VOLUME 11 ☐ NUMBER 8 IEEE spectrum AUGUST 1974

articles

departments

Until now, the only way you could buy Nova 2's was five at a time.

Which obviously discouraged people who only wanted one.

So to make sure everyone who wants a Nova 2 gets one, we've come up with five different Nova 2 systems you can buy one at a time.

The smallest is built around our Real-Time Operating System. Which makes it a great little data acquisition satellite.

Next up the line is our Stand-alone Operating System. A small single-user computation system for people who don't need a disc.

Then there's the medium-sized Real-time Disc Operating System you can use to develop software and hardware interfaces, or to build your own medium-sized computation system.

Which is followed by a big Real-time Disc Operating System with more storage and faster output for higher throughput.

And for those who need a system with a built-in backup computer, there's the Dual Nova 2.

So no matter what you want to do, there's a Nova 2 system you can get to get it done.

And 60 days after we get your order, you'll get your system.

DataGeneral

The computer company you can understand.

Data General Corporation Southboro, Massachusetts 01772. (617) 485-9100.
Datagen of Canada Ltd., Hull, Quebec (819) 770-2030/Data General Europe, Paris, France 504-23-44

Circle No. 1 on Reader Service Card

the cover

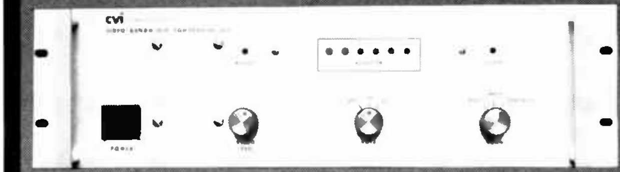
Alfred N. Goldsmith will be remembered as much for his role as cofounder of the Institute of Radio Engineers as for his 42-year editorship for that Institute. When he died on July 2, Spectrum spoke with his colleagues (p. 32) and commissioned artist Robert Heindel to do the cover portrait. Dr. Goldsmith's patents depicted include the radio-phonograph, shadow-mask color CRT, and composite delineation television.

spectrum

EDITORIAL STAFF *Editor:* Donald Christiansen

Managing Editor: Ronald K. Jurgen; *Senior Staff Writer:* Gordon D. Friedlander; *Senior Associate Editor:* Howard Falk; *Associate Editors:* Roger Allan, Marce Eleccion, Gadi Kaplan, Don Mennie, Ellis Rubinstein (Copy); *News Editor:* Evelyn Tucker; *Contributing Editors:* Nilo Lindgren, Alexander A. McKenzie, Michael F. Wolff; *Editorial Assistants:* Ann L. Battiste, Stella Grazda, Lynnette Peace; *Production Manager:* Ruth M. Edmiston; *Art Director:* Herbert Taylor; *Assistant Art Director:* Janet Mannheimer; *Technical Graphic Artist:* Morris Khan; *Art Assistant:* T. Dale Goodwin; *Business Manager:* Carl Maier

VIDEO COMPRESSOR



FOR LAB AND COMMUNICATION SYSTEMS

The CVI Model 260 Video Compressor samples conventional "real time" television signals to achieve a large reduction in bandwidth. The compressor also digitizes the signals for computer input and image analysis. A special 260 feature incorporates a "real time" video output which allows users to monitor the sampling process.

TYPICAL APPLICATIONS INCLUDE:

- Computer data input, linear or semi-random scanning
- Communications: transmission of TV images over voice grade circuits for conference or data distribution purposes
- Environmental monitoring: transmission of TV signals for remote observation and computer analysis
- Data recording: utilization of conventional audio cassette or reel-to-reel tape recorders for image storage
- Biomedical image analysis
- Industrial control
- Computer image enhancement

Video instruments for data acquisition, processing, transmission, and display.

Colorado Video, Inc. cvi
P.O. Box 928 Boulder, Colorado 80302 (303) 444-3972

Circle No. 2 on Reader Service Card

IEEE Publications Operations

IEEE PUBLICATIONS BOARD

F. S. Barnes, *Chairman*
R. W. Lucky, *Vice Chairman*

George Abraham
J. J. Baruch
W. R. Beam
Donald Christiansen
Charles Concordia
J. M. Early
E. K. Gannett
R. C. Hansen
A. L. Hopkins
S. J. Kahne
V. P. Kodali
J. E. Rowe
A. C. Schell
W. J. Spencer

STAFF

Elwood K. Gannett, *Director, Publishing Services*
Patricia Penick, *Administrative Assistant to the Director*

H. James Carter, *Manager, Editorial Services*
Elizabeth Braham, *Manager, Information Services*
Lawrence Liebman, *Manager Printing Services*
W. Reed Crone, *Managing Editor,*
Proceedings of IEEE and IEEE Press

William R. Saunders, *Advertising Director*
Henry Prins, *Research Manager*
Carl Maier, *Advertising Production Manager*
Carol D'Avanzo, *Assistant Advertising Production Manager*

IEEE SPECTRUM is published monthly by The Institute of Electrical and Electronics Engineers, Inc. Headquarters address: 345 East 47 Street, New York, N.Y. 10017. Cable address: ITRIPLEE. Telephone: 212—752-6800. Published at 20th and Northampton Sts., Easton, Pa. 18042. **Change of address** must be received by the first of a month to be effective for the following month's issue. Please use the change of address form below. **Annual subscription:** IEEE members, first subscription $3.00 included in dues. Single copies $3.00. Nonmember subscriptions and additional member subscriptions available in either microfiche or printed form. Prices obtainable on request. **Editorial correspondence** should be addressed to IEEE SPECTRUM at IEEE Headquarters. **Advertising correspondence** should be addressed to IEEE Advertising Department, at IEEE Headquarters. Telephone: 212—752-6800.

Responsibility for the contents of papers published rests upon the authors, and not the IEEE or its members. All republication rights, including translations, are reserved by the IEEE. Abstracting is permitted with mention of source.

Second-class postage paid at New York, N.Y., and at additional mailing offices. Printed in U.S.A. Copyright © 1974 by The Institute of Electrical and Electronics Engineers, Inc. **IEEE spectrum** is a registered trademark owned by The Institute of Electrical and Electronics Engineers, Inc. BPA

OTHER IEEE PUBLICATIONS: IEEE also publishes the PROCEEDINGS OF THE IEEE and more than 30 Transactions for IEEE Societies and Groups with specialized interests within the electrical and electronics field. Manuscripts for any IEEE publication should be sent to the editor of that publication whose name and address are shown on pp. 101–102 of the January 1974 issue of *Spectrum*. When in doubt, send the manuscript to E. K. Gannett, Publishing Services, at IEEE Headquarters, for forwarding to the correct party.

IEEE also copublishes, with the Institution of Electrical Engineers of London, England, *Electrical & Electronics Abstracts* and *Computer & Control Abstracts*, as well as their companion titles journals, *Current Papers in Electrical & Electronics Engineering* and *Current Papers on Computers and Control*.

MOVING? PLEASE NOTIFY US 4 WEEKS IN ADVANCE

Name (Please Print)

Address

City State/Country Zip

MAIL TO: IEEE CODING DEPARTMENT
345 East 47 Street, New York, N.Y. 10017

ATTACH LABEL HERE

- This notice of address change will apply to all publications to which you subscribe.
- List new address above.
- If you have a question about your subscription place label here and clip this form to your letter.

World Radio History

IEEE spectrum AUGUST VOLUME 11 ☐ NUMBER 8

spectral lines

Who gets published? Part II: Transactions

As one might suspect, although there are some similarities in the way publishing decisions are made by the Editors of the Institute's various *Transactions* and the way they're made by *Spectrum* (Spectral lines, July, p. 33), there are significant differences too. Furthermore, there are important variations in review methods among the *Transactions* themselves. The salient conclusion may well be that procedures are seldom dogmatic in nature, but rather are tailored to the best interests of the Group or Society in question.

Most *Transactions* deal with both invited and contributed papers, and, in some cases, convention papers. And all employ review procedures, although sometimes these are indirect. For example, invited papers may not be formally reviewed by an Editor under the rationale that if the author is so well-regarded that he warrants an invitation, then it is inappropriate to seek out "super-experts" who "know even more" to review his manuscript. (This viewpoint is by no means universally held, however, as we shall see.) And papers presented at conferences are often published without review with the rationale that they have either been invited by the organizers of the original sessions or have been subjected to an appropriate review by a conference committee. Most contributed papers, however, are reviewed, in some cases by a minimum of three referees.

Other observations regarding *Transactions* review procedures include:

☐ Most *Transactions* Editors get involved in the review process, but do not necessarily perform detailed reviews themselves, relying instead on those of their associate editors or reviewers versed in the specialty at hand. They do settle questionable cases and modify "standard" review procedures when appropriate.

In one case that is perhaps typical—that of the *Transactions on Microwave Theory and Techniques*—the Editor reads invited papers himself; no formal reviews are required. But, in the case of contributed papers, he scans them all and assigns three reviewers to those that pass muster.

☐ Most Editors neither use nor advocate a "blind" review procedure. However, in the case of *Transactions on Electromagnetic Compatibility*, the author's name is scissored out of his manuscript with the intention that the author's track record will be completely discounted. Using this technique, the Editor notes, even papers from prominent authors have been rejected. On the other hand, the Editor of *Transactions on Information Theory* avoids blind reviews, contending that they would make no difference. *Transactions on Communications* does it both ways, and finds no difference in results. Finally, the Editor of *Transactions on Magnetics* thinks it absurd to try to conceal the author's identity from a peer referee, who, he believes, is well-enough qualified to discern the author's identity—sometimes simply by glancing at the references. (He also believes an author's previous publication record is bound to have a bearing on the acceptance of papers. On the negative side, reviewers may gloss over equations of established authors; yet, on the other hand, a good peer reviewer may ask for extensive revisions because the paper is not up to the "usual standard" of that author.)

☐ Some, though not all Editors, require unanimous agreement among reviewers that a paper be published before it is accepted.

☐ Many *Transactions* Editors feel that for the most part a tradeoff between the "perfect review" and speed of publication is needed. Some feel that in questionable cases they should come down on the side of publishing unverifiable material rather than reject what may be significant, if not completely accurate, new material.

☐ Many Editors acknowledge the existence of reviewer bias and are alert to ways to minimize it. Sometimes an Editor publishes a paper that was rejected by the initial reviewers because he feels they were being excessively negative, biased, or "resistive to change." Some Editors acknowledge a sliding scale of "toughness" employed (intentionally) by reviewers—sometimes favoring well known authors and, in other cases, favoring newcomers. Most believe that in neither case does this translate to a noticeable gradation in quality of the finally published papers.

☐ In some, though not all, cases the reviewers of a manuscript are given a chance to see all other reviewers' comments. In this adaptation of the Delphi technique, the reviewers are thus encouraged to minimize caustic criticism and "shooting from the hip," and the process permits them to calibrate their opinions against the views of colleagues.

☐ Some Editors ask reviewers to categorize their recommendations as mandatory or optional. In the case of "mandatory," the appropriate changes must either be made or a satisfactory rebuttal submitted by the author.

Finally, a note on the *Transactions of the Power Engineering Society*: Its "editors" are the Technical Operations Department committees (15 of them) and each decides in a generally uniform way which papers shall be published. As part of the process, each paper is reviewed by three or more reviewers.

In a subsequent issue, we shall deal in some detail with the selection of material for publication in *Proceedings*.

Donald Christiansen, Editor

His colleagues remember 'The Doctor'

Alfred N. Goldsmith, cofounder of IRE and Director and Editor Emeritus of IEEE, is cited for his wisdom and statesmanship

We who were his students at Townsend Harris Hall and the College of the City of New York always referred to him as "the Doctor," in distinction from run-of-the-mill Ph.D.s on the faculty. Some of us were wireless amateurs (not "hams," please) and he was our special benefactor not only as a teacher but as a generous donor of equipment to the City College Radio Club, founded in 1914 but hardly a going concern until the following year. By that time we were fairly experienced: another boy of 12 and I had a primitive station in the Bronx in 1908 (wavelength unknown, range about four blocks, call letters "YF," which in American Morse had a beautiful lilt.)

Alfred N. Goldsmith was eight years older than we and already an instructor in physics at C.C.N.Y. Another few years and his name began to appear in the wireless magazines and in *The New York Times*, which from the beginning took an active interest in wireless developments. Thus, while I was still in primary school, I decided to attend C.C.N.Y., not only because it was a free (and scholastically tough) institution, but because Dr. Goldsmith taught there. I was still in Townsend Harris Hall—a member of his class in Physics 2, an elementary course in light, heat, magnetism, and electricity—when I saw him for the first time. At the other end of the scale was Physics 17, the course in radio engineering which Dr. Goldsmith gave from 1913 through 1918—for us an infinitude (five years) away.

The City College Radio Club

One afternoon three of us amateurs passed Dr. Goldsmith in the corridor outside the Radio Laboratory, a spacious room in the main building of the Washington Heights campus. We had just about graduated to long pants and were togged in the ties and jackets that were obligatory at all institutions of higher learning. Outdoors we would have tipped our caps, but since we were capless we nodded respectfully to the Doctor. He nodded back and entered the lab with his pass key, closing the door behind him. It was always kept locked.

We were dying to see the inside of the lab. Walking nervously up and down the corridor, we debated: would the Doctor show us the wonders of the lab if we could get up nerve enough to ask him, or would we be rebuffed? Finally one of us—not I—rushed over and pressed the buzzer button for about a quarter of a second. Nothing happened. At a slightly longer signal, the door was opened by a senior student. With due deference, we explained that we were preparatory school students of the Doctor's, and supplicants for a tour of the Lab. Our fears had been groundless. In a moment the Doctor appeared and invited us in, most cordially. We were dazzled. The neat ebonite bases, shiny brass fittings, the accurately spaced turns of helical inductances and the big transformers (1 kw!) were fascinating to boys accustomed to 1-inch spark coils, at best, and cigar box construction.

Carl Dreher Consultant

Dr. Goldsmith explained everything, giving us credit for greater understanding than we had—one of his characteristics as a teacher. Don't make it easy for the youngsters, was his technique; make them ask questions and look up things for themselves. And at a given stage, just let them alone. At this introductory visit, he devoted the better part of an hour to us. From that and occasional later visits, the City College Radio Club came into being.

It must have been one of the best equipped and best informed radio clubs in the country. The lab was equipped by the Physics Department, principally with measuring equipment, and with commercial transmitters and receivers by the Marconi Wireless Telegraph Company of America, with which Goldsmith had a research contract; in addition, Goldsmith himself owned a good deal of the equipment. But he took care not to spoil us. We wired and constructed a good deal of equipment ourselves, such as a long-wave receiver and tables for code practice. Our information came in part from books, but largely from Dr. Goldsmith. Whenever he could find time, he would lecture at our technical sessions, and since he was the editor of the *Proceedings of the IRE* we received early information on many developments in the art.

As I recall, Joseph D. R. Freed, who became a millionaire shortly after graduation in the radio broadcasting boom of the early '20s, was president of the Club, and all members of our later radio engineering class held some office. I was chairman of the technical committee and chief operator. Scorning an amateur operator's license, in 1916 I passed the examination at the Brooklyn Navy Yard for a first class, first grade commercial license, entitling me to operate any U.S. station on land or sea, provided I could get somebody to hire me. At the same time, Dr. Goldsmith sponsored me as a junior (student) member of IRE.

Finally I arrived, with four classmates, at the radio engineering course, the culmination of our college studies. I spent more time on it than on all the other courses in my senior year. If the value of that course could be expressed monetarily, it would come to tens of thousands of dollars—even in 1917 dollars.

I did well, but already showed a fatal propensity for journalism. In a report on "Detectors: Operating and Electrical Characteristics," I interjected, "One of Austin's early combinations was tellurium-silicon, and it is rediscovered every year, if not every month, by amateur investigators, the rediscovery being made public in some magazine on each occasion." In the margin, in red ink, Dr. Goldsmith's comment stood out: "A sad truth *of no scientific interest.*"

Goldsmith at RCA

From C.C.N.Y. I went on to war work in the test shop of the Aldene, N.J., factory of the Marconi Company, then returned to the college for four years as one of Dr. Goldsmith's research assistants. Subsequently I put in a few years at the outlying intercontinental radio telegraph stations of the Radio Corporation of America, then pioneered as engineer-in-charge of the few stations in the pre-NBC RCA radio broadcasting network. After a tour of duty at NBC, I was commandeered by Dr. Goldsmith as chief engineer of RCA Photophone, from which I escaped to Hollywood to take charge of RKO's sound recording from 1929 to 1937. At age 40, I turned to writing.

Parallel with these moves, Dr. Goldsmith rose to vice president and general engineer of RCA, and during the convulsions of the '30s established himself as an independent consulting engineer, with RCA as his principal client.

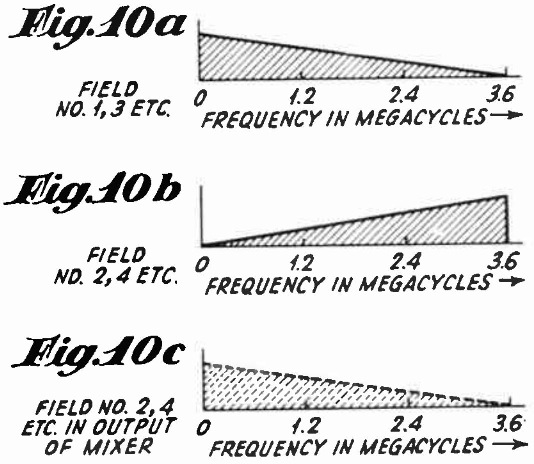
Had Dr. Goldsmith's abundant talents been concentrated in a more popular field, say in literature, he would have been better known to the general public, which cannot cope with the complexities of engineering in its various branches and has little interest in

Pioneering patents

In over 50 years of pioneering engineering work in almost every field in electronics, from communications to medical electronics, Dr. Goldsmith had had 130 patents issued to him, of which 122 were in the U.S. His major inventions show his broad involvement in communications, including television, radio, and facsimile broadcasting and receiving systems.

His most significant contribution to color television was the "shadow-mask" cathode-ray tube, patented in 1953. The concept is the basis for the design of today's color CRTs. The mask, which is a perforated plate located in front of the fluorescent target, bars the electron beam that is supposed to hit a luminescent area of a specific color, from exciting the adjacent area of a different color. A major advantage of the shadow-mask tube is the elimination of the mechanical system of color filters, required in tubes of earlier types.

Some 12 years prior to that invention, Dr. Goldsmith had helped to solve the 'flicker' problem that plagued television in its infancy, by inventing the "composite-delineation" television system. In this sytem, the video bandwidth is split; one part of it is transmitted along with an "odd" picture field, while the other is transmitted with an "even" one. This avoids repetition of similar visual information at a rate which could be detected by the eye as "flicker."



