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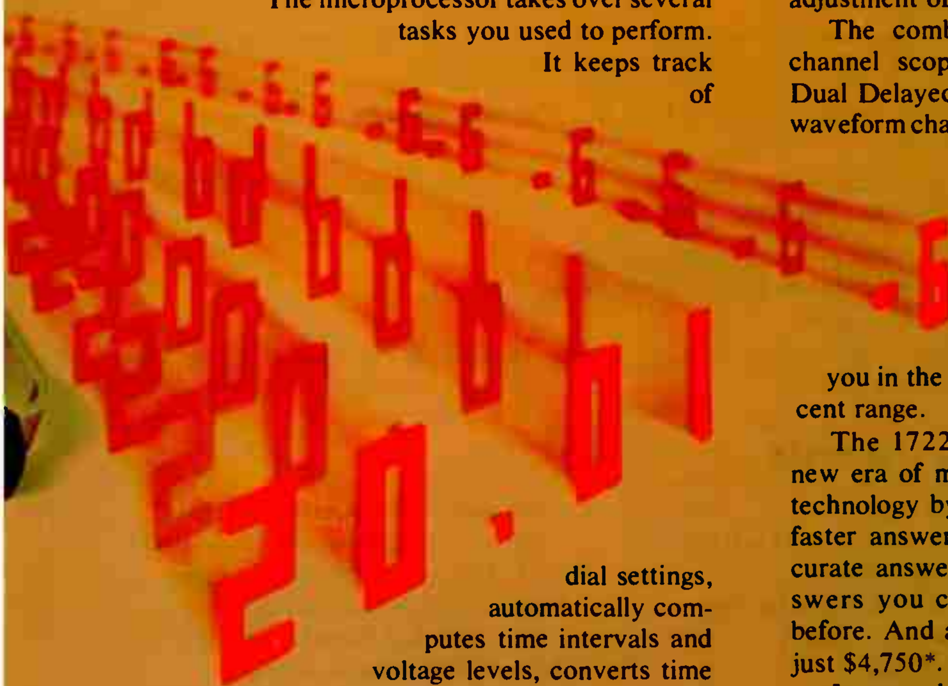

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the cover

Probing the operational characteristics of a microprocessor chip better symbolizes "probing the future of electronics" than anything else we could think of. Our "probing" report, beginning on page 41, covers components, computers, communications, and instrumentation. Motorola Semiconductor set up and took the photo for us.

spectrum

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spectral lines

A dangerous art

Engineers who have been involved directly or peripherally in forecasting the technological future know it is a game fraught with hazards—both real and psychological.

The real hazards relate to the difficulty of constructing a valid model, as well as knowing when one has finally developed a valid model. Implicit in the foregoing is an assumption that one can define "valid" when dealing with models meant to predict future events, and, of course, one cannot. One can only approximately define validity when used in this context and then judge, after the fact, that a model was or was not valid. Such judgment is empirical or, at best, statistical—not absolute. For example, if a model is used to predict a specific event or development, and indeed it does "come true," one may assume the model was accurate—but that is not a strictly logical conclusion.

If this uncertainty were not in itself enough to discourage forecasting, there is a whole raft of psychological hazards that could send the serious forecaster running for cover.

For example, technologists as a class have a natural reluctance to deal with "soft" intelligence, as opposed to facts. Thus, as a class, we virtually rebel at making predictions. We may even respond to the boss's question, "When will the project be completed?" with the answer, not meant to be flip, "When I finish it." Engineers have a sensitivity to complex factors that others (salesmen, for example) may not. Such awareness is not likely to nourish our confidence in making predictions. So we hedge. Indeed, when the concept of "alternative futures" was embraced, if not initiated, by national policy planners, it institutionalized a technique that engineers had used informally, if not unwittingly, for years: that of defining options rather than making hard predictions. It thus branded the process as acceptable, and so, possibly, eased the consciences of some of us who thought we were being merely indecisive.

A second psychological hangup that discourages technologists from indulging in forecasting is the feeling that it is neither a productive nor a creative activity—compared with, for example, designing, developing, or applying hardware. We also note some degree of truth in the observation by students of the management arts that planning and forecasting jobs in industry are often reserved for senior executives contemplating retirement rather than the young "doers."

In addition, there is a strong (and logical) tendency to discount forecasts sharply as they range further into the future. We label long-range projections with unflattering adjectives—"blue sky," "far out," or "science fiction." Such descriptions rub off on the process itself, and on the people who make them. It is little wonder that engineers urged to go on record with thoughts about the technology ten years or more hence flee the premises like mice at a cat fight.

Finally, in going on record in matters concerning our own areas of expertise, none of us wants to be wrong. We thus hesitate to be the first to participate in a forecasting exercise. It is for this very reason that some of the techniques devised for use in formal forecasting were developed.

Delphi is one. It overcomes many of the problems of a forecasting committee, which often suffers from the usual drawbacks of a jury—undue influence of a vocal minority, strong social pressures to agree with the majority, a tendency to seek agreement for its own sake, or the strong desire of the chairman to present a single "official" position of the jury. Delphi offers, instead, anonymity for the participants—in fact, they don't even know each other's identities. This permits them to respond to a "blind" administrator who controls feedback to each member during several rounds of iterative forecasting. The administrator can observe misinterpretations by one or more of the participants of certain issues or predicted events, and he is empowered to revise or clarify the questions between rounds. At each round, a participant may revise his forecast, or he may hold to a previous position even though it represents a significant disagreement from the central mode of the group, and he may support his position with elaborative statements, which are then passed back to other participants in a circumspect manner. After three or four rounds, when the administrator observes little or no change of opinions between rounds, he concludes the forecast. In so doing, certain events may wind up with little disagreement, while others may remain hazy.

For every carefully conducted forecasting exercise, there are countless informal forecasts that exploit some but not all of the elements of the formal methods. As an example, one technique borrowed in part from Delphi is to expose a "target" or dummy forecast for the experts to criticize (hopefully, not demolish!). This overcomes what sometimes seems the most difficult part of forecasting—getting started.

Indeed, the reluctance of technical experts to engage in forecasting might lead one to believe they are aware of (and wary of) statutes such as Sec. 165.35 of the New York State Penal Law, which suggests that persons "making predictions of future events for a personal fee" may be considered disorderly and charged with a class B misdemeanor!

Donald Christiansen, Editor

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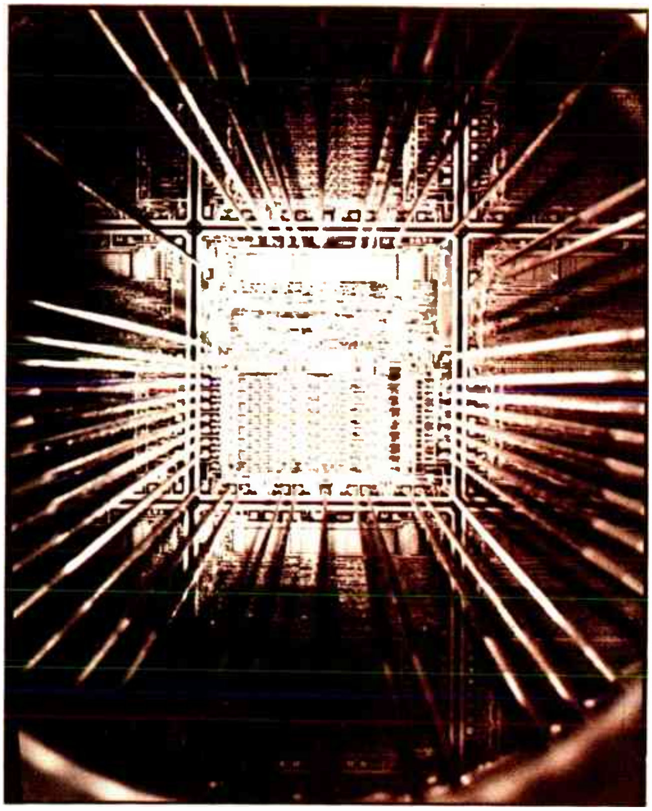


Time and technology: looking ahead in electronics

Betting men will always profit by wagering *against* the realization of technology forecasts—at least in the detail, including specific time frames, that is frequently attached to such forecasts. Perhaps the most that can be gained from long-term technology forecasting is a more accurate gage of developments in the short term. Yet even that may be worth the effort. Critics who deride forecasting as a futile exercise that cannot yield accurate results overlook its value in helping define critical prerequisite developments and in establishing probable technology trees. At the very least, forecasting helps focus the ideas of our "best guessers."

In pursuing the present study, *Spectrum* has benefited from the thoughts of experts in the four areas covered. In that regard, we have used a sort of modified Delphi process ourselves, and in the process some extremely conservative and some extremely "far out" views have fallen by the wayside. Also, in the course of generating these reports, we have, not unexpectedly, encountered some vehement, if not violent, disagreements on what the consumer/user will ultimately buy. And the farther out one projects, the greater is likely to be the "gap" among the experts. For example, some, who have time and again seen predictions of the automated "office at home" and "shopping by computer" fail to materialize, have given up hope that either will ever come about, believing that while achievable, too many people don't subscribe to the "ease" of being confined at home. Others maintain it is simply a matter of time and technology.

Regarding the series of articles in this issue, it should be made clear that while the inspiration for them stemmed in part from the Institute's Technology Forecasting and Assessment Committee's "main thrust" program initiated in February 1974, the inputs were gathered by the *Spectrum* staff from many sources in addition to the committee. As a result, the projections in no way represent an "official" forecast of the Institute or of the committee itself. Furthermore, the projections made on the following pages may raise disagreements. If so, we encourage their transmittal to *Spectrum*. Ensuing discussions, along with their supporting rationales, may help answer the question, "Do you know something we don't know?" and thereby help advance the state of the forecasting art. ◆

Donald Christiansen Editor

Communications

Fiber optics and digital microwave may be fast-moving areas in the otherwise ponderous progress of future communications

Hemmed in by a limited electromagnetic spectrum, strong competition for investment capital, consumer indifference, and even by lack of sky-room for satellites, communications technology will probably continue its deliberate progress without spectacular breakthroughs for at least a decade ahead. In telephone communications, for example, there is eventual promise in fiber optics, but even when that technology is ready, it's implementation will have to "wait on" the growth needs of the industry.

Communication satellites will soon fill all feasible synchronous orbit positions—less than 100 of these are available—and any further expansion of spaceborne communications for business, entertainment, and international contact will take place by raising frequencies to 30 GHz and higher. To squeeze costs down while boosting overall transmission efficiency, it appears that earthbound microwave links will increasingly use digital techniques. Even in cable television, an area once packed with future promise, the harsh economic realities of the late 1970s are taking their toll.

Howard Falk Senior Associate Editor

Only one way for cable

Few ideas in recent years have been more appealing to the technological imagination than two-way, wideband communications, and many attractive-sounding new services have been envisioned, for education, for business, and particularly for the home. With coaxial cable in place, connecting many TV sets to antenna facilities, the transmission medium for such service has seemed very close at hand. Experiments, using devices like frame grabbers—which allow trans-

Under the camera's eye

Part of the program for the Cybernetics and Society International Conference this year will originate in Washington, D.C., while the rest of the sessions are held at the Hyatt Regency Hotel in San Francisco. An RCA slow-scan display system, capable of operating over the telephone networks will be used—as a sort of poor-man's closed-circuit TV.

On a more permanent basis, conference TV service over telephone facilities has been in trial operation by prospective customers between Montreal, Toronto, Ottawa, and Quebec City in Canada since the summer of 1973. Here, the participants sit at a semicircular table, facing TV cameras while monitors reveal their counterparts at a similar table in another city. The conference rooms are specially designed and linked together by a leased 6-MHz channel that now costs about $300 an hour. The project was conceived as a direct means to substitute communications for travel. Bell Canada's Marketing Department checked the man-hours and money spent by employees in traveling to company meetings, and launched the system as a money- and time-saver.

Teleconferencing technology could develop, during the next decade or so, finding the right mix of low- and higher bandwidth facilities, and perfecting the display and camera equipment. On the other hand, the whole effort may be based on a misconception about what actually goes on at a conference.

Some observers believe that formal conference sessions and presentations serve mainly as a mechanism to bring together people with common interests and concerns. The truly valuable and meaningful conference exchanges, according to this view, take place across the hotel breakfast or lunch table in brief personal contacts outside conference rooms and enroute to an evening's entertainment. Mutual confidence developed through these personal contacts make the most useful flow of information possible, both at the conference and afterward. The key question may not be whether clear voices and images can flow between conferees, but whether trust, and just plain liking each other, can be built by remote control.

Bell Canada's teleconferencing system presents this array of cameras and displays to video conference participants. Life-size projection displays are to be used with the next generation of this equipment.

mission of a unique display to each individual TV set—indicate that all the other needed technology either exists or is feasible.

But, among those engineers active in cable television, there is a growing realization that the prospects for widespread two-way communications services are not bright. The cable industry has not expanded at hoped-for rates, and experimentation with two-way services has been declining. Cable has not penetrated urban areas; 90 percent of the installations are rural, designed to bring in more TV signals in places remote from broadcast antennas. Of all existing and planned cable systems, fewer than 1 percent provide for any active two-way capability. Some observers now believe that two-way cable services may not gain acceptance until the 21st century, because the basic factors inhibiting their development are economic and social, rather than technological.

Buyers and investors call the tune

When real money becomes scarce—in times, like the present, of aggravated inflation and recession—consumers become extremely reluctant to consider anything that requires added spending. Even in better times, they may be reluctant to buy services that require them to divert their attention from familiar activities. For example, instead of watching *I Love Lucy* or *Upstairs, Downstairs*, the consumer will have to want to spend time using the new services. Only dramatically attractive new services can displace existing services. But, even with strong acceptance from consumers, such services must compete with all the other areas of investment that reach out for new funds. In effect, wide-band home communications must test its worth in the investment marketplace, not only against existing communication services, but against new investments in all areas of the economy.

In recent years, the fast-growing communications and computer industries have been eating up close to a fifth of the available supply of U.S. investment funds, with the domestic telephone network accounting for more than half of this electronics share.

The total amount of private investment funds available each year now stands at just under $100 billion, and this money must cover new investments in construction, power and energy production, transportation, and all the other vital areas of the economy, as well as the areas of computers and communication.

With two-way cable television development stalled, the telephone system may be the only practical vehicle for new, and wider-band, communication services for the public. One of the most hopeful signs favoring eventual wide-band services is the recent rapid development of fiber optic technology for the telephone network. The huge capacity of these fibers promises bandwidth sufficient for each subscriber to eventually connect a 6-MHz television, and more, to his telephone line—if that is what subscribers want.

A simple overall picture of the telephone network should help set the scene for understanding how changes of this kind might take place.

A new look at the telephone

All telephone equipment can be divided into two parts: the loop plant and the trunk plant. The dividing line between them is located in the neighborhood telephone central office. Here, wire pairs from customer subsets (usually telephone handsets) connect to switching equipment. From here, individual signals are concentrated into trunk lines that connect to other central offices near and far.

By the mid 1980s, fiber optics components and techniques are expected to reach a stage where their use in telephone communications will be a practical possibility. Probably the most important missing pieces of this technology are practical methods to fabricate durable fiber-optic cables and to splice them in the field. In addition, longer-lived devices are needed, to be used as light sources. Introduction of this technology into the telephone system can be expected to begin with links between central offices, in much the same way that digital, pulse-code-modulat-

Divorce, console-style

"It's Monday morning," Bob's tape alarm announced, then added: "Approval of all specifications for the Louvay project are scheduled to be completed today." Bob stretched his toes and felt that slight tightness in his stomach that always came before he lifted himself out of bed. "For God's sake," his wife's voice was muffled and weakly complaining, "can't you save that business talk until after breakfast?"

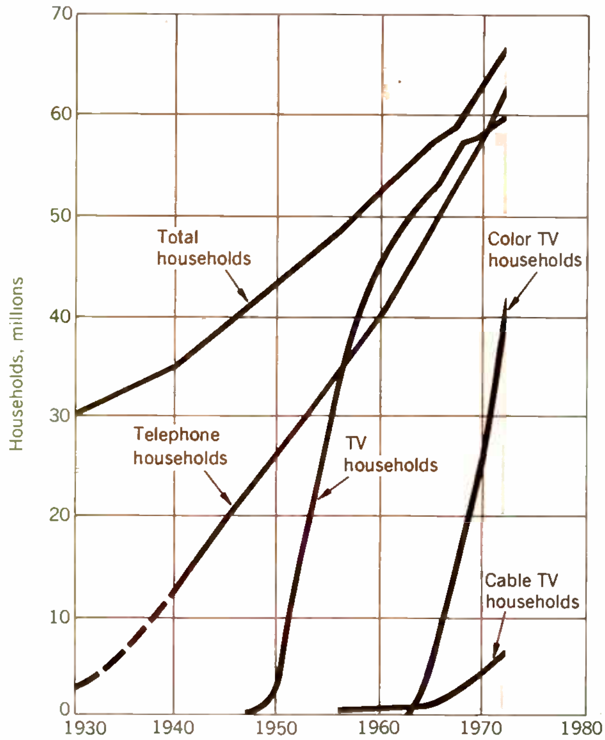
Six months ago, when his boss told him that the company's first home-office unit would be installed in his house, one of Bob's first thoughts was that Edna would be delighted. She was always complaining that they didn't spend enough time together. Now he was working at home—four out of every five working days.

From the breakfast table, after helping with the dishes, he'd go straight to the den, fitted out with a new desk, a CRT console with telephone handset, and a facsimile-duplicator unit. The console seemed to occupy most of his time. For slide-rule and other frequent calculations, he used its built-in computer. When he needed more data or had to do special design calculations, the tie line linked the console to the company's larger engineering computer at headquarters.

