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e^x	yes	yes
10^x	yes	no
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$\sqrt[x]{y}$	yes	yes
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% and Δ%	yes	no
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Trend line analysis	yes	no
Slope and intercept	yes	no
Store and sum to memory	yes	yes
Recall from memory	yes	yes
Product to memory	yes	no
Random number generator	yes	no
Automatic permutation	yes	no
Preprogrammed conversions	20	1
Digits accuracy	13	13
Algebraic notation (sum of products)	yes	yes
Memories	3	1
Fixed decimal option	yes	no
Keys	40	40
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feet	meters
yards	meters
miles	kilometers
miles	nautical miles
acres	square feet
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fluid ounces	liters
gallons	liters
ounces	grams
pounds	kilograms
short ton	metric ton
BTU	calories, gram
degrees	gradients
degrees	radians
°Fahrenheit	°Celsius
deg.min.sec.	decimal degrees
polar	rectangular
voltage ratio	decibels

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the cover

Scarcely before the smoldering equipment had cooled, engineers and technicians from all parts of the Bell System, including these from Bell Laboratories, were swarming through the burned-out New York Telephone switching center to plot repair procedures (*article, page 34*).

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spectral lines

Conflict of interest

In today's business and professional world, mention of the term conflict of interest gains instant attention. It denotes something to be avoided at all costs, when, indeed, in its general sense, conflict of interest is unavoidable. Governments, corporations, and institutions are prey to it. Whole professions exist to adjudicate conflicts of interest; lawyers do it, judges do it, managers do it, and yes, even engineers do it.

In the case of Governments, it seems almost superfluous to note that they are rife with conflicts of interest (among constituents, to cite one example, as well as between one another). The corporation encounters conflicts galore in serving its many publics—its stockholders, managers, workers, customers, and the community. And even in the case of the individual, each of us faces his own internal conflicts of interest—some of them not as simple as whether to watch baseball on TV or mow the lawn. In the case of individual conflicts, sometimes we have only ourselves to answer to. If we find ourselves in conflict with others, it may be adjudicated on a custom basis, or, in cases where we conflict with an organization (perhaps the firm for which we work), the likelihood exists of some precedent to guide the resolution.

But the "rule of conflict" is that the more varied our interests, the more frequently will our conflicts occur. The same applies to the individual organization with which we are "conflicting." So we can readily postulate an exponentially escalating incidence of conflict as a function of the activity and interests of both parties.

A classic conflict of the engineer is between "things technical" and societal concerns. In this day of rapid change, in which societal or "professional" concerns are seen as valid by a greater number of our colleagues, we even recognize a conflict between "inward" and "outward" directed professional concerns. (Inward concerns are related to such items as portable pensions, programs to limit the number of available engineers, and the like, while outward concerns relate principally to interests of the public.)

If individual engineers are conflict-prone, it is not surprising that conflict of interest is no stranger to the IEEE itself. (The phenomenon of conflict escalation clearly applies to IEEE, as both its individual members and the Institute itself are broadening their interests and concerns.)

A perennial conflict of interest that IEEE has had involves the fact that some of its members, in their daily professional duties, are more accurately describable as employees, whereas others are better described as managers—or part of "management." (This is not to imply that even the company president himself is not usually an employee.) Thus, the Institute, in addressing matters of, for example, portable pensions, may encounter conflicting viewpoints among its own members. Individual members of the Institute's Board of Directors face dilemmas stemming from such conflict. Furthermore, when the Institute finds itself acting as spokesman for the profession, members of the Board ask themselves, "Should I support the consensus among my constituents, or should I vote my own conscience and belief, independent of such consensus?" The problem is not unlike that confronting any elected official in a representative democracy.

To close one's mind to conflict of interest or to "sweep it under the rug" is folly. There is little question that such an approach may work occasionally in matters of little or no consequence, but rarely does it aid in reaching decisions in complex situations. Furthermore, it seems that, in enlightened professions such as ours, progress involving resolution of conflict is more rapid if based on advocacy techniques as opposed to adversary techniques. The point may seem a fine one to those who view the two as opposite sides of the same coin. Yet adversary techniques often tend to polarize, while advocacy tends to resolve differences. The IEEE, for example, espouses the wide publication and dissemination of information concerning engineering employment practices, to the end that it will help the profession—both employees and employers. Sometimes, "advocates" for the employees' interests see defects in existing practices that endanger their careers or earning power, while, simultaneously, "advocates" for management see easily correctable shortcomings that put them in an unfavorable position in attracting and keeping high-calibre engineering talent. In any event, enlightened decisions cannot be made in a vacuum—and changes made unilaterally may be counterproductive.

In summary, conflict of interest is unavoidable. It is neither all good nor all bad. It is bad in certain business situations, as, for example, when an individual's interests are so evenly divided that he is not sure of his own loyalties. It is bad when he intentionally misrepresents his interests, or when he gains financially because of hidden influence. However, it can be positive when individuals or organizations can openly debate the interests that they advocate. The result can be clearer delineation of the tradeoffs, solutions openly arrived at, and fair exposure of minority concerns in the process.

Donald Christiansen, Editor

The Great New York Telephone Fire

The Bell System marshaled its impressive resources to assess and repair damage in record time

On February 27, 1975, at approximately 12:15 a.m., a fire broke out in a New York Telephone Company central office, located at 13th Street and Second Avenue in New York City's Borough of Manhattan. The fire, which started in the building's basement cable vault, raged out of control, damaging or totally destroying millions of dollars worth of telephone equipment. The result: an unprecedented, total telephone communications blackout in the affected subscriber area, and its environs, disrupting service to over 160 000 residential and business subscribers.

Thus begins the story of a monumental restoration program to restore service to a 300-block area in only three weeks. Equivalent to hooking up a city the size of Albany, N.Y., or Jersey City, N.J., in 21 days, New York Telephone's ambitious objective was 95 percent accomplished on schedule and was appropriately dubbed, "The Miracle of Second Avenue."

The Bell System to the rescue

Within a matter of hours after the extent of the damage had become apparent, the Bell System was mobilizing an armada of emergency equipment and thousands of specialists from all over the United States to complement local forces. Bell System experts were flown, bussed, railed, or driven in to attack the millions of feet of wire and cable, the millions of switching components, and tons of panel and crossbar switching frames, all of which had to be repaired or replaced. Enough new wire was placed underground to circle the earth's circumference at the equator nearly 1000 times. And this did not include the hundreds of thousands of feet of inside wiring.

The organization's Long Lines Division craftsmen were there to help restore service on damaged high-density coaxial cables for long-distance transmission. A contingent of Western Electric experts was brought in on the same day of the fire from Chicago, Ill., to install the new and massive 320-foot-long trunk distribution main frame—a task that was completed within two days. And Bell Telephone Laboratories contributed chemical specialists to advise on how to clean damaged equipment, power specialists to assist in getting power in the building back on, and even fire-analysis experts to try to find out just what had caused the fire.

Considering the speed and efficiency of the operation, one might have thought that emergency procedures had been developed well in advance of the fire and were merely being adapted to the particular needs of New York Telephone. Such was not the case. In fact, according to a company spokesman, no contingency plans existed whatsoever . . . certainly, New York Telephone had none. Why? The spokesman offered a number of rationales. One was the highly remote possibility of such a large-scale emergency occurring. The Second Avenue disaster was simply unprecedented in New York Telephone's history. And even for such unlikely occurrences, the spokesman claimed that "we are always confident of our capabilities in emergency situations, since our depth is our real strength"—a boast that is supported by the Bell System's historical ability to bail its operating companies out of emergencies.

A second, and perhaps less obvious, rationale offered by the New York Telephone spokesman was that, besides being unnecessary, contingency planning is overly expensive—in fact, that it would require a consumer rate hike that would never be approved by the New York State Public Service Commission. *Spectrum* checked out this claim with the New York PSC and found it to be true.

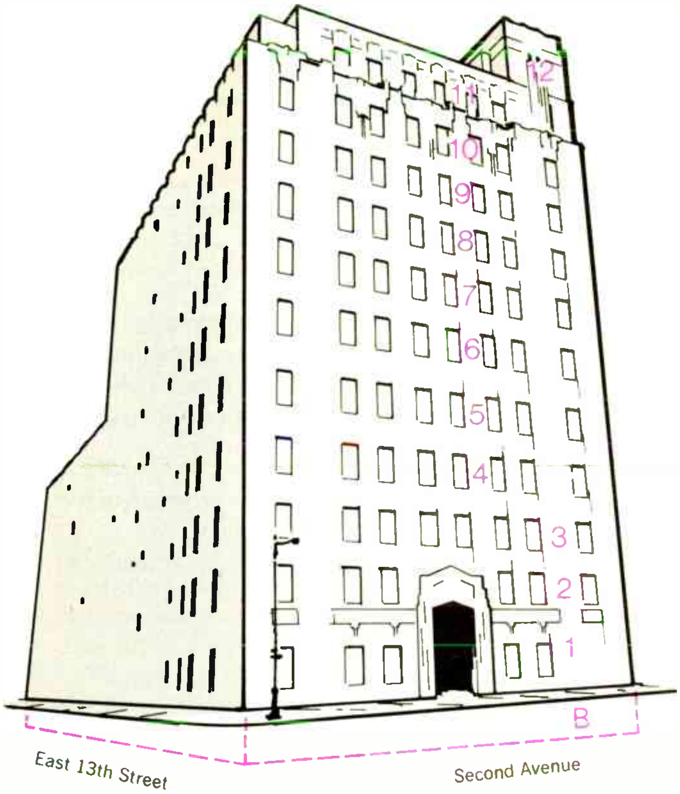
Meanwhile, questions persist, not concerning the preparedness of New York Telephone in advance of the fire, but about the fire itself.

A cable short circuit

While the official New York Telephone position as well as that of the New York City Fire Dept. is that the fire was caused by a short-circuit condition in a basement cable vault, where all incoming and outgoing cables were connected to the building, these facts are of interest:

- The telephone switching system uses 48 and 24 volts dc (130 volts, dc, for carrier pulse-code modulation or PCM equipment with vacuum tubes), and the energy dissipated in telephone circuits is generally quite low. Furthermore, it is known that proper fusing circuits existed within the switching center, sufficient to contend with *any* electric-circuit abnormality.
- A rash of subsequent fires occurred in other New York telephone offices, four of which were labeled "suspicious" by fire investigators.
- Although New York Telephone asserts that the usual building security had previously been quite adequate—a guard stationed at the entrance, requiring employees and visitors to sign in and out—security in all telephone company facilities has since been increased dramatically.
- As of this writing (over a month after the fire), a team of Bell Telephone Laboratories arson and fire specialists under the direction of D. E. Emerson, vice

Roger Allan Associate Editor

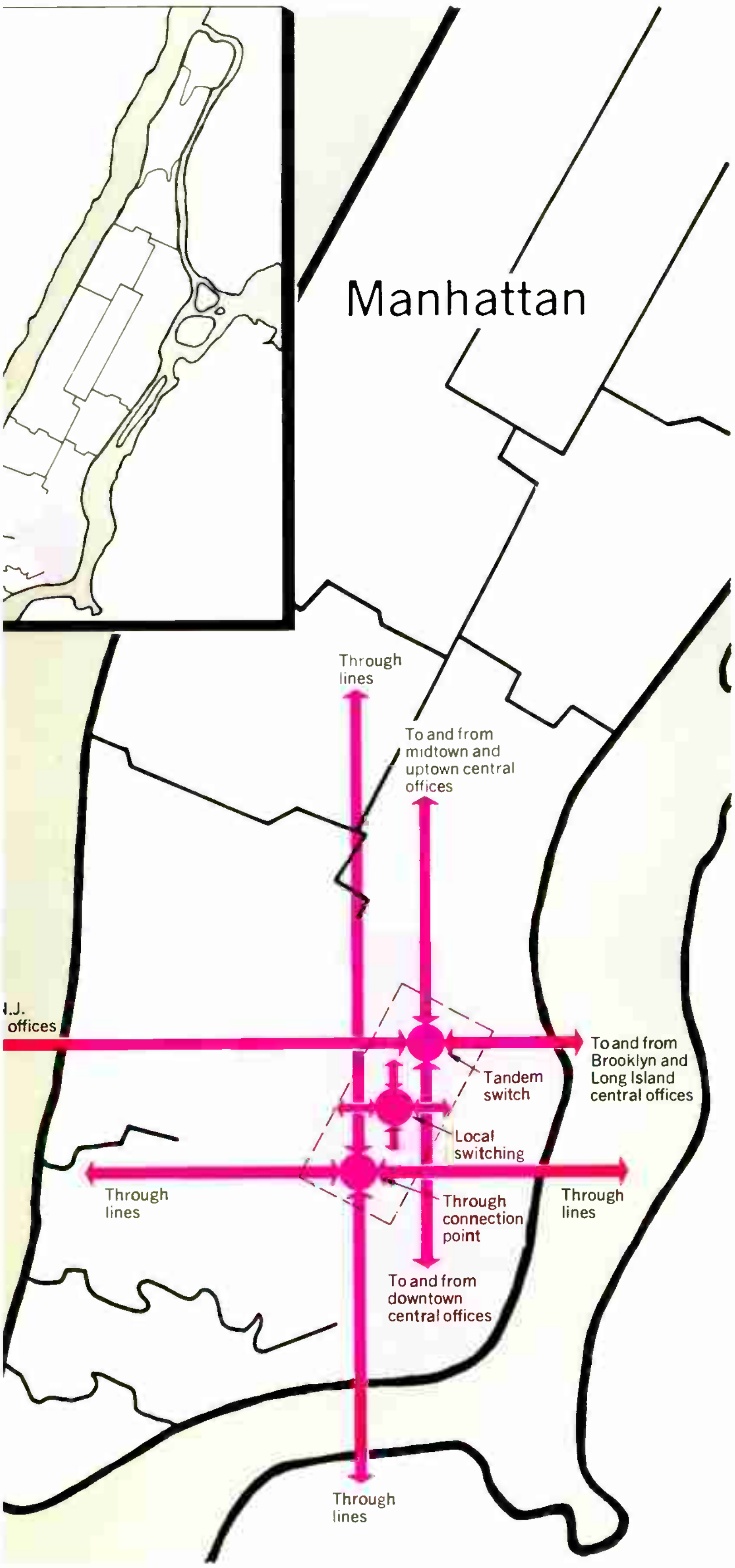


Extent of fire damage

Legend
- Destroyed
- Damaged
- Minor smoke residue

12	Elevator equipment / Water tank
11	Carrier equipment (T1, N2, and N3 types)
10	Tandem, crossbar · Administrative
9	Crossbar (exchanges 673 and 677)
8	Tandem, crossbar
7	ANI (Automatic numbering indicator) · Tandem, panel equipment · Battery power
6	Tandem, panel equipment · Tandem, crossbar
5	Panel eqpt. (exchange 475) · Crossbar (exchanges 533, 674, 777, 228, 260, 533, 982) · Subscriber main distribution frame · Administrative
4	Administrative · Cafeteria · Crossbar (exchanges 228, 260, 533, 982)
3	Vacant
2	Carrier equipment · ANI (Automatic numbering indicator) / Crossbar / Panel · Panel equipment (exchanges 254, 473, 475, 477)
1	Air conditioning · Circuits · Panel equipment (exchanges 254, 473, 475, 477) · Selector tandem · Trunk main distribution frame
B	Ac · Battery power · Diesels · Air conditioning · Miscellaneous · Cable vault

[1] The Second Avenue central office (tinted area within Manhattan island) handled tandem as well as local subscriber lines by housing switching equipment for both. Thousands of trunk lines serving other central offices also passed through the building.



president of Network Operation, is still looking intensively into the fire's cause. Results of its investigations have yet to be announced.

A major switching center

The Second Avenue wire center not only served local subscriber lines within its immediate geographic area, but was also a major tandem switching center for interoffice service and housed many trunk lines that passed through the building, acting as a through connecting point (Fig. 1). Thus, disruption of telephone service occurred not only within the area of this center, but spread to include outlying areas, where calls going from one central office to another passed through or were switched in the tandem equipment on Second Avenue. For over a week following the fire, many telephone calls between centers, other than the crippled one, were either delayed or could not be completed.

An assessment of destruction and damage showed that equipment for four panel telephone codes or exchanges was destroyed and eight crossbar (XB) exchanges were damaged. In addition, three XB tandems were damaged. Figure 1 shows how the 20 500 disrupted tandem trunk lines had been serving incoming calls from New Jersey to Brooklyn and Long Island, as well as providing two-way service between uptown, midtown, and downtown Manhattan and Long Island.

Tandem trunk lines are large cable lines that connect central offices (also known as wire centers) to one another. They differ from subscriber lines in that the latter only serve the end subscriber's telephone equipment, to and from the subscriber's central office. About one third of New York City's 70 central offices contain tandem equipment.

For four of the affected twelve exchanges, panel switching equipment on the building's first and second floors was totally destroyed. The complete destruction of the first-floor trunk main distribution frame (TMDF), however, and the destruction of all incoming and outgoing connecting cable lines, coming from the basement, was the largest single reason for telephone disruptions. The TMDF was the major input–output connecting point to all other central offices.

Also destroyed was N1 carrier equipment on the second floor. N1 is an analog transmission system for 200-mile (322-km) service at a 50-kb/s rate. N1 systems can handle 600 two-way voice channels for every 100-pair cable line. N2 (similar to N1), N3 (with a higher capacity of 1200 channels), and T1 carrier equipment on the 11th floor suffered only minor damage. T1 is a digital system for 50-mile (80-km) service at a 1.544-Mb/s rate handling 24 two-way voice channels.

Getting back the service

On the very morning of the fire, planners for the New York Telephone Company, sitting in their offices in the company's engineering headquarters on West Street, downtown Manhattan, were watching the smoking debacle from window vantage points. They immediately met to consider formulating emergency restoration plans. Even before the final flames died out, four master plans were prepared within a few hours, the first of which was implemented. The plans were:

Plan I: Temporarily reroute inoperative-panel subscriber lines to two central offices located further uptown—on W. 42nd Street and on W. 18th Street—and replace the damaged XB equipment with #1 ESS. Return all lines to the Second Avenue center later. This plan was the least expensive (estimated cost, $46.2 million) and figured to cause the minimum amount of telephone service disruption. It was eventually adopted.

Plan II. Basically the same as Plan I, except leave Second Avenue lines permanently in the two uptown offices and advance expansion plans for the W. 42nd Street office. This plan would have cost $67.1 million.

Plan III: Same as Plan I but replace the damaged XB equipment with #1 ESS in the downtown Pearl Street office at a cost of $61.5 million.

Plan IV: Similar to Plan III, involving redistributing one fourth of Second Avenue lines to the downtown Pearl Street office at an estimated cost of $54.6 million.

Immediately, a work force, under the direction of Lee Oberst, New York Area vice president of New York Telephone, was set up to implement Plan I. Except for some major building damage to the largely vacant third floor (which fortunately acted as a heat

[2] **Clockwise, below, thick toxic fumes caused by the burning PVC insulator jacketing of the telephone cables hampering fire-fighting efforts; a workman wiring up telephone lines for one of many temporary portable mobile-van telephone stations; one of hundreds of wiremen hooking up the millions of wires to each side of the enormously long (97 meters) TMDF.**

buffer, sparing upper floors from destruction), the building was determined to be structurally sound.

A new TMDF, a huge structure some 320 feet (97 meters) long by 10 feet (3 meters) high by 6 feet (2 meters) wide, was flown in from Chicago, Ill., by Western Electric Co., and was ready for installation in the building the next day. It was later assembled in two days.

The TMDF was wired up by no less than 200 men, half of whom were connecting incoming cable wires from the basement to the TMDF, on one side, while the other half were simultaneously busily connecting outgoing TMDF lines to the panel and XB switching equipment, elsewhere in the building, on the other side. While each side worked unaware of the other, the millions of individual connections on both sides of the TMDF boards were being mated to each other with near-perfect accuracy. According to a Bell System spokesman, the task of wiring up a large TMDF would normally take about one year to complete, using a normal complement of a dozen men, working one side at a time.