A composite delineation scheme for television transmission and reception, invented by Dr. Goldsmith.

While television was suffering from flicker, radio reception was plagued by "fading." To overcome this problem, Dr. Goldsmith invented, in the late 1920s, the "diversity-reception" system based on simultaneous reception by two receivers, with their antennas at different locations. With mutual automatic sensitivity control and outputs combined to the same audio stage, the two-receiver system worked in such a way as always to encourage the stronger of the two signals, while reducing the undesirable noise from the other signal.

The three-color target in Dr. Goldsmith's CRT.

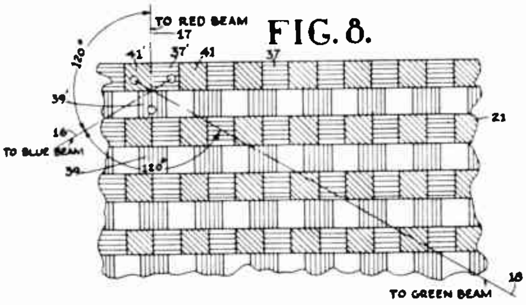


FIG. 8.

In the "hot" facsimile broadcasting days of the late 1930s Dr. Goldsmith applied for a microfacsimile system patent, which was actually granted him in 1942. The main advantage of Dr. Goldsmith's system was that the messages were recorded on film. They could thus be stored for long periods, and retrieved at will. This was not possible with machines that used other recording techniques where the copy quality decayed very rapidly with time.

Apart from the foregoing, many more of Dr. Goldsmith's inventions affect us today. Here are some of them: Combined radio and phonograph (1930); ultrashort wave repeating system (1933); methods for transmitting picture and sound within one channel (1935); synthetic reverberation systems (1938); ultrasonic remote-control system (1944); a method for slow-motion television pickup (1945); a radio-polling system (1949); color facsimile transmission and reception (1952).

the modes of thought and action that underlie them all. Goldsmith could have enjoyed the contemporary renown of a Bernard DeVoto or the elder Van Dorens; if anything, that is an understatement.

Instead, as an administrator he was overshadowed by David Sarnoff; as an inventor, by Edwin Howard Armstrong. Other comparisons could be cited, but I knew these three and they knew one another. Sarnoff and Armstrong had genius; there is not now, and never was, any question of it. Goldsmith was not a genius, although he came pretty close in some of his insights and predictions.

Sarnoff always dominated Goldsmith, not only because he had an unparalleled command presence, but because—a paradox—his education was so strikingly inferior to Goldsmith's. Hearing Sarnoff talk, you would never guess what his background had been. The headmaster of Phillips Andover, when Sarnoff and James B. Conant were his guests for lunch, said later it was impossible to judge, by their conversation, which one was the president of Harvard University, and which had been the impoverished immigrant boy who spoke only Yiddish on his arrival in the United States and whose formal education ended with the eighth grade of elementary school. But that lack of formal education (if we except his cram engineering course at Pratt Institute) was to Sarnoff's advantage, for while others were studying diverse subjects, he was studying Marconi, later RCA, from within, and events proved that was all he needed.

Armstrong had only four years of college education, including the technical courses leading to the E.E. degree. He was not a good student of electrical engineering; he was already busy with his feedback circuit and some of the Columbia professors found him a nuisance. But again, he had genius, and he bequeathed us frequency modulation. Goldsmith's inventions were largely prophecies rather than concrete devices that could be put to immediate practical use.

Yet in breadth of knowledge and general culture, neither Sarnoff nor Armstrong could hold a candle to Goldsmith. He was one of the most articulate and brilliant people I have known, certainly the foremost in that respect among engineers. I heard him once in

Random reflections: excerpts from a recent conversation

On March 27 of this year, E. K. Van Tassel (L, F) tape recorded a discussion with Dr. Goldsmith at his home, during which Dr. Goldsmith recalled his involvement with early radio and television. Selected portions from the tape follow:

Van Tassel: Can you tell us how the IRE was founded?

Goldsmith: There were in existence . . . in 1910 to 1912 or thereabouts, two major societies in the radio field. One was the Society of Wireless Telegraph Engineers . . . The other was the Wireless Institute . . . These two societies each had a couple hundred members and were competitive in a sense, and not in the least cooperative. This was a deplorable state of affairs because in a small and growing field we really needed an adequate concentration of effort . . . Consequently, a number of us, notably Robert Marriott [president of the Wireless Institute] felt there should be a single society brought about through the combination of the two. This was a much more difficult thing to do than might be regarded as possible because each of the societies wanted to be the king pin and consequently each of them was vying for a presidency and the title of the new society if there was one . . . The problem was solved by your humble servant in a very simple way. The Society of Wireless Telegraph Engineers, gave [part] of the new name . . . and The Wireless Institute in New York gave the rest, and the two . . . combined to form the Institute of Radio Engineers . . .

Van Tassel: Can you tell us about some of the first meetings that you had with Mr. Hogan and Mr. Marriott at Columbia? The three of you met together . . .

Goldsmith: We met there and fought it out, so to speak, and then thereafter we met a number of times down in Fulton Street at the White Restaurant . . . and hammered out details there. Hogan, Marriott, and myself. [Goldsmith was only 23 years old at the time!]

Van Tassel: Well, way back in those earlier days, you had some experience with the DeForest audion . . . . I believe this early vacuum tube was manufactured by a man named . . .

Goldsmith: McCandless, who was a manufacturer of the vacuum tube down on the lower east side of New York City . . . He was able to produce a product which was far from uniform. The vacuum in it was sometimes very high vacuum, sometimes very low vacuum, and the result was that conductivity was readily enough initiated in these vacuum tubes and the residual gas in them became conductive and the tubes which were hitherto high vacuum and invisible or reasonably high vacuum would glow with a bright blue . . . And it was everybody's wish to own one of them because they were, of course, far more sensitive and usually more dependable than the . . . cat whisker.

Van Tassel: May we also ask you about 1915 and 1916, when you conducted some experiments in radio transmission? You had a nice, big 5-kilowatt radio set!

Goldsmith: I was at the time a consulting engineer at the General Electric Company and I worked with E. F. W. Alexanderson, who was the chief engineer in the radio field for General Electric up in Schenectady, and I also worked with W. C. White, who was the vacuum tube man, and at times with Langmuir, who was of course a very eminent scientist and who made available the first of the high vacuum tubes.

Van Tassel: You, I believe, were a student of Pupin's.

Goldsmith: I studied under Pupin, who was a very temperamental and very capable person, and a very difficult person. He had odd ways of emphasizing things. He would, for example, get his class in a large classroom and lecture to them and when he got about two thirds of the way he would say, "No, I do not like this." Pupin had an accent and he would rub the whole business out and start all over again. He was very difficult that way. He spoke so rapidly and made so many changes in his lecture material and the field was so dubious that it became necessary for us to team up. And I teamed up with an elderly gentleman who was very bright, and each of us took notes and then combined [them] . . . I didn't know anything about my partner [but] one day I happened to mention that he and I were working together to a third man, and he burst out laughing and said, "Do you know who he is?" I said, "No, I have no idea who he is, but I know he seems to get the material very rapidly and we work together nicely." And he said, "Well, he happens to be C. L. Mailloux, president of the American Institute of Electrical Engineers."

Van Tassel: Let's go back again to the 1915 radio transmission test that you had that was conducted out to North Dakota.

Goldsmith: I was very desirous of carrying on real experiments over considerable distances. The first thing I tried out was to reach the Germans. They had a transmitter and receiver at Nauen, near Berlin, and they sent—this was a high-power transmitter with multiple amplification and repetition, they ran the thing—and we received it here . . . I received it at Sayville, Long Island . . . and that circuit was so feeble, from Germany to Sayville, that the wire, the cable that came from the receiver to the receiving set that the operator used, was kept away from anything that it could rub against because if it rubbed against something the signal was drowned out. I put this 5-kw transmitter into my laboratory, which was then at the College of the City of New York. I was a professor of electrical engineering. And I started transmitting in the late fall of 1914 and transmitted up the Hudson Valley to Schenectady. The signal was gorgeous. You would have thought it was a telephone line between my laboratory and the laboratory in Schenectady. But by February of the next year, static had come up tremendously and you couldn't hear a thing—so it was useless. . . . Now, I also wanted to reach Nauen, and hear them, so I got at the top of a high cliff near the College of the City of New York near my laboratory and tuned in to Nauen and I had this circuit running, Nauen–Sayville, very nicely.

Van Tassel: This was a telegraph circuit?

Goldsmith: That was a telegraph circuit, no telephony.

Van Tassel: You developed and pointed up the first way of having color [television] tubes. Can you tell us some of those stories?

Goldsmith: I became very much interested in the next few years in radiotelephony. I ran into real difficulties because, well, there wasn't enough power available. You needed much more power than you do for telegraphy, and so I hit on the idea that one had to have some way of picking up signals and getting them in color rather than in black and white. The method that I used was an adaptation, I believe, of something far earlier—namely, telephony over wires, and I got my signals from Schenectady coming down and tuned them in and I decided on the use of—I invented at that time—the basic thing of color telephony, color radiotelephony.

Van Tassel: The color was coded? And you used the three primary colors?

Goldsmith: Red, green, and blue . . . . An electron beam came from three guns and they started from the far end of the tube, went through the tube, through the [focusing] hole . . . and then out, and then they hit the spot, the desired spot. Of course, everything had to be very accurate.

Van Tassel: I do believe you also, in connection with television, are responsible for or invented, what was called remote control.

Goldsmith: That is right. I wanted to use a receiving set in the home and transfer the signals to a large speaker, amplified to a large speaker, across a room. Now . . . how to transfer it across a room? Well, one way of course, would just be under the carpet!

Van Tassel: With wires.

Goldsmith: Which was, of course, very obnoxious to the ladies of the house. Another way of doing it was to use a modulated tone—what tone?—well, if I used a low, a very low pitched tone, it would be heard. If I used a very high pitched tone, it would be absorbed in the walls and actuate neighboring receivers. So I hit on a tone, on tones in the tens of kilocycles, and modulated that and used that for the transmission of the tone from the receiving set to the controls of the receiver.

a radio symposium with a number of prominent educators. The only one I can remember was Jacques Barzun, one of the deans at Columbia University and a noted writer. The others were of that caliber, but Goldsmith eclipsed them all.

It was a typical exhibition. He was that way in the classroom too, and among engineers, which was not always to his advantage. During the Photophone debacle of the late '20s, when he took a hand in the perennial intercompany feuds, he could usually manage to impose agreement among the ostensibly allied General Electric and Westinghouse manufacturing engineers by his skill in logic and persuasion. But hostilities broke out anew as soon as he left town.

Goldsmith's greatest achievements, I would suggest, were his contributions to the growth of the engineering societies, which now honor his memory; the technical guidance he gave RCA in its most turbulent years; and his brief formal teaching career. I suppose he survived all of his academic contemporaries; I know many of his students predeceased him. All the more, then, his lifetime appointment as an associate professor of electrical engineering at City College symbolizes the regard in which he was held. Now all three founders of IRE are gone, and while Goldsmith's passing is an occasion for sadness on the part of those who knew him personally, young and old alike can rejoice in a life so completely and constructively lived.

Carl Dreher (LF) has been a member of the editorial staff of *The Nation* for the past 15 years and is now working on a biography of David Sarnoff. Born in Vienna, Austria, in 1896, he was brought to the United States in infancy. He has had three careers: the first as a wireless telegraph engineer; the next in radio broadcasting and motion pictures; and finally, his present career: journalism. He served on a number of IRE technical committees but regards his "outstanding" contribution as operating the stereopticon at early Institute meetings. He was elected a Fellow of IRE in 1928.

His colleagues reminisce

Harry G. Grover's signature appears on most of Dr. Goldsmith's patents, for he was RCA's general patent attorney during Goldsmith's most inventive years. Grover was a personal friend and associate, as well, and recalls many occasions during which he enjoyed Dr. Goldsmith's special humor, good stories, and knowledgeability. Of the latter, Grover says: "Dr. Goldsmith's general knowledge surpassed that of any individual I have ever had the privilege of knowing. It was broad, detailed, and accurate, and General Sarnoff relied a great deal on his judgment concerning the commercial prospects for various new business ideas. I remember that when General Sarnoff wanted a report on some particular subject quickly, he would go to Dr. Goldsmith and be able to count on getting a *pretty* darn good review." (The two men became personal friends back in 1919 when General Sarnoff was a sales manager at RCA and they remained close thereafter.)

Grover recalls lengthy discussions with Goldsmith about the tri-color dot, masked screen, color TV tube. "When the original disclosure was submitted to me some 25 years ago it was generally looked upon as a sort of Rube Goldberg idea. Nevertheless it was optioned and filed by us at a modest price. Several years later, General Sarnoff issued instructions to go ahead with color TV, and although perhaps five other applications were then pending, RCA went ahead with Dr. Goldsmith's invention." Even so, Grover feels Goldsmith never really received the credit he deserved for the invention.

George Brown first met Dr. Goldsmith in 1933, when Brown came to work at the RCA research department in Camden, N.J. "Dr. Goldsmith was a consultant and had come down to review the projects going on in the lab. I was so new I didn't have the slightest idea who he was when I sat down to chat with him about my project, which eventually turned out to be the turnstile antenna for TV. He wrote up a report—for General Sarnoff, I guess—about what we were all doing. I remember that after we read the report, we decided he wrote reports better than we did. He was really very remarkable in that way, for he could summarize and interpret what you were doing after just a very brief chat."

Regarding Goldsmith's inventions, Brown says, "It is important to recognize that they were at a broad, conceptual level. Some inventors work on the nitty-gritty details, but he wasn't that way. He was on a completely different plane, and his inventions would require a great deal of development to get them working. To me that's what made his ideas so interesting. The shadow-mask tube is an example. Some people say he didn't invent it. Well, if you mean the tube that was eventually built, then he didn't invent it—his patent wasn't remotely workable. But it did show the basic idea of the *mask*, with the three separate beams going through it to hit the phosphor dots. I don't think he had the faintest idea how to line up the phosphors, but he still had the basic idea and that's the important thing. It was really a great credit to him."

Harry Olson met Goldsmith when, in 1928, he joined Goldsmith's RCA research laboratory in New York City. "Everyday the engineers (about twenty) would eat lunch together at a large table with Dr. Goldsmith at the head. It was simply inspiring to hear him talk and exhort the men to produce new things. Sometimes he would talk about a specific project, while other times he would expound on general developments in the field, or what he had seen on his latest trip, or what he considered important to watch for in the future. He had a tremendous depth of knowledge in just about every field; he was an expert in every facet of the electronics art, and you could always count on him for an idea or an appropriate suggestion on topics ranging from the most abstract mathematics to the simplest mechanical system. These discussions served to inspire the fellows to carry on to the utmost, imbuing them with an *esprit de corps* that would make a football coach envious."

The first job that Julius Weinberger did with Alfred Goldsmith was in 1917, when Weinberger joined him in the radio laboratory of the City College of New York to develop a radiotelephone transmitter for communication with Schenectady from New York.

"When broadcasting broke loose in 1921, Sarnoff decided to induce General Electric and Westinghouse [then the "parent" companies to RCA] to develop simple receivers that could be used in the home. The only technical department that RCA had that amounted to anything was Dr. Goldsmith's small laboratory in City College. So we got the first receivers from these companies to examine and test and we were the representatives really—the technical representatives of RCA with regard to the two manufacturers. And I remember very distinctly some of the hassles that we had with these manufacturing companies over details involving design defects in the models that they submitted; and this had to be fought out, and we fought it out with them. So a good part of Goldsmith's job was the diplomatic and political handling of the technical relationships between RCA and the manufacturing companies, which sometimes was very rough going."

Weinberger recalls Goldsmith's "absolutely unique" relationships with his staff. "He made a practice of knowing every man individually. He would go around the laboratory every day and talk to each individual man and say, 'What are you doing? How are you getting along?' He would discuss his work with him at the bench and make suggestions if he could think of any. It was a thing I'd never encountered. That is, it was *not* the common situation where the head of a department would call his section heads in once a month for a meeting and have them give reports. He got the reports by word of mouth every day so to speak, and he participated in the work. He cared about his men personally and he passed that spirit on to his subheads—I mean so that all of us felt the same."

Interviews and research for this article were conducted by *Spectrum* editors Gadi Kaplan, Ellis Rubinstein, Michael Wolff, and Alexander A. McKenzie.

Automatic testing: quality raiser, dollar saver

Advanced solid-state technology means complex components and systems; sophisticated testing is a must to keep equipment 'up'

Two months ago, a U.S. Navy spokesman, citing Department of Defense cost estimates for the past year, provided a stark case for increased reliability and easier maintainability of electronics systems. Out of a more than $81 billion budget ($50 billion of which went to salaries), $15.3 billion were spent on electronics with, remarkably, more than a third ($5.4 billion) of this cost eaten up in system maintenance and support. In prognosticating future trends, the Navy spokesman declared that there is every indication that maintenance and support costs will be "going up."

Such awesome statistics as these are the direct result of ever-increasing systems complexity. Not unreasonably, most users have come to expect good reliability from semiconductor electronics. The problem has been that solid-state systems are now being asked to perform more things better, faster, and cheaper than ever before. With such exponentially increased performance parameters, even low-probability failure rates add considerably to total system down time.

Consequently, *automatic testing*—the technique of analyzing and isolating component, device, subsystem, and system faults quickly and with minimal human intervention—has emerged as one of the primary deterrents to ballooning budgets.

Unsupportable support costs

Not long ago, former Chief of Naval Operations Adm. Elmo R. Zumwalt issued a pointed memo: "Stop producing systems we can't support." What was disturbing Zumwalt was that, in the words of the Navy spokesman previously quoted, "electronic system and subsystem reliability is at a standstill."