As a project manager, Bob often had to speak to his engineers, draftsmen, technicians, and clerical people about their work and, just as often, about the interpersonal relationships involved. He was aware that Edna sometimes overheard these conversations, and that she begrudged the personal attention he gave to these coworkers. For his own part, Bob felt very inhibited now about exchanging the sometimes flirtatious remarks that he had been accustomed to use freely in the office, and he missed the off-color jokes, as well.

Yesterday, after sending a handwritten letter to his secretary, over the fax, he had buckled down to a long-postponed review of the project budget. And, just as he was deciding to call Roger, to double-check the latest bioelement circuits costs, Edna's voice had broken his concentration: "Bob, *please* feed the cat, she's been crying for ten minutes, and I'm in the midst of an important phone call." That did it! Infuriated, Bob bellowed "Damn it, can't you see I'm working. Stop gabbing and take care of the cat yourself!"

Somehow, that incident—it had been building for weeks—tore something vital in his ties with Edna. A name flashed clearly in his mind's eye. Attorney Daniel Bronson. Oh yes, he was the sharp divorce lawyer Roger used last year . . .



Trends in recent decades show that television and color TV have, with almost incredible speed, been taken into most U.S. households. The 100th anniversary of Alexander Graham Bell's invention is upon us, but from the chart it appears that the history of the telephone as a widespread home appliance goes back only about 50 years. Cable TV rates of increase are much lower than those for the other services. (These data were compiled by Joseph G. Wohl and Gope Hingorani of The Mitre Corp., Bedford, Mass.)

ed links have been put in place during the past few years.

Eventually, fiber optics may bring broad-band capabilities to individual subscribers. As with all local loop innovations, the huge investment in existing equipment will probably act as a drag anchor, limiting changes largely to new installations, even after all technology problems have been solved. One development that could greatly speed these changes would be new revenues from enthusiastic public acceptance of wide-band telephone services, but this does not seem to be on the horizon.

Even without fiber optics, the loop plant is undergoing a slow evolution, trending toward electronic technology.

Putting changes in the loop

Today, the major innovation in the loop plant is added electronic equipment—such as concentrators and multiplexers—between the local central office and the customer's subset. To the extent that electronics can reduce the gauge and number of needed loop wires, it may be economically justified. Loop electronics is finding its place most readily where wires are long, and heavily clustered. The average loop length is about two miles, so to achieve wide use, loop electronics must beat the cost of copper wire over relatively short distances.

In the future—perhaps ten years from now—more all-embracing changes may take place in the loop plant. In a typical loop, wires from 100 customers might then lead to a local unit that would digitally encode and multiplex the customers' voices on a single cable leading to the central office. Here, the switching equipment, turned entirely electronic and digital, would link efficiently into an electronic, digital toll plant.

Today's telephones with their present current and voltage levels are very effectively designed to work with electromechanical switches. The familiar telephone instrument is an economical device, but it will not necessarily make for the most economical overall system configuration when electronic networks enter

Let your fingers do the walking

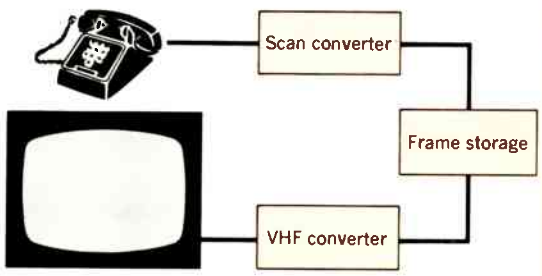
Suppose you want a stereo, a washing machine, a carpet, or a new couch to make your mate a little more comfy. Or, maybe you want to go to a new French restaurant, or take a look at the latest movie, or you might even want to take a trip to the Caribbean.

With no down payment and for only a few pennies a day, you can bring the latest, most complete information on where and how to buy what you need, directly into your own living room. No more thumbing through dog-eared, obsolete yellow pages. No more frustrating searches through the few remaining ads in your local newspaper. Just let a 1985-model Tele-vid into your home and follow these simple instructions when the unit is installed.

- Turn on your TV set, and switch to the proper channel (selected by you at the time of Tele-vid installation).
- Dial your local Tele-vid office. When you hear the clear musical reply tone, place the hand set in the cradle provided for it. Your TV should now display the Tele-vid emblem.
- Now, ask for the item you want by keying it into the touch-tone telephone. Just spell out the item: for example C A R P E T S.
- The TV display menu for carpets will appear, indicating neighborhood areas where stores are located, and showing where special sales are to take place. This menu will include the codes to get further information about particular stores. To display this information, simply key the appropriate code into your touch-tone keyboard.
- Our buying service allows you to order, or reserve, your selections immediately.

Your credit is good at Tele-vid. For convenient terms, contact our office.

With an interface to an ordinary telephone subscriber line, slow-scan techniques could be used to produce video displays, one frame at a time, on standard TV receivers. RCA slow-scan equipment now produces one complete frame-image of this kind in just under a minute. With suitable encoding techniques, this time can be greatly reduced without sacrificing the quality of the display presentation.



It's no joke, son

In New York City, you can dial 999-3838 any day and hear something like this:

One summer, Albert the Animal and two friends of his were going up to the mountains—a guy from Israel, and a guy from India—when the car broke down. They stopped at a farmhouse seeking shelter for the night. The farmer says: "Look I can put two of you up here but one of you is going to have to sleep in the barn."

The guy from India says: "I will sleep in the barn." He comes back about a minute later, knocks on the door, says "I cannot sleep in the barn, there is a cow in the barn and the cow is a sacred animal."

The guy from Israel says: "I'll sleep in the barn." He goes in the barn, and a minute later there is a knock on the door. "I can't sleep in the barn, there's a pig in the barn. I don't want to sleep with a pig."

Albert says he'll sleep in the barn. About a minute later there's a knock on the door . . . and it's the cow and the pig.

In its first month of operation, April 1974, New York Telephone's Dial-a-Joke brought in about 3 million calls. Figuring the revenues at 8¢ a call, that is $240 000 dollars in serious money. Since then, the volume of calls has varied considerably, going as low as 700 000 one month, but with expenses—mostly for advertising—running only about $25 000, it is still a going proposition.

Dial-a-joke teaches the simple, but effective lesson that, in addition to all its other roles, the telephone system can act as a medium of entertainment. Imagine what might happen if fiber optics or some other technology brought 6-MHz television bandwidth to every telephone subscriber. Dial-a-Broadway Play? Dial-a-Boxing Match? or even Dial-a-Skin Flick?

the scene. From the telephone system view, the question asked of new designs for this instrument would be: looking at the instrument, connecting lines, and local switching equipment taken as part of an overall electronic, largely digital telephone network, what is the most economical arrangement?

Satellite antennas on the roof

Businesses, particularly those that have needs for large-scale computer communications, have been aggressively seeking channels for their traffic, outside the telephone network. One of the dreams connected with these needs is that of roof-to-roof communications via satellites. Present earth stations cost about $200 000, but with such features as smaller antennas, more sensitive receivers, preassembled racks, and prefabricated housings, it is expected that rooftop units can be built for about $50 000 each. The battle for access to satellites is fought mainly in courts and Government hearings, and it is a fierce one, because the participants realize that the supply of satellite bandwidth is very limited.

Because of cross-talk, there is practical room for less than 100 communication satellites in synchronous orbit around the Earth's equator. Frequency bands used are strictly limited by international agreements. For example, present satellites are using the 4- and 6-GHz bands, but for future satellites, the 18- and 30-GHz bands will be the favored choice. Frequencies in the 11- and 14-GHz bands will not be as widely used because of restrictive recommendations made at the World Administrative Radio Conference four years ago. Considering that by 1990 there may be no more room in the sky for additional orbiting communication satellites, use of bands above 30 GHz can be expected, as the search for more bandwidth goes on.

In the sky, the trend is toward digital communication. Single-carrier-per-channel equipment, which allows the use of digital, time-division multiple access (TDMA) techniques is expected to become standard for satellites by the early 1980s. With TDMA, onboard switching will be needed, to route incoming, up-link digital signals to their proper down-link destination.

For earth-bound microwave communications, the future replacement of analog by digital equipment seems inevitable. Telephone network switching equipment, intracity links, and toll facilities are rapidly going digital, and this alone creates almost irresistible pressures to install digital equipment in microwave links—since these are used mainly for telephone-related voice transmission.

Digital transmission and multiplex equipment for microwave systems is becoming much cheaper than equivalent analog equipment. However, present poor economic conditions are slowing the introduction of new digital equipment, so that it may not be until the second half of the 1980s that the balance of existing terrestrial microwave equipment shifts from analog to digital.

As microwave equipment goes digital, it will probably also be moving upward in frequency. Congestion is evident today, in terrestrial use of 6 GHz, and the 11-GHz band is being widely used. In a few years the 18-, the 20-, and then the 39-GHz bands will almost certainly come into wide use for short hauls. Current plans for these services assume the use of entirely solid-state equipment, and the opening up of each of these bands will depend on the appearance of suitable microwave semiconductors.

Waiting in the wings for a cue from the users are inexpensive microwave systems designed to link local customers into long-haul communications facilities. Microwave manufacturers feel they already have the know-how to build equipment for short single hops that can sell for a quarter of the price of the equipment presently designed for longer-haul multiple-hop facilities. These inexpensive systems could be built to operate at lower power, with lower sensitivity, using less critical components, and they will undoubtedly be built—just as soon as there is sufficient demand. ◆

Information for this article came from many sources. Key contributors include: Eric Nussbaum (Bell Laboratories, Naperville, Ill.), Joseph G. Wohl (MITRE Corp., Bedford, Mass.), Arthur Solomon (Arthur D. Little, Inc., Cambridge, Mass.), William H. von Alven (Federal Communications Commission, Washington, D.C.), and John E. Fulenwider (GTE, Waltham, Mass.).

Computers

The scenario suggests omnipresent computers shaping future patterns of business and daily life

Shrinking processors, hardening software, and displaced programmers are some of the startling features of the possible future computer landscape. Rapid change has been the law of development of modern computers since their beginnings in the 1950s, and no one is predicting the repeal of that law during the next few decades.

How software may harden

A major driving force shaping future development of computers, is the cost of software. Today, sales are booming for the application software package, the canned program, and the partially packaged program that can be modified by the user. These represent ways of cutting corners on programming costs—letting someone devise well-written programs that can be run by many users, instead of having each user develop his own software as best he can, from scratch. In the future, canned programs may evolve into *hard software*. That is, programs would be replaced by dedicated microcomputer-type hardware. In a small business application, for example, a user might first buy a payroll-and-inventory machine, then later add chip-modules to handle automatic ordering and summary financial reporting.

The standard U.S. payroll chip might include such capabilities as the information and arithmetic needed to compute withholding taxes for each of the states, as well as the Federal government. Any one user would probably need just a few states, but this would allow a simple type of chip to be sold nationwide. As tax structures change, new chips would be produced.

One way of offering hard program chips would be to sell them out of a catalogue—the way manufacturers now sell various integrated circuits. For applications that are standard and uniform, read-only memory chips might be used. Where users require great variety, chips with at least limited programmability might be found more suitable.

The present-day computer user programs in a language that tells the computer—in minute detail—exactly *how* to do a given job. With hard programs, embodied in hardware modules, the user would determine which functions were to be performed by specifying the modules he wanted, and then using a simple instruction language to operate them. The fixed functions, possibly with some options, would be performed in a standard, predetermined way and their sequencing would be controlled by the user's language.

With hard programs, the need for programmers at the user's site would be drastically reduced. But, to put new programs in hardware form would require a large effort at the module-manufacturer's site, and that is where most of the programmers would probably be located.

The counter-trend to hardening software is softening hardware. To preserve existing software, computers—like the Burroughs B-1700—are now built so they can readily emulate a variety of different computer architectures. Considering the accumulated investments in already-written software, this emulation trend seems likely to continue.

The intense current interest in structured programming techniques may signal a future in which programming changes its character, as well as its physical location. Today, programmers are craftsmen, practicing what is often an art-form. Tomorrow, with standards, well-defined procedures, and techniques, programming may develop into a more disciplined branch of technology.

With dedicated, hard software processor-program modules, it should be possible to reduce the overhead of system operation significantly—eliminating or sim-

Howard Falk Senior Associate Editor

Optimized bargain-shopping

Many a housewife, and concerned husband, has eagerly scanned supermarket advertisements with bargain items spread across page after page of the local newspaper. So many specials, at so many different stores! But it is an almost impossible task to sort out the best combinations of bargains, so most shoppers give up the effort and remain tied to one favorite market.

This is a situation in which the handy home computer of the distant future might lend aid to those willing to forego the pleasures of touching and handling food packages, or of rubbing shoulders with their neighbors in supermarket aisles. The future housewife would dial her local ShopRcenter, and then start pecking on her 1985-model keyboard-display unit. *Cornflakes, large: 932476; chuck steak, 2 Kg. . .*" Some of the item designations would be for specific brands, like the color bar-code number *932476* that might stand for *Brand A, tiny, buttered, frozen peas.* Such numbers might be taken from the housewife's ShopRcenter printed catalog. Other items like *cornflakes, large* could indicate that any brand would do.

When the entire shopping list has been typed-in, a brief digital conversation between the ShopRcenter computer and the home computer would take place. Then, with the latest quadratic optimization routine plugged into her machine, the housewife might be gratified to learn from her display that orders had been placed at three local supermarkets at a net saving over then-prevailing prices of perhaps seven or eight dollars.

Meanwhile, back at supermarket chain headquarters, the most popular shopping optimization routines would be tested by analysts seeking to shape their plifying such items as executive programs, language compilers, and utility routines. This type of software now represents over 50 percent of the programming done for the typical user, and in the average middle- to large-scale computer, 50 percent of the processing time is spent on such overhead functions.

Like the programmer, the computer maintenance technician may see drastic future changes in his function. Maintenance now runs to 30 percent or more of computer system operating costs. In the future, with fault-tolerant system modules, this figure may drop to only a few percent.

The shape of future systems

The path of development of the computer industry is strewn with discarded systems, scrapped while they were still working as designed, thrown aside to make way for newer models with increased processing capabilities. Few people, with the exception of used-computer salesmen, have given much thought to this wasteful process. It has seemed quite natural in a society that expects a new model of every automobile every year.

But these social expectations are clearly beginning to change as energy and materials come to be viewed as limited, even precious resources. This year, some automobiles are advertised to last 20 years and more. For the future, we probably have the science—if not the technology—to make them last even longer.

Only a few decades ago there was rapid development of automobile technology, just as today there is an almost explosive blossoming of new computer developments. With processing speeds headed rapidly upward and hardware costs plummeting, new systems have seemed mandatory. But there is a new trend, now underway among computer designers, toward longer-lived computers. This trend may soon begin to shape the coming generations of computer systems. It centers around the idea of fault-tolerant modules and is motivated by the prospect of reducing system maintenance costs. Until about a year ago, fault-tolerant features were thought of mainly in connection with aerospace and military computers, but increasing thought is now being given to their possible commercial applications. While some basic design problems remain to be solved, the very low cost of integrated logic makes a fault-tolerant computer system module, which carries its own spare parts bank, economically feasible. Such fault-tolerant modules could survive for 20 years or longer, embedded in systems whose other modular sections could change. Today, the Burroughs 6700 system allows older 5500-series central processor units to continue to function while interconnected to newer units.

What will the modules of future computer systems be like? Some of them may look very similar to those we see today, but there may also be some dramatic changes.

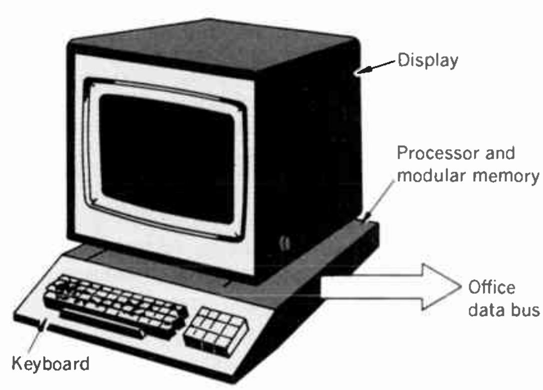
weekly specials so that their stores will get the lion's share of the ShopRcenter orders. With the development of economical automatic speech recognition hardware, the housewife could try to convey her shopping list to the ShopRcenter computer in words. For example: *Housewife:* Last time I asked for strawberries and yams, I got a jar of strawberry jam! *Computer:* Two jars, strawberry jam... next item please.

This MCM portable terminal (Micon Industries, Oakland, California) was built with telephone communication between deaf persons in mind. In quantity, this unit sells for $850, still too high for mass consumer use, but it suggests one kind of equipment the optimizing shopper might use in the future.

Filed but not forgotten

A fixture in every office, the filing cabinet holds all the records, essential and trivial, that make up the working store of information and the historical material needed to carry out daily activities. Can this familiar stand-by, raggedly bristling with odd-sized and colored papers and folders, be converted into an efficient electronic mechanism? What will happen to the scarves, gloves, and rubbers, the whiskey bottles and sandwiches, tucked away in the rear spaces of bottom drawers? Lovers of age-yellowed pages and hand-scrawled comments will be saddened by the news that the 1985 file cabinet may be nothing more than a lunchbox-sized mass-memory connected to a desktop CRT display, an electronic typewriter, and an intraoffice cable that joins to other, similar files.

If we allow for automatic speech recognition, the dictating machine of the future may also be connected to the electronic file. Then, every lightly spoken thought could become an immediate part of local office history.



