics

BY JOHN RHEA

Images "seen" by a new type of infrared missile seeker (right), being developed for the Army's Fiber-Optics-Guided Missile, appear on a video monitor. The seeker's "eye" is one platinum silicide hybrid focal plane array chip.

PHOTONICS, the technology that the Air Force has identified as the logical successor to electronics for weapon systems of the twenty-first century, is evolving along three parallel paths—but not necessarily at the same rate.

Leading the way are fiber optic data distribution networks, which convert electronic signals into streams of photons for secure, high-volume traffic within airborne systems.

Following behind are analog optical devices to replace such front-end sensors as radar and further reduce vulnerability to detection and increase bandwidth.

Bringing up the rear are new digital optical devices that would complete the job by processing the information in the form of photons rather than electrons, thus matching the immunity to electromagnetic interference (EMI) and high data rates of the other two breeds of photonics.

These are the three basic technological thrusts of USAF's new Photonics Center at Rome Air Development Center (RADC), Griffiss AFB, N. Y. Its purpose is to fulfill the Air Force's goal, as outlined in the Project Forecast II studies completed in 1986, to replace electronics with photonics wherever possible.

Of the three elements, fiber optics is the one that is here today. This technology will be employed in the generation of weapon systems currently in development, such as the Air Force's Advanced Tactical Fighter (ATF).

Fiber optic data buses will serve as the link between two types of advanced electronic systems developed under sponsorship of the Defense Advanced Research Projects Agency (DARPA): powerful front-end sensors using gallium arsenide (GaAs) analog devices from the Microwave/Millimeter Wave Monolithic Integrated Circuit (MIMIC) program, and high-capacity airborne digital computers from the Very-High-Speed Integrated Circuit (VHSIC) program.

Ever-Smaller Circuits

The reason why the Air Force identified photonics as the technology that would be pervasive throughout future systems is that today's silicon-based electronics technologies (and even emerging GaAs technologies) are approaching their theoretical limits. Individual elements on the chips, such as transistors, have to be made smaller in order to carry the increased data traffic projected for the future.

It can't be done. The goal of the VHSIC program was to get the size of the elements down to half a micron. (The human hair is about 100 microns in diameter; it would take 200 of these microminiature transistors to equal that diameter.) That ambitious VHSIC goal has been realized, and this technology is being inserted into operational systems, beginning with Westinghouse's AN/ALQ-131 jammer pod for the Air Force.

MIMIC should do a little better because GaAs has at least five times the electron mobility of silicon and should soon find its way into digital applications. Control Data Corp.,

the Navy's prime contractor on the AN/AYK-14 airborne computer for the A-12 Advanced Tactical Aircraft (ATA), is studying ways to replace conventional silicon integrated circuits on that computer with more powerful GaAs devices fabricated out of entire wafers.

Experts in solid-state physics speculate that another tenfold reduction in size—down to 1/20th of a micron, or 2,000 devices lined up in the width of a human hair—is possible before the elements become jammed so closely together that the required electrical current causes them to overheat, thereby destroying the circuits.

Beyond that point, optical devices will be needed. By handling the data traffic as photons, they eliminate the heat and power-dissipation problems inherent in electronic devices. They also reduce vulnerability to EMI and electromagnetic pulse (EMP) radiation from nuclear blasts. This is because there are fewer electrical systems to be affected.

Pushing Speed Limits

USAF is serious about pushing optical technology to its limit. One measure is the ambitious data-rate goals the service has set. According to John L. Stacy, an electronics engineer in the Photonics Center's Lightwave Signal Processing Group, the minimum goal for next-generation fiber optic data buses is to achieve data rates 10,000 times greater than that of today's 1553 data bus.

The 1553, an all-electronic device, can transfer data at a speed of one megabit (one million bits) per second, which is considered adequate for the needs of today's aircraft. Then will come the current-generation fiber optic bus, which will be seen in the Air Force's ATF and the Navy's ATA. For those aircraft, planners have specified the use of a fiber optic unit with an initial capability of fifty megabits and potential to grow to 100 megabits.