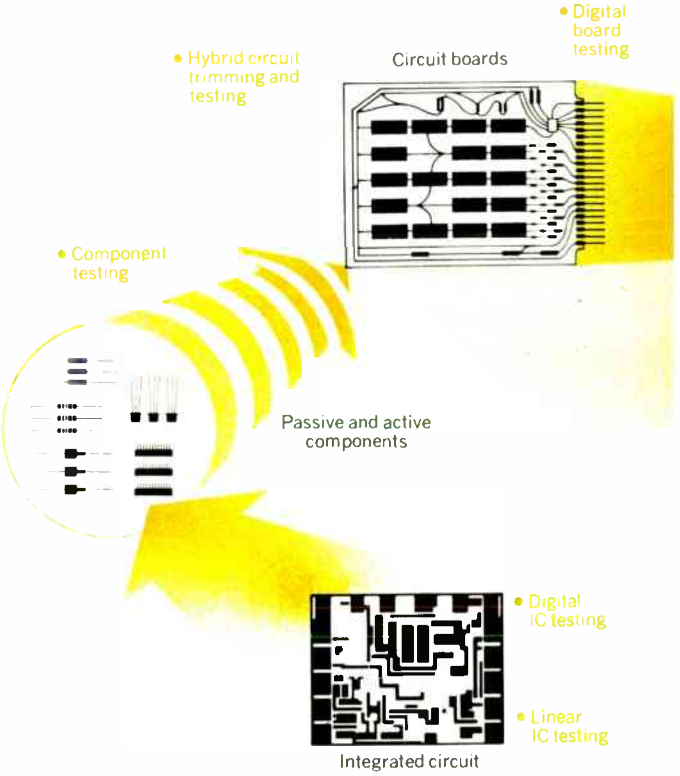
And the Navy is by no means alone when it comes to escalating support costs. According to Jerry D. Schmidt, Deputy Chief, Electronic Warfare and Equipment Division, Air Force Logistics Command: "If we consider the hidden costs incurred (such as mission aborts, prepping another aircraft to accomplish an aborted mission, etc.), we're really putting more money into support than acquisition!" In accountable numbers, it costs $2 billion to maintain all Air Force avionics, with $2.5 billion going into actual procurement. As an example, the savings anticipated on major programs to modernize the logistics of just *six* avionics items under the Air Force's new program for increased reliability of operational systems (IROS) should come to a whopping $500 million to $1 billion over the next 15 years.

But why are maintenance and support systems so costly? It has been estimated that 80 percent of all maintenance consists of labor costs, with only 20 percent going for parts. As far back as 1968, aircraft studies indicated that 87 percent of the time needed to return a piece of equipment to service was taken up by fault diagnosis and isolation. Of this, 25 percent of the time was required to locate the defective area, and 62 percent to isolate the defect. Only 13 percent of the time was spent in repair and checkout.[1]

The problem, therefore, is one of finding the best practical means of dealing with the maintenance and support problem, and specifically the diagnosis and isolation of faults. In the Navy's estimation, one way of reducing the cost disproportion would be to simplify design, introduce modular concepts, minimize software complexity,* increase on-line testing, and inte-

---

* As long ago as 1964, Vic Mayper published an account of the "Problems and pitfalls in automatic testing" and found that most of his colleagues agreed that the cost of software was a major factor to contend with in implementing an automatic test system.



Marce Eleccion Associate Editor

The Easy, Low Cost Way to Display Difficult Signals

Slowly scanned, gray scale images, low repetition rate signals, and single-shot waveforms. All of these hard-to-view signals are easily displayed on the new TEKTRONIX 605 Variable Persistence Display Monitor—at normal intensity and without flicker. At the same time the 605 combines faster writing speed and wider bandwidth with low cost ($1675) to provide more value for your display dollar.

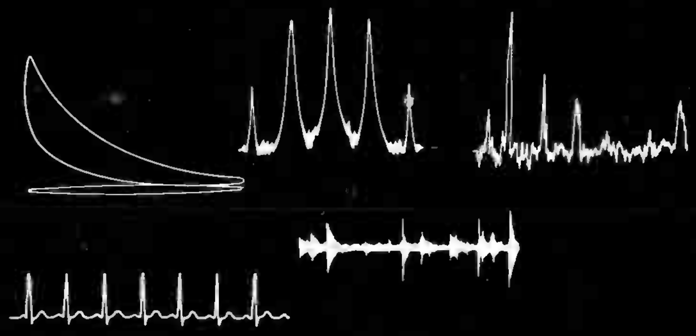
Simply turning a dial varies the length of time a display is held on the 605 from a fraction of a second to more than 5 minutes. In the save mode viewing time is even longer.

Faster spot response time results from the 3 MHz bandwidth of the X and Y channels (3 times the bandwidth of comparable crt displays). With the fast (1 div/μs) writing speed of the 605, even single-shot events are displayed as bright, easily viewed waveforms. The 605 has front panel controls and TTL compatible remote control inputs, a combination unique at such a low price. Real time monitoring applications are easy with the optional low cost time base $(125), another feature not offered on other variable persistence displays.

Applications for the 605 are many and varied. Bright, gray scale raster scan plots are obtained for ultrasound, thermographic, and nuclear scanning and for viewing scanning electron microscope images. Resolution is improved in spectrum analysis. Valuable trajectory information is provided for radar and sonar displays. With the time base option slow biophysical signals are easily monitored. In mechanical measurements flicker-free engine pressure/volume curves are readily plotted with no smear due to cycle-to-cycle variations. Uncluttered, single-shot vibration waveforms are easily displayed using the 1 div/μs writing speed.

For further information on how the 605 Variable Persistence Storage Monitor provides extra value in your display application contact your local Tektronix Field Engineer or write Tektronix, Inc., P. O. Box 500, Beaverton, Oregon 97005. In Europe write Tektronix, Ltd., P. O. Box 36, Guernsey, Channel Islands, U. K.

TEKTRONIX®
committed to technical excellence



Gray scale capability and variable persistence storage of the 605 are used with a scanning electron microscope to study metal samples in a dental research laboratory.

On Reader Service Card, Circle No. 21 for Information, No. 22 for Demonstration

grate systems with automatic test equipment (ATE), thus achieving higher overall system reliability.

Although the military and semiconductor industry were among the first to employ wide-scale automatic test systems (ATS), the technology is beginning to be used in practically every field, including industrial control, manufacturing, communications, computer networks, medical electronics, agriculture, vehicle maintenance, transportation, security systems, building maintenance, and the testing of every conceivable form of electronic circuitry. Moreover, in spite of the high initial cost of installing some automatic test systems (especially those that are computer-based), the cost-benefit trade-offs (called mission effectiveness by the military) are definitely beginning to tip in favor of ATS—if only because in many instances there is simply no other economical way to go.

Perhaps the most profound impact of automatic testing is on the everyday engineer, who is finding that the economic viability of the very system he is designing may depend upon whether that system can be quickly tested, repaired, and returned to service. The military—long accustomed to paying many times the initial purchase price of a piece of equipment on repeated repairs—has already shown its great reluctance to meet continuing heavy repair costs. Instrument manufacturers, too, have found that only their smallest buyers will return equipment for repair, making it almost mandatory to incorporate modular and other easy-test features in their product lines for better user facility.

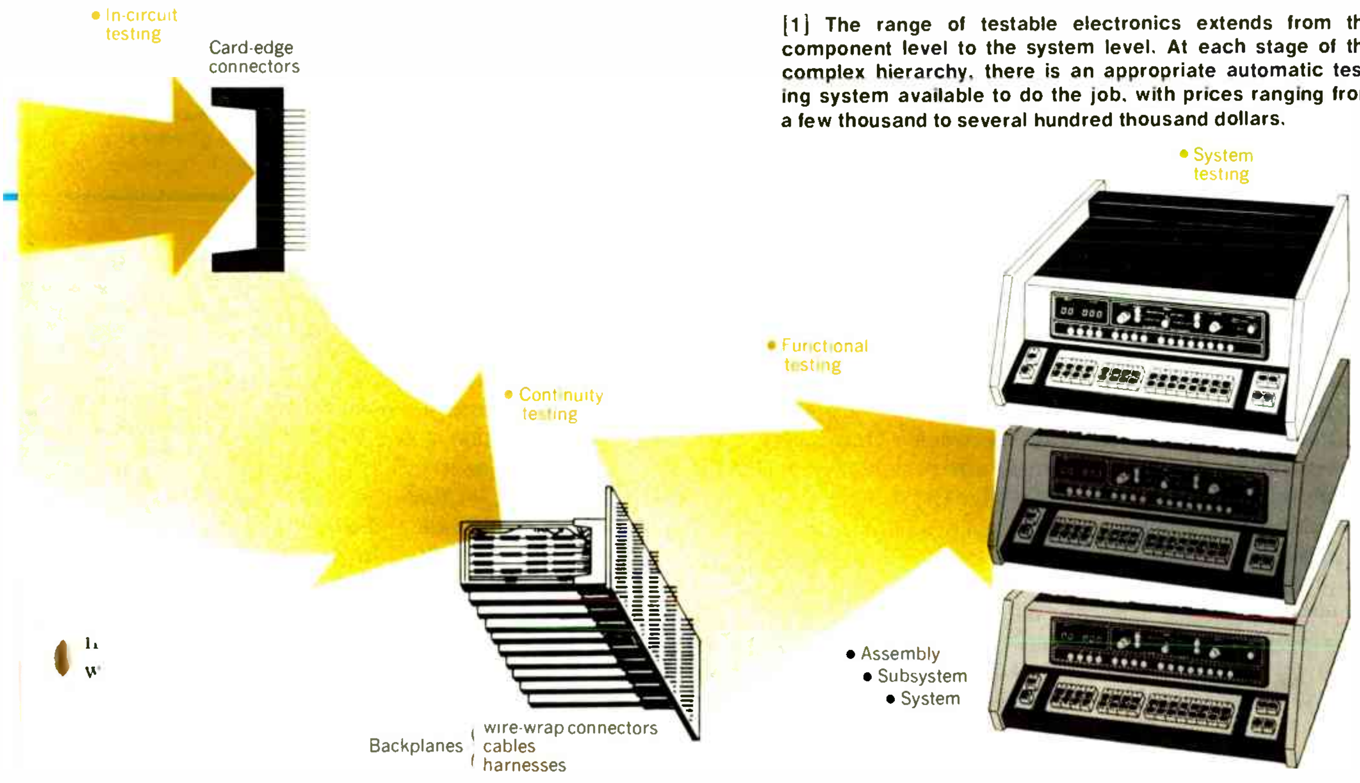
What is important is that automatic testing—whether to determine the continuity of a wire harness or the go/no-go status of an Apollo spacecraft—is now being considered at the development stage of a system. (In its effort to make systems compatible with automatic checkout equipment, the U.S. Navy has been dictating design for testability in procurement specifications since 1967.) This new philosophy has already caused design engineers at such firms as Honeywell Corporation and others to restructure their thinking in terms of future systems, and chances are that many more will follow.

What is automatic testing?

Although original attempts to automate testing procedures following World War II were usually patterned after man's efforts to accomplish the task manually (e.g., sequential testing of cable continuity), it became evident that the early electromechanical testers of the 1950s would have to give way to speedier and more flexible methods. Thus, the motorized cam, stepping switch, and relay soon gave way to punched tape, optical reader, and solid-state switch as a test program sequencer, followed shortly by computer-controlled systems utilizing magnetic tape (1958), drum (1961), and disk (1964) for even greater programming sophistication (see Table, page 42).

The prime contributing factor in escalating the acceptance of automatic testing, however, has been the *digital computer*, particularly the minicomputer (and most likely the microcomputer in the future), which is used not only to program and control, but to process, analyze, and manage data as well.[2,3] It should be remembered that the computer is not always necessary to do a testing job, especially one that can be taken care of by such methods as bench-top testers, programmer-comparators, or pattern generators.

The *programmer-comparator*—essentially a tester that compares a device under test with either a reference device or a fault simulation—is relatively simple and inexpensive, rugged, easily programmed, and



[1] **The range of testable electronics extends from the component level to the system level. At each stage of the complex hierarchy, there is an appropriate automatic testing system available to do the job, with prices ranging from a few thousand to several hundred thousand dollars.**

I. The growth of automatic testing for military systems is listed here both chronologically and by program sequencers (boldface)[1]

Name	Manufacturer	Comparator	Service and Application	Year Delivered	Special Features
Motorized cam					
AN/DSM-2	Hycon	Analog	Navy (Terrier)	1952	Used on guidance systems.
DATS	RCA	Analog	AF (airborne fire) control)	1958	Uses a dynamic closed loop test, simulates attack courses, and provides as a direct readout a quantitative measure of operational capability.
Stepping switch					
AN/DPM-7	Raytheon	Analog	Navy (Sparrow)	1958	Quantitative dynamic tests on guidance and control by simulation, go/no-go, output recorded.
MK 409 Mod 0	USN/AF	———	Navy (Sidewinder)	1964	Electromechanical, go/no-go via panel lamp indicators.
Punched tape					
SCAT	Sperry Canada	Analog	Navy (Polaris)	1960	Pneumatic-controlled tape reader using block reading technique.
EPEC	Emerson	Digital	Prototype	1963	Used integrated circuitry.
GPATS (AN/GSM-204(V))	Emerson	Digital	AF	1967	Building block concept, includes manual tape simulator for developing new routines (later version available with computer-control for arithmetic and diagnostic testing).
Magnetic tape					
RADFAC	Republic Aviation	Analog	AF (F-105)	1958	Mobile unit, 90-second test time, comparison via cockpit instruments against voice instructions, self-test.
DEE	RCA	Digital	Army Electronics Command (depot)	1961	First U.S. Army ATE to perform computer-controlled communications electronics testing to 100 MHz.
VAST (AN/USM-247)	PRD	Digital	Navy (avionics electronics)	1972	Building block construction, multiple independent test stations time-shared by a central computer, self-check capability and microintegrated circuitry.
Punched card					
13A0140	Bendix Support	Analog	Airlines	1959	Rotary stepping switches for switching functions, lights and meters for readout.
MAPCHE	RCA	Analog/digital	AF (Atlas)	1960	Mobile version of APCHE, includes analog functions and pneumatic pressure tests.
Magnetic drum					
ACRE	Lockheed	Digital	Navy (Polaris)	1961	Computerized, 1800 r/min drum with 15 360 word capacity, flexowriter printer.
MTE	RCA	Digital	Army (missile systems)	1964	Mobile shelters, pneumatic/hydraulic/electronic test capabilities.
Pinboard (patchboard)					
DY-2010	Dymec	None	General	1963	Programming via diode pins on pinboard, outputs on tape.
Magnetic disk					
DDP-224	Computer Control	Digital	NASA (Saturn V)	1964	General-purpose computer used for Saturn V launch display, fast response.
GE-225	General Electric	Digital	NASA	1964	General-purpose computer used for data acquisition, fast response.
Multiprogramming (combinations of punched tape, punched card, magnetic tape, patchboard, keyboard, etc.)					
ACE-SC	General Electric	Analog/digital	NASA (Apollo)	1964	Multiple-computer installation, real-time go/no-go, continuous sampling, manual/semiautomatic/automatic modes, high speed, self-test.
DIMATE	RCA	Digital	Army (depot-vehicular)	1965	Computer-controlled, high speed, go/no-go, building block concept, self-test.
AN/GYK-11 (CENPAC)	Burroughs	Digital	Air Force (general purpose)	1967	Controls up to 10 satellite ATE stations, modular construction.

Starting with the first ESS office in 1945, AT&T now has 500 offices in operation throughout its 123 operating companies, with 20 percent (22 million lines) of the system expected to be converted to ESS by 1980. With the down time for each ESS office anticipated to be an unbelievable *two hours in 40 years*, Bell has counted heavily on such automatic testing methods as using central control offices to initiate failure analysis automatically. That the Bell System will achieve its goal has already been seen in several ways: (1) Autovon—the military voice switching system now in operation—is *more* dependable than two hours down time per 40 years, (2) down-time/40-years was 11 hours in 1972 (315 offices on line), and (3) of the total causes for system failure during 1971–1972, human error accounted for 30 percent and 17 percent was attributed to unresolved causes (with greater automation and automatic testing, these figures are expected to be reduced drastically).

Other examples can also be cited. At Honeywell, automatic testing is being used to develop new products in-house, as well as marketed in the form of remote terminals to monitor security, fire alarm, and home conditioning systems. At Westinghouse, systems have been initiated in transportation, remote terminal, and contactless testing. Atlantic Research's interests have led them to data communications testing, with one product just released providing "handshake" controls between data terminals and host computers for both authentication and interrogation, and another product in the form of a voice/data/noise discriminator to analyze 3-kHz voice lines.

At Zehntel, calculator tester development has led to a system that is being used by Bowmar; and Grumman has announced a novel approach for automatic test generation and simulation for digital system diagnosis. Boonton Electronics may have solved the problem of matching varactor diodes for electronic TV tuners with a test-set that doesn't wait for the closest match to come along, but categorizes them in advance. And Adar Associates seems to be concentrating on semiconductor memory and microprocessor testing.

RCA, already famous for system monitoring (e.g., Disneyworld, Wells Fargo), has made advances in nonelectronic testing and is the leader in automatic vehicle maintenance. At General Radio, practically every aspect of automatic testing including automatic network analysis is being worked on; Emerson Electric seems to have something cooking in waveform analyzers; and Fluidyne Instrumentation may have a handle on the future with calculator-based ATE and control (in Canada, they're already testing engines).

Martin Marietta Aerospace should have its hands full with the automatic RF checkout of NASA's 1975 Viking exploration spacecraft of Mars. At Hughes, reputed to be one of the foremost in software simulation, they seem to have the only race-sensitive system (to predict loss of control of memory elements) for commercial application (although the Bell System and Westinghouse also have such simulators in-house). The Hughes 1024 system permits fault-diagnostic troubleshooting of complex logic modules with up to 1024 input/output pins.

In 1967, Teradyne introduced their J259, which used DEC's PDP-8 computer and was modularly expandable. Teradyne's rate of growth has been impressive, and today they feature a broad line of ATE (Box, pp. 40–41). Bendix Navigation and Control, whose activity extends from flight instrumentation to weapons release systems, is a major supplier of military avionics automatic test equipment—both computer-controlled and programmer-comparator varieties.

Digital General's contribution to automatic testing has taken the form of minicomputer-controlled systems such as their DV IV, based on Data General's Nova 1200 and designed to test PC boards and module assemblies. Data Test Corporation has recently introduced several new computer-controlled test systems, including one (Datatester 2400) that is claimed to be the first *portable* circuit board tester, ideal for remote terminal and field maintenance.

At Fairchild Systems Technology, they report that more than 1400 automatic test systems have been installed throughout the world, with a doubling of sales volume every year since 1971. In 1969, they introduced their first computer-controlled IC tester, and in 1971 their first modularized expandable test systems—the Sentry series. And at Instrumentation Engineering, the fully automated System 390 "universal" tester handles all types of circuits—digital, analog, hybrid, pulsed, high frequency—in all three test modes—functional, parametric, dynamic—under dedicated, concurrent, or sequential operation.

Finally, Tektronix is going ahead with its parametric/functional/dynamic S-3260 automatic test capability (for bipolar, MOS, RAM, ROM, and complex logic arrays). Hewlett-Packard—with a total automatic measurement systems sales volume of over $100 million based on its broad line of standard off-the-shelf automatic network analyzers, 9500-Series test systems, etc.—added a dc–500-MHz automatic test system (9510D) to its impressive product list early this year.