The central processing unit (CPU) is often mistakenly thought of as the main information-processing tool. Actually, the major tool now consists of programs and hardware interconnected with CPU functions. More and more, in practical systems, the interconnection takes place over communication links, and the memory file emerges as the heart of the system, while the CPU becomes increasingly invisible.

We can think of the future CPU as a distributed processing unit (DPU). DPUs will be the seasoning for the large system, to be sprinkled like salt and pepper over the main pieces of computer hardware: displays, terminals, memories, electromechanical devices, and communications links.

In large part, it is the relatively slow pace of technical development of bulk memory and peripherals that is likely to make them loom physically and economically huge, while the rapidly mutating CPUs shrink into relative insignificance.

What can we expect from future memories? Semiconductor memories are already displacing magnetic cores as the dominant computer main memory technology. Semiconductor registers, random-access memory, read-only memory, and programmable read-only memory will become increasingly important, as more programs and logic take the form of memory hardware. In the bulk storage area, conventional magnetic technology is still being squeezed for incremental improvements; particularly in the form of higher-density recording on tapes and disks. These improvements are likely to shut competing technologies out of wide-spread use in the bulk storage application area. Charge-coupled device (CCD) memories promise to reduce the access-time gap between microsecond, random-access main memory, and millisecond disk bulk memory, but CCDs will probably supplement rather than replace the disks.

Despite the great emphasis given to magnetic bubble technology by researchers at IBM and Bell Laboratories, there is considerable skepticism about the practical ability of this technology to compete with CCDs. For huge, archival memories, holographic optical systems remain a possibility. A promising dark horse is the electron-beam memory.

As far as existing types of conventional computer peripherals go, little or no performance improvement seems likely for card readers and punches. And demand for such equipment will probably continue to decline. Nonimpact printer developments have brought some performance improvements in recent years, and this can also be expected to continue during the next few years.

One development, which may take place even before 1980, is a low-speed optical character recognition unit selling for about $500. Such a unit would be able to input typewritten or printed pages into computers, but would probably not be able to handle handwritten inputs, since that capability involves still-unsolved pattern recognition problems.

Recent progress toward lower-cost, more powerful CRT terminals has been rapid, and this trend seems likely to continue. "Intelligent" terminals, perhaps using video tape for graphics recording can be expected—during the 1980s—to combine or replace pre-

Acidosis diagnosis

Acidosis is a condition in which the pH (acidity–alkalinity) of the blood is higher than normal. This condition was the subject of an experimental conversation between a doctor—using a touch-tone telephone keyboard—and a computer-based system that delivered spoken information. This is the way the beginning of that conversation went:

Computer: This is the acidosis program. Do you want descriptive information about this program?

Doctor: (Keys in "No".)

Computer: To begin the acidosis program, enter a value for total CO_2 in the range between one and twenty-five millimoles per liter.

Doctor: (Keys in "10.0".)

Computer: Next, enter a value for pH.

Doctor: (Keys in "7.00".)

Computer: Based on the input values of one-zero-point-zero-zero for total CO_2 and seven-point-zero-zero for pH, the computed partial pressure of CO_2 is three-seven-point-one-five milliliters of mercury. This represents a dangerously low bicarbonate and/or pH, and could be immediately life-threatening if left uncorrected. Therefore, while the etiology is being delineated, bicarbonate therapy should be commenced. . .(and). . .Appropriate pulmonary evaluation should be undertaken.

Doctor: (Keys in "continue".)

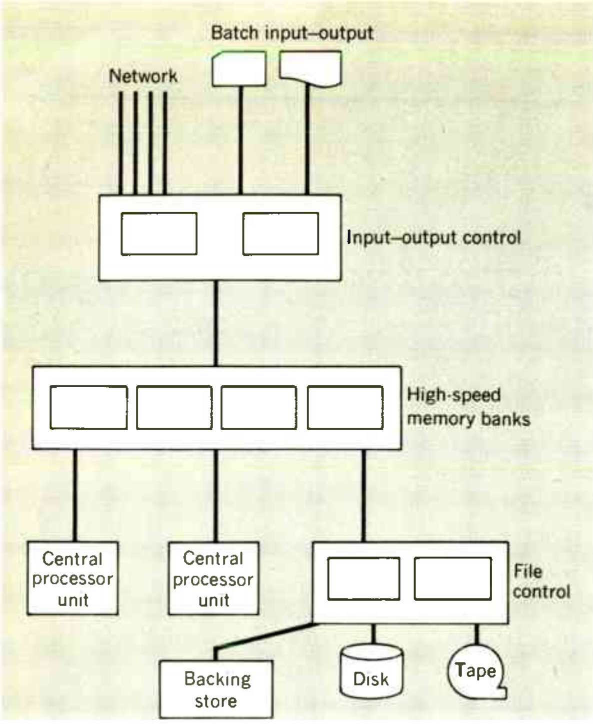
Computer: The next step in this program is to determine whether the acidosis condition is associated with a normal or an increased anion gap. Data is required for serum sodium and chloride. . .

This computer-based diagnosis was applied to a very limited area of human illness. But, in principle, it could readily be extended to many of the other areas. The needed electronic technology is available now, but reducing the necessary knowledge to computer-usable form would probably take 100 man-years of effort and a few million dollars. This may be an idea whose time is near at hand. Physicians might welcome this memory-jogging capability because it could let them handle diagnoses faster and more thoroughly. But there are also uncertainties for them: What part of their fees would flow into the service? Is is better to share responsibility for a diagnosis with a colleague, or with a computer?

Computer-driven traffic

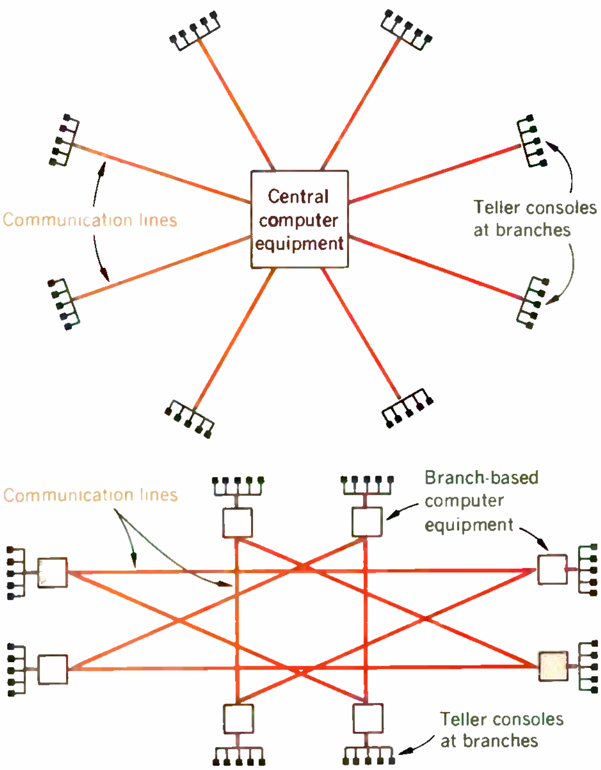
Driving to work in 1985—if you can afford the fuel to run your car—you'll probably find the traffic lights computer-controlled. The system will likely be based on street-corner microcomputers, communicating with a central traffic-optimizer. Traffic light changes, lane adjustments, and even changes in direction of traffic will probably be computed from patterns of traffic flow. The objective of the system would be to maximize the overall flow.

That's nice. Not so pleasant, however, is the realization that achieving this objective means severely penalizing drivers who try to get around established patterns; for example, by taking side streets. Those who try this become obstacles to the main traffic flow and would find themselves waiting long minutes at intersections where they tried to reenter the main flow. This penalty clause is a general principle in such flow situations. To optimize flow, there have to be optimum distribution patterns of flow. Any small deviation from a given distribution then causes a steep loss from the optimum. So, drivers who feel their judgement is better than that of the control system would be penalized for their displays of ego.



[1] **Fourth generation central computer system. According to Frederick G. Withington (Arthur D. Little, Cambridge, Mass.), this next-generation computer will offer many significant new features. These will include: automatic management of several central processors as well as of memory files and communications; fail-soft operation, with failed modules signaling their own illnesses; dynamic reconfiguration of the system to emulate other systems; interactive program development capabilities; and a simplified system command language.**

[2] **Two possible system designs for computer services to eight branch banks.**



viously separate input–output and simple computation functions economically. These could include keypunch-type keyboard input, paper-tape input, teleprinter functions, and typewriter functions, as well as those of accounting machines.

Along with new, and changing system parts, the overall shape of future computer systems may be quite different from present designs.

Computing power: centralized or distributed?

Today computer system design is still trying to absorb the full implications of the dramatic demonstration of distributed computing power afforded by the ARPA (Advanced Research Project Agency) network—a nationwide interlinking of dozens of computer installations. At the same time, advocates of the ever-larger CPU are feeling the impact of the evident failure of present-day supercomputers to meet performance expectations.

There is a running battle—at least in the minds of computer system architects—between the distributed system model, with many scattered processors, and the system built around a single, large, central computer. For a closer look at the emerging alternatives, consider the computer system serving a chain of bank branches. Today, the typical system is a large installation that reads incoming checks, prints out statements, etc., on a batch-processing basis. During the next few years, we can expect that each bank teller will have a terminal, with its own microcomputer, in communication with a large central file so customer transactions can be immediately processed against that file. Customers will be able to make deposits and withdrawals from any branch. In fact, some banks have already installed terminals of this type. The checks still come in and monthly statements are still printed out by equipment at the big central file.

An alternative future arrangement is to break up the central file into separate branch-bank files, with data communications links between them. Then, the information on each customer account resides in a particular branch. If the customer uses a teller at another branch, the system must link the transaction back to the branch where his file resides. This multifile network arrangement is used today in the nationwide Ramada Inn reservation system. Each inn holds its own status file; inquiries and reservations are handled by data communications to the desired inn.

Some central files, like those maintained by manufacturing companies, may have to respond to many different kinds of queries. For example, in response to a big order, a manufacturer may want to change his overall production schedule and distribution plans immediately—and give the customer an immediate answer about when he'll get delivery. This kind of problem still requires the use of a central data base to obtain the various dimensions of inquiry and response needed. Although there is some research into the use of multidimensional distributed files, there is no known way, at present, to manage all the necessary references and updates. ◆

Information for this article came from many sources. Key contributors include: Earl Joseph, Sperry Univac; Paul Willis, Teledyne Geotech; Frederick Withington, Arthur D. Little, Inc.; Richard Martin, The Mitre Corp.

IEEE Spectrum's key area forecasts

	1975–1978	1979–1981
Components and devices	• Some CCD memories • Large-capacity bubble memories (10^{10}b/in^2) • I^{2}L logic for consumer and instrument applications • Wider use of liquid crystal displays • LEDs as displays in most instruments • Finer ion-implantation processes	• Flat-panel plasma displays • Maturing of microprocessors • CCD TV cameras • CCD IR imagers • IC CCD chips with imaging and signal processing on the same chip • Commercial ICs with 0.5-micron lines using E-beam/X-ray lithographic techniques • IC logic with 100-ps rise times
Computers	• Hard software, packaged application programs in semiconductor chip form • Microprocessor-based computer systems for small businesses	• Low-speed, low-cost optical character recognition devices • Computer-based medical diagnosis • Microprocessor-based urban traffic control
Communications	• Electronic multiplexers and concentrators in telephone local loops • Time-division multiplex switching for data communications	• Direct satellite channels for data users • Single carrier per channel and time division multiplex equipment for satellites • 18–23-GHz earthbound microwave links
Instruments	• Economically feasible digital delay lines to store A/D converted signals for display and analysis • Economical solid-state instrument program and data storage, without battery backup • Economical dedicated annunciator panels such as custom liquid crystal displays • Lower-power, lower-cost alphanumeric multiple character displays with some autoscan logic integrated into them • Commonplace hard copy for permanent human readable records • Programmed logic in decreasing-cost instruments • Inboard microprocessors in all moderately priced analytical instruments	• Lower-cost sensors • Industrial data terminals in easily portable sizes • CMOS-SOS in hand-held DVMs and portable data terminals, all battery operated • Frequency conversion (GHz to kHz), security monitoring, data handling, and instrument programming using CCD TV cameras to read CRT oscilloscope images • IR imagers in instruments used for studying live tissue samples • Reading and executing progress from optically stored data on cards (combined microprocessor and CCD imager) • High-speed, real-time counters at the price of today's 15-MHz general-purpose counters

1982–1984	1985–1987	1988–1990
• High-reliability AlGaAs laser diodes permitting long-distance optical telecommunications lines in the 0.8–0.9-wave-length region • Wider use of aluminum and aluminum alloys to replace copper • GaAs and InP materials for devices operating in THz range • Instrument preprocessors using optical methods for signal processing (e.g., transforms, correlations)	• Electrochromic computer and instrument displays • CPUs using cryogenically cooled Josephson-junction devices • FETs with 1-ns switching speeds • Solid-state traveling-wave amplifiers	• IC functional densities to line widths of 0.1 micron or less
• Fault-tolerant long-lived computer system modules • Intelligent CRT terminals for general office use • Electronic office files and communications	• Home computer terminals connected to telephone communications • Computer optimization aids for consumers • Computer-controlled artificial organs	• Practical voice-operated typewriters
• 900-MHz portable telephone systems in urban areas • Fiber optic telephone trunks • Low-cost microwave equipment for short-haul use	• Digital encoding of subscriber telephone signals • Predominantly digital earthbound microwave equipment • 30-GHz satellite transponders	• Beginnings of local loop telephone service offering 6-MHz bandwidth
• Higher-level microprocessors in instruments • Reliability limitations to future growth in instrumentation capabilities • Optical data busses for instruments • Continued reduction in cost and size of microwave-based instruments for velocity and distance measurement, auto collision avoidance, etc. • Practical optical computers • Measurement "service bureaus"	• Drastically reduced manufacturing costs to produce man-machine interface components—more communication for less cost in instruments • High-frequency waveform synthesis, high-speed multiplexing applications, and increased time and amplitude accuracy in gating sample and hold. Very high speed D/A converter systems based on pulse duration approach • Continued expansion of microwave use in distance measuring and collision avoidance applications, as well as reduced cost, increased stability (and lifetime) microwave sources for calibration and test functions	• Microprocessors for almost any instrument application • Expansion of IC manufacturers into the high-volume, bench-top instrument business • More compact instruments with more capability (voltmeter in a wristwatch case; oscilloscope in a probe, perhaps with "eye glass" display) • New functions (heart-rate and arrhythmia counters with a tie-clip-size package, blood-pressure meters built into a wristwatch band, etc.) • Digital signal processing in a hand-held voltmeter

Instrumentation

In the offing are low-cost sensors; voltage-tuned, wide-range signal sources; signal-sequence generators; CCD displays; and much more

Complex measuring systems with sensors providing inputs much like nerves in the human nervous system, instrument "service bureaus" that receive transducer inputs from customers and return measurement data to them, and instruments that generate signals for an entire test sequence with a single key stroke —these are but a few of the exciting new instrumentation developments in the offing. The technological "breakthroughs" in the instrumentation art will occur when ways are found to meet present and future measurement needs and as technological breakthroughs in other areas motivate the conception of new kinds of instruments.

You can't measure what you can't detect

In the environs of a fast-paced instrumentation technology, the sensor and/or transducer is an enigma. During the past 100 years, there have been few basically new transducer developments other than the solid-state pressure transducer and the quartz thermometer. As a result of this dearth of new transducers, instruments have often been transducer-limited. In the growing field of pollution control, for example, no sensor (and, consequently, no instrument) presently available is as good as the human nose for identifying odors, as good as the human tongue for detecting taste-altering pollutants in fresh water, or even as good as a rainbow trout for detecting soluble, toxic liquids in fresh water.

Another transducer-limited field is that of nuclear power generation where a need exists for high-accuracy sensors. In developing a nuclear fusion system, a micro "sun" must be generated inside a container. To do so requires extremely accurate aiming and timing of any device that is used to guide atoms at the center of the container so that they will collide to produce an atomic reaction. A laser-beam instrument may be the best type of instrument for the task, but it would require attoprecision accuracies (measurements to 10^{-18}), a precision that is beyond the capabilities of existing sensors.

One promising technique for circumventing the instability problem of some existing transducers and, thereby, removing limitations on their application in measurement systems, lies in the use of microprocessors. In the past, the development of sensors has concentrated on those devices with reasonably linear outputs with respect to the quantities being measured. With the availability of low-cost microprocessors, the situation has changed. A sensor needs to be very stable or else very linear. A microprocessor can linearize the sensor's complex output curves. A sensor with poor stability combined with a local transfer standard can be calibrated quickly in the field, just prior to taking a measurement, by a microprocessor that is an integral part of the measuring instrument. Presuming the availability of a local transfer standard and good linearity or predictable nonlinearity, long-term stability becomes a minor problem, and a backward look at transducers previously rejected may be the forward-looking thing to do.

Another barrier to increased use of transducers is their cost. A major breakthrough in the sensor field may be on economic rather than technological grounds. Y. T. Li of M.I.T.'s Department of Aeronautics and director of the M.I.T. Innovation Center, who also serves as board chairman of a transducer manufacturing firm (Setra Systems), envisions a gradual reduction in the cost of sensors and an accompanying demand for large quantities of them—if the present recession ends. As a result, he says, a data channel in an instrumentation system that now costs $200 or more, may move toward $20 and, eventually, to just a few dollars. Professor Li feels that once sensors have become relatively inexpensive, they will be used for a great number of sensor points in complex systems somewhat analogous to the human nervous system. The huge amount of data generated by the sensors could be handled easily by existing computer systems.