Even that rate looks primitive compared to what is expected to emerge from the next generation of photonics research. In the new R&D cycle, says Mr. Stacy, "we're looking for a new plateau of performance. We're not interested in even one gigabit [one billion bits] per second. . . . We're starting at ten gigabits."

Current research is using a neodymium/yttrium aluminum-garnet laser with 150 watts of peak pulse power as the source to generate 100 picosecond (trillionths of a second) pulses. These signals are time-division multiplexed onto a fiber optic local area network (LAN). The researchers are looking at the pulses on a twenty-gigahertz oscilloscope and report error rates of less than one in a billion.

The work at this point is being conducted strictly on a laboratory-prototype basis, using standard, off-the-shelf optical fibers such as those already used by the commercial telephone industry. The goal is to create what are known as star-coupled networks, capable of high-volume data traffic from any station on the LAN.

That's only the beginning, according to Mr. Stacy. By using pulse-compression techniques, he hopes to reduce the time between pulses to two picoseconds and increase the data rate to 100 gigabits per second. Further improvements are expected to stem from wavelength multiplexing.

Data rates like these will be needed for other futuristic, Forecast II-type systems such as "smart skins." Mr. Stacy cites the example of how the reduced weight and interference, increased bandwidth, and precise delays made possible by this technology will enable the Air Force to build advanced phased-array antennas right into the structures of future aircraft.

These powerful new data distribution systems will also enable the Air Force to create reconfigurable system architectures for mission flexibility on future space platforms, such as the X-30 National Aerospace Plane, much as the Pave Pillar architecture contributed to today's airborne information processing systems.

Analog vs. Digital

Photonics is inherently more adaptable to analog than to digital applications. Consequently, the first optical signal processors to find their way into weapon systems are likely to be analog front-end sensors. This situation is similar to the early days of computers in the late 1940s, when analog systems were competitive for a brief period until the groundwork was laid for today's universal digital, electronic, stored-program computer. Digital technology has led the way in electronics ever since. The most recent example is the relative pace of the VHSIC and MIMIC programs.

Lt. Michael J. Ward, a physicist at the Photonics Center, is working on an analog acousto-adaptive processor that may greatly reduce the vulnerability of future aircraft to hostile electronic jamming. The rule of thumb is that a radar can be jammed by only one-tenth of its required output power, so Ward is looking into optical techniques that would separate out jamming noise. This noise is converted into a measurable time delay and subtracted from the total signal in order to negate the jammer.

Another promising analog application of optical processing technologies is pattern recognition, according to Andrew Pirich, chief of the Photonics Center's Analog Optical Signal Processing Branch. Pattern recognition is an important military requirement that has strained the capabilities of conventional electronic devices that measure the intensity of the target signal. Today, Mr. Pirich is investigating use of optical filtering to provide phase information about targets.

The idea is to find the targets faster and with greater resolution, which in turn dictates the need for more powerful processing techniques capable of generating more picture elements (pixels). This research is heavily dependent on the technology of advanced materials, including barium titanate, lithium niobate, and GaAs doped with aluminum.

Analog technologies are able to carry out the vital data-fusion and threat-assessment functions, either by themselves or through use of algorithms to convert the data to digital format, according to Dr. Richard J. Michalak, chief of the Digital Optical Computing Branch at the Photonics Center. His interest is focused on the complex signal processing functions of the early twenty-first century that will require digital optical methods.

Two are at the top of his list: the Strategic Defense Initiative (SDI) task—particularly the vexing battle-management problem—and tactical command and control. In each case, throughput performance many orders of magnitude higher than that of today will be needed to achieve real-time operations. This requires parallel processing, which is being developed today for electronic systems, but it also demands more powerful digital switches.