Equipment was brought in to remove the mass of burned-out underground cable, some of it damaged from water moisture from firemen's hoses due to a loss of normally pressurized air within the cable jacketing. The enormous task of laying down over 1 billion feet (300 million meters) of wire began, for rerouting to the uptown W. 42nd Street and W. 18th Street central offices. Fortunately, underground passageways to accommodate this very large amount of wire were in place due to planned future expansions.

Some 106 km (66 miles) of telephone cable had to be replaced as a result of the fire, much of it fed by hand into the building's cable vault, where it was painstakingly spliced and connected to the switching equipment on higher floors.

The highest-capacity short-haul digital transmission system in the United States, the new T4M from Bell Telephone Laboratories, was connected between Newark, N.J., and New York City via an underwater coaxial-cable link to restore service normally handled by about 166 T1 transmission lines that were burned out at the affected center. The T4M system has an ultimate capacity of 40 000 two-way telephone conversations and encodes messages at a rate of 274 Mb/s. A single T4M line replaces 1680 T1 lines. As this story was being written, installation of the short-haul digital T4M system was completed and transmission tests were underway.

Restoration work was not limited to replacing destroyed components and wires. Just as massive a task was the cleaning and repairing of equipment damaged from heat, smoke, and water. For example, some 10 million relays and over 6 billion switch contacts were cleaned, individually, by human hands! Damage to the building brought forth a restoration force composed of hundreds of carpenters, electricians, glaziers, construction workers, and plumbers.

Two slightly damaged tandems were repaired and reactivated, while three others, which suffered heavier damage, were rerouted through other tandem routes.

A temporary solution

To provide the thousands of subscribers with some form of telephone service during the three-week restoration project, dozens of mobile coin-telephone vans were brought in from all over the eastern seaboard and placed in various strategic locations throughout the disrupted area. They were connected to existing trunk lines that were unaffected.

A message center was also set up in office space in midtown Manhattan, particularly to assist local businesses dependent on telephone service. Callers to

Three automatic switching concepts

Automatic switching equipment in the Second Avenue center was mostly of the "panel" variety (a high-capacity electromechanical system that dates back to the 1920s), newer "crossbar" (XB) equipment, and now, the electronic switching system (ESS). Compared to the pre-1900 manual switching systems, where young boys scurried about to interconnect manually the calling and called parties with patch cords, ESS is a far cry in sophistication, speed, and handling capacity.

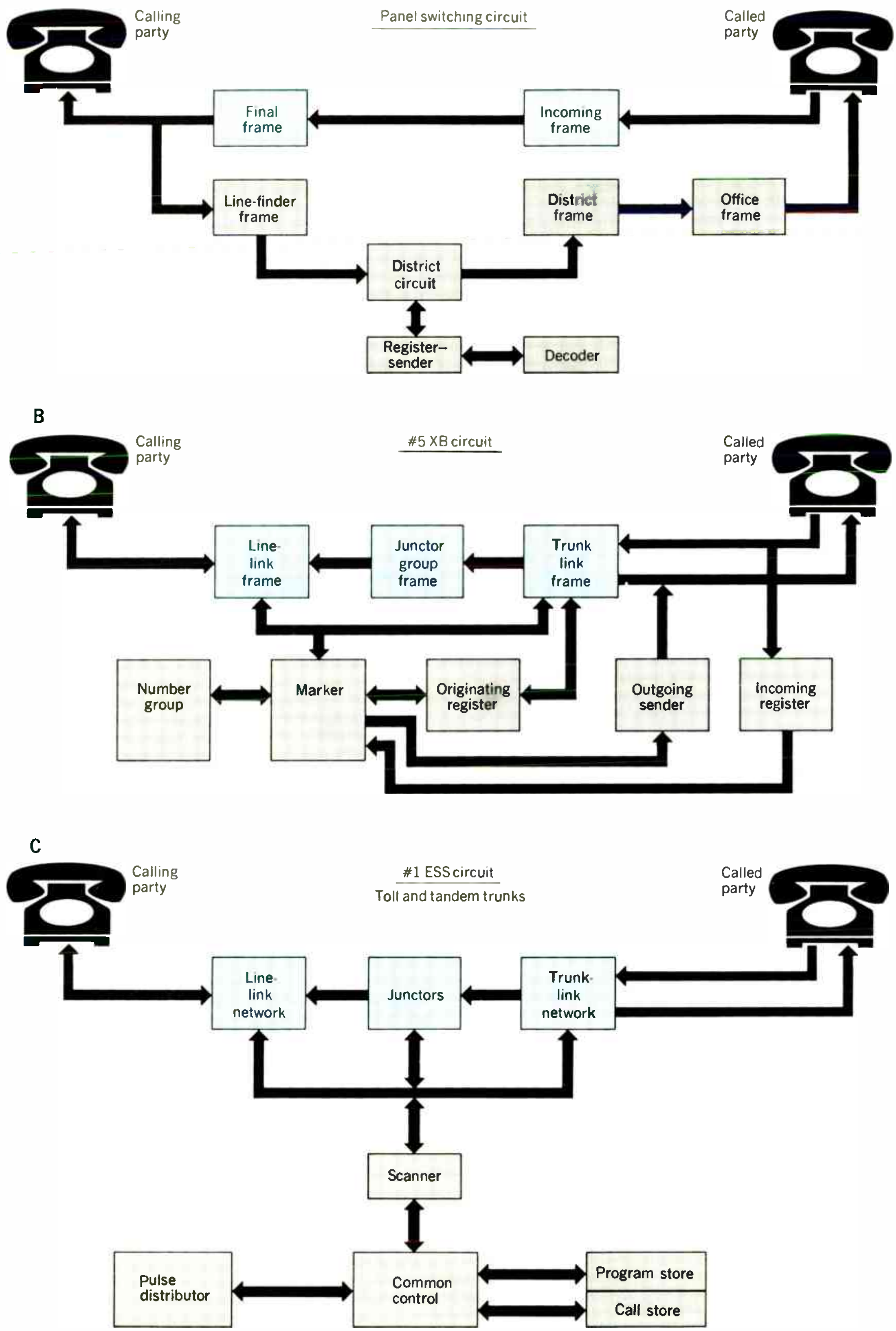
A majority of nationwide Bell System switching systems are panel, XB, and ESS types (the balance being predominantly "step-by-step"), and ESS is rapidly replacing the other types. Bell projects that, by the year 2000, all switching will be done by ESS—=1 ESS (for large metropolitan areas) and =2 ESS (for rural and suburban areas) are the most advanced switching systems in current use. A =4 ESS is now in production and is designed for switching tandem trunk lines.

Ironically, the damaged =1 XB equipment in "Second Avenue" was not slated to be replaced by an ESS until the late 1980s, but because of the fire, usable life was so shortened that a decision was made to install a =1 ESS in "Second Avenue" for operation as early as June 30 of this year—an extremely short installation period as an ESS normally takes a year or more to engineer and install.

In New York City, of the 43 central offices with panel equipment, half, according to Roy Dollard, New York Telephone chief engineer, are undergoing replacement under a panel-switching system replacement program to be completed by 1980.

The block-diagram operations of the three generations of automatic switching equipment—panel, XB, and ESS—are shown here. All three systems perform the same basic function of interconnecting calling and called telephone parties. Each system can be broken down into two major parts: a common control or logic component, and the transmission component. The logic function determines that a call is being made, and, after establishing where the call should go to, chooses the best transmission path at the time of calling. The transmission path consists of the physical wire path the telephone call is carried over, and includes interconnection structures such as frames. Both panel and XB equipment utilize electromechanical relays for the logic function, but XB makes use of a large crosspoint switch. The ESS equipment uses fereed switches, instead, for stored-program control. This provides faster, larger-capacity, more reliable, and more flexible service.

Three methods of automatic telephone switching: panel (the earliest), XB, and ESS. Both panel and newer XB systems are electromechanical. ESS is the most advanced and uses fereed switches for stored-program control, for higher-capacity, higher-speed, more flexible, and higher-reliability operation.



Some vital statistics

Here are some interesting facts concerning the restoration of telephone service to the Second Avenue switching center:

- 5443 tonnes (6000 tons) of debris removed
- 236 tonnes (260 tons) of underground cable removed
- 272 160 kg (600 000 lbs) of air freight shipped
- 6 156 000 switch contacts cleaned, by hand
- 1277 liters (1350 quarts) of special cleaning fluid used
- 10 million relays cleaned, by hand
- 1800 panes of glass replaced
- 30 480 meters (100 000 lineal feet) of lumber used
- 200 tons of steel used
- 3.66 million meters (1.2 billion feet) of wires placed underground
- 2.6 million meters (8.6 million feet) of cross-connection wire used, over 5 million wires of which were spliced underground
- 173 736 meters (570 000 feet) of inside wiring cable used

Personnel assigned

Construction	1197
Other New York Telephone	945
Western Electric	1250
Bell Telephone Laboratories and AT&T Long Lines	25
Outside contractors	538
Total	3955

The making of a telephone call

For those who aren't familiar with how a local telephone call takes place, here is a quick rundown:

When a subscriber picks up his or her telephone set, a signal is transmitted over the subscriber line to the subscriber's central office (handling the first three digits of the telephone number). The office provides a dial tone when equipment is ready and available to collect and analyze the telephone number about to be dialed.

The first three digits dialed determine which central-office equipment is to be reached (the term, central office, refers to the switching equipment for a particular exchange building). Before the final four digits are dialed, the "home" central office has searched among wires (paths) leading to other central offices, and has selected a pair of wires not in use, for use by the calling party.

Instantly (within milliseconds), appropriate relays (fereed switches for ESS equipment) go into action to hook up the calling telephone to trunk lines going to the "distant" central office selected, followed by relays closing in this central office to link the incoming trunk line to the called telephone.

Bear in mind that the two central offices discussed can be, and often are, within the same building or wire center.

The hierarchies of different switching equipment used serve the purpose of selecting the best available transmission path, depending on the calling distances involved.

the affected twelve exchanges would be told by a tape-recorded message to call another number, that of the message center, where volunteer messengers were used to transmit telephone calls, on foot.

As for the disruption of service to the thousands of subscribers outside the affected area whose calls ordinarily were routed through tandem equipment at the Second Avenue site, their calls were temporarily rerouted to other switching centers as far away as Los Angeles, Denver, Cleveland, Philadelphia, Boston, Atlanta, and Albany.

Thousands of new additional trunk lines were installed between other switching centers within Manhattan, to handle temporarily the extra rerouted calls that would normally be served by the fire-damaged center.

Four new Subscriber Loop Carrier (SLC-40) systems, normally designed for suburban/rural service, were installed between a telephone company engineering office crucial to the recovery and the West Street downtown central office, to provide partial service for the affected area. Each of these digital delta-modulation systems was capable of interleaving a multitude of telephone conversations on two-wire pairs as well as being capable of providing single-party service to 40 lines.

According to Bell Telephone Laboratories, from whose many locations the SLC-40s were brought in, an SLC-40 would normally use a T1 digital transmission line, but instead was used with ordinary TV/video transmission cables for the duration of the emergency, to provide central-office-subscriber service. Digital signals from the four SLC-40 units were combined into a T2-like signal by the use of a multiplexer.

Portable D3 channel banks, terminal trunk-line PCM signal converters, were also brought in from many Bell Telephone Laboratory locations. The normal capacity of 24 voice channels for each unit was also boosted to 96 channels by connecting four D3 units to a multiplexer.

The results

A constant monitoring of telephone service by *Spectrum* throughout the three-week restoration period showed that service to all twelve telephone exchanges was completely out during the entire three weeks. Even the highly vaunted police emergency SPRINT system (911) was disabled (busy circuit signals were received) for six days after the fire.

But by Monday, March 24, 1975—the telephone company's self-imposed deadline—service was restored to about 95 percent of subscriber lines. Of this group, a few subscribers' telephone numbers had to be changed permanently, and callers to the old numbers were greeted with a recording of the new telephone numbers. Further, because such a large number of workers was assigned to the restoration project, the company was forced to shift some priorities. Consequently, what the Bell System refers to as "Special Services" work had to be postponed in many locations far from the fire. Thus, for example, the laying down and servicing of digital data communications, teletype, and video (for cable TV) lines, as well as the transferral of specific telephone extension numbers to different facilities, have fallen behind schedule, at least in the New York City area.

As for the remaining 5 percent of New York Telephone's affected subscribers, nearly all had had their service restored at the time of writing. ◆

Telephone technology: the 'which switch' game

The answer depends on rate structures, politics, and technical and manufacturing know-how; each country finds its own unique solution

When the wires from a home telephone reach the local switching exchange, they enter a system that is unfamiliar to most telephone users—even to those who are engineers. Modern direct dial telephone systems are enormous. In fact, they are the most complex interconnected, automatic systems man has devised. As users we are generally aware of the telephone system only when it frustrates or fails us. But whether we think of them as interesting engineering designs or as increasingly important tools for daily living, telephone systems bear closer examination.

The following article considers some of the developments and decisions that have affected the British telephone system. It focuses on the technology found in English local switching exchanges, and also explores some of the economic, social, and political reasons for decisions recently reached about the future of the British telephone system. Future articles will explore recent trends in telephone switching in other countries.

In Britain, the telephone system is operated by an agency of the national government. Decisions to invest money in new equipment are then direct matters of Government policy—for example, the major decision discussed in this article was made by a Cabinet Minister. In other countries—the U.S. and Canada—private corporations operate the telephone system and Government control is exercised indirectly.

But, regardless of the local mechanisms of social and political control, the basic facts of telephone technology remain a fundamental force in shaping telephone system developments in every country. For telephone technology has long been international in scope, shared by telephone engineers around the world.

From Strowger to digital speech

Back in 1889, A. B. Strowger conceived the first automatic telephone switchboard, and it was installed, at LaPorte, Indiana, three years later. Strowger's idea developed into equipment based on a stepping switch that moved vertically and rotated horizontally in response to dialed digits. Today, 86 years later, a substantial portion of the existing telephone switching plant in most countries is still based on Strowger-type switches or their equivalent.

In 1926, the Swedish telephone system made first use of an alternative electromechanical switching device—the so-called crossbar switch—which is still widely used for new telephone construction in many countries. Initially, these crossbar switches were used in the same step-by-step manner as the Strowger switch. Later, centralized common control was used. This new approach was devised by Bell Laboratories, and was first placed in service in 1937. Starting in 1965, with the installation of the first electronic switching system (ESS-1)—manufactured by Western Electric Corp. and based on stored-program computer-like controls operating sealed-reed relay contacts—telephone switching technology took another decisive step.

Strowger, crossbar, and ESS all use metallic contacts to connect one subscriber to another. The most striking difference between these technologies is the control over the contacts. Here, the movement is from sluggish, electromechanical, per-call control to common traffic-shared relay control, and finally to high-speed electronic computer control.

In 1963, the Bell System introduced the No. 101 ESS, which switched speech samples on a time-division basis and used a centralized stored program control. This was the first step away from metallic contacts; the next one may be to electronic circuits carrying digitally encoded speech signals. In fact, starting in 1976 such circuits will be switching some trunk telephone lines in the U.S., using the ESS-4 system. However, the extent to which such digital systems can prove economical for use in switching local calls remains uncertain.

Where the consumer fits in

With computer control of telephone switching comes the capability of providing economically many new convenience services. For example, there is the "call waiting" service: When someone tries to call you while you are using your phone, a little beep signals that attempt. Then you can make apologies and suspend your current conversation for a few seconds, while you check out the new caller.

Such services are considered luxuries by the British. Some subscribers want them, but the extent of their use depends heavily on the cost. For 10¢ a month, we might all be willing to add call waiting to our home telephone service. For $10 a month, few people would consider it worthwhile.

To some small extent, the tastes of telephone subscribers can affect the development of telephone systems but, actually, subscriber acceptance of convenience services plays a relatively small role in decisions about installing new telephone switching equipment.

In an overall sense, the course of telephone development is based on a broad social consensus. Until a

Howard Falk Senior Associate Editor

country and its people decide that basic telephone service is a necessity of life, the effort and money needed to bring telephone services into every home will not be forthcoming. But even when that consensus is reached, the rate of telephone system development is limited by economic and political factors.

Choosing the most economical equipment

Looking at a simple telephone exchange, the technology choices must be based on overall, long-run economics. In the past, a frequently faced decision, when a new U.S. telephone exchange was to be installed, was whether electromechanical crossbar or computer-based technology was to be used. Today, with the possible exception of the smallest exchanges, that decision seems to favor the computer-based system.

Overall, long-run economic decisions are based on first-cost comparisons, continuing operational costs, and possibilities for additional revenues. For example, operational costs (compared to those for a crossbar system) show ESS savings because relay contacts don't have to be cleaned, and wires don't have to be reconnected to effect customer service changes. With a computer-based system, maintenance consists of plugging in new circuit packages, and customer service changes are effected by teletyped instructions. Operational costs—including those for internal telephone company services like traffic analysis and accounting—all come considerably cheaper with computer-controlled switching than with an electromechanical system. And to the extent that subscribers may buy the added services that can be offered by computer-based switching, there is an added incentive to opt in favor of a computer-based system.

Looking at an overall national system, however, it is clear that much more complex forces are in operation. For the British, the decision to emphasize the TXE-4 switching system involved such factors as the job security of workers building Strowger switches, and the desires of their manufacturers to compete in the world market with up-to-date equipment, as well as the confidence of their telephone system management in dealing with new computer technology.

In other countries, the factors are different, and the aspirations and problems of different groups shape the course of telephone system development. In every case, the telephone system of a nation reflects its unique response to developing telephone switching technology. ◆

Communications II

Telephones in the U.K.: cautious progress

A few false starts, then a low-risk selection of staid switching technology

Only about 51 percent of all British households now have telephones, and the demand for new installations is very strong. At present there are 12.6 million telephone lines in use in Britain. That number is expected to grow steadily to about 20 million by 1982. The new lines will go overwhelmingly into homes and household penetration should reach 85 percent by 1985.

Traditionally, the British telephone system has been made up mostly of small telephone switching offices, with perhaps several hundred lines per office. With current rapid growth, this situation is changing and there is a growing need for larger offices similar to those, in countries like the U.S. and Japan, that handle tens of thousands of lines.

Rapidly increasing demands for new telephones by the British public did not become apparent until the 1960s. In the more leisurely days of the early 1950s, all Britain's telephone exchanges, like those in most of the rest of the world, were electromechanical Strowger types—a design that was 50 years old and manifestly obsolescent, although a new version was successfully introduced in 1932. (About 5700 Strowger exchanges are now in service.) By the 1950s, some countries had begun to replace Strowger switches with crossbar-type electromechanical contacts. British telephone planners then thought that it should be possible to build a fully electronic switching exchange, eliminating metallic contacts entirely. In 1956, an agreement was signed with five major suppliers to develop such an exchange. So confident were they, that no plans to replace Strowger with crossbar were made, even as a temporary expedient. A small 600-line experimental electronic exchange went into trial service at Highgate, in north London, in September 1962. Tubes were used in the speech paths in this exchange, and the equipment proved interesting but impractical to operate. After this experience, some electromechanically controlled crossbar exchanges—compatible with the Strowger switches—were developed for export markets and also produced and used domestically. Over the past eight years about 250 of these have been commissioned.

In the meantime, development of electronically controlled metallic-contact switching also got underway, and, by 1967, a small system, suitable for country districts, was ready. Called TXE-2, this unit can

Michael Payne Contributing Editor

handle a maximum of 2000 lines, using reed switches as the contact devices and employing hard-wired discrete component electronic control. Today, about 600 TXE-2 systems are in service in small local British exchanges.