The transducer in the future may be the only part of an instrumentation system in the actual possession of the person requiring the measurement. Measurement service bureaus, akin to time-shared computer systems of today, may come into existence. A customer of such a service bureau would send transducer outputs, coupled to telephone lines, to the bureau. The customer would get back from the bureau the measurement result he needed without actually buying any instrumentation other than the necessary sensors and, possibly, signal amplifiers and some sort of display device.

The service bureau trend, however, is perhaps less likely than one based on the component revolution, which allows impressive number crunching for less than $100 factory cost today and probably for $12–$18 in just a few years.

What's ahead in signal sources

The proliferation of commercially available signal sources—signal generators, sweepers, function generators, pulse generators, synthesizers, etc.—operating at frequencies from the subaudio up through the millimeter wave region, will probably continue unabated as frequencies are extended, powers are increased, distortions are reduced, and stabilities are improved.

In the microwave frequency range, backward-wave oscillators are already being replaced by voltage-tuned solid-state sources that can cover the entire

Ronald K. Jurgen Managing Editor

range of 2 to 18 GHz in a single sweep. These new signal sources offer increased performance and reliability and decreased cost and power consumption. Work is underway to extend the frequency range of such signal sources even further so that low-cost, fundamental oscillators can cover much broader frequency ranges. The limit to such progress may be inability to shrink device geometries down to the submicron region. As outlined elsewhere in this issue (see page 59), X-ray lithographic or electron-beam techniques and other process innovations may make these geometries possible.

Microwave device and circuit technology has already progressed to the point where a one-to-one correspondence between the frequency of a fundamenal oscillator and what comes out its business end is no longer going to be necessary. The oscillator user doesn't need to know about all the switching, mixing, and multiplying that is taking place behind the front panel. In future instruments, it will all be taken care of automatically.

Instruments are now capable of generating sequences of precise signals of arbitrary frequency and amplitude. Frequency synthesis techniques to provide accurate frequency control and microprocessors to provide program control are making such instruments possible. So far, the sequences are just simple linear sweeps but, in time, entire test sequences may be stored within an instrument and executed with a single key stroke or system command. A sequence of signals generated by such an instrument could be used to stimulate a system over its entire operating range to check for proper performance. Margin testing could be performed by extending the operating range and watching for the first signs of failure. By being able to modify the measurement sequence, the instrument would be even more useful.

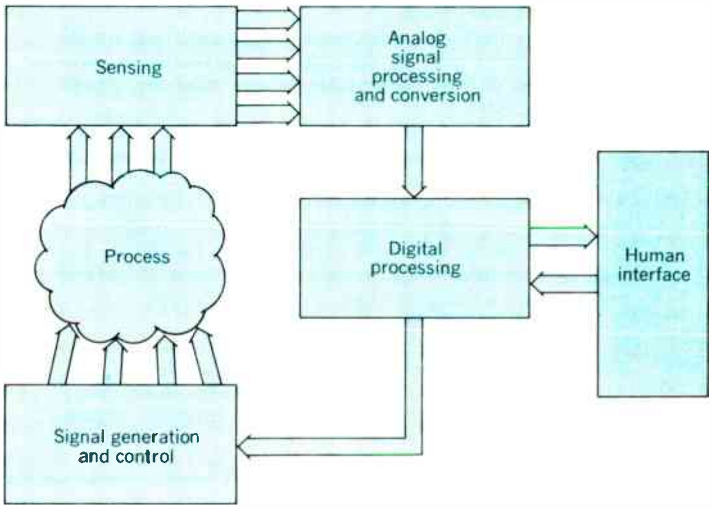
Displays and digital processing

Low-cost, multicharacter-position, alphanumeric displays, such as are now possible with charge-coupled, light-emitting devices, will become commercially available in quantity. They will replace the few-character-position, numeric-only, dedicated-annunciation displays that are now in use. With these new displays, a single front-panel design may serve entire families of instrument products. In fact, a single physical assembly may be common to several families. To make these new displays possible, programmed logic and digital, as well as analog, design approaches will be needed. As the increased use of microprocessors brings their unit price down, the programmed logic approach will be used in lower and lower cost instruments.

Hard copy for permanent human readable records will become more commonplace in instruments. Inexpensive thin-film thermal print heads are already being used as well as even simpler print heads for dry electrosensitive paper. These heads can produce parallel printing at line rates of from two to more than ten lines per second. Complete printer subassemblies are already here at a factory cost of less than $200.

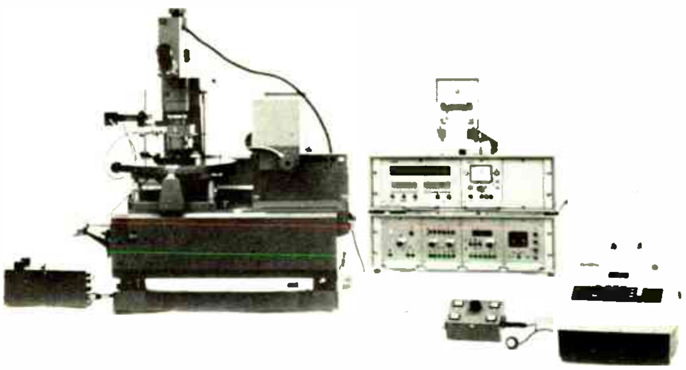
The removable media read/write form of memory will be a basic requirement for instruments of the future that will take over the bottom end of the present automated systems market. Simple, but costly, systems synthesized from conventional instruments and calculators or minicomputers will be replaced by complete systems disguised as instruments.

New levels of performance will be attained at less cost through use of digital processing capabilities combined with passive analog components (such as thin-film resistive networks) and design approaches yielding inherently linear operation (multiple-bit, successive approximation, A/D conversion). Digital integration will be possible from multiple ac line synchronous A/D conversions. More stable passive components and voltage reference drives will permit greater times between calibrations. Post A/D conversion digital error correction, including correction for zero error and gain error with linearity inherent by design, will also contribute to stretch-outs between instrument calibrations.



The hypothetical automatic test system shown starts and ends with the "process." It can be as simple as a resistor of unknown value or as complex as a complete oil refinery. Trends in the boxed areas are discussed in text.

Very close tolerance requirements for LSI, memory, and general MOS devices make necessary dimensional inspection of photomasks and reticles to extremely fine dimensions. This new linear digital comparator from E. Leitz, Inc., incorporates an optical encoder with a phase grating that controls the travel of a stage holding a photomask to an accuracy of ±0.000005 in.



Critical measurement needs and standards for modern instrumentation

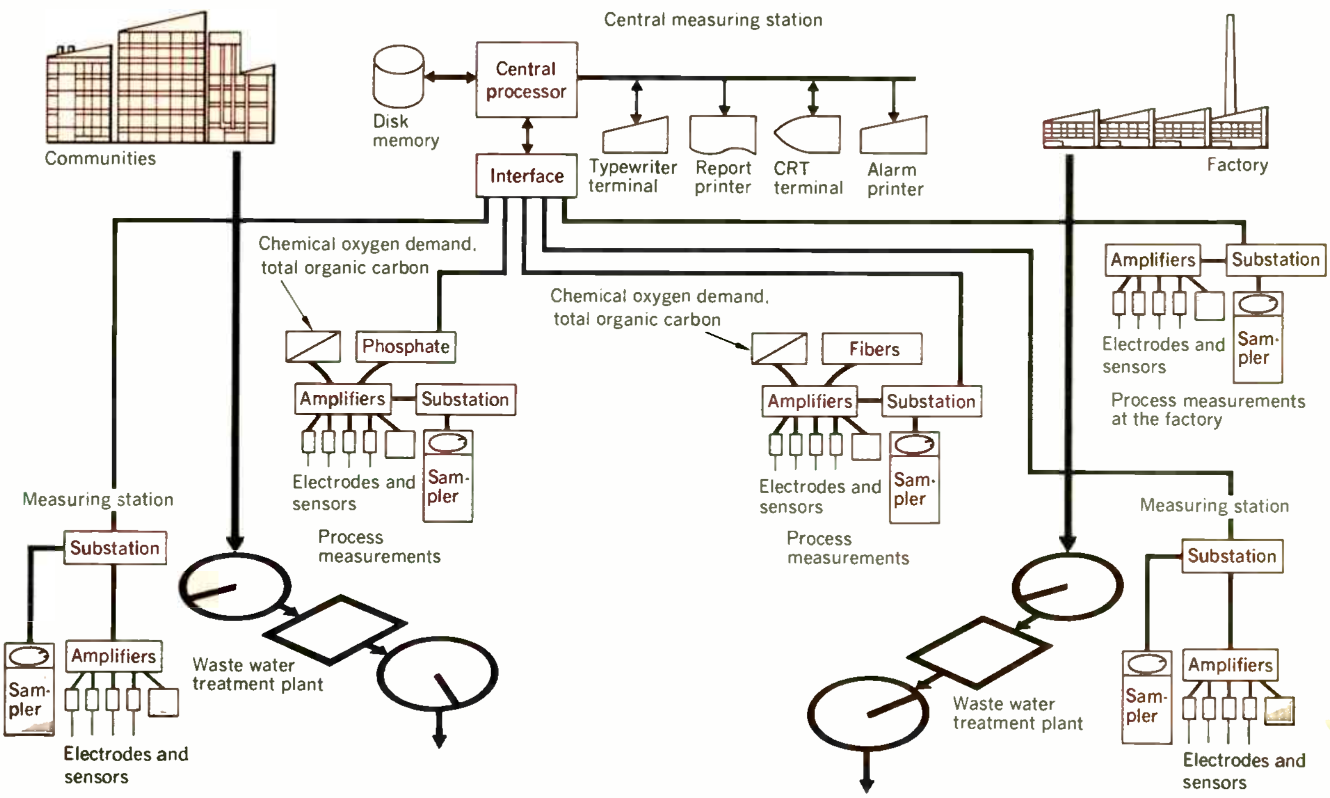
The Electricity Division of the National Bureau of Standards sponsored recently a workshop in Gaithersburg, Maryland, for the purpose of identifying the most urgent technical needs of the manufacturing and user communities in the field of dynamic electrical measurements and electronic instrumentation. The needs, as broadly delineated by the 25 instrumentation experts at the workshop, are as follows:

1. The need to introduce time as a measurement parameter has resulted from the requirements of automatic test and control systems. Specific areas considered critical are:
   - A. Pulsed component measurements.
   - B. Dynamic performance characterization for modern signal conditioning and data conversion devices: digital-to-analog and analog-to-digital converters, sample-and-hold amplifiers, comparators, etc. Required measurements include settling, aperture, and acquisition times. Basic new capabilities will be needed, including precision, nonsinusoidal waveform generation, and "standard" digital-to-analog converters.
   - C. Methodologies and techniques for characterizing precision ac and dc sources and measurement devices with respect to settling time.

2. The emergence of measurements into the "real world" of the production line via the automatic system has introduced a host of new parameters. Areas requiring significant effort include:
   - A. Investigation of transportable standards for validation of static and dynamic system performance: ac and dc voltage, resistance, pulses, and settling times.
   - B. Techniques for characterizing sources and measurement devices in regard to switched or dynamic loads.
   - C. Prediction of long-term performance, reliability, and lifetime from short-term evaluation for a host of passive components, semiconductors, and signal sources.
   - D. Noise standards and methodologies.
   - E. Continuing effort to improve transportable dc standards, and dissemination at higher voltage levels.
   - F. Characterization of the ac line voltage—waveforms, under- and over-voltages, transients, dynamic impedance, etc.
   - G. Inclusion of a capability for environmental control and variation for devices and instruments under calibration, in all new work undertaken by the Bureau.
   - H. Extension of Measurement Assurance Programs (MAPs), especially into A through G above.

3. Recent work at the leading edge of measurement technology in electronics has resulted in the need for new, or higher-accuracy measurements. For example:
   - A. Increased dependence on capacitors as storage devices has made dielectric hysteresis a parameter of importance. Significant measurement work should be started in this area.
   - B. Phase difference measurements to extremely high accuracies are needed to calibrate industrial instrumentation.
   - C. Higher accuracy power measurements, particularly for nonsinusoidal waveforms, are needed to calibrate instrumentation used in the field.
   - D. Nonsinusoidal, high-crest-factor precision signals are needed to calibrate true rms converters and meters.
   - E. High-accuracy electronics instrumentation requires reduction in ac calibration uncertainties to 10 ppm, at least over the audio range.

4. Longer-term "frontier" areas in each of the previously listed groups include:
   - A. Measurement problems in systems, including effects of history, measurement interactions, self-calibration, etc.
   - B. Evaluation and standardization of system software.
   - C. Calibration of medical equipment.
   - D. Replacement of standard cells.
   - E. Replacement of thermal ac/dc converters.
   - F. Nonswept but broad-response measurements—impulse, noise, other.
   - G. Basic work on the physics of dielectric absorption, component drift, device noise, failure mechanisms, switches, and relays.
   - H. Provision of improved measurement accuracy for virtually all dynamic measurements, at the wafer probe level.



Most low-cost programmed logic components have speed limitations. Therefore, when number crunching becomes part of a scheme to reduce the quantity of analog hardware in a new instrument design, there is an advantage to internal operation in binary, instead of the traditional decimal, system. This technique applies to both A/D and D/A conversion schemes and to the scale factors in signal conditioner circuits.

To exploit the programmed logic approach to instrument design fully, the trend will be to partition the circuits of an instrument into logically and physically separate blocks or modules tied back together by some form of bus structure. As a result, control and intelligence, interface to the outside world, and memory functions can all be centralized. Access is thereby provided to an expandable memory capability shared with the instrument controller to support user-generated stored program features. The only significant extra cost is for the human interface hardware required to implement the programming capability.

The omnipresent microprocessor

Some ways in which the capabilities of microprocessors may be used in future instruments have already been mentioned, but the potential applications are limited only by one's imagination. Presently available microprocessors are being used to solve instrument problems that had been unsolvable without microprocessors. By the early 1980s, there will probably be available higher levels of microprocessing capability to overcome microprocessor shortcomings that are not yet obvious. By the end of the 1980s, it may well be commonplace to use microprocessors for almost any instrument application. It also seems likely that by the end of this decade, IC manufacturers may begin taking over some of the high-volume, low-cost, bench-top instrument business, just as they have already done with calculators.

In industrial process control instrumentation, the microprocessor will certainly continue to make inroads. At the annual meeting of IEEE's Industrial Electronics and Control Instrumentation Group in Philadelphia last month, the theme was industrial applications of microprocessors. In a session titled, "Microprocessor Applications in Testing, Inspection, and Instrumentation," it was stated that, within a few years, it will be common practice to find inboard microprocessors in all moderately expensive analytical instruments. They will not only control the unit and perform manipulations on the data base, but will automatically optimize the instrument.

With the advent of fully instrumented automobiles, including microprocessor-based systems, a car owner of the future might be able to connect an umbilical cord in his garage to a diagnostic computer onboard his car. The other end of the cord would be connected to a central computer at a diagnostic service center via telephone or cable-television lines. While the car is parked overnight, a series of tests, such as oil level and battery voltage under load, would be conducted and the owner alerted to any problems before they caused vehicle downtime. This type of system could, possibly, even eliminate the need for routine, periodic maintenance of the vehicle and replace it with specific corrective actions as needed.

In the medical instrumentation field, the microprocessor also has a big future. An example of things to come is a new line of instruments under development at Philips Medical Systems, Shelton, Connecticut. The instruments are being designed so that all controls of a nonmedical nature—balancing pens on recorders, zeroing meters, etc.—are eliminated and directly usable, numerical data are produced. The instruments will be self-calibrating, partially self-checking, and will do a fair amount of number crunching. The first built-in microprocessor instrument in the line, an automatic cardiac catheterization laboratory system for use during diagnostic procedures, receives information from one or more blood-pressure electromanometers, scales and processes the measurements, and provides visual and hard-copy display of the results.

Peter Richman, a consulting electronics engineer with many years of experience in electronic instrumentation, is extremely enthusiastic about the future of instrumentation in medicine. He feels that a fine diagnostic machine may not be as good as the best super physician but probably is a darn sight better than the average physician. At present, he says, electronics in medicine is mainly providing better care (patient monitoring, for example) but not better medicine. But, he predicts, a medical revolution is in the making, and electronic instrumentation will make a science out of the art of medicine and produce new keys to solutions of diseases of magnitudes comparable to the discovery of penicillin.

Reliability: a sour note?

The increased usage of instrumentation in a myriad of applications could be defeated, or at least delayed, by reliability problems. Instrument manufacturers are already having problems with reliability. And the situation will probably get worse. As instruments become more and more complex, reliability will tend to decrease. In addition, components supplied to instrument manufacturers have been the cause of many reliability problems.

By 1980, at least one instrument manufacturer predicts, reliability may be the key limitation to further growth in instrumentation capabilities. In order to improve reliability and to keep it from becoming more of a problem in the future, it may be necessary to find new ways of approaching instrument design, including the design of the components that make up the total instrument package. ◆

Pollution control is a growing market for measuring instruments. The system shown at left, as reported in *Finnish Trade Review* 6/74, was supplied by Nokia Electronics of Finland for monitoring the pollution content of the River Kokemäki. The system also warns of incidental spillovers of process wastes and chemicals from Nokia's pulp paper mill. At the measuring station, water temperature, specific conductivity, dissolved oxygen, solid residue content, fiber content, pH, wind speed and direction, and water flow and direction are recorded.

Information for this article came from many sources. Major contributors were: John M. Fluke, Jr., Joseph Keithley, Y. T. Li, Eugene Mittelmann, Marco Negrete, Gordon Partridge, Peter L. Richman, and Barry N. Taylor.