All things considered, it looks like a busy future for automatic testing!

REFERENCES

1. Lustig, J., and Goodman, D. M., "Trends in the development of automatic test equipment," Project SETE report 210/106, National Aeronautics and Space Administration, June 1973.

2. McAleer, H. T., "A look at automatic testing," *IEEE Spectrum*, vol. 8, pp. 63–78, May 1971.

3. Eleccion, M., "Industrial electronics," *IEEE Spectrum*, vol. 11, pp. 44–53, Jan. 1974.

4. Martin, W. L., "Computerized approaches to analog subassembly testing," *Electronic Products*, vol. 16, pp. 53–59, Apr. 15, 1974.

5. *Automatic Test Equipment: Hardware, Software, and Management*, F. Liguori, ed. New York: IEEE Press, to be published Oct. 1974.

More to come!

This article launches a series on automatic testing that promises to examine the many facets and applications of this emerging technology. A second article will appear in September on automatic electronic circuit testing.

Editor

Reprints of this article (No. X74-081) are available at $1.50 for the first copy and $0.50 for each additional copy. Please send remittance and request, stating article number, to IEEE, 345 E. 47 St., New York, N.Y. 10017, Att: SPSU. (Reprints are available up to 12 months from date of publication.)

Riding Swiss rails: an electrifying saga

Switzerland has some of the finest all-electric locomotives and unusual rights-of-way in Europe

Like Ivory Soap, the Swiss railway network is more than 99 44/100 percent pure . . . purely electrified, that is. While remarkable, this fact is not surprising since Switzerland is a country without any fossil-fuel resources and its domestic energy wealth relies almost entirely upon hydroelectric (80 percent) generation produced by power stations along a vast network of alpine dams, and the country's major rivers. (The remaining 20 percent of the nation's power generation is today produced in nuclear power plants.)

Switzerland is also noted for its odd topography compressed into an area of only 41 400 km^2. In the north, from Basel to Zürich and Zug, the land consists of fertile agricultural plains and pasture, or gently rolling countryside, interspersed with beautiful lakes and villages. The west central and southwestern sectors from Bern to Lausanne and Geneva boast similar terrain. But the majority (60 percent) of this trilingual country (German, French, and Italian are official languages) contains craggy alpine massifs and mountain ranges whose peaks thrust skyward to almost 4500 meters (15 000 feet). Traversing this unusual landscape is the responsibility of the Swiss Federal Railways and private lines.

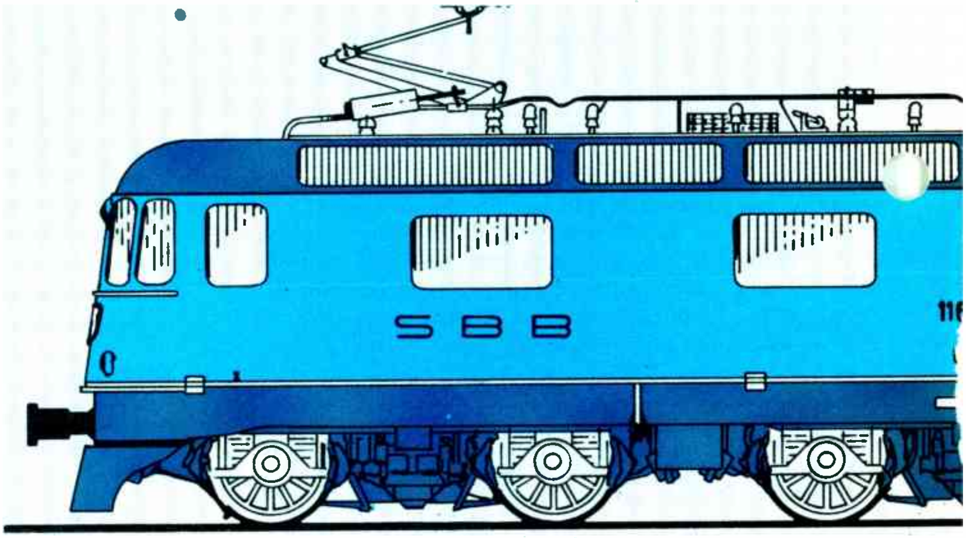
With Zürich the arbitrary focal point, main routes run northeasterly to the shores of the Lake of Konstanz (Bodensee), southerly (via the 15-km-long St. Gotthard tunnel) to Italy, westerly to Basel, and southwesterly to Bern, Lausanne, and Geneva. A second mainline to the south runs in a general easterly direction from Lausanne to Brig, at the northern end of the world's longest tunnel (the 20-km-long Simplon). A meter gage private line (Furka–Oberalp) runs east from Brig to interconnect with the southern mainline at Andermatt/Goschenen and the southeastern mainline at Chur.

Gordon D. Friedlander Senior Staff Writer

In general, the Swiss railway network is dense, well-equipped, and encompasses more than 5200 route kilometers.

SBB, BLS, and RhB

The SBB (Schweizerische Bundesbahnen)[1], or Swiss Federal Railways—see box on p. 50—represents the backbone of the nation's rail lines; the SBB owns and operates about 3000 route kilometers of right-of-way. The St. Gotthard mainline (Gotthardbahn), placed in service in 1882, crosses the main alpine range from north to south (see Fig. 1), aided by the 15-km-long St. Gotthard tunnel (whose construction was an epic story in itself). Approaching from the north, the line ascends from 472 to 1106 meters in 30 km. Beyond the tunnel's southern portal the line plunges nearly 850 meters in 45 km. To limit track grade to 2.6 percent, one spiral tunnel and two switchback loops (Fig. 2) had to be built north of the tunnel (generally referred to as the Wassen loops), plus four spirals south of the tunnel—the Dazio Grande and the Biaschina.



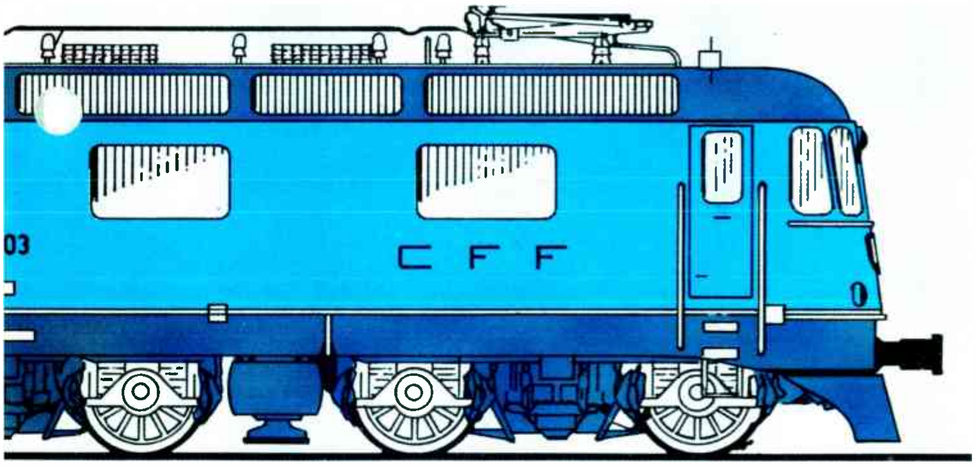
For details of SBB's Re 6/6 locomotive, see Fig. 5.

The principal private railway (see also Fig. 1) in Switzerland is the Bern–Lötschberg–Simplon (BLS)[1], which operates over its own right-of-way from Bern southward to Thun and Spiez, thence through the 15-km-long Lötschberg tunnel to Brig, where the BLS links up with the SBB. Three kilometers east of Brig (on the Lausanne–Montreux–Brig west–east line) is the north portal of the 20-km-long Simplon tunnel that crosses the southern border into Italy, where Domodossola is the terminus of the SBB system.

Following the completion of the first electrified bore of the Simplon tunnel in 1906, the SBB assumed responsibility for the traction equipment, rolling stock, and train crews from Domodossola to Brig—even though more than half this section lies in Italy. This was done so that locomotives could be changed (from Swiss to Italian) at a specially designed station and yards at Domodossola. This arrangement continues today.

The other famous transalpine bore on this line is the Lötschberg tunnel, which was opened to train service in 1913. Here, too, intricate approach problems had to be surmounted. For example, two loops (or switchbacks) were required—one open, the other in a tunnel— to reach the northern portal. But the southern ramp of the Lötschberg is unique: it parallels the River Rhône valley from an altitude of 1217 meters down to 678 meters along a route length of 26 km. The grades on this line run up to 2.7 percent.

To complete this quick overview of the principal Swiss railway systems, one must mention the meter-gage Rhaetian railway (RhB)[1] and Bernina line (part of the RhB) that operate in southeastern Switzerland from Chur to Arosa, and around a loop from Chur to Davos with 2000 volts dc on the catenary); thence to St. Moritz (with ac), Bernina, Poschiavo, and terminating at Tirano, Italy (with 1200-volts dc on the line). The RhB is almost exclusively for tourists and sportsmen, and for carrying the "jet set" to famous resorts.



Between Bergün and Preda no fewer than five loops and spirals follow each other in rapid succession as the RhB right-of-way climbs from 1376 meters to 1972 meters in only 5 km!

The Bernina line looks more like a mountain highway as it descends from Alp Grum (2091 meters) to Poschiavo (1014 meters) and near the Swiss–Italian border it forms an open spiral that is unique in European railways.

In all, the Swiss private railways are about 2200 route kilometers long—and, as we have noted, almost completely electrified.

A historical synopsis

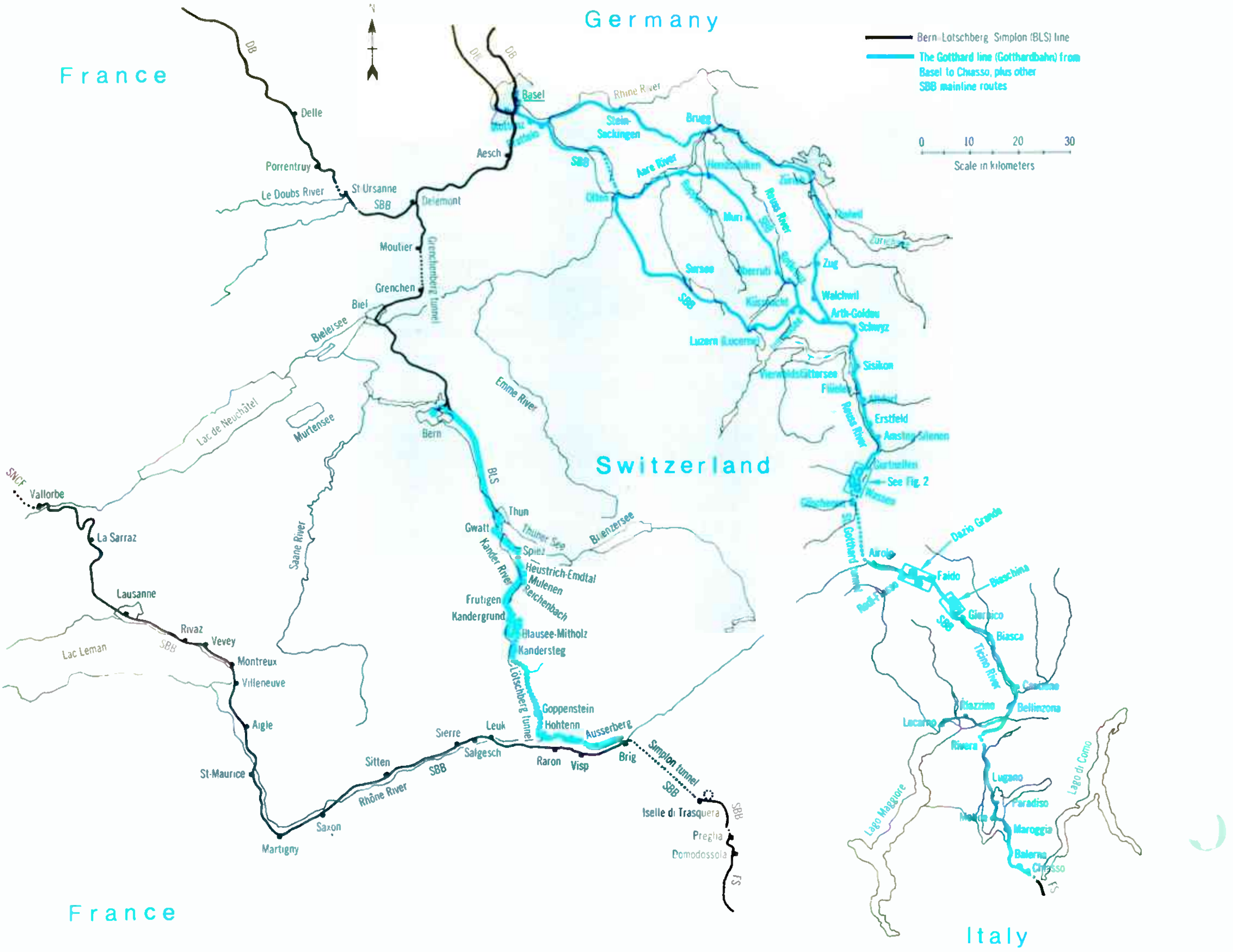
The first successful Swiss mainline electrification dates back to 1899, when Charles E. L. Brown (a founder of Brown, Boveri & Co.) designed and installed a three-phase two-wire 750-volt catenary—with the running rails carrying the third phase—between Burgdorf and Thun, a distance of about 40 km. The two quaint electric locomotives used on that run have been preserved—one at the Deutsche's Museum in Munich, and the other in Lucerne's Transport Museum.

At the same time, the Simplon tunnel was under construction and the prevailing view in 1900 was that steam locomotive traction would be employed. By 1905, however, doubts concerning the hazards of running the "iron horse" through a 20-km-long single-track bore—even if powerful ventilation blowers were installed at both ends—congealed into the conviction that steam traction was totally unfeasible.

Since the Simplon is an international tunnel link, the Swiss and Italian Governments both had a stake in its successful operation. By coincidence, in 1902, two electric locomotives for the northern Italian "Valtellina" branch line (designed for 3000-volt 16⅔-Hz three-phase service) were being built in Switzerland by the Swiss Locomotive and Machine Works, and Brown, Boveri—the latter firm supplying the electrical components. In an altruistic gesture, the Italian rail line waived delivery and turned over the completed locomotives for Simplon service—together with three additional locomotives that were on order.

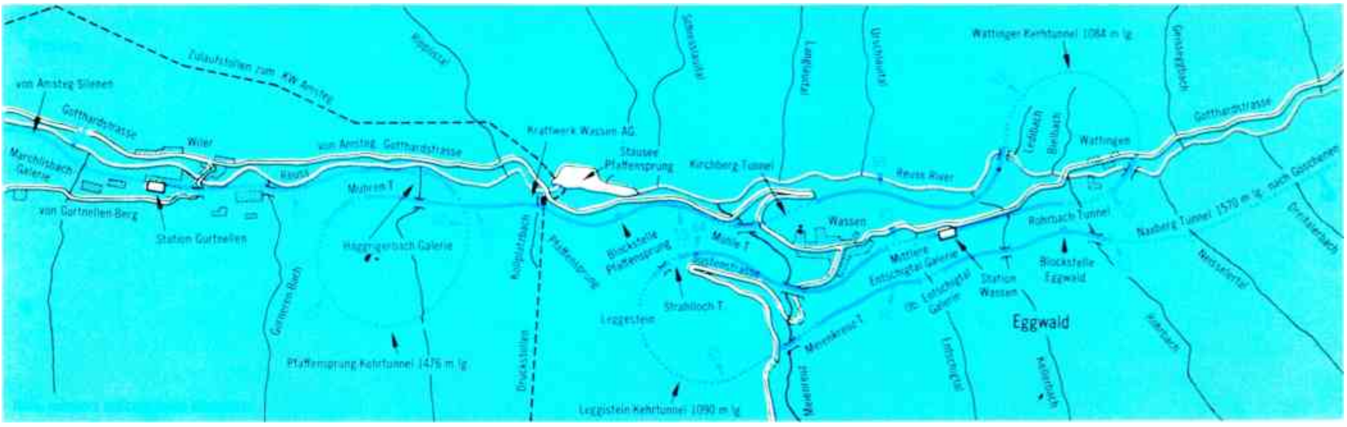
Once the traction equipment problem had been resolved, the next problem was the installation of a suitable catenary in the tunnel and the adaptation of a hydroelectric plant to furnish the necessary power at 16⅔ Hz instead of the commercial frequency of 50 Hz. On June 1, 1906, the first passenger train, hauled by an all-electric locomotive, passed through the initial bore of the Simplon tunnel.

In the early days of the Simplon service, a special train departed each morning from Brig (at the northern end of the tunnel). Since it was the tunnel section of the line in which the catenary had been installed, an electric locomotive, hauling a string of steam locomotives with fires banked to reduce the level of dangerous carbon monoxide fumes, together with passenger carriages and/or freight rolling stock, ran through



[1] Combined map of Switzerland's two principal railway systems: SBB and BLS. The famous "Gotthardbahn" is the principal north–south mainline through the heart of the country. During peak periods, more than 250 passenger and freight trains ply this route between Chiasso and Zürich (or Lucerne–Basel–Chiasso) in a 24-hour period. The line from Bern through the Lötschberg and Simplon tunnels is the BLS system. The SSB also has a west–east route, from Vallorbe to Domodossola, via the Simplon.

[2] The spiral tunnel and twin loops (switchbacks) near Wassen, on the northern ramp approach to the 15-km-long St. Gotthard tunnel. Imagine the disorientation of climbing (or descending) 170 meters while progressing only 1 km! (See the box on p.52 for a first-hand account of these impressive loops.)



the Simplon. At the southern portal, the electric was uncoupled and steam traction handled the trains between Iselle and Domodossola, Italy. Because there wasn't even room for a steam locomotive shed in the narrow Iselle valley, these engines had to be hauled back to Brig in the same manner for servicing.

Breakthrough to single phase

The three-phase Simplon electrification had two basic disadvantages:

- Although 3000 volts on the double-conductor catenary was practical, the voltage level could not be increased substantially because of the required insulating distances between the wires, and the locomotives' current collectors (a primitive type of double pantograph).
- Three-phase motors, with fixed-speed characteristics, could not meet the speed–range versatility necessary for mainline railway operation, especially on steep grades.

Swiss electrical engineers already knew that voltages of up to 15 kV could be carried on a catenary; however, the system had to be single phase, one wire.