Needed: a big city switch

But neither the TXE-2, nor the electromechanical crossbar units were sufficient as long-range solutions for large local exchanges. To meet the rapidly expanding demand for telephone service, switching equipment with a capacity of 40 000 lines was needed for urban and suburban areas. The approach taken with the TXE-2 led to a modular switching system that could be assembled in various sizes to meet the needed larger capacities. The final design for this system—called TXE-4—was completed by Standard Telephones and Cables Ltd. (STC).

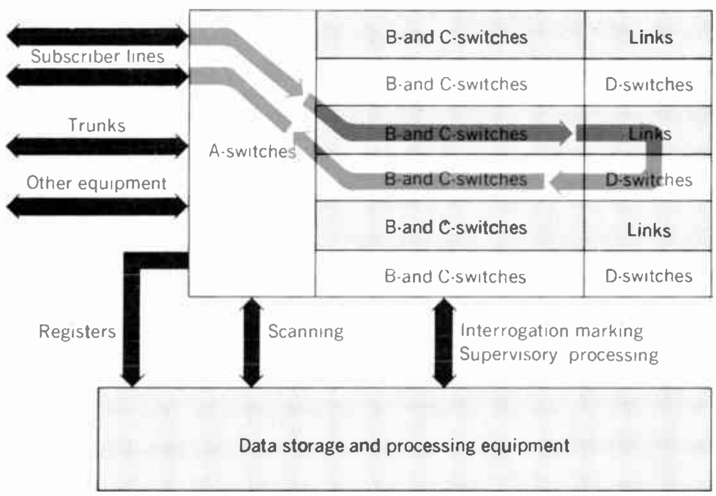
TXE-4 did promise to meet the anticipated expansion needs of the British telephone system, but, by 1969 when TXE-4 was undergoing field trials, the experience of telephone systems in other countries had demonstrated the potential superiority of switching systems based on stored-program computer control. Recognizing this fact, the attention of the British telephone equipment manufacturers, General Electric Co. Ltd. (GEC) and Plessey Co. Ltd., turned to the development of stored-program computer-based systems.

Software vs. hardware: a political decision

In Britain, as in most European countries, telephone service is provided by the Post Office (BPO). In 1969, BPO chiefs were very wary of stored-program computer control. They acknowledged that computer control was probably the best ultimate answer, but they were apprehensive about the breakdowns they heard the Bell System had to unravel when it first introduced computers in the U.S. They knew that if they had to face difficult breakdowns, they wouldn't be able to call on the sort of resources available to Bell to solve problems, at least not for many years. But demand was rising so rapidly they couldn't wait, so a decision for computers seemed to imply tremendous risk. An inadequate public service that had to be expanded quickly was not the place to take risks, so they concluded that the new system couldn't be based on stored-program computers. (Actually, it turned out that both Plessey and GEC have placed stored-program switching systems in service before TXE-4 was cut over.)

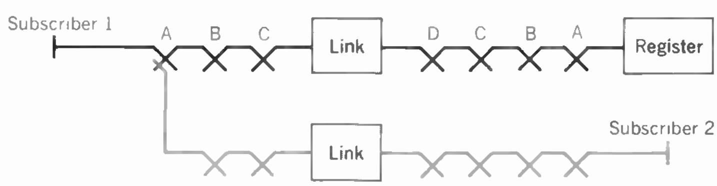
In the spring of 1971, after a two-year trial, the BPO announced that TXE-4 would be its choice. Later that year, STC got a $36 million production development contract, covering 18 exchanges and exchange extensions. Stored-program systems were not ruled out but the BPO decided to work on them slowly—initially, for trunk exchanges—and it will be well into the 1980s before there will be a significant number operating.

Plessey and GEC thought the choice a bad one—particularly Plessey, whose chiefs were (and still are) convinced that the telephone switching system must eventually be based on computers. The BPO is by far the biggest potential customer for British telecommunications equipment companies, and almost certainly an essential market base to underpin less profitable efforts in smaller markets. Knowing that the BPO is a public corporation responsible to Parliament—and that, in the last resort, the Government can change BPO decisions—GEC and Plessey took their case to the appropriate Government minister. They argued that concentrated work on computer systems would fairly soon reduce the risk to an acceptable level, and in the meantime more crossbar could be used. Further, they said, TXE-4 had serious disadvantages. Because it was hard-wired throughout, it was expensive and functionally inflexible. They claimed it had little scope for development (not strictly true, though it has less scope than stored-program computers because in the long run economics will almost certainly favor software rather than hardware). For those reasons and because it bucked the general trend, they felt it had no export potential (this time, not so according to STC, which claims some interest from abroad). They argued that if TXE-4 were phased-in to replace Strowger as quickly as the BPO wanted, it would cause serious unemployment among Strowger workers, because of its smaller and different labor requirements. Stored-program computer systems, because they would take longer to get into production,



When a subscriber picks up his telephone to make a call, a register is selected and interrogation and marking circuits operate reed relay crosspoints to establish a path to the register for the call. The digits the caller dials are then stored in the register, and read by the processor which identifies the correct output termination. Then the interrogation and marking process is repeated from input to output termination, and the caller gets a ringing tone. The path to the register is then released.

Calls enter the TXE-4 exchange through an A-switch crosspoint. Presence of the call is sensed by a scanner that checks all incoming terminations. Under processor control, the subscriber is then connected to selected B- and C-switch crosspoints, a link, a D-switch crosspoint, and then out again through another set of C-, B- and A-switch crosspoints to register and complete the call.



would allow time for less-painful reorganization.

The BPO replied that TXE-4 met its requirements and projected British stored-program systems did not. First, TXE-4 could be available fairly soon and the stored-program systems could not. Second, it used proved, even dated, technology and had sufficient development almost to guarantee reliability, the BPO argued, while believing that stored-program system reliability was largely unknown. Third, TXE-4 was modular, and the ability to expand exchanges progressively in small increments, in line with expanding local demand, is an important asset. Fourth, modules such as the interrogator-markers in TXE-4 are not permanently dedicated, and the functions of a failed module automatically redistribute over other modules, so that partial system failure does not alienate some subscribers or facilities as is possible with some stored-program computer system failures. Fifth, TXE-4 is directly compatible with the new small TXE-2 local exchanges.

After hearing both sides, the minister took until April 1973 to make up his mind. Then he backed the BPO, subject to a slower rate of changeover to TXE-4 to minimize displacement of Strowger workers.

Inside the TXE-4 system

To get a closer idea of the nature and vintage of the technology used in the TXE-4 system, let us consider some of its main features. Like all newer telephone switching systems, the TXE-4 consists of a large number of interconnected switch contacts whose action is monitored and controlled by an electronic processing system. Each switch contact crosspoint consists of four sealed-reed switches surrounded by a common coil that operates all of them. Two reeds carry the speech paths, one carries signals, and the fourth is in series with the coil and carries the coil current to the next crosspoint. That means that each crosspoint is powered through the one previously selected. Crosspoints are mounted on plug-in printed circuit boards. The number of boards used is determined by the size of the switching facility. As traffic through an exchange grows, modules of all types can be added without disturbing the existing set-up, thus painlessly increasing capacity.

In an exchange, any incoming line has to be able to connect to any outgoing line. In principle, the simplest way to achieve this capability is to build an enormous matrix of crosspoints, one crosspoint for each line into and out of the exchange. However, every crosspoint has to be able to connect with every other crosspoint so that a colossal amount of connection circuitry is necessary. Like other metallic contact systems, TXE-4 solves the problem by using four arrays of crosspoint switches called A-, B-, C-, and D-switches. Each array switches in several alternative paths to the next, so that, in normal circumstances, it's always possible to find a path through the contacts. Actually, each path is made from the incoming termination (the A-switch) through the B- and C-switch arrays to the D-switch, then back again through the B and C arrays to the outgoing A-switch termination. Each array is built up from modules of switches, and one exchange may have more or less B-, C-, and D-switches relative to the number of A-switches, than another exchange, to allow for different weights of traffic in different areas. For instance, a 10 000-line exchange in a small town may never have more than a small proportion of the lines in use all at once, so the B-, C-, and D-switch arrays can be small relative to the 10 000 A-switch terminations, but 10 000 lines in an exchange in a metropolitan business district may sometimes all be in use at once so that there must be many more B-, C-, and D-switches than in the suburban exchange to make sure that there's always a path available from termination to termination.

This first-production TXE-4 telephone exchange is being installed by Standard Telephones and Cables Ltd. (STC) for the British Post Office at Sutton Coldfield, located near the city of Birmingham, England.

Detecting that a caller wants a number, and finding a path through the switches from the caller's A-switch termination to the right outgoing A-switch termination, is the function of the control system. The important items are the main control processors, line scanners, data stores, registers, and devices called interrogator-markers that find and hold individual call paths through the B-, C-, and D-switches. The line scanners scan the terminations continuously, and continuously pass to the main processors information on the state of each line (idle, seeking response, or engaged). Together with that information goes all the fixed information about that line: the subscriber's number (or if it's a trunk termination, the line destination and number translation data), the type of service, and the coded address of the termination in the A-switch array. All this data is read out of the data store simultaneously with the reading of the line state, and it all goes to the processors at every scanning. If the line is idle, the processors take no action. If it is seeking response or engaged, the processors take appropriate action. Both data and processor storage use the Dimond ring technique, in which wires are threaded through selected cores in a matrix of cores. It is an old form of magnetic storage and its use reflects the age of the TXE-4 concept. The data storage cores are 3-in ferrite squares with 2-in holes so the data can easily be changed by manual rethreading. Processor cores are of conventional size.

Processors are identical modules, and a switching unit may have from three to 20 depending on the number of connections to be made and monitored during the busiest expected call period. All the line-state information and all the fixed line-data are presented to all the processors, and, when there is a request for action, pseudorandom selection decides which processor, out of those free, will take on the job of setting up the call. A defective processor opts out, and its work is taken on by the others. More processors can be added to increase capacity. Processor logic is diode-transistor logic, built almost entirely from discrete components for the same reasons that the data storage devices are Dimond rings.

The TXE-4 system uses a unique and flexible connection technique to handle more complex calling situations. For example, five separate reed-switch crosspoint paths are set up to handle a typical pay-phone call. (1) When the pay-phone is picked up by a caller, a contact path is set up from the pay-station A-switch to a register. The register holds the calling line busy, while a coin and fee check (C&FC) unit is being found and connected. (2) When this happens, a second path is set up from the pay-station A-switch to the C&FC unit. (3) A third, return path is also set up back to the register. When the continuity of these last two paths has been checked, the first path—now redundant—is released, and the register sends a dial tone. (4) Later, when the caller has dialed enough digits for the system to identify a correct outgoing A-switch termination, a fourth path is set up from that termination back to the register; this path is used to send outgoing information from the register. (5) Meanwhile, a final, fifth path is established between the outgoing junction and the A-switch connecting to the C&FC unit. This final path is linked-in when the dialing and register-sending of dialed digits is completed. Then paths 2 and 4 are released, leaving only paths 3 and 5 to be held during the call.

The prospect for luxury services

TXE-4 systems will eventually make several "luxury" features available to British telephone users. At present, push-button telephones, must send out pulses at the slow 10-impulse-per-second rate used in dial telephones with the Strowger switching equipment. TXE-4 can accommodate fast, multifrequency signals but these will probably not be in use until the 1980s.

The BPO started field trials of faster push-button units about two years ago. These instruments use a nickel-cadmium battery in the telephone to power MOS chips. The battery recharges from the telephone line when the phone is not in use. However, a more recent design powers the chips directly from the line. Read-only storage in the chips makes sure that the right number of pulses is dispatched to the exchange at the right time. TXE-4 can accommodate modules to provide other new facilities but, in general, these will not be offered while the main system objective is to expand the basic telephone service. The push-button telephones and a limited scheme for transferring incoming calls to alternative numbers ("follow-me" call transfer) will probably be offered fairly soon. A factor inhibiting quick introduction of luxuries is the BPO policy of not offering a service at all until it can be widely offered. BPO follows that policy because it is a public authority. However, some extra services are generally available now, including automatic number senders, direct dialing to PABX numbers, radio paging, radio telephones for cars, transferred payment for calls, and charge meters adjacent to telephones. The system lacks the flexibility in storage capability, however, to provide other services such as "speed calling."

As for future developments, the sealed-reed switching network is likely to be adequate for the foreseeable future but the control section of the TXE-4 system will be steadily developed. STC has a contract to get the construction cost down by developing alternative techniques such as incorporating integrated circuitry in place of some portion of the present entirely discrete construction, and using semiconductor stores instead of Dimond rings. Processor power will be increased to cope with the luxury facilities that eventually will be offered, and an interface for insertion between complete switching units and a remote network management computer will be developed. Real-time network management by central computer will eventually improve network efficiency and allow further facilities such as centralized accounting, centralized exchange maintenance supervision, and further subscriber services such as telephone conferences and automatic alarms. ◆

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Seeking super safety

Quality assurance and in-service inspection required by law help to approach "zero defects"

The year 1975 can almost be considered the go/no-go year for nuclear power in the U.S. Three key decisions are scheduled for Congress—namely, whether to begin the use of plutonium as a supplemental fuel to the uranium now being used in U.S. reactors, whether to continue to support the development of breeder reactors, and whether to maintain the Government's supplemental insurance coverage, in the form of the Price-Anderson Act, of the nuclear power industry. In addition to these Congressional concerns, the nuclear debate in the U.S. has recently intensified on issues even broader than nuclear safety—into areas like the economic viability of nuclear power. And in January of this year, 32 scientists, headed by Dr. Hans Bethe of Cornell University, signed a letter addressed to the public, saying that there is no reasonable alternative to an increased use of nuclear power to satisfy future U.S. energy needs. A counter letter, promptly mailed to President Ford and signed by eight scientists from Ralph Nader's group, expressed that group's anxiety about any massive speedup in nuclear power plant construction—a development that would exacerbate, these scientists believe, the tendency to overlook necessary safety precautions.

While the pro and con nuclear power crusades gain momentum, engineers of many disciplines keep striving to upgrade safety in nuclear power plants. However, the bulk of the population in the U.S.—and, to some extent, even the engineering community—remains ill-informed about many technical and nontechnical aspects of the safety issue in nuclear power generation. "Our greatest need is for communication," wrote nuclear expert Philip Hammond, in the *American Scientist*, and *Spectrum* will be trying—with this article and more to come in the near future—to fill the information gap.

"Defense-in-depth" philosophy

The basic philosophy employed in the design of nuclear power plants is "defense in depth," described in detail in the report, "The safety of nuclear power reactors (light-water-cooled) and related facilities" (WASH-1250), issued in July 1973 by the Atomic Energy Commission (now the Nuclear Regulatory Commission).

The defense-in-depth term is derived from the fact that nuclear power plants are designed to be safe, not only during normal operation, but also in large accidents of a remote likelihood. The defense-in-depth concept manifests itself in three levels of safety. The first level addresses prevention of accidents through the design of the plant, and employs concepts like quality assurance, redundancy, inspection, and testing. Protection devices and systems designed to act against assumed equipment failures or operating errors are provided as a second level of defense. The third level adds a further safety margin by postulating a hypothetical accident that could only happen if both the first and second defense levels fail, and by providing additional safety systems to control such a situation, thereby protecting the public.

Multiple barrier protection

What is the basic design requirement for nuclear power plants? The Code of Federal Regulations (see box opposite) requires "multiple barriers" between radioactive fission products and the public. This is implemented by enclosing nuclear reactor fuel within at least three separate and distinct "containers." In light water reactors (LWRs, see box on pp. 48–49) these barriers are fuel cladding, the reactor vessel itself, and the reactor containment building. The fuel cladding in an LWR consists of long, thin stainless-steel or zircaloy tubes (typically 4.0–5.5 meters long and about 1 cm in diameter and 0.4–0.8 mm thick), designed to withstand the thermohydraulic and radiation environment within a reactor during both normal and abnormal operation. In particular, zircaloy has low neutron absorption and good heat transfer characteristics. With the fuel "pellets" inserted (a typical UO_2 sintered pellet is about 1.5 cm long and nearly 1 cm in diameter), the tubes become fuel "pins" or "rods." Such rods are bundled together (about 60–200 at a time, depending upon reactor type and size), to form fuel "assemblies," and they are designed to last three to four years inside a reactor before being replaced.

The next barrier for the LWR, the reactor vessel itself, is made of thick high-quality steel, and it is able to withstand pressures considerably greater than those that occur during normal operation. For example, a typical pressurized water reactor (PWR) vessel (see box on pp. 48–49), intended for around 3200 thermal megawatts power output, is designed for a pressure of about 17×10^6 N/m², and actually operates at 90 percent of that value, when the reactor is at full power, but the vessel will tolerate up to three times the designed pressure and will still remain intact. Vessel thickness varies according to reinforcements needed at its specific locations. The lower head, for example, which is basically hemispherical in shape, is about 12.5 cm thick, whereas the upper wall at a nozzle area has about a 27.5-cm thickness. The cylindrical portion of a 3200-thermal-megawatt PWR, which comprises the major section of the over 14-meter-long vessel, with an inside diameter of nearly 4.5 meters, is over 20 cm in thickness.

One boiling water reactor (BWR) vessel (see box on pp. 48–49), of similar output power, that is already in

Gadi Kaplan Associate Editor

Regulations, codes, standards

Perhaps one of the most highly scrutinized of industries, the nuclear power industry, in the U.S., is regulated by Federal as well as by State laws. In addition, the industry must comply with a host of codes and standards of various engineering societies. Most regulations and codes aim, either directly or indirectly, at securing maximum public safety, and all of them are continuously reviewed and updated. For example, Title 10 of the Code of Federal Regulations, issued by the Nuclear Regulatory Commission (NRC), and known as the "10 CFR" set of rules, covers standards for protection against radiation *(10 CFR 20)*, licensing procedures of production and utilization facilities *(10 CFR 50)*, and operators' licenses *(10 CFR 55)*. Other areas regulated by the NRC are special nuclear materials *(10 CFR 70)*, packaging of radioactive material for transport *(10 CFR 71)*, and reactor site criteria *(10 CFR 100)*.

Very prominent among engineering codes pertaining to nuclear safety of mechanical equipment is Section III of the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME). At its inception in 1965, this section related only to nuclear vessels, but, in 1968, it was expanded to include other pressure-retaining components like valves, pumps, and piping. Section III specifies the minimum requirements for the design of all of these components so that they will withstand design pressure and temperature conditions. It also discusses materials and fabrication techniques for the components, as well as their examination, testing, and installation. The more recent Section XI of the same code, introduced in 1971 and revised every six months thereafter, relates to in-service inspection of all components within Section III. Section XI requires a set pattern of nondestructive examination (NDE) during the life of each such component. It specifies the type and frequency of examination, as well as the action to be taken according to the results of the examination.

Among many standards put together for the nuclear industry by the IEEE, the master document is IEEE Std 279-1971—Criteria for Protection Systems for Nuclear Power Generating Stations. Another often quoted standard of the IEEE is that dealing with seismic qualification of "Class 1E equipment" for nuclear power generating stations. "Class 1E" embraces equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal—or other systems that are essential in preventing significant release of radioactive material to the environment.

[1] Uranium oxide pellets like these, produced by Westinghouse, are used as fuel in pressurized water reactors (PWRs). When the fuel assemblies containing such pellets are placed in the reactor's core, each pellet can produce more energy than that produced by one tonne of coal.