Components

Silicon technology will underlie the next generation of higher performance ICs, and optical devices will play a bigger role

What will the next decade or more of components and devices bring forth in performance? While no one can accurately foresee the future, reasonable predictions can be made, based on current research and development efforts in these areas. Two basic premises underlie such predictions: future components and devices will be designed based on an understanding of material behaviors, and tools and techniques will be developed to manipulate these behaviors to best advantage for functional products.

There can be little argument that the material of the next 20 to 30 years will be silicon—the "new steel," as it is called by some. Advanced processing techniques, such as electron-beam lithography supplemented with X-ray radiation (Fig. 1), are expected to increase IC functional densities for lower costs per function and to advance component and device performance manyfold. Such techniques will be ready for commercial application on a large scale within five years. Other materials such as GaAs (gallium-arsenide) and InP (indium-phosphide), particularly the former, will be used extensively for devices whose operating frequencies extend beyond 1 GHz. And magnetic-domain materials for use in memory applications are also likely in the future.

It is interesting to note, in retrospect, that during the early Sixties, when the first ICs were produced,

Roger Allan Associate Editor

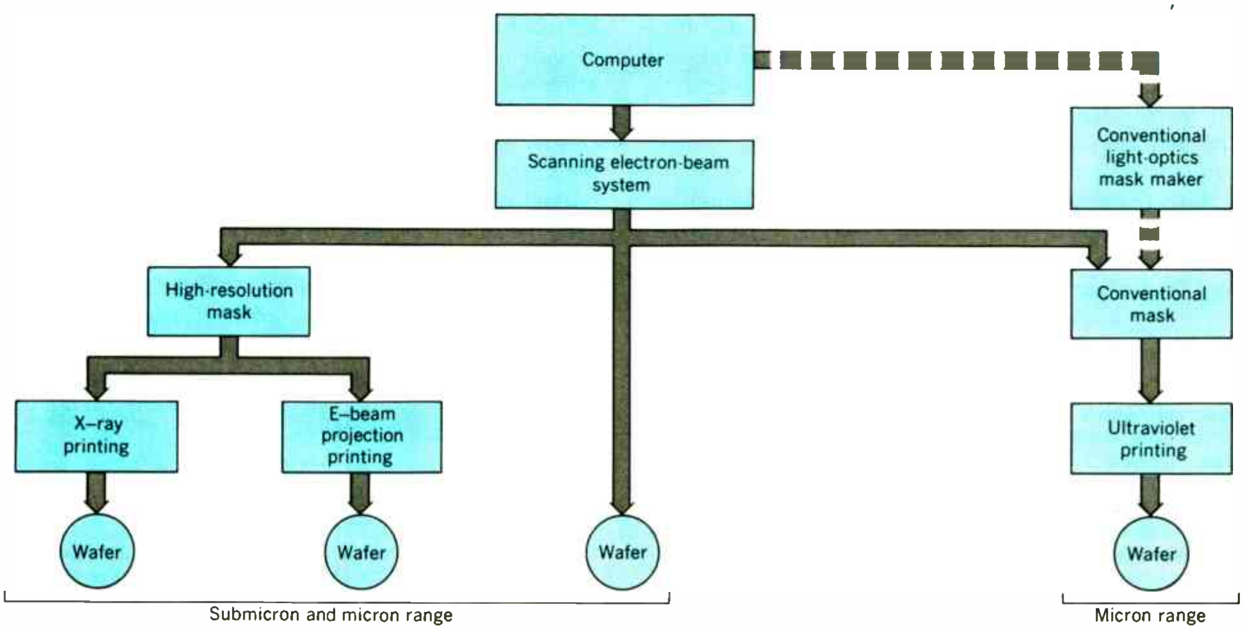
IC advocates were predicting a limit on how far functional densities could be pushed. Many believed that 2 or 3 microns were the maximal silicon device geometries. Today, such geometries are not uncommon, and predictions are being made for commercial IC products with line resolutions down to 0.1 micron within 10 to 15 years. Such predictions are based on actual demonstrations of products with such line geometries, in the laboratory. While a limit may eventually be reached, no universal agreement exists among component and device experts as to when or what that limit will be. Some point to physical limits; others claim economic limits.

Higher-performance devices are coming

Future bipolar and FET devices are certain to be faster, more efficient, and lower in cost, due to the expected increases in IC-chip functional densities (Fig. 2). Predictions of bipolar structures with gate delays of 100 ps within ten years are finding wide support among device experts. As for FETs, switching speeds of a few tenths of a nanosecond are forecast within ten years. Functional densities are expected to reach hundreds of thousands of devices on chips less than 1.6 cm^2, within the next few years. The current move toward making n-channel FETs will eventually eliminate the p-channel process.

One logic technology, I^2L (integrated injection logic), is being acclaimed as easily integratable on linear ICs. In fact, many device experts foresee I^2L

[1] Electron-beam lithography can be used, with conventional photolithographic process, to: expose a silicon wafer; expose patterns on a wafer directly; or expose a wafer with high-resolution masks, either with projection printing of the electron beam, or with X-ray exposure.



logic and memory with linear circuits, on the same chip, for mixed digital–analog signal processing, within five years. Commercial I^2L products are already on the market.

At Hughes Aircraft Research Laboratories, an important project is to make low-noise FETs working up to *X*-band frequencies. GaAs FETs with low-noise characteristics, at such frequencies, have been developed with 0.5-micron geometries, using a scanning-electron-beam system. By next year, Hughes expects to develop production GaAs FETs with 4-dB noise figures at *X*-band. The best available commercial devices exhibit noise figures of 5 to 6 dB, currently.

Surface acoustic-wave devices such as programmable transversal filters and solid-state millimeter-wave components, both active and passive, are destined to play a large role in signal-processing and communications applications. However, no projections were available for these areas.

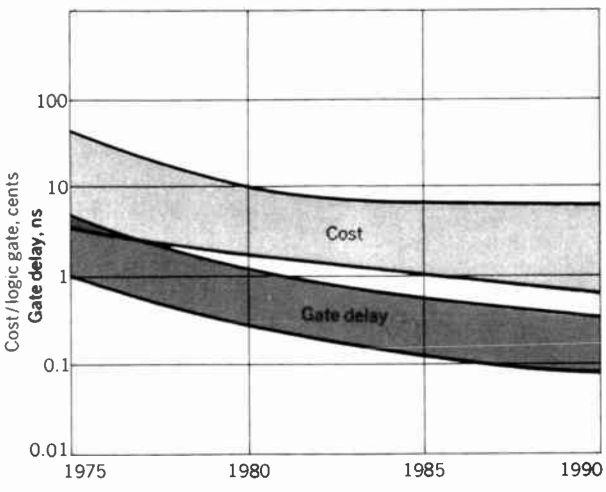
Optics to play a larger role

Whether guided-wave optics, optical ICs, integrated optics, or thin-film optics, all have something in common: the integration of optical components such as lenses and fiber-optic cables with solid-state components, either on the same chip, or within the same system. Actually, two of the largest areas of application for "integrated optics" (the term most agreed upon by experts) are communications (Fig. 3) and optical signal processing.

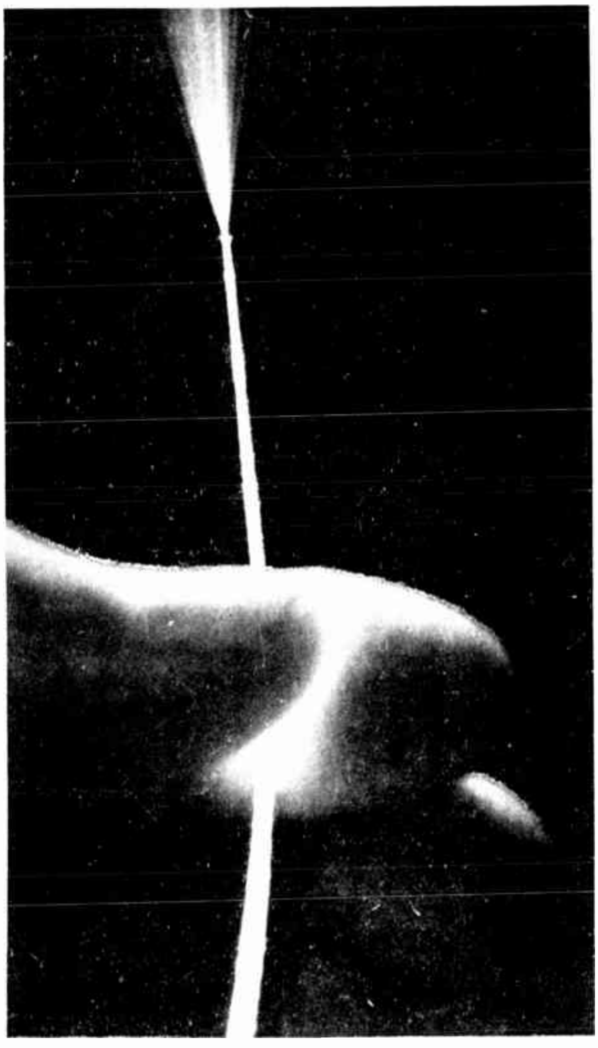
To generate, control, and detect optical signals for these purposes calls for combining four basic system functions—light source, modulator, light carrier, and detector—onto a thin-film chip. Developing an effective and low-cost method of light modulation and achieving the proper alignment between the light source and the carrier for maximum transmission efficiency are problems yet to be overcome. AlGaAs light emitters appear to be the most promising light sources. For the longer transmission range, AlGaAs laser diodes are the most promising. AlGaAs LEDs, on the other hand, are excellent prospects for short-range communications. AlGaAs devices are likely to be future light-source elements because of the minimum losses experienced by high-silica fibers at the AlGaAs operating wavelengths of 0.8 to 0.9 microns. Another advantage is that AlGaAs devices can be modulated up to GHz frequencies. An earlier problem of reliability has been largely overcome: early lifetimes of a few hours have given way to demonstrated (by high-temperature stress aging) lifetimes in excess of 100 000 hours.

Predictions by experts are that local data communications over fiber-optic cables, which are able to carry thousands of voice or data channels using bandwidths tens-of-MHz wide, over a few miles, should start by 1980. By 1985, they see the large-scale manufacture of fiber-optic cables with maximum losses of just 1 dB/km (currently available only in small-quantity laboratory developments), which would facilitate the use of optical communications lines on a much larger scale. Bell Telephone Laboratories is a major force in the research and development of materials and components for long-distance optical communications lines, and is expected to be the first to make

[2] Bipolar ICs are expected, by 1990, to drop down in buyers' cost to about 1¢ per logic gate for the simple low-speed structures, and to the 10¢ range per logic gate, for ultrafast structures. Gate delays of about 100 ps should be available by then. MOS ICs (not shown) should cost even less (up to a factor of 2), by 1990.



[3] Like water from a hose, light spews out from the end of a 0.8-km length of glass fiber. Within five years, local information-carrying fiber-optic transmission lines, extending for a few miles, will carry thousands of signals, tens-of-MHz-wide in bandwidth, at a higher level of reliability and lower cost than metal-wire conductors can provide.



use of optical communications lines in the company's telephone network.

There has been much talk about making use of integrated optical devices to perform logic functions. However, most integrated-optics authorities discount this as a future possibility, pointing out that it is very difficult to switch light as rapidly as electrons. And trying to perform the same switching functions with light requires much more power than with electrons. What is possible, however, is the use of integrated-optical structures to perform data-processing functions—such as signal transforms, correlation functions, etc.—at a faster rate than with conventional techniques. Such calculations are useful for real-time instrumentation and computer applications.

CCDs find many applications

Three major areas of application await the CCD (charge-coupled device): imaging, signal processing, and memory. Some commercially available CCD products have recently been introduced. CCDs are a form of charge-transfer device, another type of which is the bucket-brigade device (which is largely on the way out). The most promising applications potentials exist for imaging and signal processing, where the advantage of low cost looms large.

Such products as analog delay lines, multiplexers, and transversal filters are possible with CCDs. In fact, predictions are that, by 1980, they will be available as low-cost commercial products.

The consensus of CCD experts is that it will be three to seven years before an economical CCD TV camera for video imaging can be developed. CCD cameras already exist, but at a higher cost. The problem is to make a low-cost visible-light imaging array with sufficient defect-free high-density elements. For example, a typical CCD array could have at least 500 by 500 elements, which would mean close to one-quarter million defect-free elements; to do this is now very difficult. In the shorter term, it is likely that CCD TV cameras will find applications in the low- to medium-resolution market.

One possibility is to use CCDs for future low-noise imaging applications. To reduce the 5 to 10 nA/cm² of CCD dark currents down to the competitive level of under 1 nA/cm² exhibited by Plumbicon tubes, minor cooling apparatus, such as small cryostats, might be utilized for the required 30 to 40°C temperature reduction.

Because requirements for defect-free elements are not as stringent in infrared imaging, where arrays of 10 000 elements are common, it can be expected that such imagers will be incorporated in equipment prototypes within two to four years.

Rockwell International's Electronics Research Division has developed a bulk-channel CCD that can read in data at 80 Mb/s, and can read out data at about 100 kb/s, nearly a 1000:1 step-down ratio. This is useful for low-cost signal processing of signals from transducers and sensors. Within five years, CCDs with even higher step-down ratios will become commercial products.

At the Hughes Aircraft Research Laboratories, work is underway to make a monolithic focal-plane-array CCD, with an infrared detector array, preamplifiers, and multiplexing electronics, all on the same chip. The idea is to eliminate the normally very large number of wires employed in conventional chips. Within the next few years, CCD linear imagers, which combine imaging and digital-signal-processing functions, will appear.

As for memory, the best market foreseen for CCDs is between relatively higher speed and higher cost semiconductor RAMs (random-access memories) and lower speed, lower cost disks. CCD memories are basically shift registers. Designs with worst-case bit-access times of 25 μs to about 1 ms are reportedly in development. CCD memories are forecast to achieve bit densities two to six times greater than semiconductor RAMs, and correspondingly lower cost, at slower access time. Bit rates are forecast to be two to four times those of comparable RAMs.

Bubble memories are promising for high-density, low-cost memory applications where nonvolatility is an important consideration. Such memories have demonstrated (in the laboratory) densities greater than those of any current commercial technology. These densities do not include on-the-chip peripherals, something semiconductor CCD and RAM memories are capable of accommodating. Despite the criticism by "non-bubble-memory" spokesmen that bubble memories have yet to be put to the test on the production line, where packaging and related factors

The look of future displays

The talk in future displays is that liquid-crystal and electrochromic displays are excellent candidates for large-screen displays. LEDs, on the other hand, are seen as ideal for small alphanumeric displays in instruments and computer systems.

Liquid-crystal "light-valve" displays have been developed by Hughes Aircraft Co. for use as a large-screen display in live-TV and military applications. A photoconducting layer of material is sandwiched with a layer of liquid-crystal material. A dim image—say, from a CRT—is projected onto the photoconducting layer, and a bright light beam is projected on the liquid-crystal layer. The result is that the display acts as a programmable slide projector, throwing an image on a screen. Resolutions good enough for 525-line TVs have been obtained, along with contrast ratios up to 50:1 and eight to ten shades of gray. Future improvements in the speed of the liquid-crystal-material response to the light signals, and in higher contrast levels, should make such displays commercially possible within five to ten years.

Liquid-crystal matrix displays are being investigated, as possible future "solid-state" CRTs, where liquid-crystal material is put on tiny silicon slabs or chips. One possibility is to use SOS (silicon-on-sapphire) chips instead, since light could be shined through the SOS material, instead of bouncing off the silicon.

Some scientists see electrochromic displays as the likeliest in computer-output terminals, and for consumer, calculator, and watch applications. Such displays have excellent contrast levels, have good appearances, operate from very low voltages (about 2 volts), and dissipate low power. For large-screen graphics-display applications, an optical beam can be used to address the electrochromic material.

In the immediate future (the next five years), experimental flat-panel plasma displays such as Owens-Illinois' Digivue and Burroughs' Self-Scan systems will become commercial possibilities, as low-cost, high-resolution displays.

Fabrication refinements are the key

The conventional methods of photolithographic IC processing are approaching diffraction limits, due to practical clearance problems between wafer and mask, for making device line widths much smaller than 2.5 to 3 microns, for LSI commercial production. Some devices have been fabricated with photolithographic techniques down to 0.5 micron in resolution, but great care is required and such techniques are now used only for microwave devices.

The alternative technology that is now being investigated, and should be ready for commercial application in about five years, is electron-beam lithography, in which a fine beam of electrons is used to expose resists. With electron-beam lithography, this resist pattern can be formed directly on the device or can be used for making high-resolution masks for photolithography or for two other new technologies—X-ray lithography and electron-image projection lithography. At the moment, most processing engineers agree that some combination of electron-beam lithography with X-ray or electron-image projection lithography might be useful.

The vector-scan method of electron-beam fabrication has contributed to the speeding up of the conventional method of raster-scan lithography. In the vector-scan method, the IC device pattern is made by programming the electron-beam system to access a series of previously laid-out patterns in the form of geometric shapes. This is more efficient and faster than the latter method of serially scanning a chip, line by line over its entire surface, and exposing certain defined pattern positions within that surface, making for small system throughputs. In fact, this problem of insufficient system throughput for electron-beam systems is recognized as a possible limiting factor in their usefulness. Currently, scientists at IBM's Thomas Watson Research Center have been developing an electron-beam fabrication process using vector scanning to evaluate its ultimate throughput capability with special reference to pattern geometries in the micron and submicron regions.