The world's first single-phase electrified line[1] was constructed in 1904 by the SBB between Seebach and Wettingen (about 20 km) in northern Switzerland. Meanwhile, the first locomotive to be compatible with this line was being designed and built by Swiss Locomotive and Machine Works (mechanical components) and by the Oerlikon Engineering Company (electric equipment). This first locomotive, completed in 1903, featured

- A 15 000-volt, 50-Hz, single-phase power supply
- A step-down transformer
- AC–dc conversion equipment
- DC traction motors
- Two pivotless monomotor bogies (one motor for two axles, with connecting rods)

Because of the primitive technology of those days, the ac–dc conversion equipment comprised a rotary converter set that included a single-phase synchronous motor coupled to a dc generator.*

At about the same time, the BLS began the construction of a second transalpine mainline linking Thun with Brig. However, the electrification chosen for the catenary system was 15 kV at 16⅔ Hz.

Some of the earliest operational locomotives for BLS service were built in 1910, with a six-axle arrangement and monomotor trucks (one motor per axle, and counterweighted drive wheels attached in series by driving, or connecting, rods). These machines developed 1500 kW, and a top speed of 60 km/h. (This design was so advanced that it is commonly used today.) A more popular type, however, had what is called a "1-E-1" axle configuration, with two transformers and associated tap changer. The two traction motors, also connected to the drive wheels by rods, provided a combined rating of 1870 kW at a maximum speed of 75 km/h. Thirteen were ordered for service to begin in 1913, and each locomotive performed quite satisfactorily for 40 years!

Also in 1913, electric traction provided by low-frequency ac was introduced on the RhB. Eleven kV at 16⅔ Hz was selected for the catenary because of a desire to reduce clearances, plus the limited power demands (compared to SBB and BLS).

Completion of electrification

The early days of electrification witnessed many problems in operating single-phase commutator-type motors at 50 Hz, and the solution seemed to lie in the adoption of a frequency between 15 and 25 Hz, with a line voltage of 15 kV. As a compromise, 16⅔ Hz was

[3] One of the famous Class Ce 6/8^{II} "Crocodile" freight locomotives, originally built between 1920 and 1922 for service on the Gotthardbahn. Weighing 131 tonnes, with a rating of 1840 kW, they are still going strong in 1974, as may be seen by the modern high-rise structure at the right center of the photo. Thirteen more of these machines, designated Class Ce 6/8^{III}, were built in 1926–27.

[4] An Re 4/4^{II} (two-bogie, four-axle) high-speed passenger locomotive of the SBB. A modified version of this 4600-kW machine is a thyristor-controlled locomotive used on BLS service. The Re 4/4's have been built since 1964.

* The first locomotive was barely running when H. Behn-Eschenburg of the Oerlikon Engineering Co. perfected the straight ac traction motor by applying an ohmic shunt in parallel to the interpole windings—a simple solution that has survived to the present day. Thus the ideal locomotive equipment consisted of a transformer, tap changers, and traction motors. A second locomotive was built, and the first machine was converted to straight ac. Two restrictions, which are still valid, had to be observed: the frequency must be between 15 and 25 Hz; and the terminal voltage should be about 500 volts, maximum.

heavy trains at 140 km/h up a 0.65-percent grade, such as that planned for a new tunnel on the Gotthardbahn, a one-hour rating of 7300 kW is required. Using the two-axle-per-bogie configuration, a new motor, with a field-weakening technique, had to be designed. Figure 5 shows the outboard profile and interior plan of the single-frame version of the Re 6/6.

The requirements for electric regenerative braking of the Re 6/6 are stringent and specify that a trailing load of 400 tonnes must be braked dynamically on the Gotthardbahn to a steady speed of 80 km/h on the downgrade. This specification demands a braking force at the wheel of about 11 tonnes for 40 minutes.

Four-current-system "TEE" trains

In July 1961, four all-electric, four-current-system, five-coach TEE train sets were introduced* on two mainline routes through Switzerland:

- Zurich–Milan (via St. Gotthard tunnel)
- Milan–Paris (via Simplon tunnel)

Two trains, "Ticino" and "Gottardo," make the 293-km Zurich–Milan alpine run (Fig. 6) at an average speed of 72.5 km/h; while the "Cisalpin," plying between Milan and Paris, covers the more level 822-km route at an average speed of 103 km/h.

By contrast with the earlier diesel-electric (RAm) TEE trains, that ran on routes not completely electrified, the present all-electric TEEs perform far more efficiently on the steep alpine gradients and the long tunnels on the routes.

The TEEs, as international trains, are run cooperatively by the SBB (Switzerland), the French National Railway (SNCF), and the Italian State Railway (FS).

---

* A few years later, a fifth TEE train set—with six cars—was commissioned, and the others were augmented to a six-car configuration as follows, from the head end: driving trailer, intermediate passenger coach, motor coach, dining car, intermediate trailer, driving trailer.

The Swiss experience

Last September 24, I arrived at "Gleis (track) 2" of Zurich's *Hauptbahnhof* (main railroad station) at precisely 0800 that morning, where I met with my Swiss host, Beät Steiner, of the Brown, Boveri Company's Oerlikon Works. Herman Bruhlmann, of the SBB, completed our trio as we boarded a Class Re 4/4 locomotive at the head end of a passenger express bound for the St. Gotthard line (Gotthardbahn) to make the one-hour-long, 75-km first leg of our run to Erstfeld, a major marshaling yard for freight trains, as well as a locomotive-maintenance point.

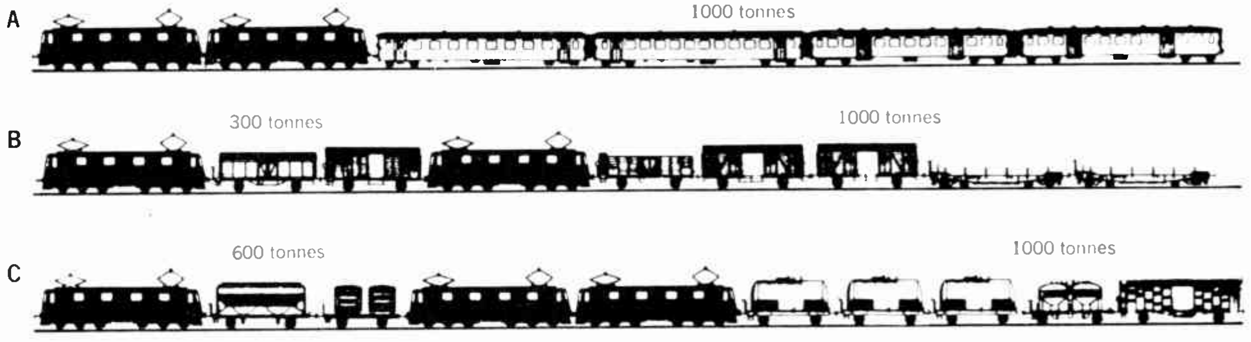
On this segment of our journey, we traversed rolling Swiss countryside and sliced through picture-book villages like Zug, with its lovely lake bordering the right-of-way for some 15 km to Goldau. Beyond Schwyz, our train rounded a sharp bend to bring the first "alp" dramatically into view. Then, along the shore of an arm of the Vierwaldstattersee the distant alpine massif came into sharper focus.

We descended from the locomotive cab at Erstfeld, strategically situated at the foot of the northern approach ramp to the St. Gotthard tunnel. During our 1½-hour layover (while awaiting the arrival of a 1300-tonne-haul fast freight train bound for Chiasso, on the Swiss–Italian border), we visited the unexpectedly large SBB locomotive maintenance shops. A quick lunch on salami and bologna sandwiches at a village inn preceded a 100-meter dash to board the powerful Class Ae 6/6 head-end locomotive. Under SBB regulations, freight trains of over 1000 tonnes on the Gotthardbahn cannot be hauled "double-header," with two locomotives operating in multiple-unit mode at the head of the train (see diagrams) because the maximum permissible drawbar traction limit would be exceeded, with the attendant risk of failure of couplings.

As we swung into the high cab of the lead Ae 6/6, I noticed the second all-electric of that same class at about the ¼ point to the rear of our locomotive (or about three fourths of the distance from the rear of the long train of laden freight cars). With such a configuration, MU operation was not possible. The answer to the separated coordination and synchronization of traction is that there is an operator in *each* locomotive, and the commands for advancing the wheel controller through the 27 tap-changer traction steps, and 16 steps in dynamic braking, are given via two-way radio by the operator in the lead locomotive.

I had my first example of the excellent coordination when the heavy freight train eased out of the Erstfeld station—and immediately entered a 2.5-percent grade from a level run. Our lead locomotive shuddered momentarily (and I noted a bit of wheel slippage), then accelerated slowly and steadily up the ramp to begin the 29-km-long approach, in which the right-of-way ascends 634 meters, to the St. Gotthard tunnel. During the startup and acceleration to an incredible speed—for a freight haul on the upgrade—of about 70 km/h, the increasing noise level of the traction motors was punctuated by the operator's crisp commands to the driver of the second locomotive. During this entire period, there was no perceptible jolt or lurch as the two machines seemed to perform as if they were under true MU control.

A—Passenger or freight train of up to 1000 tonnes trailing load is hauled by two six-axle all-electric locomotives (double-header). B—Freight train of 1300 tonnes, with one "in-between" locomotive, operating one quarter back from head-end locomotive. C—Freight train of 1600 tonnes, with two in-between locomotives in addition to head-end machine.



Thus, the TEEs had to be designed for the following power-supply systems:

1. Direct current, 1.5 kV, on a section of the SNCF between Dôle and Paris.

2. Direct current, 3.0 kV, on the FS sections: Chiasso–Milan–Domodossola.

3. Alternating current, 15 kV, 16⅔ Hz, on all SBB sections.

4. Alternating current, 25 kV, 50 Hz, on the SNCF section between Vallorbe and Dôle.

These specifications are met by four traction motors in the six-axle motor coach (consisting of two 3-axle motor bogies, in which the two outer axles are powered by a traction motor, and the intermediate is the trailing axle). The traction motors are fed directly through starting resistors in dc operation, and by the main transformer and silicon rectifiers in ac operation. The Oerlikon Engineering Company developed a pulsating-voltage motor that permits the use of silicon rectifiers when operating on ac catenary systems without smoothing coils.

On the roof of the motor coach are four pantographs, with bows and strips adapted to the respective current and catenary systems. In service, only one pantograph, compatible to the respective railway system, is raised. The entire electric equipment is controlled automatically (see Fig. 7). In the driver's cab, a nine-pushbutton console is provided* for every current system, by which—with the aid of a current-system selector switch—the circuits of traction motors and auxiliary equipment (such as air condition-

---

* These buttons include the 3000-volt dc systems of the Italian State Railways (FS) and the Belgian State Railways (SNCB); the 15-kV 16⅔-Hz systems of the SBB, the German Federal Railway (DB), and the Austrian Federal Railways (ÖBB); the 25-kV 50-Hz system of the northern and northeastern portions of the French National Railway (SNCF); and the 1500-volt dc lines in use on the Netherlands Railways (NS) and on the southern and southeastern portions of the SNCF.

The scenic grandeur and splendor of the alpine panorama increased with every kilometer of the long climb. About 2 km beyond Station Gurtnellan (see map, p. 46), we entered the 1.5-km-long spiral tunnel (Pfaffensprung-Kehrtunnel) near Wassen, where the right-of-way completes a full 360-degree loop. A minute or so before entering the tunnel, Mr. Steiner pointed out a village church situated about 160 meters above and ahead of us on the right. (Once inside the closed spiral, one's sense of orientation becomes confused.) When we emerged from the tunnel, the church was behind us, on the left—only this time, it was about 100 meters below us! And moments later, we crossed over, at a closed angle, the same section of track we had traversed only a short time before!

Three kilometers beyond the spiral—still climbing—we reached the first of the two loops, or switchbacks. Some 7 km farther on, and past the second loop, we were about 1 km west (but no farther south) than the point of curvature of the first loop! However, we had climbed about 170 meters in the process! Ahead was the St. Gotthard's north portal.

The passage through the 15-km-long, virtually level, straight-line tunnel from Göschenen to Airolo was a rather odd experience: the locomotive's headlamps were turned off (but the exterior "marker" lights were on), and only the pale-green glow from the six ammeters (one for each traction motor) on the operator's console eerily illuminated the otherwise black interior of the tunnel and cab.

Emerging from the south portal of the St. Gotthard is like traveling from Germany to Italy in 15 minutes: north of the tunnel, the language, architecture, and atmosphere are decidedly German; south of the tunnel, the ambience is Italian (though, geographically, the countryside is still Swiss). Instead of German-style chalets, there are shuttered, stucco buildings with red-tiled roofs. Also the names of en route stations and villages change abruptly—Göschenen, for example, to Airolo! North of the St. Gotthard, our locomotive operator had been speaking, via radio, in German to the second locomotive's driver and to the wayside signal cabs; south of the tunnel, his words were suddenly Italian.

After the St. Gotthard, we began the long defile in descending the southern ramp in the Lepontine Alps. This leg of the trip was no less spectacular than the ascent portion in the Oberland. On this descent, I was particularly grateful for the Ae 6/6's dynamic braking that is especially designed for alpine service. The brake, which can be controlled in 16 steps, permits the weight of the locomotive (120.5 tonnes), plus a trailing load of 300–400 tonnes, to be held at a steady 70 km/h on all down gradients of the Gotthardbahn. This feature also greatly reduces the wear on the wheel-shoe (air) brakes.

The next adventure began about 15 km southeast of Airolo. We passed through the roller-coaster-like twin spiral tunnels of the Dazio Grande—the first of which is counterclockwise, and the second clockwise. Then, about 10 km farther down the descent, we traversed the two final spirals of the Biaschina in quick succession. These are particularly disorienting since they are both counterclockwise in the southerly direction, and the double rotation puts one through 720 degrees over a total distance of about 4 km!

Another half hour's descent brought us into Bellinzona, where the second Ae 6/6 was detached, along with some freight cars. From Bellinzona southward, the terrain and the grade level off but then there is an unexpected 2.6-percent climb from Giubiasco to the Ceneri tunnel.

By midafternoon, we had crossed the viaduct that bisects beautiful Lake Lugano and were passing many of the city's magnificent resort hotels. About 25 km south of Lugano, we reached Chiasso located on the Swiss–Italian border.

Chiasso is one of the principal freight marshaling yards in western Europe. Because of its strategic location, loaded cars on merchandise trains heading north from the heavy-industry areas of Italy are destined from that border point to virtually every country in Europe. Thus, a comprehensive semiautomated man–machine marshaling and "hump" operation system has been installed for expediting the make-up of these trains, as well as their dispatch to and from Italy.

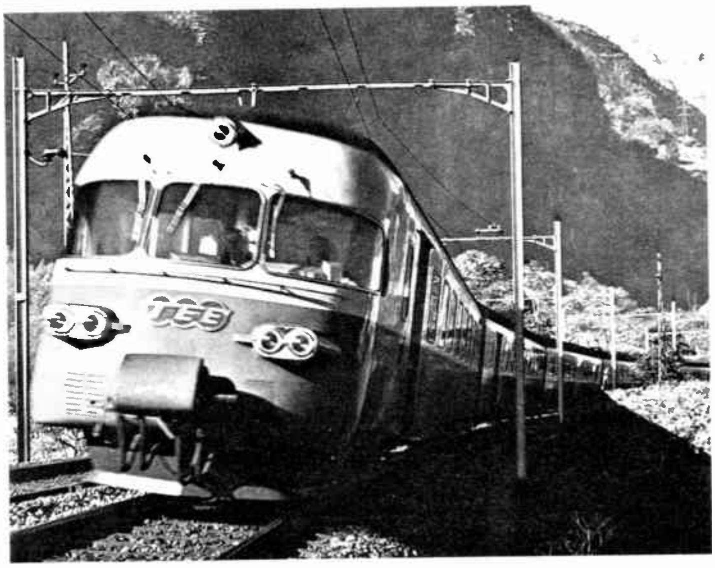
Following our tour of the Chiasso control cabin and the "gare de triage" area, we hopped aboard a local train to Como, Italy, to await the arrival of the de luxe TEE (Trans-Europ-Express) train "Gottardo" (all TEE trains have colorful or romantic names!) that runs daily between Milan and Zurich, stopping only at Lugano en route (the Swiss train crews board at Como).

After leaving Lugano, we proceeded at a rapid clip up the southern ramp of the St. Gotthard and through the spiral tunnels and loops we had traversed only hours before in the opposite direction.

North of the St. Gotthard tunnel, we left the driver's cab and went back to the restaurant car to enjoy an excellent five-course dinner. The train was booked to capacity, mainly by businessmen making a one-day trip between Zürich and Milan. About three hours after leaving Como, we were back in Zurich's Hauptbahnhof, from whence we had departed 13 hours earlier—capping an eventful day.

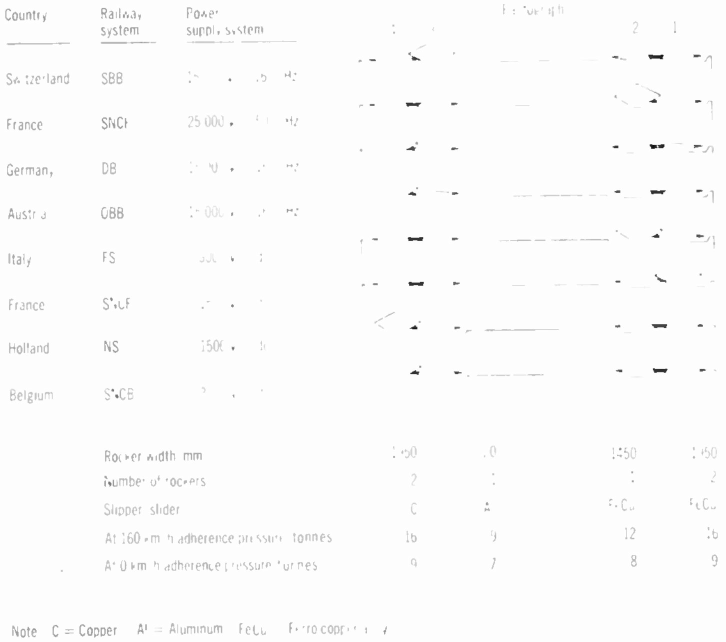
ing, heating, etc.) are adapted to the current system in operation. The pantograph regime for the four currents is shown in the Fig. 7 diagram.

Furthermore, in the TEE design, track, and speed conditions—as well as the moving gage and pantograph standards—of the various national railway systems differ. Such factors necessarily influence the design of the electric equipment. For example, TEE train performance had to meet the tough requirements of negotiating the 2.6-percent grades of the Gotthardbahn at speeds of 80 km/h, the 2.0-percent grades at 120 km/h, and a maximum speed on level track of 160 km/h.



[6] TEE train "Ticino" in the area of the Wassen spiral tunnel and loops, north of the St. Gotthard tunnel.