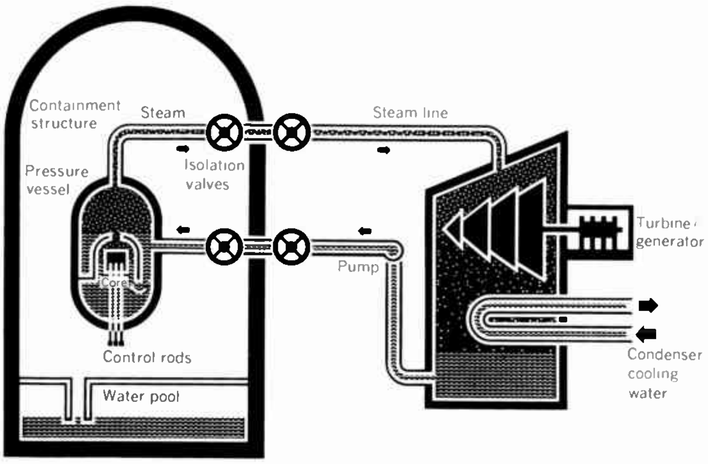
commercial operation in the U.S. is designed for 8.5 $\times$ 10^6 N/m^2 and operates at 80 percent of this value when the reactor is at full power. The dimensions of this BWR are different from those of the PWR; the BWR vessel wall is about 20 cm thick while its internal diameter and length are considerably bigger than those of its PWR counterpart—about 6.4 and 22 meters, respectively.

The reactor's containment building, the third designed barrier between fission materials and the neighborhood surrounding the nuclear power plant, is of thick, leak-tight, steel liner and reinforced concrete. It contains the reactor pressure vessel and all equipment that is in direct contact with the pressure vessel. The primary function of a containment building is to confine any leakage of radioactive gases and liquids, allowing less than 0.1 percent of the substances included within its volume to escape in a day at the building's design pressure. Containment buildings must fulfill very severe requirements, such as remaining intact during tornados and severe earthquakes.

According to recent specifications, containment buildings must remain functional (no release exceeding the specified limits at the boundaries of the plants' sites) in tornados with wind speeds above 500 km/h. Such buildings must also remain functional when hit by objects like utility poles more than 10 meters long and over 30 cm in diameter and weighing as much as 670 kg. Again, they must stand up to the impact of an 1800-kg automobile. And they must hold up against internal projectiles breaking off of high-pressure equipment.

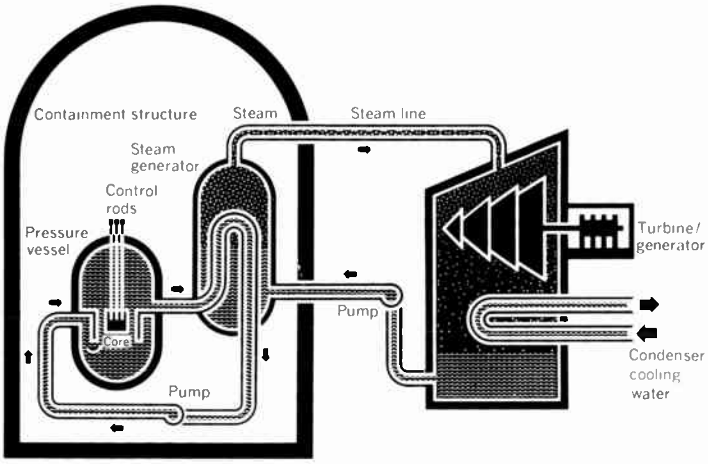
When a plant's site is near an airport, its containment building must be designed to withstand the impact of an airplane. In one existing plant, the containment building is designed to survive intact the crash of a Boeing 707 at about 240 km/h during a landing approach. In connection with these requirements, the Electric Power Research Institute (EPRI) has recently announced its sponsorship of a research project, at the Stanford Research Institute, that will examine the strength of reinforced concrete impacted by flying debris during a tornado.

Similar to LWRs, high-temperature gas-cooled reactors (HTGRs, see box, pp. 48–49) must also be designed with a multibarrier approach, but HTGRs utilize other barrier types. One barrier is a dense, ceramic, multilayer coating of the uranium and thorium carbide or oxide fuel particles. A second barrier is the graphite block that encases the fuel. The third barrier, the pressure vessel itself, has evolved from a steel vessel, employed in the Peach Bottom Unit 1 plant owned and operated by the Philadelphia Electric Company (a first-generation HTGR), to steel-lined prestressed-concrete reactor vessels (PCRVs) in subsequent designs. PCRVs act both as pressure vessels and biological shields. Originally, PCRVs were



In a boiling water reactor (BWR), the steam from the reactor is passed directly through the turbine.

In a pressurized water reactor (PWR), water pumped through the core transfers heat to the steam generator, and the steam in a second loop drives the turbine.



Basics of fission reactors

On absorbing slow neutrons, the nucleus of a uranium-235 atom undergoes "fission" into two fragments of unequal size with high kinetic energies. In the process, an average of two or three neutrons are also emitted. The major characteristics of this reaction are:

- High kinetic energy released (about 200 MeV/fission, compared to a few eV for an ordinary chemical reaction).
- Possibility of self-sustaining ("chain") reaction, due to surplus of released neutrons that are not absorbed during the process.

The mass of fission fragments approximately equals the initial fuel mass. About one tonne of fission "waste" is produced each year from a 1000-MW (electric) nuclear power station.

Fission reactors can be roughly classified into "fast" and "slow" (or "thermal") reactors. In fast reactors, neutrons with velocities corresponding to the velocity at the release in the fission reaction are used. In thermal fission reactors, on which most work has been done, emitted neutrons are slowed down by a "moderator," before reentering the fuel material (to increase the probability of sustained chain reaction). In the U.S., light water has been used as the moderator in the boiling water and pressurized water reactors (BWRs and PWRs), whereas moderation by "heavy water," that contains deuterium (instead of lighter hydrogen atoms) has been implemented in the Canadian "Candu" reactors. In the U.K., on the other hand, the effort has mostly concentrated on graphite moderation, in the "Magnox" reactors, but recently, heavy water moderation similar to that employed in Canada has been considered.

In a BWR, water is boiled in the reactor and the resulting steam is passed *directly* through the turbine. The steam is then condensed and returned to the reactor. In the PWR, on the other hand, the reactor vessel is maintained at a pressure of about 15.4 × 10^6 N/m^2, and the moderator temperature is kept at about 315°C. At this temperature and pressure, the water does not boil and is passed through a heat exchanger and back to the reactor. The secondary side of the heat exchanger is maintained at a lower pressure of around 5 × 10^6 N/m^2 and is used to raise steam to about 260°C for the turbine. In the Candu reactor, the heavy water fills an unpressurized tank, and the nuclear fuel is contained in tubes that pass through this tank. These tubes are also used as a path for the reactor coolant—light water at high pressure to prevent boiling. A conventional heat exchanger is used to raise steam in the Candu reactor.

intended also as a substitute to containment buildings (one HTGR plant in the U.S., Fort St. Vrain, north of Denver, Colo., does not have a containment building), but about four years ago the Atomic Energy Commission began requiring containment buildings for HTGRs.

Inherent safety of LWRs

What about the "sound design" of reactor cores? Inherent characteristics of reactors rule out any possibility of nuclear explosion under accident conditions, followed by a hypothetical complete meltdown of fuel and core materials. (This has been proved in tests in the National Reactor Testing Station in Idaho.) One inherent safety factor in LWRs that precludes nuclear detonation is predesigned dilution (low enrichment, about 3–4 percent) of fissile material. Another reason why the core cannot go off is that the material, when melted, is not rigidly contained for a sufficient amount of time. Still a third reason is the slow rate of rearrangement of the molten material (about six orders of magnitude slower than that necessary for detonation).

Apart from their inherent safety from nuclear detonation, all light-water-moderated reactors (i.e., PWRs and BWRs) are so configured that over their entire operating range, they experience a negative coefficient of reactivity. This feature is basically an inherent stabilizing negative feedback mechanism whereby an increase in output power reduces the core's reactivity, which, in turn, tends to reduce the output power. (As water gets hotter, its density decreases, and the probability lessens of neutrons colliding with water molecules and imparting energy to them. Hence, fewer neutrons are slowed down and the number of fissions is reduced [see box above]. The core's reactivity is measured by the extent of neutron production in two consecutive generations.) Another negative feedback mechanism, sometimes referred to as the "Doppler effect," is particularly useful in stabiliz-

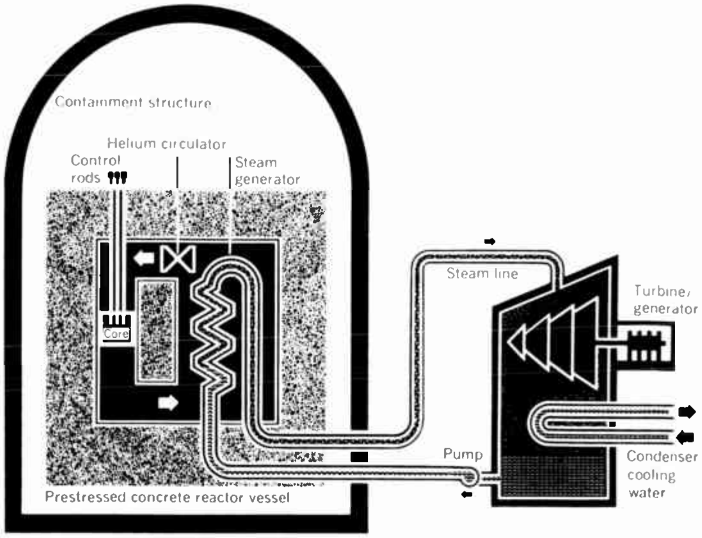
Another thermal reactor is the high-temperature gas-cooled reactor (HTGR). In this reactor, the core is cooled by helium at high pressure (around 5×10^6 N/m^2), and the temperature of the helium coolant at the reactor's outlet is much higher than similar water coolant temperatures. For example, in the Peach Bottom No. 1 plant of the Philadelphia Electric Company, the designed helium outlet temperature is about 700°C.

While helium is employed as coolant in the gas-cooled reactors in the U.S. and some European countries, other European gas-cooled reactors, like the Magnox reactors in the U.K., use pressurized CO_2 for cooling. As far as the pressure vessel itself is concerned, the first HTGR to be constructed in the U.S. (Peach Bottom No. 1) has a steel pressure vessel, whereas current designs employ prestressed-concrete vessels that house both the reactor core and the steam generators.

Graphite is used both as moderator and as structural material in HTGRs and the fuel employed in these reactors is a mixture made of tiny particles of thorium oxide and enriched uranium-235.

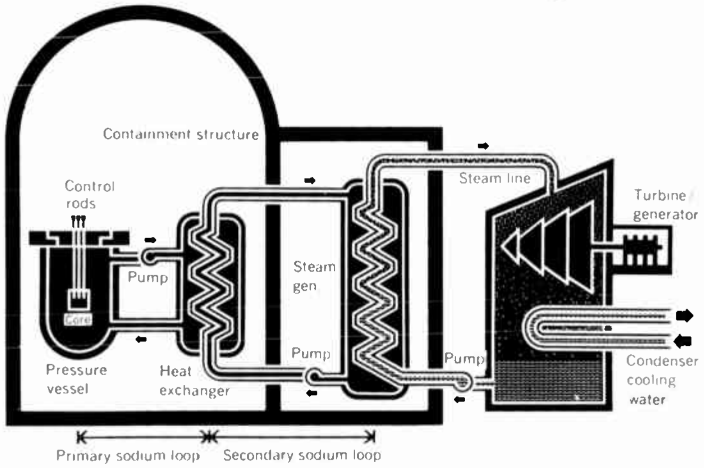
One type of fast reactor is the liquid-metal fast-breeder reactor (LMFBR, discussed in detail in *Spectrum*, Feb. 1974, pp. 85–89). The "breeder" has two basic functions —to generate heat for generation of steam, and to produce, or "breed," one fissile material (plutonium) at a faster rate than the consumption of another one (uranium). The merits of this second feature can be best expressed quantitatively, by the "breeding ratio"—the ratio of production and destruction rates of fissile materials involved. Another useful measure of breeding effectiveness is "doubling time"—that is, the amount of time it takes to produce an amount of fuel equal to that consumed. A doubling time of about 5 years (equivalent to a breeding ratio of about 1.2) is required to keep pace with increasing demand for electric power generation, bearing in mind the continuous depletion of economically viable uranium resources that are used for present thermal reactors.

The production of additional fuel in the LMFBR is accomplished by surrounding the reactor core with a "blanket" of "fertile" material. As the chain reaction within the core takes place, the blanket is bombarded by fast neutrons, and part of it is converted into "fissile" material. Typically, plutonium-239 is used as fuel in the core, while the blanket material, uranium-238, is converted into plutonium-239. Liquid sodium is used for cooling the reactor.



High-temperature gas-cooled reactors (HGTRs) use helium coolant and the gas outlet temperature exceeds 700°C.

The liquid-metal fast-breeder reactor (LMFBR); see text.



ing fast power increase transients up to a few percent in output power.

Fuel's temperature is limited

An important design criterion, also related to reactor performance at different temperatures, is the "fuel design limit"—that is, the maximum temperature allowed for the reactor fuel, sometimes expressed in terms of maximum power per unit length of fuel rod. This limitation is imposed to avoid overheating and melting of fuel pellets and cladding at hot spots (usually centers of fuel pellets). Design limits of fuel "centerline" temperatures n light water reactors now range between 800 and 970°C, depending on reactor type and size. For this purpose, the linear power of fuel rods is limited to values under 70 kW/m.

Turbines shielded; water treated

In spite of fuel rod power limitations, the rods may develop tiny pinholes and current design practice allows for about 1–1.5 percent of the rods to develop such pinholes during operation, allowing some fission products to dissolve into the cooling water. In BWR plants, these radioactive materials even pass through the turbine, since the reactor cooling water and the turbine steam are in the same loop in a BWR. However, the main radioactive isotope carried over to the turbine is nitrogen-16, with a half life of about 7.4 seconds. Thus, it decays considerably, in the plant's piping, before ever reaching the turbine. Nevertheless, turbines in BWRs are shielded by a surrounding concrete wall, and special care is taken in the design of BWR plants to prevent the continuous exposure of the public to radiation from the roof of a BWR turbine building (a phenomenon called "shine" effect).

Complementing turbine shielding, the cooling water in BWR plants is treated for removal of radioactive (as well as nonradioactive) materials. Any of the fission products or other elements dissolved in the

(Continued on page 52)

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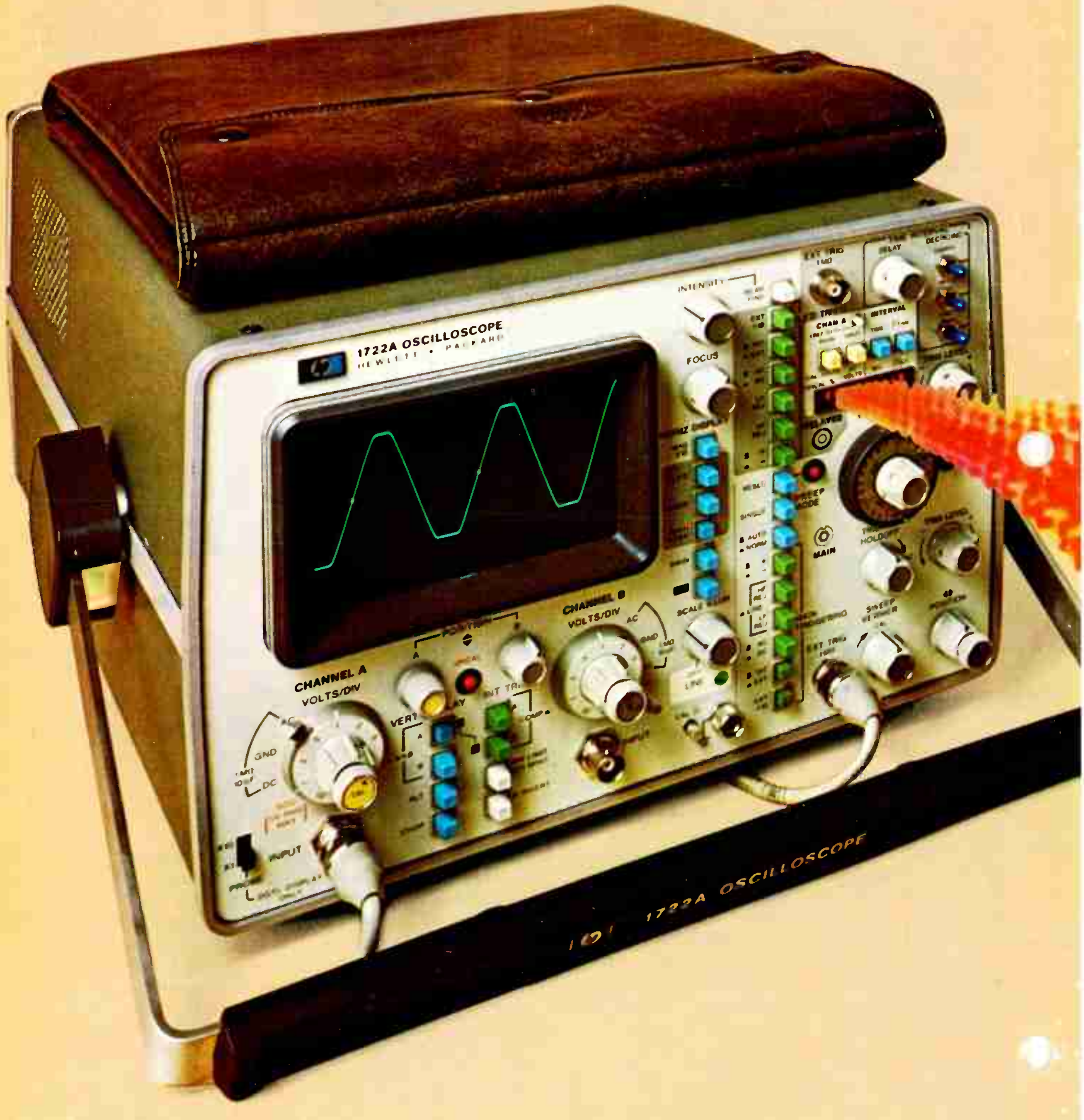


(Continued from page 49)
water are fed through demineralizers, or "ion exchangers," that absorb or retain these dissolved materials. Periodically, these materials are removed to storage drums.

Redundancy of systems

Treating cooling water to filter out radioactive materials from it is one thing, but designing such a dependable cooling system to provide an uninterrupted circulation of cooling water for the reactor is also essential, since uninterrupted cooling in LWRs is of vital importance. A leading principle in the design of such vital systems is redundancy. For example, equipment of the emergency core cooling system (ECCS), which is discussed later in this article, includes two redundant subsystems that are physically separated and separately powered, each of which is capable of adequately cooling the reactor core.

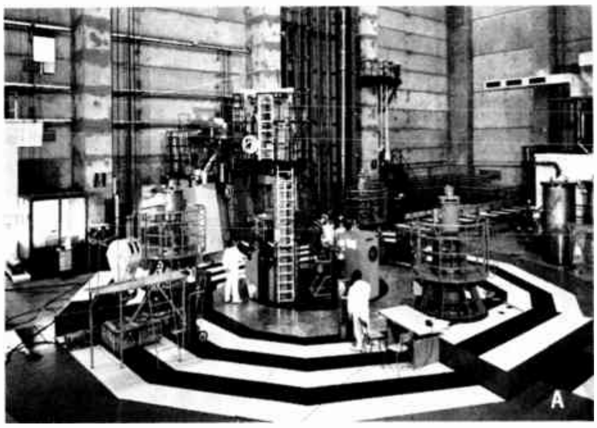
The vital importance of redundant systems for cooling water was recently demonstrated during a fire in a Tennessee Valley Authority nuclear plant containing two reactors—Brown's Ferry Units 1 and 2. Although at press time the matter is still under investigation, and the full details are not yet known, it has been disclosed that, during the fire, one half of the low-pressure pumps of the ECCS of Unit 2 did not operate when called upon to normally cool the reactor after shutdown. However, alternative sources of cooling were provided by redundant pumps from the same ECCS. In Unit 1, on the other hand, all automatic and remote control of the ECCS was totally inoperative and it took alternative systems to provide normal cooling. This scenario, serious in itself, could have been even worse had a loss-of-coolant accident (LOCA) occurred simultaneously with the fire. One must bear in mind, however, that the probability of such a combined event is extremely low.