At Bell Telephone Laboratories, the EBES (Electron Beam Exposure System) technique, developed jointly by Bell and Western Electric, is capable of exposing chrome master masks and devices on silicon substrates in an economical and practical way. Key to the system's practicality is the refinement of a scanning technique in which small-amplitude electronic scanning is simultaneously combined with large-amplitude mechanical scanning of the silicon substrate, on an X–Y table. The table moves in a serpentine fashion and continuously feeds laser-interferometer signals to the electronic-scanning system for position-error corrections. Complementing the development of the Bell Telephone EBES system has been the development of a sensitive electron-resist technology.

At the moment, many processing engineers feel that the electron-beam systems of the 1980s will be used mostly for mask making. Pattern delineation on the wafer will be accomplished either by conventional photoexposure, by electron-image projections, or by X-ray lithography, when making high-density, low-cost LSI circuits. Direct-electron-beam exposure, it is felt, will be limited mostly to the manufacture of high-performance devices, such as microwave ICs with critical performance parameters, where the problem of low throughput rates and higher processing costs are not significant.

are certain to cut down high laboratory yields and functional densities, the very high yields and functional densities achieved so far (densities of 10^7 bits/in^2 are easily obtained) are an indication that future bubble memories are bound to be competitive in high densities and low cost with other types of large-capacity memories.

A future "dark-horse" candidate for imaging and memory applications is the CID (charge-injection device), a MOS structure that has the same integration process as that of the CCD, but is simpler to fabricate, has lower noise levels when read out, and is more easily accessed randomly.

Solid-state TWAs

To a certain extent, vacuum tubes of the 1950s survived the advent of the transistor and the IC, mainly in the field of microwave power generation. Vacuum tubes of the next two decades are bound to lead even more specialized lives, as microwaves ICs begin to chew at the bottom end of the power-performance line. As refinements of GaAs and InP, the two principal microwave-device materials, reach fruition, high-power TWA (traveling-wave amplifier) and IMPATT (impact avalanche transit time) devices in semiconductor form will take over some functions heretofore only fulfilled by vacuum tubes.

Within ten to fifteen years, the IC microwave power accumulator will materialize to replace bulkier TWAs at comparable efficiency levels. The current concept is to put together about a dozen GaAs IMPATT devices and sum up their outputs to obtain 50 to 100 watts of power, at X-band frequencies.

Josephson devices

In forecasting future logic ICs, discussions generally stop at about the 50- to 100-ps speed range, for semiconductor devices. This is where Josephson-junction devices (a major research effort being conducted by IBM's Thomas Watson Research Center) can play a role.

These cryogenically cooled devices can be switched in about 10 ps and have power-delay products that are three to four orders-of-magnitude lower than any known semiconductor device. They are predicted to be the future ultra-high-speed devices for use in very large computer central-processing units and RAMs.

But Josephson devices are still laboratory items, and a few more years of research are needed to solve problems now preventing them from becoming commercial realities. One of these problems is the thermal shocking encountered by Josephson devices when being removed and returned into a cryostat. Another is to find suitable input-output configurations relative to the cryostat and outside circuitry. ◆

Information for this article came from many sources. Major contributors were: David Alles, Wilhelm Anacker, Andrew Bobeck, Ifay Chang, Phillip Chang, Robert Collier, Clifton Cullum, Bernard DeLoach, Frederick Dill, James Early, Marcus Heritage, Eric Lean, Cedric O'Donnell, Fabian Pease, George Smith, Lewis Terman, and Michael Tompsett.

Where to look to look ahead

Articles outnumber books as recommended references on the complex, but intriguing, art of anticipation

A bookshelf on forecasting? Why would a skilled engineer already bombarded with trade journals, books, and extension courses relating to his or her specialty be concerned with activities long tainted by tea leaf and tarot card? After all, doesn't current technical literature already contain the few relevant estimates and trend lines of real concern?

The key to the answer is *inbreeding.* The engineer inhabits a very special world of peers, technicians, business associates, and educators. Their communications consist of personal contacts, conferences, memos, and reports—plus a hefty complement of technical books and magazines. The result is a view of the world inevitably biased and distorted.

Extrapolation is not enough

Like ancient Greek temple builders—unmindful of steel, cement, or even the arch—the modern engineer extrapolates the possible *only* from the known. Resulting forecasts reflect a myopic *Westanschauung* that makes them of questionable value. At best, they are accurate projections of what *can* be accomplished by extending existing capabilities. However, large discrepancies are still possible. For example, two forecasts of central processing unit storage speed in 1975 performed by experts four years apart differed by a factor of 20!

"I have seen the future and it works"
Lincoln Steffens

"I have seen the future and it doesn't work"
Zero Mostel

Usually the engineer equates forecasts with trend extrapolation of subsystem parameters. Consider some relatively recent history: In 1929, Nevil Shute, then an aeronautical engineer, forecast that passenger aircraft would fly with speeds of 209 km/hr by 1980. He concentrated on the subsystem—propeller aircraft—without regarding it as just *one* solution to a larger problem—efficient passenger air transport. In the future, even the concept of passenger air transport will be an unsatisfactory parameter for forecasting. Communication provides a potential substitute for transportation if alternatives to oil as a vehicle energy source are not forthcoming. And even this expanded view is still too narrow.

A meaningful forecast must not only consider technological alternatives but interactions of a nontechnological nature with the external environment. For example, the emergence of a "steady-state economy" with altered concepts of incentives, rewards, and quality of life could drastically impact electronics technology. In preparing a valid technological forecast, *needs* are as important as *capabilities.* Cultural-social-behavioral and nature aspects are as significant as purely technological ones.

Consequently, the technological expert can by no means assume that either his intuition or his reliance on trend extrapolations of parameters will prove to be adequate guides to planning. Analytic models, use of analogies, and Delphi are among the available tools. The latter is a kind of remote conferencing procedure based on questionnaires with iterative feedback and individual anonymity. It has become very popular since its development at the RAND Corporation, not only for technological forecasting, but as a group communications technique (including on-line computer-aided conferencing).

Up from guesswork

Technological forecasting methodology has evolved rapidly over the past two decades. The first survey (Jantsch's *Technological Forecasting in Perspective*) appeared only eight years ago and is already partly obsolete. The most thorough and satisfactory book available today is Joseph Martino's *Technological Forecasting for Decision-making* (American Elsevier Publishing Co., 1973, $30). It has an undisputed right on the reference shelf of the future-oriented engineer. The book should be augmented with an occasional perusal of the two journals that cover this field, *Futures* (IPC Science Press, Ltd., England, personal subscription, $35 per volume comprising six issues), and *Technological Forecasting and Social Change* (American Elsevier Publishing Co., N.Y., personal subscription, $15 per volume comprising four issues).

How do we implement the idea that technology must be viewed in a larger system context, one that includes nature, man, and society? The systems approach would seem an essential underpinning to such a concept. "System dynamics" has had astounding influence in developing insight into the characteristics of the complex global system (see The Club of Rome's *Limits to Growth,* Universe, 1972, $2.75 in paperback, and *Mankind at the Turning Point,* Dutton/Readers Digest Press, 1974, $12.95).

In 1972, the U.S. Congress established an Office of Technology Assessment to consider the impact of technology on the natural, human, and social envi-

Harold A. Linstone
Portland State University

Future file

Only two books comprise the future-oriented engineer's "must" reading list—Joseph Martino's *Technological Forecasting for Decisionmaking*, $30; and Francois Hetman's *Society and the Assessment of Technology*, $9.50. But, as the foregoing titles imply, two distinct, interwoven subjects are involved: *forecasting* and *assessment*. Complimenting Martino's book on forecasting are three anthologies published over the past few years. Each contains some valuable material:

Bright, J. R., ed., *Technological Forecasting for Industry and Government*. Englewood Cliffs, N.J.: Prentice-Hall, 1968.

Bright, J. R., and Schoeman, M. E. F., eds., *A Guide to Practical Technological Forecasting*. Englewood Cliffs, N.J.: Prentice-Hall, 1973.

Linstone, H. A., and Turoff, M. A., *The Delphi Method: Techniques and Applications*. Reading, Mass.: Addison-Wesley, Spring 1975.

Many recent articles in *Futures* and *Technological Forecasting and Social Change* also make worthwhile reading. Of particular interest to engineers are:

Blackman, W., "New venture planning: the role of technological forecasting," *TF&SC*, vol. 5, p. 25.

Day, L. H., "Travel/communications substitutability," *Futures*, vol. 5, p. 559.

Eugster, C., "Corporate planning in an unstable environment," *Futures*, vol. 3, p. 357.

Foster, R. N., and Rea, R. H., "An integrated technological forecasting and R&D planning system," *Futures*, vol. 2, p. 231.

Henry, N., "The future as information," *Futures*, vol. 5, p. 392.

Martino, J. P., and Conver, S. K., "The step-wise growth of electric generators' size," *TF&SC*, vol. 5, p. 465.

Strehlow, W. H., "Memories are made of this. . . ," *TF&SC*, vol. 6, p. 65.

Thompson, G. B., and Herbert E., "A gentle approach to corporate change," *TF&SC*, vol. 5, p. 179.

Turoff, M., "Delphi conferencing: computer-based conferencing with anonymity," *TF&SC*, vol. 3, p. 159.

When the role of technology assessment is being explored, a few outstanding articles can be added to the Hetman reference:

Coates, J. F., "Some methods and techniques for comprehensive impact assessment," *TF&SC*, vol. 6, no. 4, 1974.

Jones, M. V., "A technology assessment methodology: project summary," The MITRE Corp., MTR-6009, June 1971.

Rose, D. J., "Energy policy in the U.S." *Scientific American*, vol. 230, p. 20, Jan. 1974.

Portions of three books can also be added to this list:

Cetron, M. J., and Bartocha, B., eds., *Technology Assessment in a Dynamic Environment*. New York: Gordon and Breach, 1973. (Particularly—Boucher, W. I., "The future environment for technology assessment" and Coates, V. T., "Executive agencies and technology assessment.")

Dickey, J. W., Glancy, D. M., and Jennelle, E. M., *Technology Assessment*. Lexington, Mass.: Lexington Books, 1973.

Medford, D., *Environmental Harassment or Technology Assessment?* Amsterdam, N.Y.: Elsevier, 1973.

ronment, and to provide an improved basis for legislation. Hopefully, it will prove more effective than the Executive Branch's ill-fated National Goals Research Staff (1969–70) and its pedestrian report "Toward Balanced Growth: Quantity and Quality" (U.S. Govt. Printing Office, 1970, $1.50).

With "impact" and "assessment" becoming popular labels, publications capitalizing on these terms are proliferating. Many promise much and deliver little. Too often, known methods are laboriously applied to a solvable but irrelevant problem mistakenly perceived as the primary concern—like the drunk scrounging for his lost key under a street lamp simply because of the convenient illumination.

One book that has avoided the folly of such temptation is Francois Hetman's *Society and the Assessment of Technology* (Organization for Economic Cooperation and Development, Paris, 1973, $9.50 in paperback). It too deserves a place in the library of any engineer seriously concerned about the future.

Lost in the ozone?

The search for better techniques to forecast complex interactions continues. The subtlety of relationships between technologies and between technology and the other "systems" confounds the best minds. Did anyone in the Middle Ages recognize that the introduction of the spinning wheel in Europe would have a major impact on mass book production (through low-cost linen rags) or that the chimney would accelerate social stratification (documented by Lynn White in "Technology assessment from the stance of a medieval historian," *American Historical Review*, Feb. 1974)?

Today, we find (belatedly) that supersonic jet exhaust can affect the skin cancer rate (through atmospheric ozone decrease). The keys to unlock the mysteries of many of our complex systems must be found—and there is neither very much time nor very much illumination for the search. Our bookshelf is still uncomfortably bare! ◆

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Ways around the cash crunch

Options for retracking the U.S. utilities onto their traditional path of adequate and reliable supply

Unless effective measures are quickly taken, the United States is faced with the grim possibility of electricity shortages by the end of the decade. These shortages could manifest themselves in localized brownouts and even blackouts—the all-too-possible nadir of a decline in reliability and service stemming from the currently forecast effects of continuing utility financial difficulties. Such brownouts and blackouts would certainly have a dire effect not only on the residential consumer, but on an economy trying to recover from present recessionary trends.

Last month, *Spectrum* reported on the landslide of new construction cutbacks, by electric utilities throughout the U.S., that presage an electricity shortage. This month, it is our intention to probe the industry-wide constraints shackling the U.S. utilities and then to discuss some of the options currently being proposed as potential solutions to the power industry dilemma.

Plight . . .

No statistic better conveys the peculiar difficulties faced by the power industry in the U.S. than that describing the electric utilities' capital-intensiveness. As shown in the table opposite, the electric utilities have a gross plant investment per dollar of sales revenue seven times higher than the average of all manufacturing corporations, and a net plant investment ten times higher than that average. Further, they are four times more capital-intensive than their nearest "competitor"—the petroleum refining industry. In fact, according to testimony at a hearing on utility finance problems held by the U.S. Senate Committee on Interior and Insular Affairs, "Even with the form of financing typically employed by investor-owned utilities [and, today, by the Tennessee Valley Authority as well], the use of relatively high debt ratios, the cost of servicing that investment (i.e., interest, dividends, and associated income taxes and depreciation) generally accounts for about half of the cost of supplying electric service." And as if this percentage weren't high enough already, its potential for rising further depends in large measure on the tight money policies of the Federal Reserve (attacked bitterly by, for one, Donald Cook, president of American Electric Power in an interview with the authors), and on the still higher capital investments required for the construction of nuclear power plants. No wonder, then, that so many U.S. utilities have curtailed new nuclear construction!

Thus, to state the case broadly, a historically cash-hungry power industry is presently being starved for lack of sufficient capital. While its cash needs skyrocket, a variety of recent events have drained even its normal cash resources—a resource drain that is at least as serious as, and interwoven with, the fuel resource drain. To review briefly, the factors clotting utility cash flow are:

- Vaulting fuel costs. (The effects of these on the power industry have been exacerbated by local regulatory lag.)
- Inflated construction and labor costs. (Again, the effects have been magnified by local regulatory provisions preventing "normalized accounting"—or the inclusion in earnings reports of capital tied up in construction. While normalized accounting, by itself, cannot increase cash flow, it can bolster earnings reports, thereby attracting corporate investors.)
- High state and local taxes.
- Sharply declining profits. (These have resulted from two sources—on the one hand, many utilities have reported an ever-increasing percentage of customers who are slow to, or fail to, pay their bills, and, on the other, a number of utilities were hard-hit first by the energy conservation efforts that followed in the wake of the Arab oil embargo and then by the effects of the current industrial recession. Detroit Edison, servicing the automobile industry, is an excellent example of the latter.)
- The high cost of debt financing (which has already been mentioned).
- Environmental requirements.
- The deteriorating position of utility stock and bond issues in an increasingly competitive investment market. (Today, tax-free Federal and municipal bonds look more attractive to many investors than do their investor-owned utility counterparts and this situation is further exacerbated by the dismal financial state of most privately owned utilities, many of which were discussed in last month's *Spectrum*.)

Stopgap measures

In the face of this litany of difficulties, the utilities have already taken a number of stopgap measures that must be considered prior to any discussion of even near-term solutions. By far the most comprehensive of these self-protective actions has been the previously mentioned cutbacks of new construction. The difficulty here is that such cutbacks may solve the immediate problem by mortgaging the future.

When a financial crunch is produced by a recession or a runaway inflation, the first thing to be chopped —or drastically curtailed—on an industry's agenda for the future is its new construction program. At the top of the utilities' list of construction cutbacks will be nuclear generating plants, primarily because, in terms of capital costs, they are the most expensive of all sources of power generation; and, as we have al-

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ready cited, their very long lead time from initial construction to putting power on the line makes them additionally vulnerable in economic terms. Fossil-fuel thermal plants require 20-30 percent less capital funding per kilowatt of generating capacity than nuclear reactors, and gas-turbine generators run about 70 percent less. Thus, one can readily see that substituting fossil-fuel plants and gas-turbine facilities for nuclear reactors can save a utility a "bundle" in capital investments—at least over the short haul.

In brief, then, many utilities are "buying time" on the long lead required for nuclear plant installations. As a factor in this delaying action, such utilities are gambling, perhaps hazardously (it may turn out to be Russian roulette), that future load growth, aided by a voluntary and/or enforced energy conservation regime and a continued industrial recession, will not be as great as predicted, and that previously projected energy generation capacity will not be needed x years hence. However, if this rationale falls on its face, the industry reasons that it will still be ahead of the game, because a new fossil-fuel plant could be constructed and completed by about the same date as an equivalent capacity nuclear plant (for which ground would have had to have been broken a few years earlier than that of the conventional station).

To be fair to the utilities that have cut back on plans for new nuclear capacity, most will say that this is no gamble but a necessary course. Whether or not this is true, the emergency action, like all deviations from a master plan, has its drawbacks and pitfalls. The major one is fuel consumption. In a drastic shift from nuclear to fossil-fuel generation, fuel consumption would become a major factor by 1985, and beyond. For example, a conventional thermal plant of 1000-MW generating capacity will require about 11 million barrels of oil per year. Thus, during the plant's expected 30-year lifetime of efficient service, it would consume more than 300 million barrels. If all of this fuel were to be low-sulfur-content imported petroleum, the price tag for the hypothetical plant —in terms of fuel alone—would be more than $3 billion! Although few such plants are currently being planned, the moral is clear. Should a utility find its requirements suddenly too great for its capacity and therefore opt for a fossil-fuel "catch-up-power" program, its customers will end up paying the price.

Cutting back on construction, however, is not the only stopgap remedy being employed by the U.S. utilities. For one thing, they have become somewhat more militant, as might be expected, in their demands of not only the state regulatory agencies, which must act on their rate-increase requests, and individual state governments, which set what many feel were overzealous environmental standards, but also the Federal government which has prohibited the issuance of new leases for the strip-mining of abundant and cheap low-sulfur western coal.