[7] Scheme of pantograph use by four-current TEE trains. The four rooftop pantographs installed on the motor coach are employed in the indicated sequence in the seven countries in which they can operate.



On downgrades (up to a theoretic 3.0 percent), the dynamic (resistance) braking holds the entire train in check, and operates also as a deceleration brake for speeds from 160 km/h down to 20 km/h. The maximum continuous rating of a TEE unit is 2148 kW; the one-hour maximum rating is 2376 kW.

Suburban commuter and "U-Bahn"

The SBB operates more than 150 multiple-unit and single-unit (railcar) electrically powered dc train sets for suburban commuter and high-speed interurban service (Table II). These trains operate in and out of major cities such as Zürich, Basel, Bern, Geneva, etc.

At the new SBB station in Bern, there is a direct and convenient access, on the lower level. Here two meter-gage lines provide both intra- and intercity service; one is from Bern to Worb, and the other extends as far as Solothurn, a city about 35 km north of Bern. Although, the Bern terminus is underground, and there are tunnels leading to the station, these systems really cannot be classified as U-Bahnen.

Latest news on Swiss rail

As we go to press, we have been apprised of the following significant developments:[3]

- SBB has 45 Re 6/6s on order; deliveries will start in 1975. (Together with the DB's E 103s, they represent the world's most powerful locomotives.)
- Four prototype thyristor-controlled train sets (each with a total of eight traction motors, having both series and parallel excitation) will be delivered later this year for suburban service.
- The RhB now has four thyristor-controlled suburban train sets in operation. This line also has ten thyristor-controlled 1700-kW locomotives, with a tare weight of 50 tonnes each, in service.
- Late in 1973, the SBB placed an 800-kW experimental locomotive in revenue service. It incorporates a converter that produces three-phase ac of variable frequency and voltage (from the 15-kV, 16⅔-Hz single-phase ac at the catenary); and four squirrel-cage brushless traction motors.

REFERENCES

1. Steiner, B., "Switzerland—the country of electric railways," internal paper, Brown, Boveri & Company Ltd., Aug. 1973.
2. Meyer, K., "Swiss Federal Railways perpetuate modern conventional electric-traction techniques for its latest 8000-kW locomotives," *Rail Eng. Internat'l*, pp. 384–392, Oct. 1973.
3. *Brown Boveri Rev.*, Dec. 1973.

A look ahead

The concluding installment on Swiss rail will take up signaling, telecommunications, train-control and safety features, and computer-controlled issuance of passenger space reservations—as well as semi-automated freight train marshaling yard operations.

Reprints of this article (No. X74-082) are available at $1.50 for the first copy and $0.50 for each additional copy. Please send remittance and request, stating article number, to IEEE, 345 E. 47 St., New York, N.Y. 10017, Att: SPSU. (Reprints are available up to 12 months from date of publication.)

European satellites to 'fly'

Finally out of the research stage, the European space program will aim at telephone, data, and TV traffic

With a new organization, expanded budgets, new facilities, and detailed communication satellite plans, European space efforts are moving into higher gear. In just a few weeks, the new European Space Agency (ESA) will become the official successor to the European Space Research Organization (ESRO).

With the name change will come a new director general (not yet named), extended responsibility, and several new programs.

The new organization will be firmly based in an inheritance of experience and resources built up under ESRO. That inheritance includes a European Space Technological Center at Noordwikj, Netherlands; an Operations Center at Darmstadt, Germany; and facilities at Frascati, Italy. ESA also inherits such ongoing space projects as METEOSAT (for meteorology), MAROTS (for marine navigation), and AEROSAT (for aircraft navigation), along with an annual budget of about $350 million, and about 1300 employees.

I. Telephone, TV, and more

Forerunner of a permanent European Communications Satellite (ECS) system, the Orbital Test Satellite (OTS), now in development, is the most important space project yet taken on by the nine European countries who have joined forces to set up ESA. Expected to compete with earth-bound long-distance telephone links, the planned ECS system will be designed to carry as much as one half of the phone traffic exchanged between cities more than 800 km apart. At that rate, estimated satellite traffic would handle almost 12 000 telephone circuits by 1985, and over 21 000 circuits by 1990.

In addition, television will be able —through the ECS system—to reach the whole of Europe, as well as the countries of North Africa, the Near East, Cyprus, and Eire.

Planners hope to get maximum use of the satellite channels by shifting between telephone and TV traffic. But here they face some difficult problems. Telephone traffic is reasonably predictable—since it follows fairly regular daily patterns—but TV traffic includes heavy demand periods that can crop up in unpredictable ways.

Added satellite-links services that will be tested for technical feasibility include: computer-to-computer interconnection, remote access to data banks and computers, data collection, closed circuit TV for such applications as educational and medical services, electronic mail delivery, and facsimile transmission. To provide for these added services, the initial Orbital Test Satellite will be equipped with narrow-band equipment to accomodate transmission, and reception from small, relatively inexpensive earth terminals operating at frequencies above 10 GHz. By combining efficient digital modulation techniques with small, operationally flexible earth terminals, it is hoped that a wide variety of added services can be made available at reasonable cost.

II. Cost-conscious beams

Some 30 earth stations are planned for the initial implementation of the ECS system. Some countries will have two but most will be using a single station. Each country will bear the cost of its own earth stations in addition to paying for a portion of the satellite.

To allow minimum earth station costs, the system is being designed to accomodate earth antenna reflectors no larger than 15–18 meters in diameter. With larger size antennas the cost would likely increase steeply, particularly if high requirements were put on polarization characteristics used for frequency spectrum conservation. The peak power of transmitters is assumed in the design to be compatible with the use of air-cooling techniques; this sets a ceiling at a level of about 2 kW. For further economy, it is being recommended that low-noise receivers should be uncooled for easy maintenance, that the number of transmitting and receiving chains should be minimized, and that this kind of equipment should be standardized.

Two satellite antenna beams will be used. Broad coverage of both central and peripheral geographic areas will be provided by the "Eurobeam." Its elliptically shaped 3-dB beamwidth will span 7.5 × 4.25 degrees. The second, called "Spotbeam," will have a circular beamwidth of 2.5 degrees to cover only the central area.

Present plans call for a satellite receiver noise figure of 5 dB; the peak gain of its Eurobeam receiver antenna is to be 27 dB. The satellite transmitter will have an output power of 20 watts, and the peak gain of its spotbeam antenna will be 35 dB, while its Eurobeam antenna peak gain will be 27 dB.

III. Polarization techniques

Frequency bands available for fixed satellite service in Europe were defined by the World Administration Radio Conference of 1971. From these, a total 1000 MHz of bandwidth has been chosen for use in the ECS system. Up-links are to cover 14.00 to 14.50 GHz, while the down-links are to be in the 10.95–11.20- and 11.45–11.70-GHz bands.

Because of the expected heavy telephone and TV traffic, the system will be severely bandwidth-limited, and spectrum conservation techniques are felt to be necessary. In particular, polarization discrimination experiments are planned. The basic idea is to transmit two polarized signals at the same frequency. Such polarization may be linear, with one signal at right angles to the other; or it may be circular, with the two signals having opposite senses of rotation.

Atmospheric depolarization is one of the main concerns in the experiments, since occasional degradations of 20–40 dB have been observed with both linearly and circularly polarized signals. Experimenters hope to discover which of the two types gives better results.

As a second approach to frequency conservation, system designers are considering using the same frequencies on several satellites at different geostationary locations. However, such a system would require added costs in the form of multiple earth-station antennas. And there is some reluctance about using added geostationary orbital space—an increasingly precious world resource.

IV. Launching the satellites

U.S. launch vehicles are expected to be used, at least during the early stages of the system, and the Thor Delta rocket has been selected to launch the OTS. Type 2914 Thor Delta has a payload of 315 kg, and the type 3914 has a 410-kg payload (620 kg after 1977). If larger satellites are used, Titan III and Atlas/Centaur rockets offer payloads from 700–1520 kg.

Costs will decide the choice of launch vehicles. Taking probable failures into account, a total of six to nine ECS launches are expected to be needed over the next ten years. Launch costs vary from about $9.8 million, for a 315-kg payload, to over $24 million, for the larger payloads. With a total budget of only about $200 million per year, launch costs are a very significant factor in the system design.

The initial Orbital Test Satellite will be launched early in 1977 and will be placed at longitude 10°E in geostationary orbit. It will be maintained within ±0.1° of its nominal position both in the North–South and East–West directions.

OTS is a three-axis-stabilized unit designed for a three-year life. It consists of a service module capable of providing all the basic service functions, and a communications module that carries the payload. Two solar array paddles, each with two-hinged panels, are attached to bearing and power-transfer assemblies mounted on the north and south sides of the satellite; these paddles are steered to track the Sun. Six SHF antennas are mounted on the face of the satellite pointing toward the Earth.

The OTS satellite will carry two communications modules in its payload. The first module is a reduced-size version of the payload planned for future operational satellites. Included in the first module are telecommand and telemetry transmitters. Receive antennas for this module are of the Eurobeam type, as is the transmit antenna for the 40-MHz chains. The transmit antenna for the 120-MHz chains has a Spotbeam pattern.

Special propagation and narrowband transmission experiments will be accomodated by the second OTS module. It contains a single repeater chain with a 5-MHz bandwidth and high-gain circuits. Receiving and transmitting antennas both have an aperture of 5 × 3.5 degrees at the 3-dB level; circular polarization is used. This module also contains a beacon transmitter.

V. Light, long-life circuits

Hardware for the Orbital Test Satellite has been chosen to meet payload weight limitations and to provide as long a service life as possible. The primary payload is the repeater equipment designed to translate received signals in the 14-GHz band into retransmitted signals in the 11-GHz band. The intermediate frequency was chosen to be 1 GHz, allowing the use of microwave integrated circuits.

An outstanding feature of the repeater design is the use of a parametric amplifier for the low-noise front end of the 14-GHz receiver circuit. Up to now, parametric amplifiers have been limited to ground equipment use due to power consumption and reliability limitations. The main problem has been the low efficiency of circuitry to generate high-frequency pump power. Only 5 mW of pump power at 10 GHz is required for the gallium arsenide varactor diode used in the OTS paramp. This pump power is derived from a 2.5-GHz transistor oscillator followed by varactor diode multipliers. The transistor oscillator is placed in a coaxial cavity.

To save weight and space, waveguide multipliers, as well as the main diode mount and a five-part circulator in the signal path, are all mounted evanescent-mode waveguides. Long-term drift of pump power is controlled by an AGC loop, and temperature stabilization of the amplifier diode is achieved by a thermistor network. No external temperature control is necessary to guarantee performance over a temperature range from 5 to 35°C.

A traveling wave tube amplifier is used as the onboard 11-GHz transmitter. The present design has two collector stages for improved efficiency and easier thermal interface. A life-test program is now underway to confirm the design goal of seven years of successful operation.

To avoid multipath and adjacent-channel interference, the burden of channel selectivity in the OTS is being placed on 1-GHz intermediate frequency channel filters. Linear phase filters have been developed to provide optimum amplitude, and group delay characteristics. The high selectivity requirements made it necessary to use 14-cavity filters. Although these units have greater mass and a more complex design than Chebyshev filters, their choice was dictated by the very pressing need for optimum transmission performance.

The linear phase filters are similar in mechanical design to conventional interdigital filters, but are folded to achieve coupling through the common wall between nonadjacent resonators. These additional coupling slots allow adjustment of both amplitude and phase characteristics. Electron beam welding technology together with lightweight design is used to achieve a mass of 750 grams.

All signals used for frequency conversion are derived from one common master oscillator. This crystal oscillator operates at 55.4 MHz and has a long-term frequency stability better than $\pm 10^{-5}$. Coherent signals for the 13.3-GHz down-converters and the 10.65-GHz up-converters are provided by suitable multiplier chains. The total available HF power of 120 mW requires a dc power of input of 6 watts.

In addition to the main communication-band equipment, there is a beacon generator that uses an impatt avalanche diode for direct generation of its 11.76-GHz signal.

The main advantage here is simple design that avoids multiplier chains that would be needed in a more conventional circuit. The mass of this fully redundant generator is less than 600 grams, and its dc power consumption is 2 watts.

Microwave integrated circuits are used throughout the 1-GHz equipment. Amplifiers at the down-converter output, the intermediate frequency main amplifier, and the driver unit for the up-converters, as well as the branching network—consisting of interdigital 3-db couplers—and the PIN-diode attenuators, are all built on sapphire substrates.

The microwave integrated circuits will be fully qualified for space application, and tight control will be exercised over all process, inspection, and assembly steps.

Howard Falk

Ultrasonics in medicine: strong; getting stronger

Two- and three-dimensional imaging breakthroughs may spark the next generation of ultrasonic imaging systems

Ultrasonic diagnosis of the living human heart, in real time and noninvasively, has been used to display cross sections of the heart just as if it had been cut open with a surgeon's knife. By this technique, congenital heart defects can be revealed in situations where, previously, catheter inspection—with a small but finite probability of mortality from the examination alone—had been the only equivalent diagnostic means.[1,2] In another recent development, an ultrasonic instrument is used to reveal disease in the prostate and bladder with the aid of a plan-position-indicator type of display obtained from a small radar-like ultrasonic probe inserted into the rectum. In this application, the patient experiences no more discomfort than during a barium enema used for lower-tract X-ray diagnosis.[3]

Dramatic applications such as these are becoming increasingly prevalent. Because ultrasonic diagnosis can reveal, noninvasively and in pictorial fashion, tomographic cross sections of most internal human organs, ultrasonic instruments are selling 300 percent ahead of 1971 and may exceed X-ray instruments in sales by the early 1980s.

Although ultrasound is also used in medicine at moderate intensities for producing heat deep inside the body and, at much greater intensities, to destroy tissue as an alternative to its surgical removal, the very-low-intensity diagnostic uses are by far the most prevalent. They began in the mid-1940s as a spinoff from nondestructive ultrasonic flaw-detection techniques first used in industry a few years earlier.[4] Since that time, improved scanning techniques and instrument technology have led to a host of research and clinical applications for examination of such disorders as cysts, tumors, or cancer in organs such as the prostate, kidneys, liver, heart, bladder, and breast. In many cases, complete diagnosis would not have been possible by radiography or other means because those techniques were either inapplicable, insufficient, or unacceptably hazardous. Table I indicates the extent to which ultrasonic imaging is already being used (or being developed for use) in medical diagnosis.[5]

Despite the prevasiveness of ultrasonics in medicine, there are drawbacks to the technique. For example, great dexterity is sometimes required of the person using the instruments, displays are not easy to interpret, resolution is still too low, and more automatic testing would be desirable.

To assess the state of the art in ultrasonic imaging in medical diagnosis and to speed its further development, the National Science Foundation's Office of Experimental Research and Development Incentives, in March of 1973, formed a team to survey the technique. Nine internationally recognized experts in various disciplines associated with ultrasonic diagnostic imaging devices were brought together with a threefold mission: to provide a state-of-the-art summary of worldwide developments in diagnostic ultrasonic imaging instruments, to generate a specification for an instrument that could be produced in the U.S. within two years,[6] and to prepare a research agenda that could lead toward enhanced capability in the future.

The NSF team's recommendations were published in a report issued in November 1973.[5] Its first recommendation was that programs should be supported by the U.S. Federal government to remove existing barriers to widespread clinical use of ultrasonic imaging in medical diagnosis in the U.S. Some of the elements of this recommendation have already been implemented. Second, it called for a research program that would be conducted to produce the new knowledge required for enhancing capabilities. And, third, it urged support of programs to assure continuing information exchange by scientists and engineers in academic, clinical, and industrial institutions through workshops, seminars, problem assessments, and other means on a national and transnational scale.

As a result of the recommendation concerning research, a series of task groups were organized by the Alliance for Engineering in Medicine and Biology (IEEE is a member) under a grant from the NSF RANN program with the goal of assessing four aspects of instrumentation: interaction of ultrasonic energy with biological structures, ultrasonic transducers, displays and scans, and signal processing. The assessments are to be integrated into a final recommendation leading to new capabilities for ultrasonics in medical diagnosis and therapy.

The task force concerned with possibly hazardous effects of ultrasonic energy on biological structure and function released a report this April.[7] Reports of the findings of the three remaining task groups were released last month. A summary of these reports follows.

Ultrasonic energy and biological structures

This group, in its report, emphasized that presently used diagnostic ultrasonic levels probably present no hazard to the patient, but made a series of recom-

Ronald K. Jurgen Managing Editor

1974 WESCON TECHNICAL PROGRAM (Los Angeles Convention Center Mezzanine)

Date and Time	Room 212A	Room 212B	Room 217A	Room 217B
Tuesday September 10 10 a.m.– 12:30 p.m.	**Session 1** Teaching Nontechnical Personnel to Understand and Use Electronic Equipment	**Session 2** Introduction to Charge-Coupled Devices	**Session 3** Microwave and Millimeter Solid-State Components	**Session 4** Strategy for Crisis
Tuesday September 10 2 p.m.– 4:30 p.m.	**Session 5** How to Prepare an Effective Business Plan to Raise Capital	**Session 6** Advances in CCD Memories	**Session 7** Modern Radar Technology	**Session 8** New Markets in Agriculture for Electronic Technology
Wednesday September 11 10 a.m.– 12:30 p.m.	**Session 9** Status of Plastic Encapsulated Semiconductors—Fact, Not Fiction	**Session 10** What To Do If the Lights Go Out—The Uninterruptible Power Story	**Session 11** Microprocessors—Market, Design, Applications	**Session 12** Needs and Trends in Medical Electronics—1974
Wednesday September 11 2 p.m.– 4:30 p.m.	**Session 13** Taking Your Technology to New Markets	**Session 14** The Real World of Digital Communications	**Session 15** Microprocessors—The Second Generation	**Session 16** Quo-Vadis Electronics?
Thursday September 12 10 a.m.– 12:30 p.m.	**Session 17** Hybrid Microelectronics Clinic on Semiconductor Bonding	**Session 18** Selling Your "Better Mousetrap"	**Session 19** The Microprocessor Revolution—Part I	**Session 20** Fault Detection in Transmission Lines Using TDR and FDR Techniques (Panel)
Thursday September 12 2 p.m.– 4:30 p.m.	**Session 21** The Status of Additive Printed Circuits Today	**Session 22** LSI Testing	**Session 23** The Microprocessor Revolution—Part II	**Session 24** Design-To-Price
Friday September 13 10 a.m.– 12:30 p.m.	**Session 25** Automatic Testing of PCBs—Ways and Methods	**Session 26** Emerging Display Technologies	**Session 27** Applications of Digital Logic to High-Speed Amplitude and Timing Measurements	

mendations aimed at eliminating and/or circumventing the obstacles that prevent adaptation of advanced technical knowledge into practical, commercial, clinical ultrasound units. The report states that the task group believes that measurements establishing the safety of U.S. techniques will hasten the acceptance of clinical ultrasound.