Quality assurance

With all the multiplicity and complexity of systems and components in nuclear power plants, some means are required to assure that all systems will be designed, manufactured, installed, and operated in a satisfactory manner. Extensive quality assurance (QA) programs are implemented to provide confidence in the functioning of all vital systems that comprise a nuclear power plant. And the reactor vessel itself is constructed in accord with specifications for the highest class (Class 1) among nuclear components. All such components must conform to the special standards developed by the American Society of Mechanical Engineers (ASME) for nuclear vessels and components (see box on p. 47). An *individual* stress report is compiled by the designer for each vessel, discussing in detail stresses in all parts of the vessel under all design conditions; and all the stresses must comply with Section III of the ASME Boiler and Pressure Vessel Code.

But there are tests, too. Among many tests that are performed to insure compliance of the vessel with the ASME standards is a complete volumetric examination of the entire reactor material for flaws prior to construction. Detailed testing of the material as to its chemical and mechanical properties is also performed. And then, during manufacturing, every type of weld must be qualified and documented prior to its application in the actual construction of the vessel itself. Nondestructive examination (NDE) is implemented to assure vessel integrity. Previously identified as nondestructive testing, NDE permits the examination of a property of a vessel without submitting it to a harsh test (like overpressure) that may destroy it. All reactor suppliers in the U.S. have ultrasonic testing programs for all welds.

But what about imported reactor vessels? In this regard, Adolph Ackerman, an independent consulting


A


B


C

[2] Extensive safety-oriented research is underway in the U.S., Europe, and Japan, relating to liquid-metal fast-breeder reactors (LMFBRs) similar to this one, the Phenix 250, that began operation in 1973 in Marcoule, France. One question not fully resolved is the consequences of a postulated rearrangement of fuel to a possibly more reactive configuration than the normal one as a result of a loss-of-coolant accident—one in which a loss of scram capability (see text on p. 54) is also assumed. Other research questions are: the reaction between molten fuel and the sodium coolant, sodium fires, and sodium-water reactions.

[A] Above the reactor, control rod mechanism can be observed (white, in center). [B] A fuel element. [C] Spherical expansion reservoir for secondary sodium loop.

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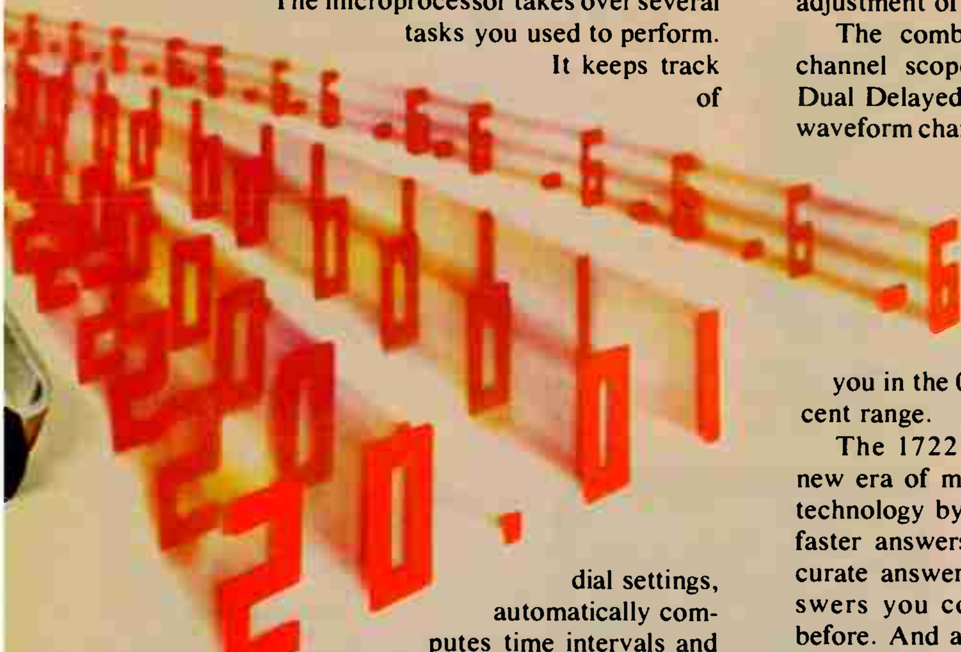

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Physicists' study of reactor safety

No reasons have been discovered for substantial short-range concern regarding risk of accidents in light water reactors, concludes a study by a group of 12 physicists, headed by Prof. Harold Lewis of the University of California. The one-year study, which assessed technical aspects of the safety of light water nuclear power reactors, was sponsored by the American Physical Society (APS), with the support of the National Science Foundation (NSF) and the Atomic Energy Commission (AEC), and the results of the study were made public on April 28, 1975. In it, the scientists express their belief that, although the safety record to date of the light water reactors (LWRs) has been excellent, there should be a continuing major effort to improve LWR safety as well as to understand and mitigate the consequences of possible accidents. Among the major recommendations of the study are: improved human engineering and more automation of reactor controls, quantitative analysis of the effectiveness of quality assurance programs, refinements in techniques used for the calculation of accident sequences, and quantitative evaluation and, if necessary, improvement of the safety margin of the emergency core cooling system (see main text, pp. 52–55).

engineer from Wisconsin, has questioned the adequacy of procedures that have been developed to insure compliance of overseas vendors with the ASME Codes (see *Spectrum*, Jan. 1975, p. 104). Indirectly, argues Mr. Ackerman, this fact may have a serious impact on safety in nuclear power generation, and should be given review. However, Mr. Ackerman's opinions are not supported by other experts in the field.

Quality assurance does not end with mechanical components. Among other QA efforts to date, two quality assurance standards have been generated by a subcommittee of the Nuclear Power Engineering Committee of the IEEE, and these standards have already been issued as national ones by the American National Standards Institute, as part of the N45.2 series. However, IEEE's QA effort has been slowed by the requirement that all QA standards be compatible with the basic N45.2 series. Other impeding factors are a shortage of experienced nuclear personnel with QA qualifications, and the financial crunch in the power industry (see *Spectrum*, March 1975, pp. 40–44, and April, pp. 62–65).

Quality assurance, even if implemented extensively, for mechanical components, cannot guarantee continuous faultless operation in all cases, and small cracks in piping have been discovered twice within a period of about four months in the Dresden No. 2 plant of Commonwealth Edison in Illinois. In September 1974, instrumentation indicated a small leak of radioactive water in the plant. It was later found that the leak came from a pipe in the auxiliary cooling loop, about 10 cm in diameter, in the BWR plant. And in January 1975, cracks were visually observed during inspection in a larger pipe, 25 cm in diameter and about 1.3 cm thick, used in the emergency core cooling system. In both cases, more than 20 similar reactors throughout the U.S. were scrutinized by the NRC, as a precautionary measure. The reactors, by NRC order, were to be inspected for possible similar defects in their systems, and, if necessary, were to be taken off line for proper inspection. No significant defects were found in the other reactors, which were returned to their normal operating schedule, and the Dresden 2 plant is expected to be back in service by press time, its two faulty pipes replaced.

The cause of the Dresden defects is believed to have been stress-assisted corrosion, a phenomenon that has been investigated for nearly 20 years. Stress corrosion in stainless steel is very difficult to analyze or control as it depends on minute quantities of a phase called "delta-ferrite" in the metal, as well as on the stress level, sensitization of the microstructure of the metal, and the oxygen level in the coolant. A new research and development program to investigate these phenomena is contemplated by the NRC, and some work along these lines will probably get started beginning in July.

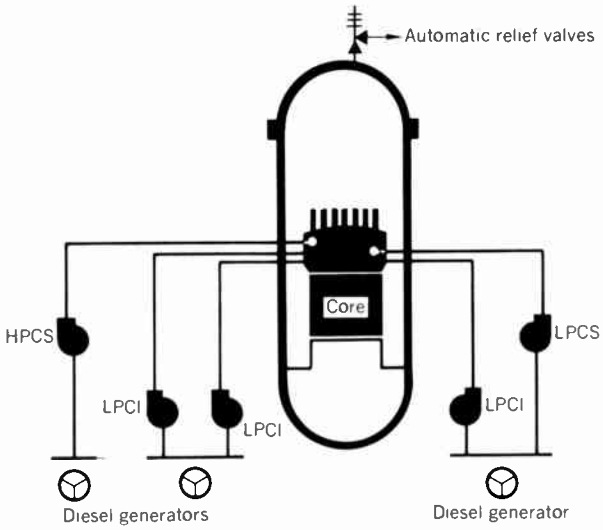
As for compulsory plant inspections by the NRC, sometimes involving the shutdown of plants being inspected, such shutdowns may be regarded by antinuclear groups as indicative of how unsafe nuclear plants really are, but, in contrast, the nuclear industry and the NRC consider them to be one of the strongest points of the industry in that, unparalleled by any other industry with safety hazards, the nuclear industry takes no chances when it comes to public safety.

Another recent shutdown due to faulty mechanical components was related to tube corrosion in a steam generator in a PWR plant and to vibrations of the reactor internals. In this case, the shutdown in the Palisades plant of Consumers Power Company of Michigan, in August 1973, was an extended one (the plant started up again in April 1975), and the company is now suing, for "no less than" $300 million in damages, five firms that either provided components or design services to the plant. The relatively simple "microvibration" problem was eliminated by increasing the mass of the retaining ring of the nuclear vessel. The corrosion problem of the tubes, on the other hand, was much more serious, and involved extensive, sophisticated testing to pinpoint faulty tubes in the steam generator. Hundreds of faulty tubes had to be plugged.

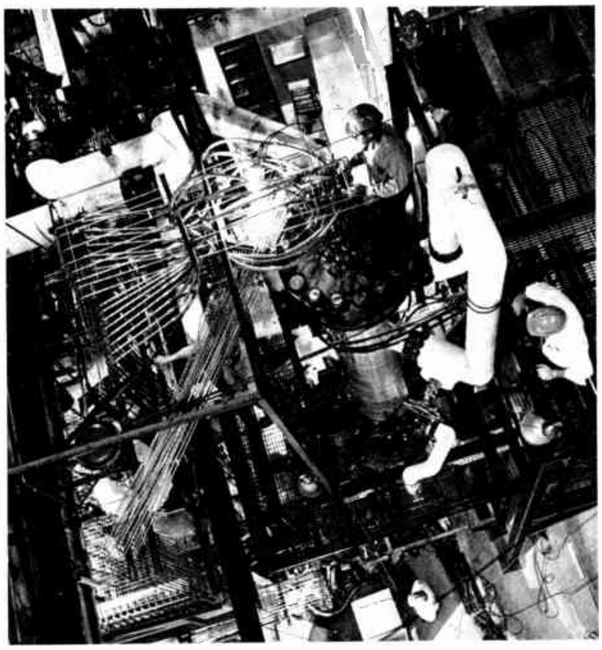
Of these two undesirable phenomena, vibrations and corrosion, the latter is more difficult to detect, particularly when it takes place in the internal parts of a system. But vibration can be monitored, and recently much attention has been given to this problem, both by the industry and the NRC. The agency addressed the problem in its regulatory guide 1.20. Prototype programs and systems for monitoring vibrations of "loose parts" within a vessel, or those of dynamic machinery throughout a plant, have been suggested and are presently being designed and implemented, but a need is stressed for the establishment of vibration criteria for diagnostic purposes.

In-service inspection, using NDE

Aimed at verifying the continued mechanical integrity and correct functioning of pressure equipment and components within a nuclear power plant, in-service inspection became mandatory for utilities in the U.S. in 1970. Defined by Section XI of ASME's Boiler and Pressure Vessel Code, in its revised 1974 version



[3] Three independent subsystems for emergency core cooling are incorporated in the BWR/6, the latest boiling water reactor, manufactured by General Electric. These include high- and low-pressure core spray (HPCS, LPCS) and a low-pressure coolant injection (LPCI). Automatic relief valves are activated to reduce vessel pressure—in the case of breaks that are too small to depressurize the reactor—in order to enable coolant flow into the reactor from both low-pressure systems.



[4] The 950-liter test vessel in Westinghouse's "G loop" for testing the PWR emergency core cooling system (ECCS) in the company's Forest Hills facility. The mechanical components of the loop are designed for pressures up to about 14 × 10^6 N/m^2 and temperatures to about 350°C. The reactor fuel is simulated by 480 electrically heated rods. During transients, the test loop is automatically controlled by a PDP-II-DEC-16K computer that acquires data from 600 points within the loop, at a rate of 40 000 points/second.

(see box on p. 47), in-service inspection is implemented by using various NDE methods. As NDE develops, more sophisticated methods are being implemented for in-service inspection. For example, remote ultrasonic examination of these high-pressure components has recently been implemented, to minimize radiation exposure of technical personnel. Typically, such ultrasonic equipment is controlled by computer, in both the acquisition phase as well as the processing of measured data.

Another new technique for surveillance of pressure vessels, already being tested by a few utilities in the U.S., is based on monitoring acoustic emission from such vessels. Recent research has demonstrated that acoustic energy is emitted from solid material as it undergoes deformation or fracture. This technique, which employs highly sensitive microphones, looks promising, not only as an independent new NDE method but, during both preoperational testing and the operation of a pressure vessel, as a warning against possible incipient failure of the vessel.

Other new NDE techniques, currently under investigation, are intended for direct visualization of flaws in the examined objects. One such method involves the use of holography; another one is the "Schlieren" technique, based on an optical phenomenon in which a coaxial system of two identical lenses with coincident foci can produce a three-dimensional image of the same shape as the object being observed. In another direct visualization method currently being examined, a photoelastic phenomenon is implemented to detect flaws in a tested object. According to this method, an ultrasonic transducer transmits acoustic waves and the sound is reflected by the defects in the object under test. To make the defects visible, the reflected ultrasonic beams are transmitted into a photoelastic medium. The stresses caused in the medium by the return beams are observed through polarizing filters while the photoelastic medium is illumined by stroboscopic light.

Reactor control and protection

While in-service inspection periodically verifies the integrity of pressure-carrying components like the reactor vessel itself, the nuclear chain reaction that takes place within the vessel is constantly controlled and monitored. For example, changes in reactivity, and consequently in the core's output power, are implemented by insertion or withdrawal of neutron absorbing control rods, and a control system is employed for these actions. In PWRs, signals derived from turbine load may be used as inputs to the control system of the control rods, whereas in BWRs, the turbine's output is defined by the selected reactor power. In both systems, however, the position of each rod or bank of rods can be controlled manually. While hydraulic systems are used to drive control rods in BWRs (as in General Electric's BWR/6 reactor), rods in Westinghouse's control systems for PWRs are solenoid driven. Both systems use solid-state circuitry to control the drive mechanism.

Apart from step-by-step, gradual reactivity control, a system for complete shutdown (also called "scram" or reactor "trip"), to prevent abnormal situations from developing into hazardous ones, is included in every reactor. The major features of a typical reactor protection system—redundancy and diversity of instrumentation channels, which are used to sense abnormal conditions, as well as their physical separation from each other—have already been discussed by *Spectrum* (Nov. 1974, p. 78). An important asset of the "two-out-of-four" coincidence logic, implemented in such systems, is that a single instrumentation channel of the protection system can be maintained, tested, or calibrated on-line, without risking an accidental, undesired plant trip.

Emergency core cooling system

The NRC requires that while analyzing reactor safety, hypothetical scenarios beginning with sudden and complete double-ended break of the largest reactor coolant pipe, whose diameter can reach about 70 cm in large reactors, must be taken into account. Although very unlikely, such rupture is nevertheless considered, and it is assumed to result in a sudden depressurization of the reactor vessel with water flashing out as steam from both broken pipe ends. To counteract this loss-of-coolant accident (LOCA), an emergency core cooling system (ECCS) is incorporated in every LWR nuclear power plant. The principal purpose of the ECCS is to flood the fueled portion of the reactor immediately and remove the residual heat produced by radioactive decay, after the reactor has been shut down and the chain reaction stopped.

Unlike LWRs, high-temperature gas-cooled reactors do not require the fast-acting ECCS, as complete loss of coolant in HTGRs is impossible. In the worst postulated cooling system failure in HTGRs, the pressure of the helium coolant will drop to atmospheric pressure, and the circulation of helium at this pressure is sufficient to remove radioactive decay heat during core shutdown periods. Another important safety feature of HTGRs—closely related to the ECCS topic—is the high heat capacity of the graphite core used in HTGRs, a capacity that permits the initiation of action up to 20 minutes after cooling system failure with no damage to the plant or the fuel. In LWRs, in contrast, ECCS must be operative within seconds after a loss-of-coolant accident.

If supplementary cooling in the form of an ECCS were not provided in LWRs, the core might melt, and some of the radioactive molton mass, still generating after-heat due to residual radioactivity, could conceivably leak from the overheated pressure vessel and, possibly, even from the containment building. What is ECCS comprised of, and how can its performance be verified? Basically, ECCS is a reserve system of pipes, valves, pumps, and water supplies, powered by standby diesel generators, as well as by on-site or off-site conventional power sources. The system is designed to get sufficient water into the core, soon enough after a LOCA so that the core will not exceed a safe temperature.

Characteristics of ECCS are verified in testing performed on scaled-down models of such systems. Westinghouse's test facility in Forest Hills, near Pittsburgh, Pa., includes a whole system, called "G" loop, to test a PWR core model with its complete associated scaled-down emergency cooling system. The tests conducted in this loop simulate conditions existing from a few seconds following a LOCA.

The effectiveness of part of the ECCS of BWRs is demonstrated in the testing of "core spray" nozzle systems in General Electric's Vallecitos Nuclear Center near Pleasanton, Calif. The two systems, one for low pressure (when a large break in coolant piping occurs and the vessel depressurizes) and one for high pressure (intended for small breaks), each have a combined flow rate of about 38 000 liters/min. GE has been performing combined heat transfer as well as spray and "flooding" tests since 1959. Recently, such tests have been conducted at full power on single, full-scale, 20- by 20-cm, zircaloy-clad, electrically heated bundles, similar to those used in all BWRs, including the company's latest reactor model BWR/6. According to GE, results of testing of a single bundle for its heat transfer behavior during LOCA are adequate for predicting the behavior of the entire core as the zircaloy channel of each bundle thermally isolates it from its neighbors.

In spite of these testing efforts, the effectiveness of the ECCS has recently been questioned by nuclear power critics like Daniel Ford and Henry Kendall of the Union of Concerned Scientists (UCS). Testing has to be performed on an *integrated* system, under *real* thermohydraulic conditions that take place during LOCA, the critics argue. A test program of exactly this nature was begun by the NRC in Idaho, in the early 1960s, when construction of the loss-of-fluid-test (LOFT) facility was started. The construction was completed in 1970. More than 20 tests are to be performed over a period of 2–3 years in this heavily instrumented facility, built around a 55-MW (thermal) PWR, intended solely for this testing purpose. The testing will start this coming fall with a simple hydraulic (nonnuclear) experiment and will culminate in a few full-scale LOCA experiments that will include nuclear as well as thermal, hydraulic, and structural processes.

Although about one sixtieth the size of PWRs currently in operation, the LOFT reactor has fuel rods with identical power density to those existing in commercial PWRs, and the tests are expected to yield valid data to assess many engineering aspects of the ECCS. It is believed that these data will not only enable evaluation of the adequacy of the analytical methods employed to predict LOCA response of PWRs, ECCS performance, and margins of safety of the engineered safety features of such reactors, but also identify and investigate any unexpected event or threshold in the response of either the whole plant or the engineered safety features. In the tests, a specially designed valve will be opened at the assumed pipe rupture rate and such experiments will be carried out in various break areas. ◆

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'Troubleshooting' color TV

More smoke than fire may emanate from widely publicized consumer surveys and hazard data

Worried, wounded, and wondering why, the U.S. television receiver industry has come under seige on three fronts. A confluence of sagging sales, massive recalls, and the growing promise of mandatory safety regulations have made the past year particularly painful. Hardly the expected reward for an industry that claims today's color sets (thanks to solid state and improved testing) represent the best entertainment bargain ever offered consumers since commercial TV was introduced.