Examples of this stance are many. Before the Senate Committee on Interior and Insular Affairs, Donald C. Frisbee, chairman of Pacific Power & Light, Portland, Oreg., urged an "extension" in the "time frame for the accomplishment of the worthwhile and importan clean air and water objectives set forth in laws and regulations emanating from the Congress." And in an interview with *Spectrum*, AEP's Donald Cook deplored the governmental strictures on strip-mining of western coal, saying that AEP would be willing to pay not only the $300 per acre for reclamation required in the 1974 Congressional bill vetoed by President Ford (the bill had called for 35 cents per tonne, which averages out to about $300 per acre), but at least $4000 per acre—the amount currently being spent by the company in Ohio. However, AEP's "generosity" doesn't necessarily agree with the positions of the majority of strip-mining advocates. Most lobbied strenuously for the Ford veto.

Meanwhile, the increased militancy of the utilities in the public forum has been met, in many states, by increased consumer lobbying, and the result has been hard-won rate increases that have barely skimmed the surface of the utilities' cash shortages. Even if the President signs a strip-mining bill this year, it will be a while before western coal can begin to flow east —something that would help only some of the coal-using utilities. Thus, some of the hardest-hit companies have gone beyond construction cutbacks to cutbacks of personnel.

Beyond the bandaid to the wound

While employing stopgap measures in varying degrees, many utilities have proposed a variety of financially based near-term solutions. John G. Quayle, president of Wisconsin Electric Power, concentrates his hopes on tax legislation and the current regulatory policies delineating the maximum permissible return on equity. Speaking before the previously mentioned Senate Committee on Interior and Insular Affairs, Quayle noted that:

"Tax legislation in four areas could be helpful in improving cash flow for many of these companies. One area would be legislation to encourage normalization, rather than flow-through of the tax effects of accelerated depreciation and other capitalized overheads. Greater utilization of higher book depreciation rates in today's rapidly changing technology is another. A third would be the encouragement of the inclusion of construction work in progress in the rate base instead of today's prevailing practice of capitalizing allowance for funds used during construction, an approach which does not aid cash flow. A fourth suggestion would be to change the investment tax credit rate for electric utilities from 4 percent to 7 percent, the rate specified for other corporations.

"The second major area of need for electric utilities

Capital-intensiveness of the power industry

Industry	Gross Plant Investment per Dollar of Sales Revenue	Net Plant Investment per Dollar of Sales Revenue
All manufacturing corporations	$0.60	$0.31
Transportation equipment	0.44	0.21
Primary metals	1.19	0.59
Basic chemicals	1.11	0.52
Petroleum refining	1.36	0.75
Electric utilities	**4.42**	**3.46**

Source: Electric Utility Policy Issues, U.S. Senate Committee on Interior and Insular Affairs (No. 93-46 [92-80]), p. 84

today is for a higher return on equity. Rates of 12 percent or less being allowed by many regulatory commissions are too low to begin with in today's economy, and the problem is aggravated by the inability of most companies to earn even these allowed rates of return due to regulatory lag and the continued pressure of inflation. There is no way that utility common stock can be attractive with a 12-percent return when well-protected bonds of the same company are selling with a return of 11 percent or more."

One of the more outspoken regulators in the U.S. approaches the financial problems of the utilities in a rather different vein. William Rosenberg, chairman of the Michigan Public Service Commission, agrees that it is vital to "restore the orderly flow of capital funds" to the power industry. But to do this, Mr. Rosenberg has suggested Federal insurance and guarantees of investor-owned electric utility debt. This, he says, would keep the utilities "in private hands" and, at the same time, would assure the public of adequate service at reasonable prices—the latter, because the utilities' cost of financing, representing a large share of the utility bill, would be considerably reduced.

"In a nutshell," says MPSC commissioner Rosenberg, "the proposal allows for cheaper debt and more of it. In concept, it would give to the consumers of electricity similar benefits to those received by homeowners [from] FHA .... A nation that subsidizes and guarantees financing of electric service to its rural citizens through the REA [Rural Electrification Administration] must also assure service to the urban areas through the investor-owned electric industry."

A third, entirely different, approach has been suggested by Alfred E. Kahn, chairman of the New York Public Service Commission. Like Mr. Rosenberg, Dr. Kahn wants greater Federal intervention in utility problems, but the focus for Federal concern, according to Dr. Kahn, should be "the technique of marginal cost ratemaking," where the Federal government could play an "educational, advisory, and even proselytizing role." In particular, Dr. Kahn points to the potential of peak load pricing as a method for better distributing usage and thereby reducing the need for new construction. Says the N.Y. regulator,

"The required meters are comparatively expensive. The resource savings that they are likely to make possible, by inducing people to shift from peak to off-peak, will undoubtedly justify the investment for large users, and probably not for very small users. It seems to me the Federal government might appropriately sponsor an intensive research effort to develop an efficient, cheap, time-of-day meter, or even remote sensing devices that would enable the distribution company not only to measure consumption from one moment to the next, but actually to dispense with meter readers.

"Second, maybe [the government could] conduct controlled experiments to measure the effectiveness of various peak/off-peak rate combinations in shifting consumption and saving capital resources. Finally, [it could] consider subsidizing the installation of such meters by utilities for developmental purposes."

A fourth, and again very different, view of the U.S. utilities' problems comes from two sources—Senator Henry M. Jackson (D-Wash.) and a Washington University (St. Louis, Mo.) economist, Murray L. Weidenbaum. Both men are deeply concerned about the position of the utilities within the overall U.S. investment pool.

Dr. Weidenbaum states the general case as follows: "Government policy should encourage more private saving and investment. The basic way to provide more capital for the needs of the nation is not to subsidize an industry but to increase the size of the pool of investment funds available to all borrowers. The Federal government should reduce the massive extent to which it now competes with the private sector for the limited supply of investment funds."

In a somewhat more earthy vein, Sen. Jackson, speaking at his own committee's hearing, said, "Government policy should encourage more private saving and investment. Of course, the government is out today with a 33-month, 9-percent bond. I am just a country boy, but what in the world is that going to do, not only to the utility industry but [to] savings and loans and mutual banks. I don't know who's running what. But just elementary economics tells you that this kind of competition [is] very unhealthy . . . The Government [is] not only siphoning the money out of savings, but out of the utility market."

The long term: restructuring the industry?

It seems hardly likely that all of the five proposals just considered will be adopted, but even if they were to be, it is doubtful that they could effectively solve the problems that will confront the U.S. utilities by the end of the century. Two forecasts illustrate the point: According to the Federal Power Commission, by the year 2000 more than 50 percent of all energy consumed by end users will be in the form of electricity—*double* 1974's percentage! Further, a scenario devised by the Urban Affairs Subcommittee of the U.S. Congressional Joint Economic Committee suggests that in a mere 15 years—between now and 1990—the utilities will require some $650 billion to meet the estimated electricity demands. This staggering figure, based on a projected average load growth of only 6 percent per annum, is no less than four times the power industry's present net investment in total plant and facilities, and $400 billion of this sum will have to be underwritten by the utilities.

Where will they get this kind of money? And if they can get it, what is the likelihood that, distributed into the hands of at least 300 different companies, the money will be used with maximum efficiency?

The answer to the latter question *may* be that 300-plus utilities and nearly 50 regulatory commissions cannot reasonably be expected to deal with future exigencies in a uniformly efficient manner. Consider the following, unusually dismal, case history:

Consumers Power of Jackson, Mich., is a utility servicing all but the southeasternmost section of Michigan's lower peninsula. It recently made headlines in the business journals as a result of a series of "misfortunes" that have brought it to the brink of financial collapse. The story begins in 1966 when it decided to diversify its resource base away from coal in the direction of nuclear. Touted as a forward-looking company, it planned, in that year, a $93 million nuclear installation to be located on Lake Michigan. By 1972, this Palisades plant was producing electricity —but only after costing $188 million, or twice the original estimate. Within a year, it had broken down and, since early in 1973, $3 million in repair work have yet to produce a kilowatt of on-line power. Supposed to be back on-line any month now (a forecast that has become a joke in Michigan), Palisades has also cost the company $32 million in replacement power and $19 000 in fines levied by the Atomic Energy Commission (AEC) for operating procedure violations. The amount of the fines could not, of course, bankrupt the company, but it was significant in that it represented one of only three such penalties ever handed down.

Knowledgeable *Spectrum* readers will be aware that these kinds of misfortunes can occur in high-technology ventures and, furthermore, they are not always the fault of those capitalizing the project. In this particular case, Consumers Power has instituted suit against its contractors (Bechtel, Combustion Engineering, and Wolverine Tubes), accusing the firms of faulty design. But, unfortunately, the Consumers Power story has several additional chapters. The second involves its next venture in nuclear capacity—the large plant currently being built at Midland, Mich. Originally supposed to cost $349 million and to open this year, it has been hit by three major delays. An environmental suit was one. A Justice Department antitrust suit—aimed at opening the plant, along with the rest of Consumers Power's network, to freer access by small neighboring utilities—was the second. And the third was perhaps the most damaging to the company's image: The AEC again stepped in and, this time, forced the utility to suspend construction due to alleged inadequate welding-inspection procedures for some reactor parts. The result of all these delays has been to set back the completion date four years (to 1979) at a final cost of nearly *$1 billion*—almost *three* times the original estimate.

But chapter three is yet to be told. Desperate for electricity as a result of the failures in its nuclear program (Consumers Power has had to purchase as much as 30 percent of its needs), management felt its only hope was to rush two shorter-lead-time, fossil-fuel-fired plants on line. One seems to be ready on schedule this year; the other is slightly behind schedule. The horror here is that, rather than go with coal, the utility's management opted for oil! To make matters worse, neither plant can be converted to coal and CP is left with the prospect, not only of paying the huge price of oil, but of being dependent for its supply on Canada (which recently threatened to stop exportation to the U.S.).

Finally, the (hopefully) last chapter in the Consumers Power story involves its gas operation. Several years ago, the company decided to become one of a handful of U.S. utilities to construct a synthetic-gas plant. The installation at Marysville, Mich., was to end Consumers Power's historical dependence on a single natural-gas supplier and thereby assure competitive rates. Unfortunately, a synthetic-gas plant uses oil, which it converts to natural gas. The Marysville dream plant, already plagued by $70 million in cost overruns, quickly became a nightmare. It presently produces 20 percent of the utility's gas at a cost of $3.25 to $3.50 per 1000 ft^3 as compared to about $1 per 1000 ft^3 for today's pipeline gas!

The implications of the Consumers Power story are serious. Management performance is never easy to evaluate. Accompanying every corporate misfortune is a rationale closely followed by the axiom that hindsight is better than foresight. However, without leveling accusations at individual managers or utilities, it can at least be said that "too many cooks may be diluting the broth." Thus, Michigan PSC chairman Rosenberg told *Spectrum*, "Maybe there ought to be several Exxons in the utility field." What he means is that one long-term solution to the current financial débacle in the power industry would be to encourage the giants in the industry—especially those with a relatively successful track-record—to become the generators and suppliers of power. This is already the case with many municipal systems that happily buy most of their power from relatively cheap hydroelectric utilities (see the case of Messina, N.Y., described in the authors' March article, p. 44).

A second suggestion for the long term involves Federal financing of energy R&D. The thought here is that utility R&D funds and programs have been too little and too scattered and that new technological breakthroughs may require greater concentrations of effort and money than they have in the past. When one considers the likely sources of technological breakthroughs capable of revolutionizing the power industry—huge storage batteries to meet demand peaks; novel power-conversion equipment capable of increasing utility conversion efficiencies from the current 33–40 percent to perhaps 50 percent; and, of course, potentially more cost-effective technologies, such as solar, geothermal, and fusion—it becomes immediately apparent that even the new interutility research organization, the Electric Power Research Institute (EPRI), may not be up to the task required.

And, finally, there are the more radical, but increasingly discussed, proposals calling for the takeover of the privately owned utilities by local, state, or even Federal government. The concept is hardly new or shocking, at least in neighboring and overseas countries. In the Western European democracies and the United Kingdom, for example, power generation and transmission was nationalized years ago. In Canada, too, the provinces have taken over the private utilities and have reorganized them as provincial power commissions. In the United Kingdom, the Central Electricity Generating Board (CEGB) is the national agency charged with the responsibility for electric power in England, Scotland, Wales, and Northern Ireland.

In response to such proposals calling for the federalization of the power industry, most, if not all, utility spokesmen will quickly assert that the European model is hardly the ideal (they cite interruptions in service that have hit England in the recent past). But when major utilities like Con Edison, Boston Edison, Consumers Power, and Detroit Edison are plunged into such deep financial crises that future reliability of service becomes an open question, perhaps it is time to ask: Is it the proper role of Government to "bail out" these companies, at the expense of the taxpayer, with massive infusions of Federal funds (à la Lockheed and Penn Central), or should Government, as long as it is involved anyway, be in the driver's seat, fully responsible for the quality of electric service being supplied to the citizen? ◆

What EPRI is up to

The power utility industry is rooting for its new offspring to uphold its initial high promise

Public pressure stemming from blackouts, energy shortages, environmental concerns, and the growing threat of Federal intervention in the power field have combined to galvanize the utility industry into taking action by forming the Electric Power Research Institute, or EPRI. Set up in 1973 to manage a coordinated R&D program on behalf of the entire utility industry, EPRI has embarked on a four-pronged program that is presently looking into nuclear power; fossil fuels; transmission and distribution; and energy systems, environment, and conservation. Some of the more interesting efforts, which will be described in greater detail further on in this article, include: a computer code for plutonium recycle in light water reactors, coal conversion into fuel products containing low quantities of ash and sulfur, and simplified methods of effecting cable splices.

It may be too early to gage the impact of EPRI's work on the difficult problems facing today's power industry, and the U.S. as a whole, but it is certainly not too early to look at how the new organization plans—through its quasi-private, quasi-public activities—to begin answering some of the real needs of the territorially sprawling, yet fragmented power industry.

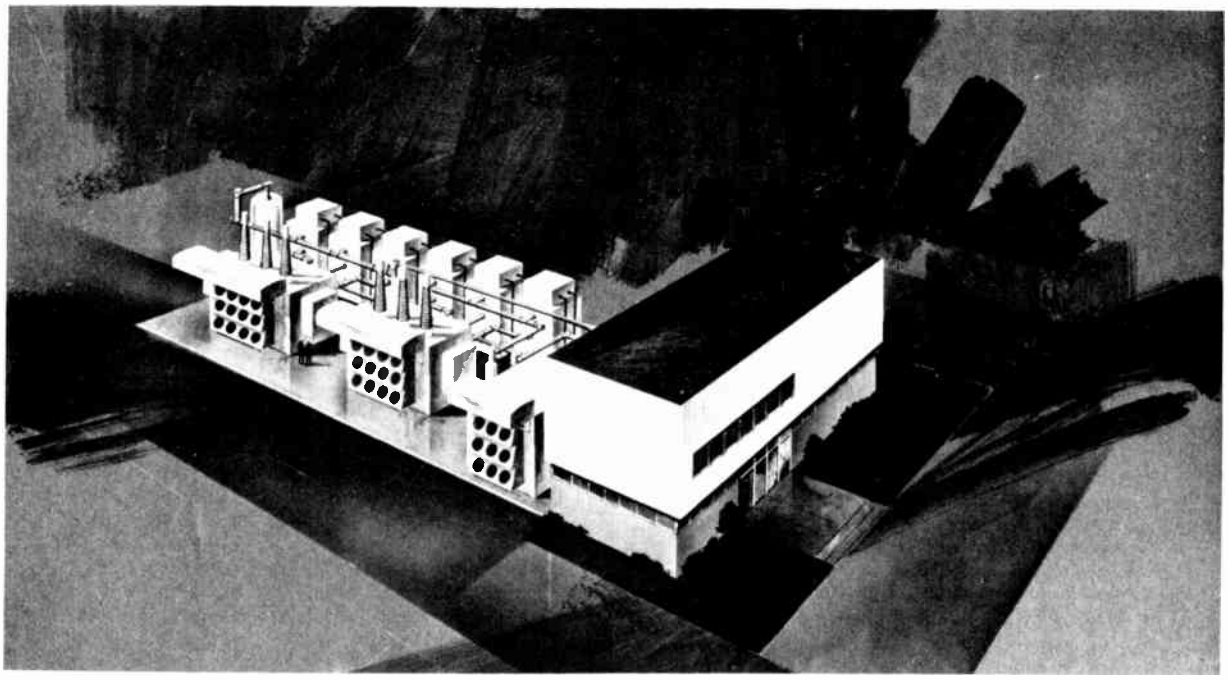
Nilo Lindgren Contributing Editor

In the area of "generic" R&D problems, it appears that a central organization such as EPRI could serve as a focal point for all parties, not only to unburden the utilities of the general R&D problems that they all share, but also to allow them to make better investments in "local" R&D questions which differ from region to region. Thus, one of EPRI's roles—as well as managing a broad-scale R&D program interfacing with utilities, manufacturers, public, and government agencies—is to pull together a central information bank that is available to all utility people who must make individual decisions as to the kinds of R&D that should be funded within their own organizations.

It has come almost as a surprise to EPRI officials that the latent need for industry-wide communication and education is so deep. Even in those power industry problem areas that were assumed to be well in hand, it has been discovered that there have never been any intensive programs of research. The classical problem of steam-boiler corrosion is one example. EPRI virtually backed into this problem when it found that some nuclear plant shutdowns were caused by such corrosion and that basic research had been lacking.