The specific recommendations, in priority order, are

1. Obtain detailed information that establishes the ultrasonic energy levels at which alterations occur in living systems for the purpose of quantitatively assessing the risk, if any, of clinical ultrasonic procedures.
2. Obtain additional information on the physical interactions and acoustical properties of normal and pathological tissues for use in ultrasonic equipment design.
3. Investigate the presence and importance of cavitation in tissue subjected to ultrasonic irradiation.
4. Investigate the physical mechanisms of interaction of ultrasonic and biological systems.
5. Encourage improvements and innovation in measuring techniques so that the collection of the physical and biological data can be accomplished more efficiently and reliably.
6. Establish a data repository or clearinghouse and expand efforts to collect and disseminate currently available data on ultrasonic interactions and propagation properties in tissue.
7. Encourage and promote the continuing education of scientific investigators in ultrasonic techniques.
8. Conduct a series of epidemiological studies on patients and progeny exposed to diagnostic ultrasound procedures.
9. Investigate the effects of synergism, if any, of ultrasound and other forms of radiation, particularly ionizing radiation.

I. Present status of ultrasonic imaging in medical diagnosis

Applications and Status*

- Breast
  - Differential diagnosis of malignant and benign tumors (R)
  - Localization of tumors (R)
- Cardiology
  - Cardiac output (R)
  - Diseases of other valves (CE)
  - HOCM (CE)
  - Mitral valve disease (CU)
  - Pericardial effusion (CE)
- Cardiovascular
  - Aortic aneurysm (CU)
  - Pericardial effusion (CE)
  - Pulmonary embolism (R)
  - Septal defects (using intracardiac probe) (D)
- Dentistry
  - Examination of pulp cavity (R)
- Gastroenterology
  - Liver volume (D)
  - Liver abscess (CU)
  - Liver disease (R)
  - Operative use in cholelithiasis (D)
- Genitourinary
  - Bladder volume (CE)
  - Localization of renal calculi at operation (CE)
  - Prostate (CE)
- Miscellaneous
  - Ascites (CE)
  - Differentiation of cystic and solid masses (CU)
  - Pleural effusion (CE)
  - Radiation treatment planning (D)
  - Soft tissue thickness (D)
- Neurology
  - Amplitude-averaging technique (P)
  - Intracranial pulsations (R)
- Obstetrics and gynecology
  - Fetal abnormalities (R)
  - Fetal cephalometry (CU)
  - Hydatidiform mole (CU)
  - Placental localization (CU)
- Ophthalmology
  - Axial length measurement of eye (CU)
  - Diagnosis of disease (R)
  - Foreign-body localization and extraction (CU)

* Keys to the status of effort underway, but not necessarily complete R—research, D—development, CE—clinical experiment, P—prototype, CU—serial production and clinical use.

Ultrasonic transducers

The primary criterion of another task group concerned with ultrasonic transducers, for selection of transducer research and development objectives, was maximum likelihood of enhancement of ultrasonic imaging system performance to achieve the largest possible impact (benefit-to-cost ratio) on health care. In this context, a set of objectives was recommended with priority ranking, relative resources to be allocated, current status of development, and estimated time to commercial application designated for each objective. The recommendations are summarized in Table II.

II. Recommended objectives for ultrasonic transducers

Objective	Priority*	Relative Resources*	Current Status*	Time To Begin Payoff* (years)
1. Two-dimensional ($N \times N$) piezoelectric transducer arrays	A$^+$	L	R	1–5
2. Ultrasonic imaging systems using electronic detector array	A	L	R/D	1–5
3. Electronic delay lines	A	M		2–4
4. Acoustic components	B	M	D	1–3
5. Preprocessing circuits	B	M	D	1–5
6. Discrete transducers	C	S	R/D/A	1–5
7. New transducer materials	C	S	R	3–5
8. Electrostatic and electret arrays	C	S	R	3–5

* Priority A, highest Relative resources: L—large, M—medium, S—small. Current status, R—research, D—development, A—application.

The A+ priority given to two-dimensional arrays, the report explains, was on the basis that the principal obstacle to potential benefits from future ultrasonic imaging systems is the lack of arrays of ultrasonic transducers that can generate "pictures" generally comparable to those produced by high-resolution radar, an ordinary camera, or an X-ray system. The capability to produce such pictures, according to the report, would overcome the severe "tunnel-vision" limitation of ultrasonic instruments now in clinical use.

Aside from transducer arrays, the report states, the most crucial devices affecting the overall performance capabilities are electronic delay lines used to equalize effectively the ultrasonic transit times between an object point and the various elements of a transducer array—i.e., electronic focusing. While, at present, multistage lumped inductor-capacity delay lines, distributed electromagnetic delay lines, switched capacitor delay lines, and surface acoustic-wave delay lines are in various stages of use in a variety of experimental sector scanning systems, the most promising type appears to be the charge-coupled-device delay line, or possibly the silicon-bucket-brigade delay line.

Ultrasonic displays and scans

A third task group concerned with displays and scans was charged with assessing the current status of ultrasonic imaging displays, anticipating their role in five years, making recommendations for maximizing ultrasonic imaging display system performance, and establishing a priority list for clinical research and instrument research and development aimed at the implementation of the recommendations. The group's recommendations fall into three general categories: developing means for improved tissue discrimination; upgrading the clinical capabilities of dynamic imaging systems; and optimizing the data presentation to

Ultrasonic scanning detects arteriosclerosis

A new diagnostic scanner[8] that yields dynamic Doppler information from blood flow, as well as both static and dynamic echo information from stationary and more slowly moving tissues, was designed for performing ultrasonic echo-Doppler arteriography where the location and geometry of the interface between occlusive atherosclerotic tissue and blood are of prime concern.

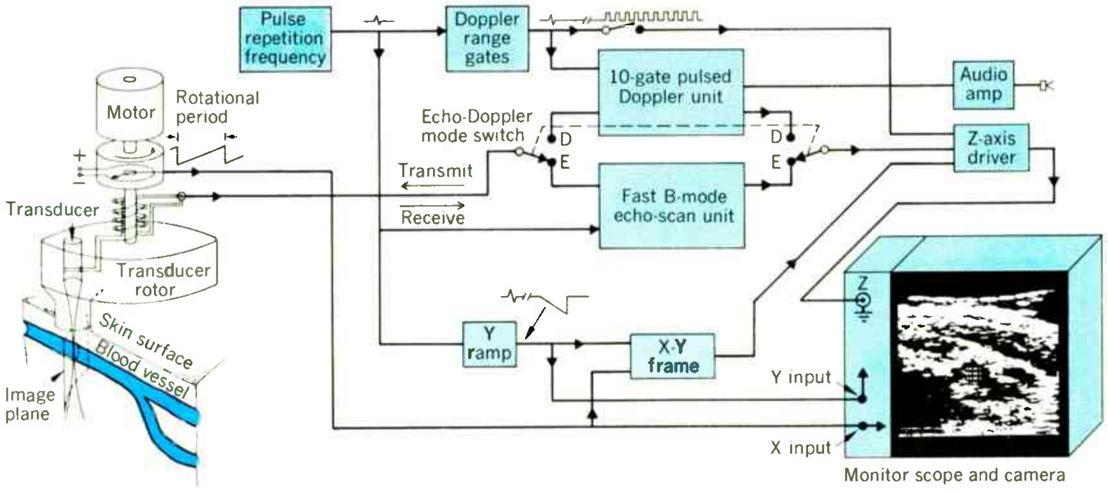
A functional block diagram of the duplex scanner is shown in Fig. 1. In the echo mode, with the transducer stationary, a focused ultrasonic beam propagates into the tissue. After a delay set to correspond to the distance through a water column from the transducer to the skin surface and return, the *Y*-ramp output begins a vertical trace down the screen. The *X* position of this trace is set by the output of a potentiometer attached to the transducer rotor. As the trace sweeps down the screen, the intensity is proportional to the output of the "fast B-mode echo-scan unit," which receives the echoes from the tissue, amplifies them, and detects the envelope of the waveforms.

A variable-persistence storage oscilloscope is used as a monitor. Using the scope in the normal nonstore mode, wall motion, as well as the low reflectance of blood, identifies arteries. Veins are identified by low blood reflectance and by changes in diameter with respiration and mechanical pressure of the transducer against the skin surface.

In the Doppler mode, operation is the same as in the echo mode up to the detection of the signal, at which point the phase of an echo is measured rather than its amplitude. The time rate of change of phase is the Doppler frequency which, after amplification and filtering, drives a speaker as in the conventional ultrasonic Doppler instruments. Additional circuitry allows this signal to intensify spots on the scope corresponding to those points where flow is heard above a preset threshold.

Figure 2 shows examples of cross sections through the neck of a normal individual. The circular array of dots on the left in each image corresponds to the area of flow in the common carotid artery about 1 cm below the point where it bifurcates into its internal and external branches. The other array of dots corresponds to flow in the jugular vein. In Fig. 2A, the flow points are widely spaced, making a clear picture. For a clean artery with no occlusive disease, this type of image containing a relatively low density of flow points (dots) is adequate. The

[1] Duplex echo-Doppler scanner operates in both modes and has located atherosclerosis.



the interpreter and provisions of means for universal comparison of data. The specific goals recommended for a five-year research program aimed toward the next generation of ultrasonic imaging systems are:

1. Develop clinical measurement techniques for the measurement of bioacoustical tissue characteristics.
2. Generate on-line, two-dimensional cross-sectional images depicting physical tissue parameters.
3. Obtain "signature" data from selectable tissue regions (graphic displays of various bioacoustical characteristics and related parameters that can be strongly indicative of specific structural features).
4. Improve the quality and data content of on-line, two-dimensional dynamic images.
5. Generate three-dimensional images of organs and body regions with provisions for useful image manipulation.
6. Establish minimum requirements for standardization permitting comparison of clinical results and the building of a clinical data library.
7. Advance clinical capabilities of ultrasonic angiography.
8. Generate synergistic displays of images obtained by sonography and other biophysical imaging techniques.
9. Identify the most useful image features and develop techniques for their enhancement.
10. Assess data storage and retrieval for optimal use in a clinical environment.

In commenting on the recommendation, the report states that on-line, rapid two-dimensional ultrasonic imaging has great significance in examinations of dynamic cardiovascular and respiratory phenomena. By permitting detailed study of the motion of heart walls and values during the cardiac cycle, the assessment of cardiac function and the detection of congenital defects, and possibly pathologic myocardial alterations,

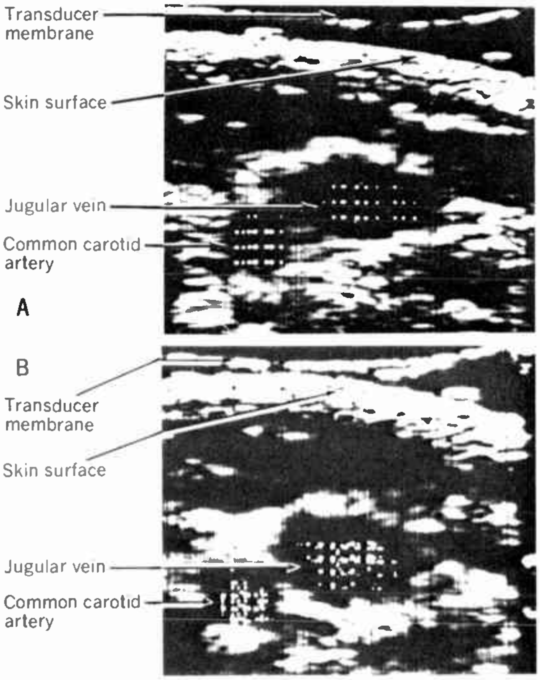
higher density of flow points in Fig. 2B would be more useful for an accurate measure of geometry in determining the extent of occlusion in a diseased artery.

Clinical tests of patients exhibiting symptoms of atherosclerosis (known from X-ray arteriograms) were promising. It was possible to locate areas of disease and to differentiate between points of flow and points of static tissue.

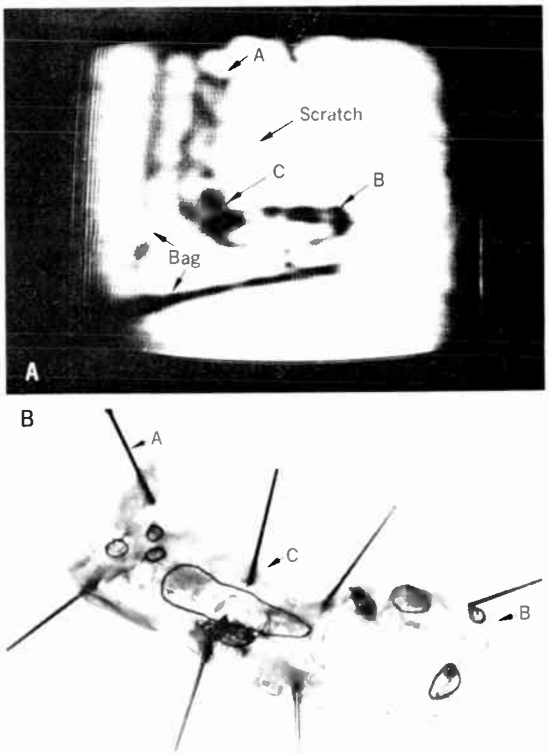
In another technique, a laser scan acoustic camera is used for obtaining pictures of calcified arteriosclerotic deposits in a femoral artery.[9] The camera operates at 2.2 MHz with a resolution of about 1.2 mm. Figure 3A shows the ultrasonic image of calcium deposits and Fig. 3B shows the same artery after it was opened to determine the location of the calcified deposits.

Although the technique was applied to an artery taken from a cadaver, the researchers are hopeful that further developments may lead to useful observations *in vivo*.

[2] Low-density echo-Doppler cross-sectional arteriogram, made with equipment in Fig. 1, showing the carotid artery and jugular vein of a normal subject (A) and a multiple-scan arteriogram of the same area (B).



[3] Ultrasonic image of calcium deposits in a femoral artery (A), and (B), the same artery after it was opened with the circled areas indicating heavy calcified deposits, with locations A, B, and C corresponding to those same locations in (A).



are facilitated. This form of ultrasonic imaging, the report emphasizes, could also be used to examine the pulsations exhibited by aneurysms of large vessels. Dynamic images would also be useful for motility studies of hollow, fluid organs such as the stomach.

Accurate three-dimensional displays could be of great use in many diagnostic and therapeutic applications, according to the report. Precise topographical localization of pathological structures with reference to organs would be permitted and assessment of the effects of tumors on surrounding structures could be made. Identification of complex internal architecture of organs and tumors would be greatly facilitated by three-dimensional image displays, and biometric data, such as tumor volumes, could be accurately predicted from three-dimensional image displays.

Possible techniques for three-dimensional displays include computer processing of data obtained from a series of B-scans (time is plotted as ordinate and azimuth as abscissa so that the brightness of the display indicates the intensity of the echo) to generate various views of tissue anatomy, acoustic holography, and optical processing of a series of B-scan images.

Ultrasonic signal processing

The final task group, in its report, presented an assessment of the future possibilities in the use of signal processing in medical ultrasound imaging technology and identified the most promising areas of research and development.

Recommendations of the group were divided into two classes according to whether they refer to signal processing associated with existing clinical ultrasound systems or to research tasks leading to new developments in the field.

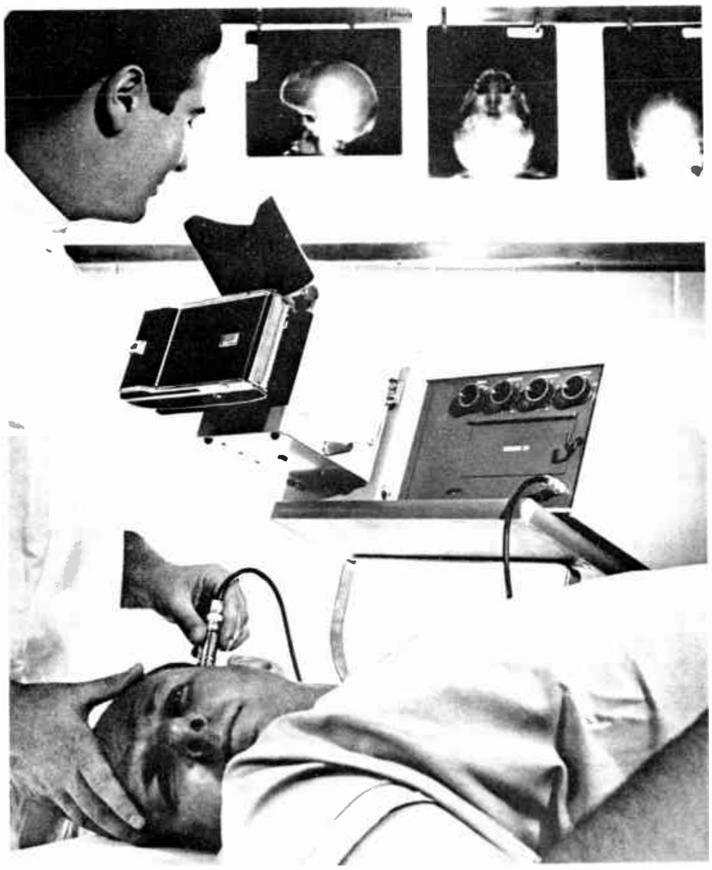
For existing systems, the following areas were identified: insertion of tissue identification information into the image, automated systems, storage of image information for playback with operator control of image parameters, and minimization of effects caused by frequency-dependent velocity and attenuation changes of tissue.

For the future, several tasks were pinpointed, including signal processing to identify normal and pathological tissue—the processing of scattered energy to evaluate surface and volume scattering (holography) and improvement in image quality using deconvolution and apodization techniques (selective weighting of signal values in one coordinate system with the intent of controlling the clustering of signal values in a transform coordinate system). Other tasks are multielement array control, focusing and manipulation, reduction of limiting effects of aperture and aberrating media to improve image quality, and design of transmitted signal and processor to increase the information in the image.

In the task group report, it was emphasized that the use of signal processing can enhance or retain information in the display image that potentially can give valuable clinical information to the physician. An example of a simple signal-processing improvement in this category is commercial pulse-echo systems that have the capability of displaying gray levels in the image. The gray level produced is a direct function of the received ultrasonic intensity and has the potential of producing additional clinical diagnostic information.

Further research and development in the areas identified by the task groups of the Alliance for Engineering in Medicine and Biology hopefully will lead to exciting breakthroughs in medical diagnosis in the years ahead, even though there may be problems and disappointments along the way.