Reliable vs. fail-safe

Recent Government-sponsored reports and data-gathering efforts on the question of TV safety seem a volatile mixture of praise and persecution. For instance, a report, "TV receiver analysis and existing standards critique," dated July 1974 and prepared by the U.S. Bureau of Engineering Sciences, readily admits, "Few pieces of electronic equipment of comparable complexity [to TV sets], including those developed at great expense for the military or space programs, achieve this level of reliability [expected operation of 6000 hours without repair]." Meanwhile, in December 1974 the U.S. Consumer Product Safety Commission (CPSC) released part of a Bureau of Census survey estimating that TVs nationwide (black-and-white and color) were involved in 196 000 "fire incidents" per year.

These contrasting comments raise an interesting question: How could electronic equipment—credited with space-age excellence—also be cast as the villain in a crusade against hazardous consumer products?

At least part of the answer lies in the sheer number of TV sets presently used throughout the U.S.—about 117 million at last count. And in 1974, an off-year for TV sales, better than 7.8 million color and 5.9 million black-and-white sets were sold to U.S. dealers. Simple arithmetic quickly illustrates the impact of a seemingly insignificant failure mode.

For example, the U.S. Bureau of Engineering Sciences report explains that a hypothetical cause of fire occurring in only one out of 100 000 TV receivers each year would result in over 1000 fires annually throughout the U.S. TV set population. Burn-in type testing was termed "essential to assure that a major relaxation of safety measures does not inadvertently occur," but was thought "of little value" in controlling the one in 100 000-type failure. Consumer feedback was identified as a very important data base in identifying a pattern among rarely occurring breakdowns that may present a hazard. (Extrapolating such data is a tricky business, and—like the CPSC's "fire incidents" survey—invites challenge.)

Don Mennie Associate Editor

As a U.S. Bureau of Radiological Health-instituted recall of over 400 000 color TVs for potentially excessive X-radiation this past January would seem to indicate, U.S. regulatory agencies are *not* swayed by demonstrated TV set reliability strictly in terms of failures exhibited per thousand, per year, or whatever (so far the January recalls have uncovered no sets in the hands of consumers actually producing excessive X-radiation). It is the *nature* of the problem that is all-important. Benign breakdowns causing widespread consumer irritation are a secondary concern to identifying and disarming potential fire, shock, or radiation-producing failure modes whose presence may only be evidenced via simulated faults under laboratory conditions.

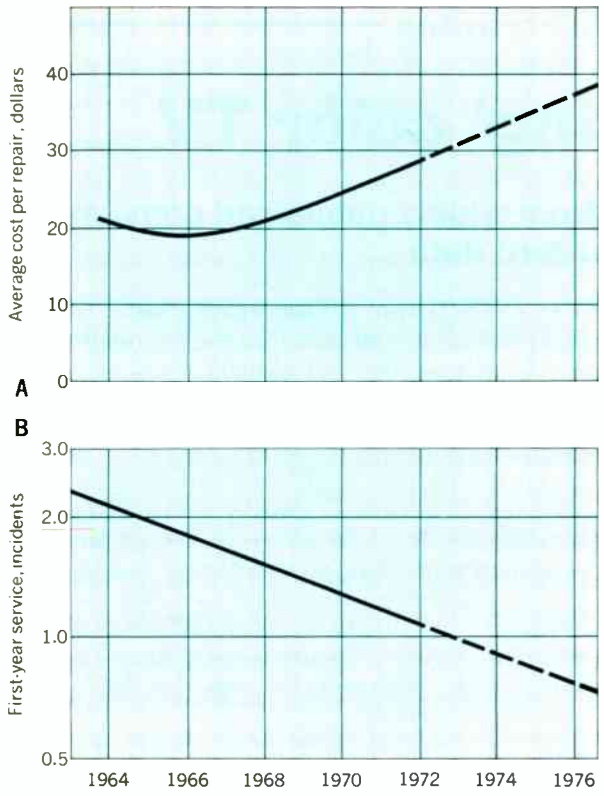
Indeed, compared to the small number of sets for which hazardous conditions have actually been observed and reported, routine service calls, warranty problems, and questions relating to overall performance quality are far more likely to involve the individual consumer. Trends in this area are documented in a recent study conducted by the Massachusetts Institute of Technology with the Charles Stark Draper Laboratory, Inc. This report shows that while greater reliability due to solid-state circuits has been offset by inflation and rising labor costs, the overall expense of color TV repairs has actually gone down in recent years (Fig. 1). Today a typical color TV set fails approximately once per year as opposed to six times per year in 1954 and about three times per year in 1960. And power consumption has been reduced significantly, from 300–400 watts in earlier all-tube sets to only 140 watts in some of the latest solid-state designs.

Why color TV?

Over the past decade, the color television industry has been subject to occasional flurries of bad publicity concerning real or suspected dangers lurking in home receivers. Only a few years ago, one of the most publicized "hazards" was X-radiation. But this worry has been largely offset by the employment of solid-state replacements for the vacuum tubes, once used in all TV high-voltage circuits, coupled with technical advances in CRT self-shielding and high-voltage control circuits.

Color sets require higher voltages on their picture tubes to deliver crisp, bright images than do black-and-white sets of equal size. In the high-voltage power supplies of older color sets, the potential difference between tube elements (high-voltage rectifier and shunt regulator tubes) was large enough to cause X-radiation when high-speed electrons collided with internal metal parts (e.g., the anode). Even the metal shadow mask situated just behind the picture tube's phosphors contributed to the problem slightly.

The switch to solid state that eliminated vacuum



[1] Cost per repair on a color TV (including parts and labor) has increased slightly more than 50 percent since 1966 (A), but the number of repairs needed during a new set's first year of operation has decreased from two to less than one during this same interval (B), according to an M.I.T. report. The result: reliability is improving faster than the cost of servicing is rising.

tube X-radiation from power supplies was coupled with the ongoing quest for brighter, higher contrast color pictures. Soon, the second anode voltage on color tubes was boosted to nearly 30 kV, about 5 kV above the levels commonly used in older sets.

According to John Sheldon, staff consultant for the TV products division, Corning Glass Works, Corning, N.Y., modifications were made in the composition of picture tube glass to block the correspondingly higher level of X-radiation produced by increased voltage inside the finished tubes. Starting in 1973, glass "funnels" (the tube body without a faceplate) were made with an additional percentage of lead oxide, and the faceplates themselves were fabricated with both strontium oxide and lead oxide additives. Previously, emissions through the faceplate were controlled by adding barium oxide to the glass during manufacture. But it is a curious fact that strontium (atomic number 38) is actually superior to barium (atomic number 56) at absorbing X-radiation energy produced by 30-kV operation. Barium oxide faceplate glass was supplanted by strontium oxide glass in 1970.

Lead oxide, though a very effective X-radiation screen, was not used in faceplates before 1973 because of possible "electron browning" (glass darkens with cumulative electron beam exposure). This problem is no longer considered serious because the tube's shadow mask and color phosphors block most electrons before they can reach the faceplate glass. But color picture tubes can still emit X-radiation above the prescribed 0.5-milliroentgen-per-hour maximum if driven with excessive second anode voltage from a supply with reasonably good current regulation.

A case in point is the recall of over 400 000 color sets distributed in the U.S. by the Japanese-based Matsushita Electric Corp. of America. Public awareness of the problem began in January 1975 with news reports naming the affected brands. These include Matsushita's own Panasonic line, and private-label models made for J. C. Penney (Penncrest) and W. T. Grant Co. (Bradford).

Matsushita's troubles can be traced to design oversight and a BRH requirement that TV sets must not produce excessive radiation—even with any *single* component open or shorted. David Carpenter, manager, television engineering, with Matsushita's product engineering division, explains that sets affected by the recent recall are *not* inherently defective. Rather, their initial design did not compensate for the possible failure or disconnection of a critical component. Flyback transformers in the recalled sets are driven from the horizontal output power transistor shunted by essentially a single large capacitor that limits the flyback's input pulse amplitude to about 800 volts peak (Fig. 2). At this drive level, the picture tube's second anode voltage is around 28 kV, and the X-radiation level is well within the 0.5-mR/h maximum.

However, should this capacitor fail open or its leads break (a BRH-specified fault), the flyback input would then see a ragged spike of 1100–1200 volts. As a result, approximately 40 kV is supplied to the picture tube, and X-radiation (from high-energy electrons hitting the mask and phosphors) rises many times above the prescribed limits. (Matsushita reports that in lab tests the horizontal output transistor often breaks down soon after the simulated capacitor fault is introduced, instantly terminating the excessive voltage and associated radiation.)

Visible evidence of the malfunction is also plentiful. The picture suddenly shrinks, and the image quickly fades (or disappears) behind a bright field of diagonal lines. However, the consumer who fancies himself a TV repairman *can* restore a viewable image simply by removing the ailing set from its cabinet and adjusting the B+ (normally set at about 115 volts dc) and the three screen voltage controls atop the picture tube. Such tinkering will not yield true color or restore the picture to proper size, but it might tide an otherwise disappointed viewer through a critical football weekend.

Matsushita will be modifying all recalled sets with redundant capacitors—so single component failure (or lead failure) cannot cause excessive X-radiation—and with two-percent resistors to restrict B+ adjustment. This is one of the several acceptable cures Matsushita considered. Some manufacturers have successfully used feedback techniques to control overvoltage conditions. Others employ special taps off the flyback transformer coupled with a zener diode to detect problems. When operating, this type of overvoltage sensor purposely scrambles picture sync, forcing the set owner to seek immediate repairs.

Instant replay

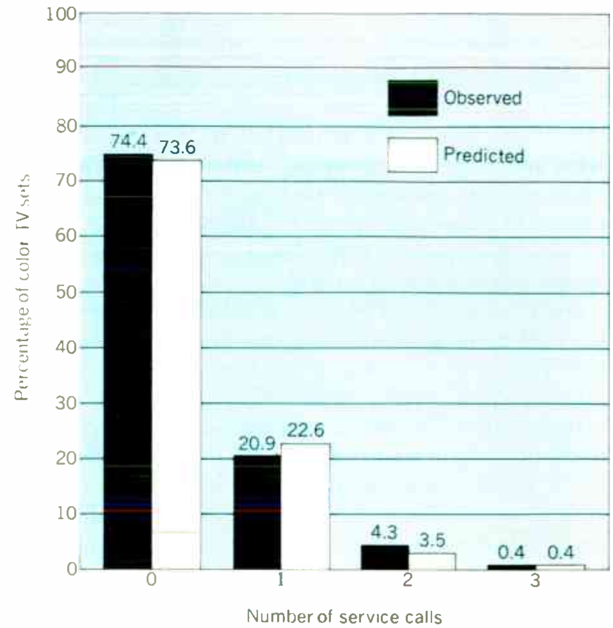
X-radiation worries aside, television fires are primarily associated with color sets. This was first documented in the U.S. by the National Commission on Product Safety's (NCPS) final report issued in 1970. Citing an incident rate of 40 to 1 for color versus monochrome (based on manufacturer-supplied data), the NCPS report tied this trend to the higher voltage required for color set operation.

However, Zenith engineers regard the voltage stress effects as secondary to the presence of higher power required by color CRTs (beam currents run ten times above those found in a typical black-and-white set, while the high voltage is only 20 to 50 percent greater). Color sets are also characterized by increased component congestion, more heat dissipation per unit volume, and higher operating temperatures.

The attention color TV is now receiving from the CPSC is a relatively recent phenomenon. Back in the summer of 1973, the Commission's product hazard index placed color sets low in the top 100 list of product trouble spots needing prompt action. However, several dramatic incidents said to involve TV failure quickly changed these priorities.

The most significant events include three New Jersey fires, all thought to be started by TV sets, which caught the Commission's attention in rapid succession. One of the victims, a man who lost not only property but several members of his family, has been particularly active in prodding Government officials into taking action.

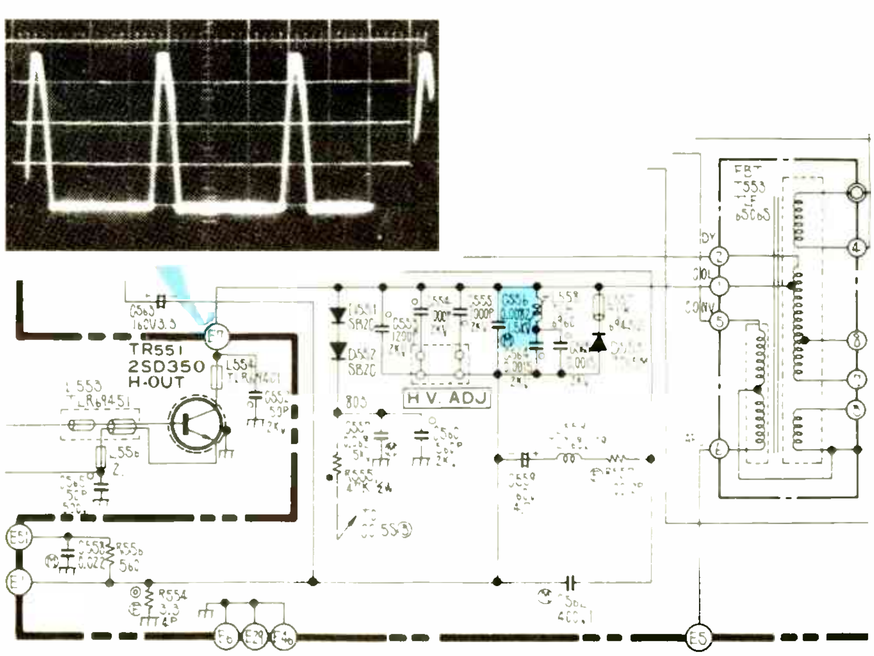
The CPSC has also made its own judgments on the number of such fires occurring in the U.S. annually. Their Fact Sheet No. 11: "TV fire and shock hazards" estimates that "there may be 10 000 television fires each year and some of these result in serious injuries and deaths." More recently, the CPSC released summary data on the incidence of household fires—televisions were named as the source of ignition in 196 000 fires annually. The CPSC data sheet generated headlines, but an important section went largely unquoted or misinterpreted by newspaper accounts. This portion said: "An incident was considered a fire if it emitted smoke or flames and was not started intentionally. The smoke or flames may have been confined to an appliance and did not result in other property damage."



A service history summary for 234 hotel color TVs prepared by M.I.T. researchers reveals that most sets never failed during 27 months of observation. The observed breakdown pattern matched closely the theoretical failure rate predicted by a Poisson distribution.

TV manufacturers were duly outraged, and the essence of their opinion was contained in a letter sent to CPSC Chairman Richard Simpson on January 16, 1975, by the Electronic Industries Association. Briefly, the EIA claimed that the original questionnaires used by the Census Bureau revealed that most "fire incidents" were "only service call type situations" (burned-out components). The CPSC was accused of a "shoot-from-the-hip approach to publicity about television receivers."

Indeed, the EIA even takes exception to the CPSC's earlier estimate of 10 000 TV-related fires an-



[2] This detail from a Panasonic color TV service manual shows the normal 800-volt pulse train generated by horizontal output transistor 2SD350 in conjunction with the flyback transformer. However, should capacitor C556 in the "H.V. ADJ" circuit fail open, 1100- to 1200-volt pulses would be produced, resulting in about 40 kV on the picture tube and excessive X-radiation.

nually, apparently because all kinds of inconsequential TV failures are lumped under the heading of "television fires." Besides genuine disasters, these are said to include the smoke, smell, or drippings from self-destructing components that do not cause problems much beyond disabling the set. The EIA also observes that unsophisticated local fire marshals may choose to name the family TV as the source of a suspicious fire rather than leave unexplained blank spaces on their official reports.

Right now the CPSC has solicited "offerors"—interested persons or organizations who will draft a formal TV safety standard. When this standard becomes mandatory, it should eliminate (or reduce to an acceptable level) electrical, mechanical, thermal, and implosion problems within the TV set. Meanwhile the CPSC's Fact Sheet provides many hints that can help consumers increase their odds against trouble. Of particular note is that the "instant-on" feature has been suspected of causing some TV fires, and that many TV-related fire incidents have involved portable TVs with plastic cabinets. Consumers were cited as contributors to the problem when they place TVs in cramped corners or pile them with newspapers, blocking needed ventilation.

With or without future CPSC regulations, the question of plastic cabinet flammability is already a major concern of manufacturers distributing TV sets in the U.S. These companies regularly submit their products to Underwriters' Laboratories for testing, and the UL "Standard for safety: radio and television receiving appliances" (UL 492) will contain a stricter flammability grade on polymeric materials used for cabinets effective July 1, 1975.

Ramon Cabrera, a product safety project engineer with Matsushita, told *Spectrum* that developing a plastic to meet the UL requirements represents a difficult trade-off between impact resistance, machinability, and color retention—all important properties of cabinet plastic that are adversely affected by flame-retardant additives. He expressed confidence, however, that Matsushita could obtain quality plastic that would meet the UL flammability requirements. Zenith began its transition early last year and foresees no problems of compliance.

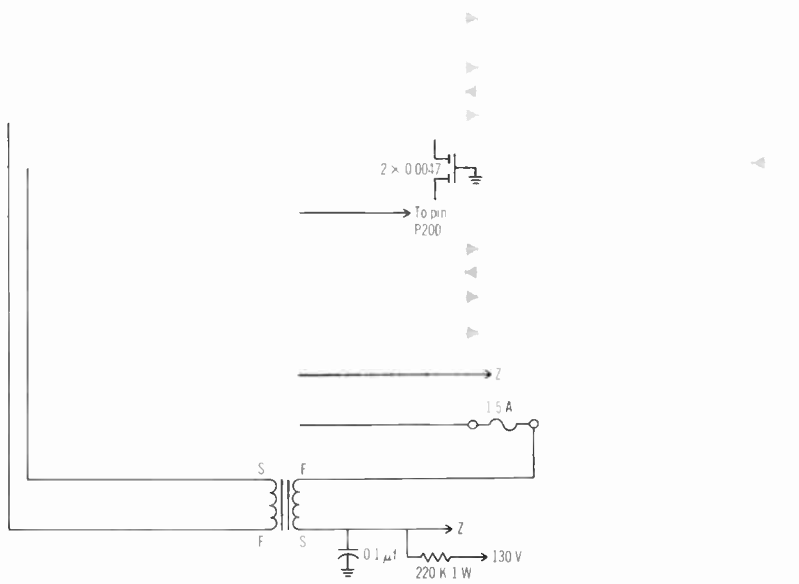
Since July 1, 1974, UL 492 has required that self-extinguishing (SE-rated) materials be used in all circuits handling 15 or more watts of power, and in all parts operating above 2500 volts. Materials in contact with low energy (less than 15 watts or 2500 volts) must be rated slow-burning (SB).

Whether or not the "instant-on" feature was ever a serious threat to home-owners, the question is rapidly becoming academic. Zenith (one of the world's largest TV manufacturers) discontinued the feature on all sets manufactured after June 1974. Claiming the change was based on energy conservation considerations, Zenith said it had no reports of any accident related to the instant-on circuits in Zenith sets. However, Curtis Mathis, an independent-minded color TV manufacturer from Athens, Tex., plans to keep "instant-on." James A. Long, vice president and director of reliability for Curtis Mathis, says the feature "greatly extends the life of the picture tube by eliminating the turn-on surge" and is as "safe as an electric clock," consuming only 6 watts to keep the picture tube filament energized at partial voltage.

Not burning, just broken

But what about performance, reliability, warranties, and service—issues that nearly every consumer is bound to face over the useful life-time of his TV set? The previously mentioned research study performed by the Center for Policy Alternatives at

The low-voltage power supply used in many Zenith solid-state TVs (color schematic) has been updated with a magnetic voltage regulator for 1975 (black schematic). Besides a significant savings in electricity, sets equipped with this new regulator (known as the Power Sentry) should exhibit longer-lived picture tubes and components. Zenith explains that isolation from line transients and voltage surges protects solid-state circuits, while a carefully regulated cathode voltage (and therefore operating temperature) allows maximum picture tube life.