One of the basic issues facing the whole EPRI program is how to get the results of its R&D efforts applied or, in other words, to avoid having its reports merely ending up on utilities' library shelves. One ap-

Artist's conception of one terminal of a prototype, 400-kV, 100-MW HVDC system to be built in Consolidated Edison's Astoria (N.Y.) Station. EPRI has awarded a $21 million contract to General Electric for design and construction.



proach has been to have the EPRI staff composed of about three fourths permanent members and one fourth borrowed employees—people from the electrical equipment manufacturers and vendors, research institutes like Battelle, universities, and the utilities. After a year with EPRI, these individuals return to their home base, hopefully as "carriers" of new ideas, outlooks, and interests. Conversely, such internship helps EPRI keep in touch with the real problems of those who run the utilities. Another mechanism is to fund a significant amount of R&D in the facilities of the vendors and manufacturers. (Although EPRI retains patent rights in most cases, these are negotiable, especially where a company has had a long-standing predominant position in a technical area.)

Other communication channels include the industry task forces and advisory committees and EPRI's Board of Directors, made up largely of executives from the electric power field.

"When we first started," comments Chauncey Starr, former dean of the School of Engineering and Applied Sciences at U.C.L.A., now EPRI's first president, "I had the concept that we would concentrate primarily on the intermediate and long-range technical needs of the utility industry, assuming that the current problems were more or less well-handled. Perhaps the biggest change in our total program is that immediate problems, like stack gas cleaning, are in great need of centralized, coordinated development. And it creates a problem for us, for we find more and more pressure building up to get into here-and-now problems. Present crises always seem more pressing than the ones a few years down the road, and we have to be very careful that our long-range and intermediate-range programs don't get swamped by these pressures."

In the programs of the four major EPRI divisions, discussed in the following sections, R&D on current technical problems forms only a small part of the total effort, but it is expected to grow.

Nuclear Power Division

Under the direction of Milton Levenson, formerly of the Argonne National Laboratory, the Nuclear Power Division of EPRI is organized into three departments: Safety and Analysis, Systems and Materials, and Engineering and Operations. As Table I may suggest, the R&D program of the Nuclear Power Division includes nearly everything related to getting electricity from nuclear power (except for fusion, which is covered by the Fossil Fuel and Advanced Systems Division). EPRI looks to nuclear power as a major source of energy for the long-term future, and budgets accordingly. Thus, it is contracting research on the problems of design and analysis of nuclear plants, of methods of assuring their safety, and so on. The three departments take responsibility for R&D in multidisciplinary calculation (including thermal, neutronic, and hydraulic) and computer code development, in materials (including fuel and pressure vessels) and systems development (including fuel cycle and materials application), and in specific operational and maintenance problems.

In these areas, EPRI is concentrating on the long-range maintainability and reliability of operating plants. Federal government concern has been almost entirely with safety, whereas the manufacturers—the

How EPRI sees itself

EPRI has actually been germinating for many years. Its roots go back to 1965 when the Electric Research Council (ERC) began to bring together various electric-energy groups (from EEI, TVA, the American Public Power Association, and others) to encourage cooperative sponsorship of research. Technical goals were initially formed around a "Year 2000" study which an ERC special R&D Goals Task Force completed in 1971. Thus, the new organization was able to get quickly into an R&D program without too many false starts, and is evolving its own set of priorities.

Concurrent with the "Year 2000" blueprint, ERC worked out the details for setting up EPRI, whose R&D programs were to be funded by the bulk of the power industry. Headquarters for EPRI were set up in Palo Alto, California, in late 1973, and Chauncey Starr, former dean of the School of Engineering and Applied Science at U.C.L.A., was appointed its first president.

In two years of formal existence, EPRI has organized its professional staff, now numbering over 200, and assumed responsibility for 265 projects, which are now either under its management or in contract negotiation. These projects, which are farmed out among the utilities, electrical manufacturers, and universities, have a lifetime value of $206 million. EPRI's actual annual research budget was $68 million in 1974 and will be slightly over $100 million in 1975.

For its operations, EPRI has organized an industry committee structure of task forces involving several hundred professionals who act as consultant-advisors on all major R&D areas. It has also negotiated formal working relations with various Federal government agencies such as ERDA (the Government's new Energy Research and Development Administration), the Department of the Interior, and NASA. With ERDA, it is entering into the joint planning, management, and funding of programs.

Although EPRI has been touted as a unique organization, Dr. Starr says that for the management of R&D programs, he and his staff have simply adopted the management methods of the Government agencies and other high-technology industries which have had national experience in large R&D programs. So EPRI really behaves more like an NSF, though its financial support comes from private industry. What is unique about the EPRI organization is that it is a nongovernment entity, working on a national level, stemming from a fragmented industry that hasn't had this kind of experience.

Unique or not, EPRI confronts the double problem of building its credibility both with the utility industry and with the public. It must demonstrate to the industry that it is really useful in R&D and demonstrate to the public that it is not just a showpiece of the power brokers who have earned a bad name from the environmentalists' point of view. Building credibility in areas of professional judgment, in which many polarized interests are involved, will be difficult.

Dr. Starr is confident of success. "The utility industry," he says, "has not tried to use us to gloss over problems or to take a position that is to their near-term benefit, but which may not be technically complete." The way EPRI plans to handle this is to develop a complete spectrum of analyses and options on technical problems, to evaluate probabilities of success, to assess technological consequences. Out of this, he concludes, "we will let the industry and public decide what *they* want to do. We don't make decisions for the industry."

reactor vendors—have been more concerned with the problems of designing and selling plants on something like a one-year warranty basis. In practice, this has meant that questions relating to the continuing operation of plants over a 30-year period have remained something of an R&D stepchild.

An example of the kind of "general" problem that EPRI is tackling has to do with the fracture toughness of pressure vessels (when does the metal break rather than just stretch?). The industry has worried for a long time whether or not the safety codes for fracture toughness for various steels are too conservative, since they were originally set up on a limited data base. Clearly, such codes have a significant impact on both economics and safety. On a proposal/bid basis, EPRI awarded three nearly identical contracts to restudy this question. Two of the contracts went to two companies in the pressure-vessel business, both of whom have some vested interest in the problem. The third contract went to a testing laboratory, not in the business. All three were to work with actual materials from the vessel fabrication shops. When the research is done, there will be 25 times as much data on this issue than has been available heretofore and, hopefully, there will be a more realistic basis for determining whether or not the code is or is not as conservative as some people assert. EPRI's objective is to determine the facts surrounding a standing controversy.

EPRI has awarded a contract for research in providing computer code for plutonium recycle in light-water reactors (just as is now done for conventional reactors). In effect, the code will allow analysis of thermal-hydraulic safety issues. When the code is successfully completed, it will be made available to all utilities on a royalty-free basis through one of the national computer systems. Any user (whether pro- or antinuclear) will be able to use the code just by paying for the cost of the machine time in running a problem.

Fossil Fuel & Advanced Systems Division

The largest single item in EPRI's R&D budget—9.2 percent for coal gasification—and the next largest—6.3 percent for coal liquefaction—reflect EPRI's conviction that coal will become increasingly important to the power generation field over the coming decade. The six program areas listed in the Fossil Fuel Department, amounting to more than a quarter of EPRI's total R&D funding, aim at developing improved technology for the continued use of coal in power production, and an array of new technologies for converting coal to clean liquids and gas for fueling electric power plants in an environmentally acceptable form. The purpose of liquifying coal, for instance, is to convert it into storable fuel products containing lower quantities of ash and sulfur. The emphasis on coal as a major energy source in the medium-term future stems from projections that supplies of natural gas and low-sulfur fuel oils are threatened.

Although the utility industry does not see the improvement of coal mining as its responsibility, and looks to the Federal Government and the mining industry to lead the way, EPRI indicates that it might sponsor some small R&D efforts in that field, if it would catalyze some new technology for increasing production, lowering costs, and automating mining.

I. EPRI's proposed financial guidelines for 1975 R&D programs in its four divisions. Total budget for 1975 is slightly over $100 million so percentages can be roughly translated into millions of dollars. EPRI now manages 265 separate projects

Division	Percent of Total Budget
Nuclear Power	
Water reactor safety	5.1
Plutonium recycle	2.9
Pressure boundary	2.3
Reliability and diagnostics	2.7
Fuel performance and fuel cycle	2.7
Earthquake and tornado	0.7
Advanced nuclear systems	5.6
Operating benchmarks	0.9
In-service inspection	2.4
Chemistry	1.2
Operations and maintenance	0.7
Division total	27.2
Fossil Fuel and Advanced Systems	
Gasification	9.2
Liquefaction	6.3
Direct utilization	2.8
Environmental control and combustion	4.8
Resource production	1.5
Supporting research	1.6
Electrochemical conversion and storage	5.3
Thermomechanical conversion and storage	5.7
Fusion	3.7
Solar	2.3
Geothermal	2.1
Division total	45.3
Transmission and Distribution	
Ac overhead	4.0
Underground	5.6
Dc transmission	6.0
System security	1.2
Distribution	1.3
Division total	18.1
Energy Systems, Environment, and Conservation	
Environmental assessment	5.1
Energy supply	2.1
Energy demand and conservation	1.3
Energy modeling	0.9
Division total	9.4

In addition to its effort on coal conversion, the Fossil Fuel Department is sponsoring some environmental work on improving existing power generation —through improved stack gas cleaning, electrostatic precipitators, and more advanced concepts.

Quite separate as a department, though interactive with Fossil Fuels in some respects, is Advanced Systems, which is characterized by three major areas of R&D. First, it sponsors a range of work on improving energy conversion, from improving present steam turbines to "exotic" systems based on fuel cells, MHD, and the like. Second, it sponsors a variety of energy storage projects—batteries, flywheels, superconductive magnets, pumped storage, etc. Third, it is studying new or advanced sources of energy, including solar, geothermal, and fusion.

In the solar area, programs are being developed in

INTERCON '75

The week in brief

IEEE INTERCON this year breaks with past tradition. It moves to a new month—April; the exposition is a three-day show, with one late evening; and it adds several new programming features and special visitor services. What's more, the traditional awards banquet has become a dinner-dance, complete with big-band entertainment.

When and where

The product exposition will occupy the first and second floors of the New York Coliseum. Show hours are 9:30 a.m. to 6 p.m. on Tuesday, April 8, and Thursday, April 10; on Wednesday, the show also opens at 9:30 a.m., but remains open until 9 p.m.

All technical program sessions are at the Hotel Americana, accessible to the Coliseum by subway. Visitors can board the "D" or "B" trains directly from the Americana lobby and exit in front of the Coliseum at 59th Street and Broadway (first stop). The technical program committee has organized 37 half-day sessions. Additional sessions prepared by IEEE Groups and Societies will be presented Monday, April 7, the day preceding the official INTERCON opening.

Registering

Except for working exhibitor personnel, there is no advance registration for INTERCON. Registration opens at 8:30 a.m. on Monday April 7, in the Hotel Americana (Princess Ballroom), and at 8:30 a.m. on Tuesday, April 8, at the Coliseum.

Sen. Goldwater keynotes INTERCON

A special keynote session will be held at 9 a.m., Tuesday, April 8, in the Imperial Ballroom of the Americana Hotel. All INTERCON registrants are welcome.

Featured speaker will be Sen. Barry Goldwater, senior senator from Arizona, and one of the nation's leading constitutional spokesmen. Sen. Goldwater is a member of the Senate Armed Services and Aeronautical and Space Sciences Committees, a long-time amateur-radio operator, and a skilled aviator.

The new product panorama

The INTERCON exposition highlights the latest products, systems, and services of more than 250 manufacturers on two floors of the Coliseum. For a sampling of some of these new products, see page 85 of this issue.

Microelectronics, components, and packaging and production equipment will be demonstrated on the first floor. Instrumentation, computers and EDP peripherals, and communications equipment will occupy the second floor.

The exhibition also offers salon booths—a European exhibition device that combines the exhibit booth and conference room. Application forums are scheduled for the exposition as well. Exhibitors can schedule one-hour time slots to present a product or system story in a private theater area at the Coliseum.

INTERCON after dark

IEEE's major awards event, traditionally a formal banquet, will be presented in an entirely new format at the Imperial Ballroom of the Hotel Americana on Tuesday evening, April 8.

There will be big-name orchestra music for listening and dancing—a departure from the traditional banquet of previous years. The single price of $30 per person includes the All-Industry Reception, the meal, the awards presentations, and dancing.

The All-Industry Reception—open to all visitors—precedes the banquet. Planned around a "swinging years" theme, the reception includes decorations, favors, and refreshments typical of the big-band era of the '30s. Reception tickets for nonbanqueteers are $9.50 each.

Eta Kappa Nu, the electrical engineering honor society, will present its 39th annual awards dinner during INTERCON, Monday, at 6:30 p.m. in Constitution Hall of the Americana City Squire Inn in New York. Price per person is $14 (half-price for students).

AES luncheon-talk

Walter LaBerge, U.S. Air Force Assistant Secretary (R&D), will speak on "Integrating Air Force Command, Control and Communications in the 1980s," at the annual Aerospace and Electronic Systems Society luncheon at Ramayana restaurant, 52nd Street and Avenue of the Americas, April 8, at noon. Tickets may be bought at the door. For more information, contact Irving Meltzer at (201) 256-4000.

Scanning the sessions

The INTERCON technical-program committee has selected 37 three-hour sessions, all to be held at the Hotel Americana and designed to cover technical and professional subjects of broad and immediate interest. They will be held, six concurrently, on the mornings and afternoons of April 8, 9, and 10, with a highlight session on Wednesday evening. On Monday, April 7, there are ten specialized sessions, organized by IEEE Groups and Societies for more "vertical" interests.

A new kind of programming will reprise selected high-interest sessions in what is called a "one-on-one technical forum" at the Coliseum. Authors, equipped with blowups of their illustrations, will be available to discuss their work informally with individuals.

Full-manuscript preprints of most INTERCON sessions will also be available during the convention.

Microprocessing—the buzz word

Some of the sessions reflect the current interest in computer power on a chip: the LSI processor. Session 7, for instance, emphasizes technical applications, the hardware, firmware design decisions, and the economic impact of using microprocessors.

Session 19 answers questions such as why, where, and how to use microprocessors—as well as what type to choose for instrumentation applications. Speakers will highlight the advantages of microprocessors over conventional logic.

The extreme functional complexity of LSI devices, coupled with the limited accessibility for test, presents a unique testing challenge—aspects of which will be discussed in session 32.

And, in still another spinoff of the interest in microprocessors, Schweber Electronics has invited a half dozen suppliers of microprocessors to display their wares at the Coliseum (Booth 1423, 1425, 1427). According to Seymour Schweber, the presence of competing suppliers in the same booth reflects the maturity of the industry. Firms sharing the booth include Intersil, Motorola, RCA, and Signetics.

Computers—from hardware to humans

Computers are also high on the list of INTERCON session priorities. The number of microcomputers shipped in 1975 may exceed the quantity of computers installed to date. Session 1 analyzes the impact and advantages of microcomputers, their economics, and their use in general-purpose computation.

Computer storage technology is another area surveyed by INTERCON sessions. High-speed cache memories, solid-state "drums," and very-large-capacity stores are among the novel characteristics of new storage devices explored in session 20.

Computer networking has become a dominant form of computer use. Many network users have a need for access to programs and data available on two or more computer systems, or even on different networks. Session 25 examines the problem of network access.

Session 23 addresses the problem of improving the performance of computer communications networks in terms of channel utilization, message delay, and efficient control.

In hard times, do you fire people *or* do you retire the computer? The panel for session 26 discusses a wide range of money-saving policies associated with tradeoffs like hardware and humans. What does hardware standardization save? Do you scrap basic research? Are there promising new technologies for low-cost processing? According to session organizer W. J. Poppelbaum, the panel hopes to prove that "there are alternatives to despair."

Areas of application

Session 31 reviews a broad group of medical applications of computers by focusing on four representative examples: real-time diagnostic and management assistance, automated recognition of cytological images, medical consultation by artificial-intelligence methods, and a computer/paramedic-based health-care delivery system.

Not all the applications sessions are computer-related. Session 2 looks at another area of medical concern: instrumentation. Sales of medical electronic instruments by U.S. companies have grown at a compounded annual rate of more than 12 percent and were in excess of $700 million in 1974.

Transportation and oceanographic applications are also surveyed. Session 16 reviews the electronic requirements of modes of modern transportation, such as automatic train control, air-traffic control, automotive on-bound controllers (another microprocessor application), and magnetically suspended ground transportation. Session 22 describes measurements, techniques, telemetry from animals, and advanced suspended-array technology—all are aspects of instrumentation for oceanography.

. . . and much more

These are but a few of the topics to be discussed at INTERCON sessions. For INTERCON earlybirds, there are Monday's "vertical" sessions: "Data Privacy and Security," "Systems Approach to Energy Management I," "Control and Reduction of Automotive Pollution," "Energy: The View from 2000," "Space-Shuttle Experiments," "Technology Forecast: The Future of Components," "Systems Approach to Energy Management II," "The Engineer in Transition to Management," "Advanced Industrial Applications of Infrared Techniques," "Open Forum on The Society/Technology Interface," "A Forecast of Computer Hardware and Software: 1975–85," and "Physically Short Antennas for MF and HF." A highlight session on Wednesday evening explores the social implications of nuclear power plants.

The IEEE Educational Activities Board will present four special-fee short courses during INTERCON week: "Microprocessors," "Electronic Information Processing," "The CAMAC Modular Computer," and "Computer Network Tutorial," on Monday, Tuesday, Wednesday, and Thursday evenings, respectively. Cost for each course is $60 for IEEE members, $75 for nonmembers, and $25 for student members. This includes a luncheon, course materials, and admission to all INTERCON exhibits and sessions for the week.