"The premier challenge is [developing] low-power, high-speed optical gates," Dr. Michalak says. The first prototypes have been successfully fabricated. Under an Air Force study contract, Professor Chung Tang of Cornell University's electrical engineering faculty has developed such a prototype gate. In this prototype, laser diodes on a GaAs substrate can switch signals by turning the laser output at right angles. This technique, known as "mode switching," promises to bring greatly expanded efficiency. Unlike conventional electronic switches, in which the devices are turned on and off, digital optical devices can be left on at all times.

There is a problem, however. The cost of such gates will have to come down drastically. The prototype gate costs $10,000. After more than twenty years of production, the most common electronic gate—transistor-transistor logic, known in the semiconductor industry as "T-squared L"—is down to a cost of one cent per gate. That's a price differential of a million to one. Of course, T-squared L didn't start at a penny per gate, but it didn't start at $10,000, either. More economical fabrication techniques will have to emerge if optical devices are ever to challenge electronics in digital logic.

Dr. Michalak isn't sure that this will ever happen. "Electronics is good and getting better," he says. One technology that might keep electronics progressing—and at a rate at which photonics would not be able to catch up—is superconductivity. Potentially, at least, superconductivity could replicate the single most important attribute of optical devices: their lack of damaging heat and power dissipation.

There is another problem. Although optical switches don't generate excessive heat, the same cannot be said for the lasers needed to operate them. This is another worry for Dr. Michalak, who says the heat of the laser today is greater than that of comparable electronics.

As a result, says Dr. Donald W. Hanson, head of the Photonics Center, there may ultimately be a technological marriage of electronics and optics (variously known as opto-electronics or electro-optics) in which each party will retain some degree of independence in a hybrid arrangement.

The ideal solution, explains Dr. Hanson, would be to do everything within a computer optically, because optical technology possesses inherently greater bandwidth. He adds, however, that there would still be the problem of communicating with the outside world. This external connection, in which the signals have to be converted to electronic or even electromechanical formats, also is the point of vulnerability for EMI and EMP.

This, in turn, requires that technologists place great emphasis on coming up with the right overall system architecture, according to Dr. Hanson. "Replacing an optical part with an electronic part is not the best way to go because of their different properties," he notes.

That's what the Photonics Center is all about: determining the rate at which photonics can be inserted into future systems in order to complement existing electronic methods. Dr. Hanson calls this "a catalyst for technology transfer," adding, "We have to get the technology out of the lab and into some sort of product."

When the Air Force established the Photonics Center in 1987 as its focal point for photonics research, it comprised only four persons, working in temporary offices. Now, two years later, the staff numbers twenty-seven and is projected to grow to fifty. This summer, the Center is moving into remodeled facilities of its own at Griffiss AFB. This will triple its work space to 8,500 square feet of laboratories and another 7,500 square feet of offices.

Basically, the Center's work is an in-house operation at the 6.2 and 6.3 levels of research, although the Photonics Center is eager to tap local universities and industries for experts it can hire for temporary projects. "People from the outside have fresh ideas," Dr. Hanson says, "and when they understand Air Force and DoD needs, they can also take them back to their universities."

The Center is also working with the Air Force Office of Scientific Research and the National Science Foundation on some contracted research and has had discussions with the New York state government about cooperative projects. Even so, the focus remains on building an internal capability. The research program is budgeted at about $30 million a year (out of the total Rome Air Development Center budget this year of an estimated $465 million, from 6.1 to 6.4). Dr. Hanson emphasizes that it is applications-driven, not technology-driven.

RADC's commander, Col. Raymond A. Shulstad, gives special attention to practical applications. "RADC is first and foremost a laboratory and the Air Force's center of expertise in C^3I [command control communications and intelligence]," he says. "Photonics will be pervasive . . . and the drivers will be optical processing for speed and capacity."

Thus, photonics researchers stand at the brink of a potentially enormous technological advance. Barring unforeseen technical barriers, or the rise of another technology such as superconductivity that obviates the need for optical signal processing, photonics could bring about a revolution comparable to the replacement more than forty years ago of the vacuum tube by the transistor. That revolution provided the foundation for all of today's advanced electronic circuits. If such indeed proves to be the case, photonics would be very pervasive indeed. ■

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