M.I.T. with the Charles Stark Draper Laboratory, Inc., takes a careful look at what's been happening in this area. Sponsored by the National Science Foundation, the study's findings and recommendations were released in June 1974. The M.I.T. studies' stated objectives were to "evaluate alternatives for increasing productivity of servicing consumer durable products and/or reducing the need for service, in the context of total product acquisition and use cost." The refrigerator and the color TV receiver were selected as representative consumer appliances for intensive study.

M.I.T. researchers found the color TV industry to be a classic example of free enterprise. They observed, "Because of warranty costs and the intensity of competition between manufacturers, a TV set is designed with the objective of getting the greatest reliability and most performance features for a given manufacturing cost." Hard-nosed tradeoffs are maintained between the costs of parts, labor, warranties, meeting Government regulations, and satisfying consumer desires (styling).

Competition, especially from Japanese companies, whose government has subsidized the development of solid-state receivers, is credited with spurring U.S. manufacturers toward a more sophisticated approach to reliability. Up through 1973, the one-year warranty practically became an industry standard, highlighting the serious effort given to weed out parts failures before they could become expensive repair bills. TV design engineers enjoyed more flexibility in their choice of parts simply by demonstrating how warranty costs would be decreased. However, continued inflation and a sharp downturn in consumer spending made 1974 an off-year for TV sales, forcing many manufacturers to reinstate the 90-day warranty.

Practically all manufacturers use accelerated life testing with the set operated at high line voltage and elevated temperature while power is switched on and off to induce thermal cycling effects. The resulting failure data can help identify design flaws or bad components, but it is not perfect. Problems that might not occur under normal use can be induced by such testing methods.

Even computers are getting into the act. They are used for reliability prediction, data gathering, and cost analysis. Though a relative newcomer to consumer electronics, computer-aided design is now used extensively for worst-case analysis, thermal analysis of semiconductors, and in designing nonlinear circuits, such as some closed-loop feedback systems. However, any decision to use the computer is based on convincing management that the money spent will produce larger profits.

Lemon aid

Besides these changes in technology and design philosophy, the scope of color TV warranties has also undergone a major overhaul. The M.I.T. report explains that until the late 1960s, most sets were covered only for parts during the first 90 days of ownership. Labor was charged to the customer. If labor coverage did exist, it was "outboarded"—i.e., the retailer was given a certain fixed payment per set to handle all the warranty service.

But since 1969, consumerism (and bad publicity) have caused warranty coverage—whatever its duration—to include both parts and labor, plus one other important change. Service labor costs were "inboarded" with costs billed directly to the manufacturer.

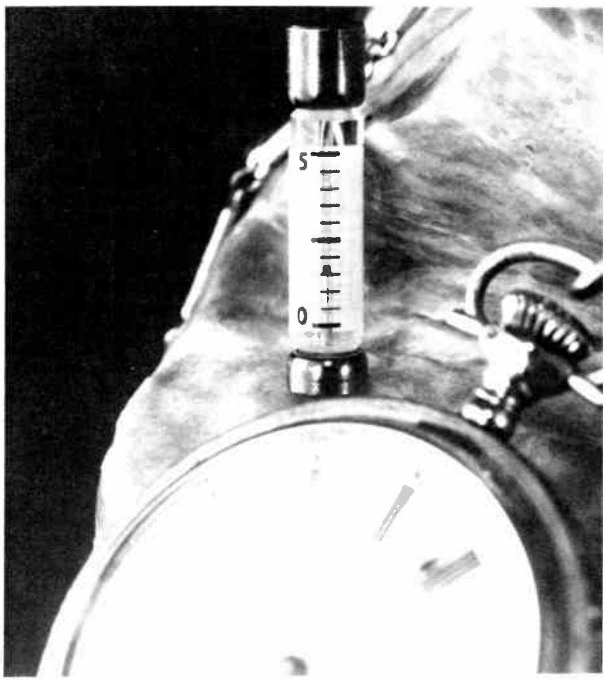
The economic impact of this improved coverage is easily found by comparing the old 90-day parts warranty (costing the manufacturer about $3 per set) with parts and labor coverage running a full year ($15 to $25 per set). Clearly, improved reliability can give a manufacturer a very significant advantage over producers of less reliable sets boasting equivalent warranties.

While the concept of increased coverage is appealing to consumers, implementation involves considerable tension between manufacturers and those who do the actual repair work. M.I.T. researchers report that the history of mistrust between manufacturers and servicemen is long. The conflict centers around four topics: fraudulent claims submitted by servicemen, labor warranties that have been poorly honored by manufacturers, endless argument over who pays for "consumer education" calls, and the trend for warranty service to be concentrated in a small number of larger service shops in any given area. Items one and two are finding at least partial solution in statistical analysis that helps the manufacturer spot suspicious operations where claims are being padded, and in more liberal payment rates for labor, which allow the serviceman to do business profitably.

Consumer-education calls involve a response to "problems" occurring during the warranty period that are *not* caused by set failure. Typically, the customer has misadjusted his TV—or may even have inadvertently pulled the plug. Before discovering these oversights he calls the repair shop. Manufacturers refuse to pay for such service calls because the product was not at fault. Customers won't pay because they were assured that all service costs would be taken care of during the warranty period. The serviceman is left holding the bag. But not for long. He simply replaces a couple of components (or claims to have done so) and files for warranty costs from the manufacturer. Based on admittedly scanty and conflicting information, M.I.T. researchers estimate that perhaps 30 percent of all warranty service calls are of the consumer-education type.

Where legitimate repairs are concerned, new labor warranties are supposedly designed so servicemen will find warranty work no more or less attractive than customer-paid service. The M.I.T. report finds this has only been partly true, especially considering the already mentioned practice of concentrating warranty repairs in larger service shops.

A recent example of this trend in the Philadelphia area aroused the wrath of independent local service technicians who expressed their views through the *TSA News*, a monthly publication of the Television Service Association of Delaware Valley. In 1973, Peirce-Phelps, the Zenith distributor for metropolitan Philadelphia, restructured its repair capability by opening a second service center in North Philadelphia (their downtown shop has been in business for over 40 years). But the TSA independents saw the new Peirce-Phelps facility as a direct threat to their own service business, especially since the independent serviceman must seek authorization from Peirce-Phelps before performing in-warranty work on Zenith sets.



[3] This miniature elapsed time indicator from North American Philips Control Corp. offers a practical, inexpensive way to measure the hours of service given by an electrical appliance. Warranties based on readings from such a device should help eliminate inequities built into any scheme that simply covers a product for a fixed period of ownership.

Unfair advantage was claimed by the independents because they buy parts from, have claims processed by, and get final payment forwarded through this same distributor who was now "enlarging" his competitive position for in-warranty service.

According to Peirce-Phelps president, Grant Peirce III, the new shop is really a "logistics problem solver" allowing North Philadelphia customers easy access to Peirce-Phelps without coming downtown. Technicians were transferred from the old location to work in the new shop and no extra people were hired.

Some new understandings have reportedly been forthcoming between Peirce-Phelps and the TSA since the initial conflict (a simplified, in-writing qualifying procedure now exists for independent shops seeking in-warranty Zenith repair work), but Stephen Robert Goldman, editor of the *TSA News*, told *Spectrum* that the issue is not yet fully resolved. Mr. Goldman explained that this is only one of many problems between servicemen, franchised dealers, and set manufacturers. Each major producer has a different collection of forms and accompanying requirements that must be respectively filled out and met before payment is made for in-warranty repair work. Perhaps consumer advocates are not alone in their frustration!

Measure use, not age

An important flaw in any time-based warranty is the inability to gauge actual use of the product. Some families watch TV for hours every day, while others only glance at occasional programs, yet each is given just one year's or 90 days' protection under present arrangements. A fairer policy would guarantee the set for a given period of actual operation. A new product introduced in June 1974 by North American Philips Controls Corp., Cheshire, Conn., should make such warranties practical.

Identified as Series 49800 miniature elapsed time indicators, the cylindrical devices are no larger than a standard automobile fuse and cost only $1 each in large quantities (Fig. 3). They employ a simple electroplating process to provide an accurate, nonreversible, direct readout of actual operating time.

Suitable for monitoring many types of electrically powered appliances, a single indicator operates from a controlled direct current which causes predictable buildup of a copper column in the unit's calibrated glass tube. The physical length of the copper deposit is directly proportional to how long current has been applied. Indicators are available to measure 1000, 2000, 5000, or 10 000 hours. Naturally, appliance manufacturers will demand a tamper-proof hookup before entrusting the device to consumers.

Tomorrow's servicing

On the subject of TV serviceability, M.I.T. researchers identified modular design as being used by almost all color set makers. Not only are repairs easier, but the production problems are also simplified. And modular design permits the assembly and testing of subfunctions before they are plugged into a complete receiver.

Manufacturers do differ significantly when it comes to designing throw-away or repairable modules. Degree of modularization is also highly variable, with present designs having anywhere from two to 15 modules per set. And partitioning—i.e., deciding which functions go on module cards and which remain on the chassis—adds even more variety to the mix. Since the designs among various manufacturers differ so greatly, the M.I.T. report finds no trend toward standardization of modules in the industry (but some commonality was noted for modules used on different chassis all made by the same manufacturer).

The effect on servicemen is that all modules must be treated as "black boxes." It is impractical for anyone to understand the detailed design of all modules. And only the rare serviceman is thought capable of troubleshooting an unfamiliar module. According to Mr. Goldman, the required inventory for modules is also a worry for dealer/servicemen who must stock an ever expanding quantity of circuits to service sets and keep their franchises. The potential for dead inventory is staggering since modules, unlike components, are typically good for repairing just one brand of TV.

As an added thought, Matsushita's David Carpenter observes that modular construction is liked by the customer (lower service costs) and the service trade (simpler in-home repairs). But the TV industry is so competitive that cost pressures may force manufacturers back to one-piece assembly with, for example, plug-in integrated circuits and transistors. ◆

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The microprocessor: in the driver's seat?

In the research laboratory, the microprocessor looks promising; in the real world, sensor/actuator problems may stall progress

In the highly cost-conscious automotive industry, an electronic product is rarely used on board a vehicle unless: it is cost effective both initially and from a reliability/warranty viewpoint; it's the only way to get a mandatory job done (e.g., seat-belt ignition interlock systems); or it's an optional, extra-cost item. As a result, technological progress in electronics, in itself, has never guaranteed acceptance by automobile manufacturers. But with today's expertise in LSI technology, the situation may change—if the price is right.

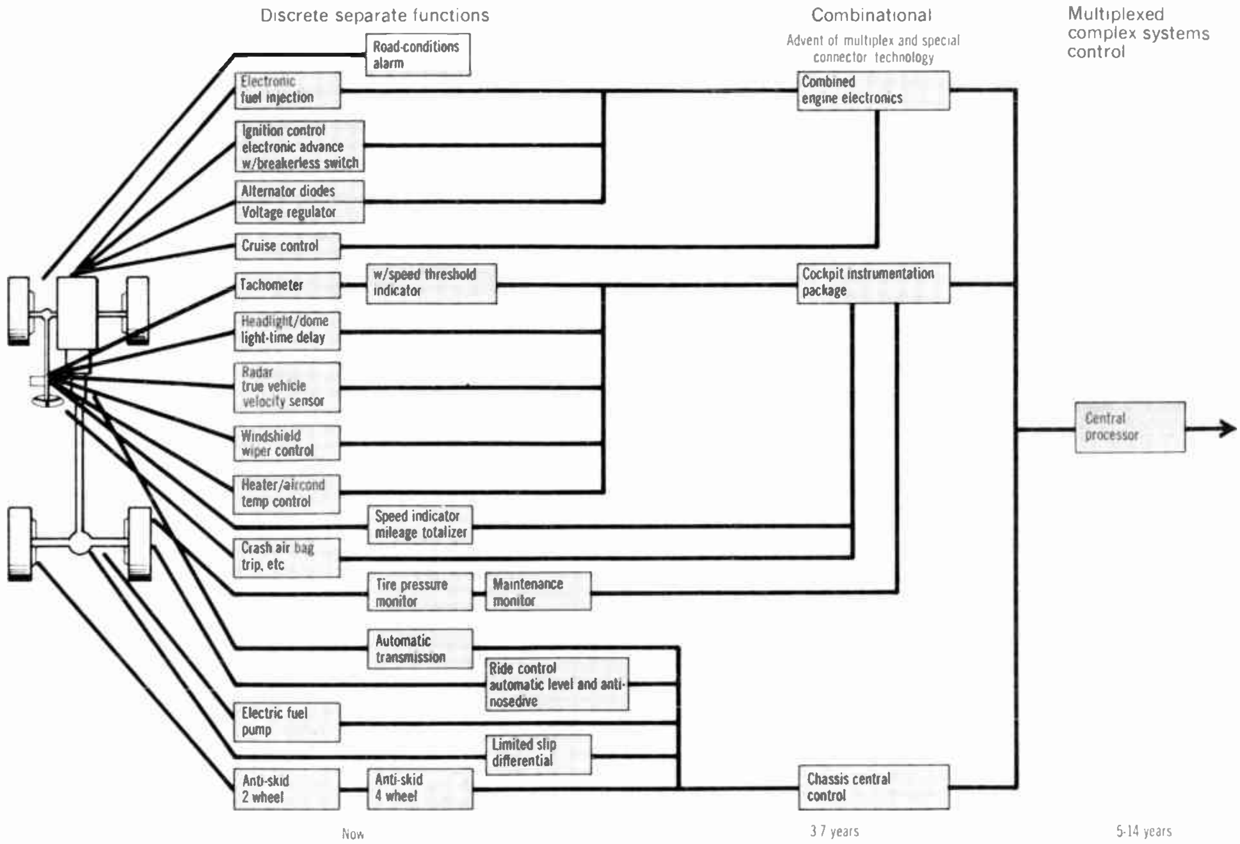
The control portions of every electronic subsystem presently used in automobiles (see Table I), other than those for entertainment or communications, could be incorporated on a single chip. This is, today, technically feasible. And it is the number and complexity of these presently available subsystems, together with the more than 60 electronic subsystems for future automobiles now under investigation (also see Table I), that is spurring interest in a new type of total systems approach, one that would incorporate an automotive central processor.

Ronald K. Jurgen Managing Editor

Why an automotive central processor?

At the heart of a total systems approach would be one or more microprocessors. The use of microprocessors in automobiles, many automotive experts feel, will be technically feasible by 1980. But, they say, the decision of whether or not to use them will be more economic than technical. Important factors in such a decision, for example, are emission-law and marketing uncertainties. It is becoming increasingly difficult and expensive to meet Government mandates for pol-

[1] **Electronic control systems or subsystems in automobiles are presently packaged as discrete separate functions. The next step forward will be combinations of subsystems with the aid of multiplexing and special connectors and harnesses. The last step in the progression is the central processor, probably in conjunction with one or more subsystem microprocessors.**

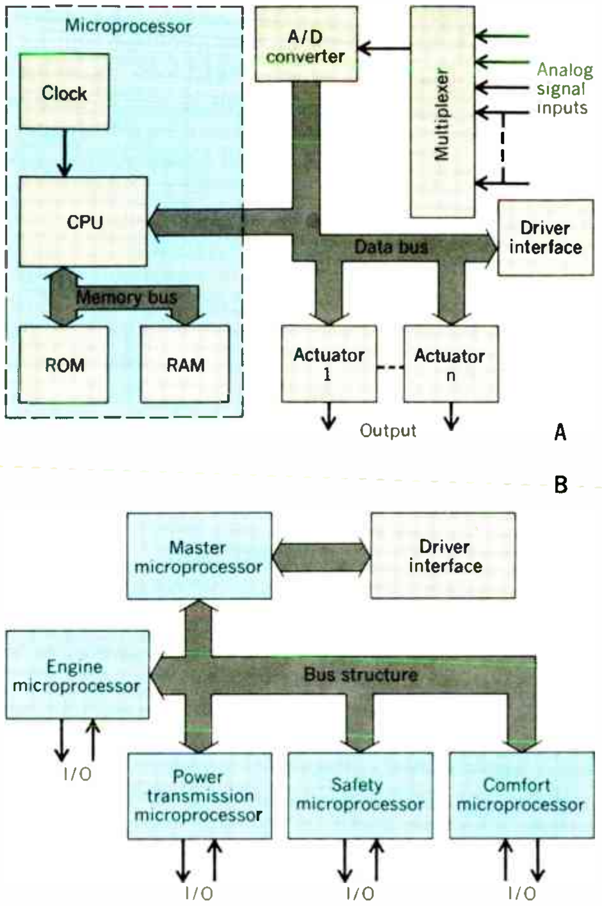


I. Proposed and presently available automotive electronic subsystems

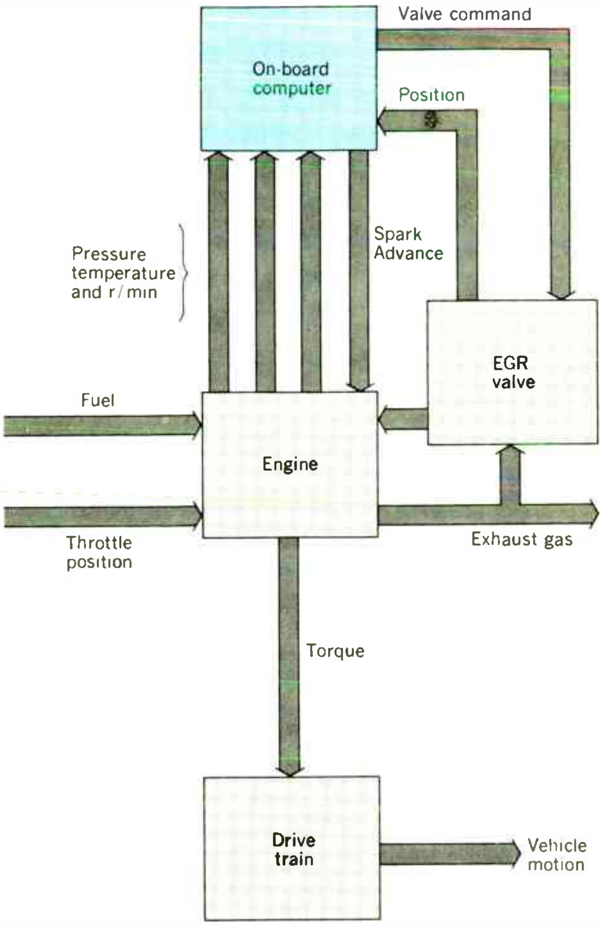
		Major Development Required				Major Barrier		
Proposed Subsystems		Transducer	Processor	Actuator	Display	Cost	Technical	Other
Automatic door locks				X		X		
Alcohol detection systems		X			X	X	X	X
Flasher control systems				X		X		
Programmed driving controls			X	X		X	X	
High speed warning						X		
High speed limiting				X		X		
Lamp monitor systems		X				X		
Electronic horn						X		
Crash recorder		X	X		X	X	X	X
Traffic controls		X	X	X	X	X	X	X
Tire pressure monitor		X				X		
Tire pressure control		X		X		X	X	
Automatic seat positioner						X		
Automatic mirror control		X		X		X	X	
Automatic icing control		X				X	X	
Road surface indicator		X			X		X	
4 Wheel anti-lock				X		X		
Vehicle guidance		X		X		X	X	X
Station keeping	Radar	X		X		X	X	
	Infrared	X		X		X	X	
	Laser	X		X		X	X	
	Sonic	X		X		X	X	
Automatic brakes	Radar	X	X	X			X	
	Infrared	X	X	X			X	
	Laser	X	X	X			X	
	Sonic	X	X	X			X	
Predictive crash sensors	Radar	X				X	X	
	Infrared	X				X	X	
	Laser	X				X	X	
	Sonic	X				X	X	
Electronic timing						X		
Multiplex harness systems				X		X		
Electronic transmission control				X		X		
Electronic cooling system control				X		X		
Closed loop emission control		X		X		X	X	
Accessory power control		X		X		X		
Cruise control				X				
Theft deterrent systems		X				X		
On board diagnostic systems		X				X		X
Off board diagnostic systems		X				X		X
Leveling controls		X		X		X		
Radio frequency display						X		
Digital speedometers					X	X		
Digital tachometers					X	X		
Elapsed time clock					X	X		
Electronic odometer					X	X		
Trip odometer					X	X		
Destination mileage					X	X		
Miles per gallon		X			X	X		
Miles to go		X			X	X		
Estimated arrival time					X	X		
Trip fuel consumption		X			X	X		
Average speed					X	X		
Average miles per gallon					X	X		
Digital fuel gage					X	X		
Service interval					X	X		
Digital temperature gages					X	X		
Digital pressure gages					X	X		
Digital voltmeter					X	X		
Digital metric conversions					X	X		
Acceleration gage		X			X	X		
Drunk drivers		X	X				X	X
E K G		X	X	X		X	X	X
Sleep detectors		X	X				X	X

Presently Available Subsystems

Alternator, voltage regulator, electronic fuel injection, electronic ignition, intermittent windshield wipers, cruise control, wheel lock control traction control, headlamp dimming, climate control, air cushion restraint system, digital clock



[2] One approach to the use of microprocessors in automobiles is a single microprocessor system (A). The other basic approach is the use of multiple microprocessors (B).



[3] Key elements of the Ford microprocessor control system used for maximizing fuel economy and drivability for a given level of Government-mandated level of emissions.

lution control by use of catalytic converters or other devices that remove pollutants from exhaust emissions. Microprocessors open the doors to sophisticated engine controls that can prevent pollutants from being produced by the engine—or at least reduce the level of pollutants that are produced. In fact, the microprocessor's arrival in automobiles will probably occur when the crossover point is reached between prices of microprocessors coming down and the costs of alternate methods of implementing pollution control going up.

A main advantage of an automotive central processor is that all control modules are in one location. This approach contrasts with the industry's present discrete phase of control construction, Fig. 1, wherein a number of boxes are placed in locations of individual convenience around the car with each box operating as a semiautonomous element in the system, having its own voltage regulator, sensors, input signals, and output actuators or displays. For example, three separate sensors may be used for drive-line speed to provide inputs to three different control boxes. So one important disadvantage of discrete construction is that, even though each control box may be relatively simple, the total complexity of the wiring harness and of sensors and interconnects is high.

With an automotive central processor, a single wiring harness approach is possible that could save money. Also, since the processor communicates with all encoder and decoder stations throughout the car, the incremental cost of adding functions is small. With standard units available, an automobile manufacturer only has to change the number of encodes and decodes to suit his own particular system needs.

With an automotive central processor, a car-wide self-analysis system would be conceivable if multiplexing capabilities were incorporated in the processor. Without multiplexing, the added cost of the logic circuits needed to go through self-check functions would probably be too expensive.

One microprocessor or several?

Two basic approaches, common to all systems under consideration, to microprocessors in automotive applications are shown in Fig. 2. The first approach, Fig. 2A, is one in which a single microprocessor system operates and controls an entire range of functions in the vehicle. This type of system has the advantage of requiring relatively little hardware, but does not offer redundancy or easy fail-safe implementation. And, since the microprocessor might be required to handle 20 to 30 functions at any given time, it would need state-of-the-art architecture with high execution speed and complex input/output structure.

The second basic approach is shown in Fig. 2B. Here, instead of using just one microprocessor, several dedicated microprocessors are employed—one each for the engine controller, power transmission controller, safety, and comfort functions. Other microprocessors could be added to accommodate additional functions if desired. The system in Fig. 2B also contains a master microprocessor which interfaces directly with the driver. The master microprocessor is the prime operator of the diagnostic programs that monitor the system and advise the driver of any malfunctions or possible errors. There is the added advantage that any one microprocessor could take over the functions of any other microprocessor as a fail-safe mechanism. However, for such fail-safe implementation, many common paths between microprocessors would be necessary and state-of-the-art architecture would be required.

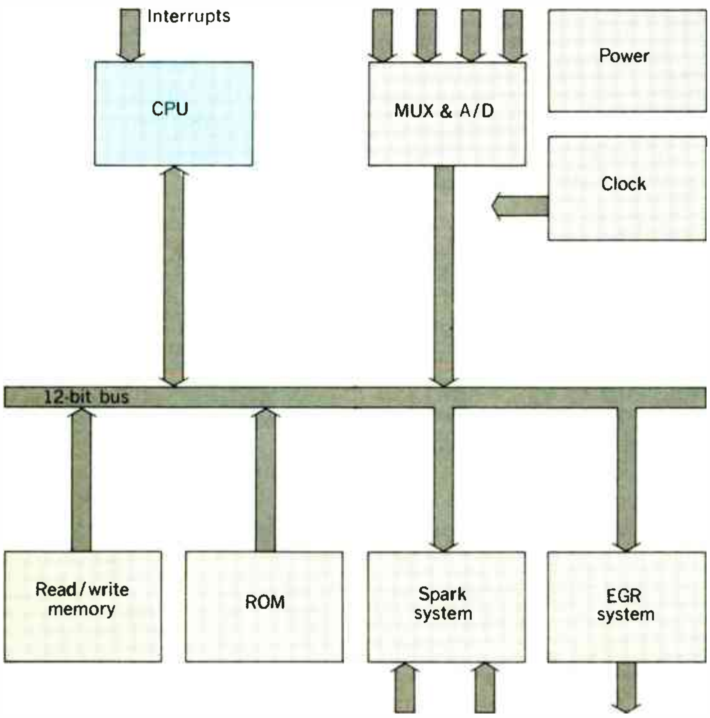
Transducer and actuator problems

The development of a suitable automotive central processor presents more of a technical challenge in the input and output sections of the system than it does with the microprocessor or microprocessors. If the microprocessor has sufficient execution speed and function-handling capacity for the system in which it is to be used, the only other principal area of concern is its ability to survive in the extreme electrical and physical environments of the car. Transducers or sensors and actuators, however, must not only cope with these harsh environments but must also meet requirements for precision, range, etc.

One of the shortcomings of most available transducers, from an automotive applications viewpoint, is that they are analog devices. They cannot interface directly with the central processor and require the use of analog-to-digital converters. If available, digital transducers might cut costs by eliminating the need for the converters. But even analog transducers are not always available for specific needs. For example, a need exists today for a small, reliable tail-pipe emissions sensor as part of a closed-loop engine and emissions control system. Without it, one alternative approach is the use of brute-force design techniques to eliminate the necessity for the feedback loop. And other potential electronic controls for automobiles are stymied by lack of suitable sensors (see Table I).

Actuators present even greater problems. They are usually mechanical, hydraulic, or pneumatic devices and their interface with an electronic system is difficult. For this reason, actuators are often cited as the largest single barrier to introducing cost-effective electronics to the automobile. In an electronic wheel-lock system used to prevent wheels from locking when the brakes are heavily actuated, the largest cost item is the hydraulic brake pressure modulator, not the electronic control.

[4] System structure for the Ford microprocessor system is based on a 12-bit data and instruction word length and an 8-bit analog-to-digital converter with an 8-channel analog multiplexer under central processor control.



Microprocessors at GM and Ford

With their exciting potential, microprocessors are being carefully studied by most major automobile manufacturers in the U.S. Less interest is evident in Europe.

General Motors has had an extensive research program underway for some time in which several in-vehicle, experimental, integrated, automotive electronic systems have been studied and built, each with a particular objective. Each of the four systems—Alpha, Sigma, Delta, and Beta—will ultimately be superseded by Omega, an automotive central processor. Overall systems integration has been studied in the Alpha series of systems, display systems in the Sigma series, diagnostics (both on-board and off-board) in the Delta series, and driver physiological considerations in the Beta system. The findings from these studies have been combined and analyzed to form the basis of Omega.

Alpha IV, or the fourth version of the Alpha series, was the first attempt by GM at applying MOS/LSI technology in the design of a cost-effective automotive computer. It used a single-chip, 4-bit parallel microprocessor with subsystems for both digital display and control functions, which included: speedometer, odometer, trip odometer, time of day, elapsed time, engine speed, four-wheel-lock control, cruise control, traction control, ignition timing, ignition dwell, automatic door locks, speed warning, speed limiting, and anti-theft. Preprocessing of the data and output latches in the Alpha IV system took some of the load from the microprocessor by taking care of data gathering and output execution. The microprocessor handled the control and display logic and calculations. All functions were performed in a time sequence on a fixed, real-time computation loop, while interface circuitry handled the asynchronous load associated with the vehicle operation.

The Alpha IV system proved that a 4-bit microprocessor can be applied to the automotive control and display problem. CPU, scratch-pad memory, and program memory capabilities were found to be compatible with requirements. Alpha V, the most recent version of the series, was oriented toward solving the central computer design problems that had manifested themselves in the other Alpha vehicles, particularly Alpha IV. It is interesting to note that during the four years that elapsed between Alpha I and Alpha IV, the total number of components in the central processor dropped from 4000 discrete components in Alpha I to just four LSI chips in Alpha V.

Ford Motor Company is, meanwhile, working on the development and demonstration of a digital control system that maximizes fuel economy and drivability for a given level (Federal government regulation) of emissions. The system is said to be manufacturable in production quantities on a cost-effective basis. The present system uses a microprocessor and a small number of other custom LSI devices to control the spark ignition timing and exhaust gas recirculation mass flow based on a number of engine variables (Fig. 3). The system is under test on the road in several vehicles.

The system structure shown in Fig. 4 is based on a custom microprocessor with a 12-bit data and instruction word length (Ford apparently finds a 4-bit microprocessor inadequate whereas GM, as noted previously, has found it suitable). The computer program and associated coefficients, which describe the engine control algorithm, are stored in a read-only memory. Engine control software is contained in about 1500 12-bit words. Input/output data and intermediate results are stored in a 128-word, read/write semiconductor memory. The system also includes an 8-bit analog-to-digital converter with an eight-channel analog multiplexer under CPU control. This converter measures the outputs of the various transducers that are used in the system.

Spark ignition timing or angle of spark firing is determined by a special-purpose, custom LSI control chip. The CPU calculates the desired angle, loads this value into the controller, and the LSI control chip continually compares the instantaneous engine crankshaft rotation angle with the desired one, issuing a pulse to initiate spark firing when they are equal. The controller determines the angle by interpolating between pulses which are generated by the motion past a magnetic sensor of reference notches cut in the engine flywheel.

The exhaust gas recirculation valve controller is a digital interval generator. It controls a pneumatic linear actuator for the mass flow EGR valve. The servo loop that positions the valve, using feedback from a linear potentiometer indication of actual position, is closed through the software.

Ford researchers feel that the microprocessor system has proven to be an effective and flexible on-board vehicle controller. If cost, reliability, and sensor/actuator problems can be resolved, they say, it is possible that similar systems could be in mass production by the end of the seventies.

And at Chrysler

The Chrysler Corporation has not made any public comment about work that may be underway with microprocessors for use in Chrysler cars. But Chrysler, unlike GM and Ford, does not have a research staff per se. Innovations on Chrysler cars are apt to be the result of work of production design groups. If an innovation, such as a microprocessor, does not appear to have immediate possible application in Chrysler cars, it does not get top priority. An example of Chrysler's way of getting things done is the ordering into production for some of its 1976 cars a computerized (ICs and discrete components) engine that does away with the catalytic converter and improves fuel economy. A pair of small computers, mounted under the hood, will accomplish combustion of lean air-fuel mixtures—mixtures where the ratio of air to fuel is 18 or more to 1 instead of the conventional 15 or 16 to 1. Improvement in fuel consumption is said to be at least 5 percent.

The lean-burn system requires seven inputs of data on such conditions as accelerator position, outside air temperature, and coolant temperature. The data are used by the computers to calculate the exact instant at which individual spark plugs should be ignited in order to minimize emission of pollutants and to maximize miles per gallon. The lean-burn system will be used in conjunction with Chrysler's standard electronic ignition already in use on Chrysler cars.

The decision by Chrysler to go ahead with the electronic version of the lean-burn system was apparently based, at least in part, on the fact that the company had been unsuccessful in attempting to do the job with nonelectronic, pneumatic vacuum-sensing devices. These devices, it is reported, were not able to transmit proper spark-timing instructions to the cylinders with the required precision. ◆

This is an introductory article to a series on automotive electronics. Other articles in the aperiodic series will discuss advances in such subsystems as electronic fuel injection, electronic ignition, and emissions control systems.

For further reading

There are many excellent sources for detailed information on microprocessors in automotive applications. A good overview can be obtained from the following:

Automotive Electronics II. IEEE Catalog Number 75CHO976-1VT, $24 (members), $30 (nonmembers). Mail order and payment to IEEE, 445 Hoes Lane, Piscataway, N.J. 08854. Included in the 203-page proceedings are four papers on microprocessors:

1. Boufaissal, J., "What is a microprocessor?" pp. 51–63.
2. Jones, T. O., Schlax, T. R., and Colling, R. L., "Application of microprocessors to the automobile," pp. 65–74.
3. Moyer, D. F., and Mangrulkar, S. M., "Engine control by an on-board computer," pp. 75–77.
4. Oswald, R. S., Laurance, N. L., and Devlin, S. S., "Design considerations for an on-board computer system," pp. 79–84.

Texas Instruments Microprocessor Videotape Course, Lesson 14, "Microprocessors in automotive applications." Contact Learning Center, Texas Instruments Inc., P.O. Box 5012, Dallas, Tex. 75222.

Hood, R. B., "Electronic penetration in autos—systems on wheels," 1974 IEEE INTERCON paper, Session 36.

Temple, R. H., and Devlin, S. S., "The use of microprocessors as automobile on-board controllers," *Computer*, pp. 33–36, Aug. 1974.

New product applications

Production 16-kb CCD memories are offered for bulk designs

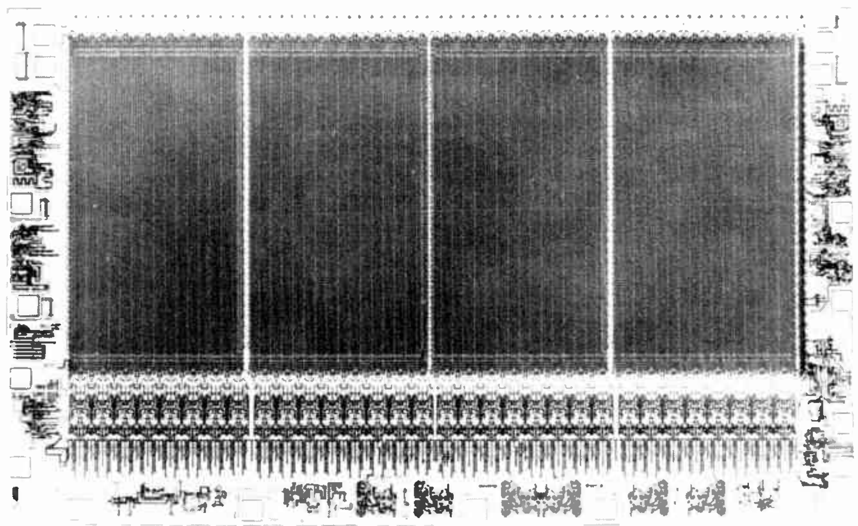
Low cost per bit and high packing densities are two features of charge-coupled device (CCD) memories. For the digital equipment manufacturer, the commercial availability of a CCD memory with a capacity of 16 kb means the potential of changing from magnetic drum and mechanical fix-head disk peripherals to solid-state bulk memories.

The model 2416 CCD serial memory offers this capacity on a single chip in a standard 18-pin memory circuit package, less than 2.5 cm long. The chip is an array of 64 shift registers—each 256 bits long—and input/output (I/O) control logic similar to a random access memory (RAM) circuit. This configuration gives the CCD the high operating speed and data storage versatility of an assembly of small registers, while providing storage capacity of 16 384 bits per package.

CCDs store data by recirculating data bits through shift registers. Each of the 64 registers in this memory stores 256 bits, and all registers recirculate in parallel. However, the I/O control logic, which is similar to a 64-bit RAM, allows any individual register to be accessed by application of a 6-bit address code to the CCD's address inputs. One register, or a succession of registers, may be accessed between individual shift cycles. Accessing a series of registers increases the serial data rate and also changes the array's logical configuration.

Read, write, or read-write operations are performed during RAM cycle time, which can occur between any two shift cycle times. The minimum RAM cycle is 460 ns, which provides a serial data rate transfer greater than 2 Mb/s. The minimum shift access time is 750 ns, providing a maximum access time to any of the 16 384 bits of less than 200 μs. The CCD operates from +12 and −5 volts and with a 4-phase clock.

Total data storage of 16 384 bits is available on this CCD serial memory chip. It is available in a standard 18-pin memory package, less than 2.5-cm long.



At the end of each shift cycle, one bit of each register becomes accessible for nondestructive readout or modification. A succession of registers may now be addressed to access a group of bits—such as a byte or a word. Or, one of the bits may be accessed at random. After the RAM cycles are completed, the next shift register transfers all 64 bits—whether modified or not—forward, into their respective registers. This operation also refreshes the data levels. The maximum interval between shift cycles is 9 μs, which permits a 16-bit word to be accessed between shift cycles.

Conventional shift registers store 256, 1024, or 2048 bits per package. Because of their relatively high system cost per bit, their use has generally been limited to small serial memories and to high-reliability bulk memories. Like CCDs, registers can simulate the mechanical rotation and serial access of a drum or disk. Although the model 2416 can be used as a low-cost replacement for registers in these applications, its highest volume applications are expected to be in new bulk memory designs.

The 16-kb capacity permits bulk memories with a system storage density of at least 1 Mb (1 048 576 bits) per card to be built into equipment at low cost.

The 2416 is now available from stock in two packages: an 18-pin plastic DIP and a 22-pin ceramic package.

The 18-pin version costs $85.50 for a single unit, $62.50 for 25 to 99 units, and $55.50 for 100 to 999 units, available at distributors. The 22-pin version costs $89, $65, and $58 in the same quantities.

For additional information, contact Intel Corp., 3065 Bowers Ave., Santa Clara, Calif. 95051.

Circle No. 40 on Reader Service Card

Single-chip IC combines TV IF amplifier, synchronous detector, and FM detector

This device for TV receiver designers features a video IF amplifier, a synchronous detector, and an FM detector.

The SL437 provides a video IF amplifier with AGC, video detector and noise limiter, AGC generator with gating input, tuner AGC with variable delay limiting sound IF, quadrature detector, and dc volume control. The designer needs to add only tuning elements.

The video IF amplifier has an AGC range of 65 dB and conversion gain of 96 dB (15 μV/V). The AGC system also serves the tuner and includes terminals for a variable delay network. The video output zero-carrier level is typically 7 volts, with sync tips at 2.3 volts. Video output impedance is 25 ohms. The SL437 also provides an AFC output.

In the SL437C (for a pnp interface), the AGC output to the tuner is a current source of 0 to 5 mA. For the SL437D (npn interface), the tuner AGC output is a voltage source from 1.5 to 10 volts, at a maximum current of 10 mA.

The FM detector offers AM rejection of 55 dB. Audio output is 4.5 volts p-p into 5000 ohms at 50-MHz deviation. The volume control range is 75 dB. The supply voltage requirement is +12 volts, with current consumption of 80 mA. The device is in a 24-lead ceramic DIP.

Price is $10.56 in quantities of 100 or more. Delivery is from stock.

For more information, contact Plessey Semiconductors, 1674 McGaw Ave., Santa Ana, Calif. 92705.

Circle No. 41 on Reader Service Card