Ultrasonic diagnosis is used for determining shift of mid-line structures of the brain. Such shifts are indicative of the existence of a blood clot or tumor. The instrument shown is the Ekoline 20 manufactured by Smith Kline Instruments, Inc., Palo Alto, California.



REFERENCES

1. Kikuchi, Y., "Development and present aspects of ultrasonic-cardiotomography," *Proc. Second World Congress on Ultrasonics in Medicine,*" Rotterdam, June 4–8, 1973. Amsterdam: Excerpta Med. Int. Congr. Ser. (in press).

2. Gramiak, R., "Cineultrasound cardiography," see Ref. 1.

3. Watanabe, H., "Development and application of new equipment for transrectal ultrasonotomography," see Ref. 1.

4. Lindgren, Nilo, "Ultrasonics in medicine," *IEEE Spectrum*, vol. 6, pp. 48–57, Nov. 1969.

5. "Perspectives for ultrasonic imaging in medical diagnosis," National Science Foundation, Washington, D.C., Nov. 1973.

6. "Medical instrumentation experiment," Pub. NSF 73-34, National Science Foundation, Washington, D.C., Nov. 1973.

7. "Interaction of ultrasonic energy with biological structures," Pub. No. N-1974-1, The Alliance for Engineering in Medicine and Biology, Chevy Chase, Md., Apr. 1974.

8. Barber, F. E., Baker, D. W., Nation, A. W. C., Strandness, Jr., D. E., and Reid, J. M., "Ultrasonic duplex echo-Doppler scanner," *IEEE Trans. Biomedical Engineering*, Vol. BME-21, no. 2, pp. 109–113, Mar. 1974.

9. Korpel, A., Whitman, R. L., Ahmed, M., Davies, H., Steele, P., and Barnes, F. S., "An ultrasonic image of arteriosclerotic deposits" (letter), *IEEE Trans. Biomedical Engineering*, vol. BME-21, no. 3, p. 171, Mar. 1974.

Fuses and circuit breakers: dispelling some myths

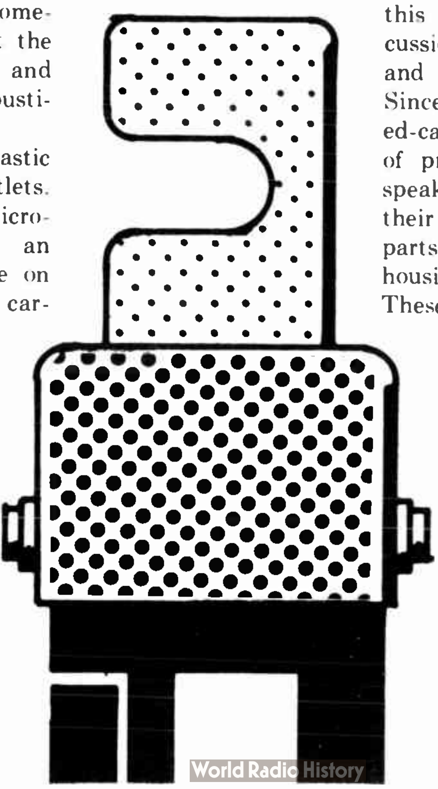
Both have advantages and shortcomings. For home and light commercial use, a hybrid fuse-breaker combination is recommended

A misconception tenaciously held by the general public is that systems protected by fuses or circuit breakers cannot suffer electrical fires unless the protective devices themselves are defective. This notion is neither correct nor easy to dispel. Without fuses and circuit breakers to protect electrical systems there surely would be more fires. However, whereas fuses and circuit breakers do greatly reduce the incidence of fires, there are many examples of fires that start without an abnormal flow of current.

An incandescent light having a normally lit filament is hot enough to ignite any combustible material in contact with it. The filament reaches a high temperature by design; but similarly high temperatures can occur in the circuit wiring or hardware by accident. If some defect in the wiring or equipment electrically connected to the circuit results in a line-to-line or line-to-neutral resistance of about the same value as a typical incandescent light, and if the heat produced by the current through that resistance is concentrated in a relatively small volume of material, the temperature of that material will rise and ignite contiguous combustible material. There is no protection against such an occurrence other than care and vigilance to prevent the defect.

A fire hazard can also exist when *abnormal* current flows in a circuit even if the fuse or circuit breaker is functioning properly. For example, bare metal parts of opposite polarity may make momentary contact with each other somewhere in the circuit. The metal at the point of the short circuit will melt and shower sparks that can ignite combustible material, and thus lead to fires.

Another hazard involves plastic parts of electrical appliances or outlets. Leakage currents of the order of microamperes and passing through an accumulation of dirt and moisture on the plastic insulation surface can carbonize a path between adjacent metal parts of opposite polarity. This process will continue with increasing current until massive carbonization takes place. Not until the insulation is already burning may the current be large enough to overload the protective device.



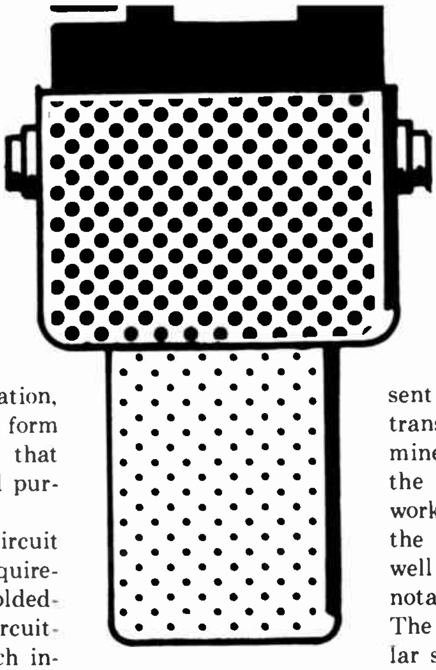
If mishaps can occur even with properly functioning fuses and circuit breakers, what then is the purpose of these protective devices? Ever since Edison invented it, the electric fuse (and later, the circuit breaker) has been designed to protect the insulation of undamaged wire, with a current rating corresponding to that of the fuse or circuit breaker, from catastrophic degradation due to heat caused by current overloads and short circuits . . . no more, no less.

The explanation of how fires can start despite a protected circuit resides in the concept of power density. A 15-ampere, 120-volt fuse or circuit breaker can deliver 1800 watts of power without exceeding the ratings for which it was designed to remain closed. If this power is distributed over a large volume with sufficient mass and cooling surface, a harmless heat balance will be established. On the other hand, if the power is concentrated in a relatively small volume having small surface area, the temperature of the material rises rapidly. As an example, neglecting heat loss, 1800 watts applied to one cubic centimeter of copper raises the copper's temperature 400°C per second, melting it within seconds and igniting any nearby combustible materials.

However, while such limitations in the protection afforded by fuses and circuit breakers can be worrisome, they can also be minimized, as this article will demonstrate. The discussion will be limited to residential and light commercial installations. Since, for these applications, the molded-case circuit breaker is the only type of protective device used, we will be speaking of circuit breakers that, as their name implies, have all their parts, except the terminals, enclosed in housings made of molded insulation. These devices are listed by Underwriters' Laboratories (UL), and are specifically designed to provide service-entrance, feeder, and branch-circuit protection in accordance with the National Electrical Code.

In the face of ever-present, if unlikely, fire hazards in protected circuits, a large measure of confidence

William H. Middendorf
University of Cincinnati



can be provided through UL testing and standards. All residential and light commercial electrical installations require approval by an inspection authority, and almost without exception, these authorities require any circuit-breakers and fuses employed to be listed by UL. Thus, the initial UL investigation, surveillance, and follow-up tests form an important part of the proof that these devices satisfy their intended purpose: to supply adequate protection.

To merit listing by UL, a circuit breaker must comply with all requirements of its "Standard for Molded-Case Circuit Breakers and Circuit-Breaker Enclosures," UL 489, which includes performance and accelerated life tests. A clear distinction must be made between molded-case and other types of circuit breakers with regard to UL testing. Only the molded-case type is subjected to the battery of sequential tests described. Such devices with 15–100-ampere ratings are designed to clear a 5000- or 10 000-ampere short circuit (by opening up) in one half cycle (1/120 second). Actually, they open mechanically in about one eighth of a cycle and extinguish the arc at the next current zero. Furthermore, the impedance of the circuit breaker's arc during the half cycle offers current-limiting action.

Protecting the insulation

A primary problem in discussing insulation life is that catastrophic destruction is not an acceptable end point. From a practical point of view, insulation life is considered to be over when the probability of electrical or mechanical failure increases to an unacceptable level. As a result, investigators have devised various tests to define end-of-life. All leave doubt as to their relevance to short-term real-life destruction. The problem is to determine the temperature limit of a high-current fault, for the short term, in such a way as to win general agreement that the probability of electrical or mechanical failure of the installed insulated wire will not increase measurably.

From available literature,[1,2,3,4] the conclusion can be drawn that 200°C is an acceptable short-time limit for insulation to withstand after a high-current fault cleared by a circuit breaker or fuse. This conclusion is verified by test results which will be presented later. To test the reasonableness of the 200°C temperature limit, the current and time (I^2t) necessary to produce this temperature in No. 12 American Wire Gage (AWG) copper wire were computed—200 amperes for 17.5 seconds. This size wire represents a worst case of temperature rise for a given current fault. It was found that the temperature of the wire's innermost insulation rose from 25°C to 200°C as predicted and then decreased to 100°C, in 68 seconds. Testing of the wire insulation's integrity after being allowed to return to room temperature did not show any surface or internal cracks.

To determine the extent of the damage, if any, done to an insulated conductor during a short circuit, research was performed at the University of Cincinnati to ascertain the temperature rise within and upon the surface of the insulation for various sizes of wires and cables when subjected to a high-current, short-time fault. An electrical analog network was used to represent the heat-transfer system, and the transient temperatures were determined using a computer to calculate the node voltages of the electrical network. This study took into account the specific heat of the insulation as well as the conductor. Other studies, notably Ref. 1, neglected the former. The results are consistent with a similar study by Goldenberg,[5] although several assumptions made in that work do not apply here.

For experimental verification, the transient temperatures on the outer surface of the insulation and within the insulation were measured by No. 40 American Wire Gage (AWG) copper and constantan thermocouples using minute drops of mercury to provide intimate contact with the insulation. Additional tests using No. 36 AWG thermocouples showed that the mass of the thermocouple did not appreciably affect the data. Further verification was obtained using a set of minute mixtures of liquid-crystal materials painted in bands around the wire. The bands change color at successively higher temperatures, and the temperature within the range of a single-mixture band can be estimated by noting the particular color (orange to blue).

A typical result of this study is shown in Fig. 1 which is for No. 12 AWG copper wire with polyvinylchloride (PVC) insulation 0.069-centimeter (0.027-inch) thick when subjected to a half cycle of 4000 amperes rms at 60 Hz. This is the expected value of let-through current when a 20-ampere circuit breaker is subjected to a short circuit with 10 000 amperes available. As can be seen in Fig. 1, the insulation temperature is well within the 200°C limit. According to the mathematical model, this limit is reached if 4000 amperes rms flows for 2.65 cycles or 9300 amperes rms flows for ½ cycle.

Experience from UL tests, as well as calculated temperature-rise and direct measurements, show that PVC insulation does not reach a dangerous temperature during high-current faults when the wire is protected by an appropriate fuse or circuit breaker.

The hybrid approach

Although both fuses and circuit breakers limit to various degrees the magnitude of the current during a short circuit, the value reached is a function of the current available from the source. Improvements made on distribution transformers have resulted in lower internal impedance and higher available current in their output terminals during a short circuit. Paragraph 230-98 of the National Electrical Code addresses itself to this problem by stating: "Service equipment and its over-current protective devices shall have short-circuit current rating equal to or greater than the available short-circuit current at its supply terminals." As a consequence, a number of utilities and inspection agencies are requiring residential installations to use equipment having an interrupting rating of 10 000 amperes or more.

Five thousand-amperes interrupting capacity (abbreviated AIC) is required by UL for circuit breakers having a full-load rating of 15–100 amperes; however, within the past year, 10 000-AIC circuit breakers have become the industry standard and are made to fit the same mounting method. Circuit breakers with a full-load rating above 100 amperes are required by UL to have a 10 000-ampere interrupting rating. Panelboards having 10 000-AIC main and branch circuit breakers are suitable for circuits having available fault currents of 10 000 amperes or less without further testing.

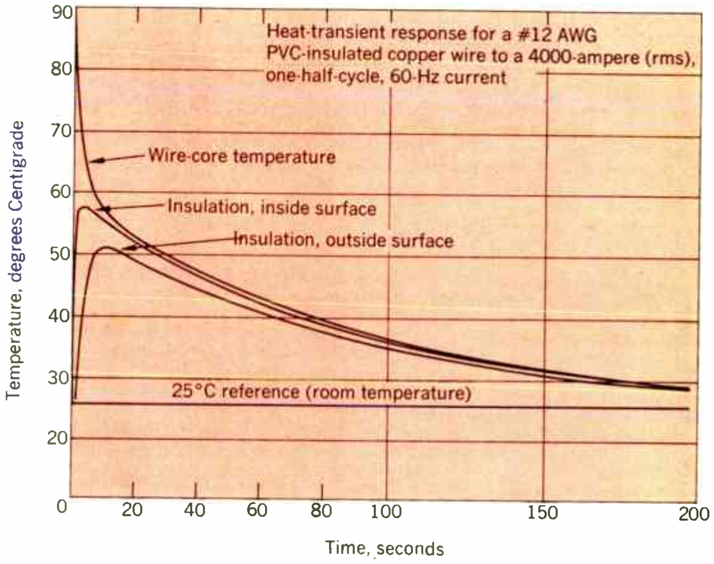
Some economy can be effected by using protection devices in series. For example, in panelboards having an overall (main) circuit breaker and branch circuit breakers, it is possible to show by tests that a 22 000-AIC main circuit breaker and 10 000-AIC branch circuit breakers in combination perform satisfactorily on circuits having more than 10 000 amperes available. The upper limit must be determined for specific combinations of circuit breakers. The National Electrical Manufacturing Association (NEMA) standard for panelboards, PB1-1971, includes a test procedure that manufacturers can use as the basis for self-certification of a protective system for high-current interrupting ability. Furthermore, UL is presently developing a similar test procedure.

As one considers the alternatives available to protect residential wiring, the possibility of using fuses as the main protective device and circuit breakers as the branch circuit protection comes to mind. This is especially attractive if the use of current-limiting main fuses would permit the use of branch circuit breakers with a 10 000-AIC rating in installations where the available current greatly exceeds 10 000 amperes. In normal installations, the main protective device very seldom trips; thus, it is not likely to cause inconvenience.

Current-limiting fuses and molded-case circuit breakers have been used for some time in industrial applications. The conclusion reached by studies[6,7] almost two decades ago was that the current-limiting-fuse/circuit-breaker combination affords a method of effecting economies in distribution systems when the problem of protecting against increased short-circuit current appears. Industrial systems are much more varied and they involve problems that do not exist in the installations being considered here. It is reasonable, therefore, to consider the introduction of the current-limiting-fuse/circuit-breaker combination into industrial systems as a precursor to its use in residential and light commercial systems.

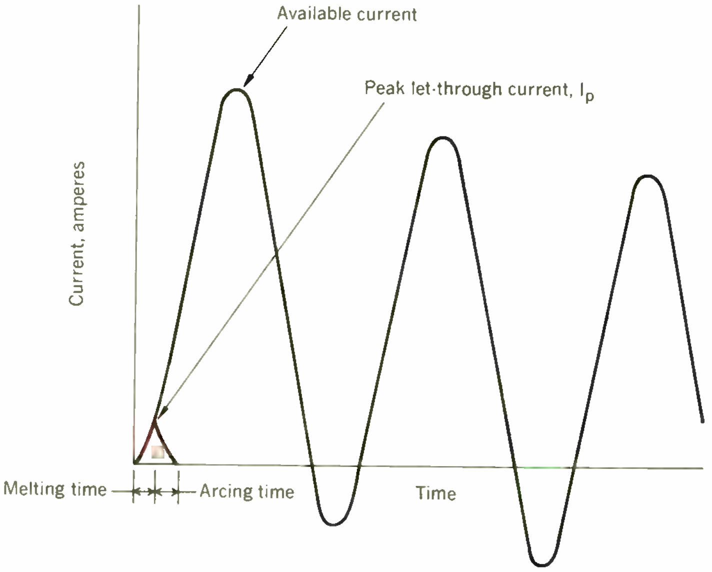
A matter of class

Fuses are made in a number of class designations depending upon their operating characteristics and configuration. Classes G, H, J, K, L, and R power fuses will be discussed. Those fitting the standard National Electrical Code mounting means, and thus could be placed in panelboards presently made for residential and light commercial installation, are class H units having 10 000-ampere interrupting ratings and class K devices having interrupting ratings of 50 000, 100 000, and 200 000 amperes. The class K fuses truly limit the fault current; that is, above some threshold value, they limit the peak current to less than would occur if the fuse did not rupture, and they limit the duration of the current to less than one half cycle. Fig. 2 shows an ideal current pulse through a current-limiting fuse during a short circuit. It is nearly triangular in shape and of considerably less dura-



[1] Temperature variation of conductor and its insulation after a short circuit trips a 20-ampere circuit breaker in a circuit with 10 000 amperes available. Note that within one minute after the circuit breaker operates, the temperature rise from innermost-insulation part to the outermost part is substantially the same—16° to 17°C—and is well within the 200°C limit given for PVC insulation.

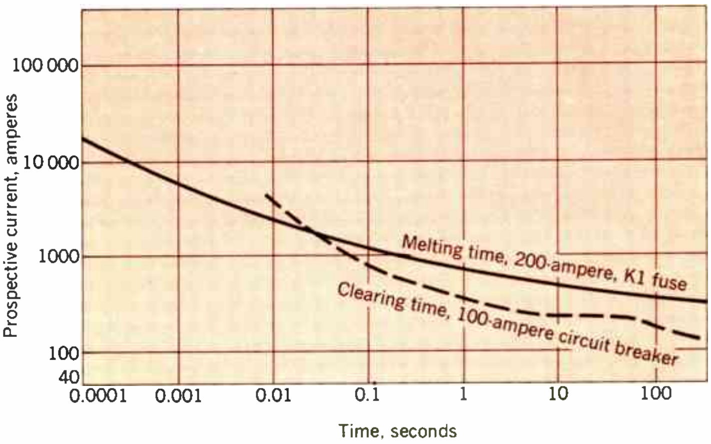
[2] An ideal current pulse through a current-limiting fuse during a short-circuit condition. The pulse is nearly triangular in shape and is considerably less than one half cycle in duration.



tion than one half cycle.

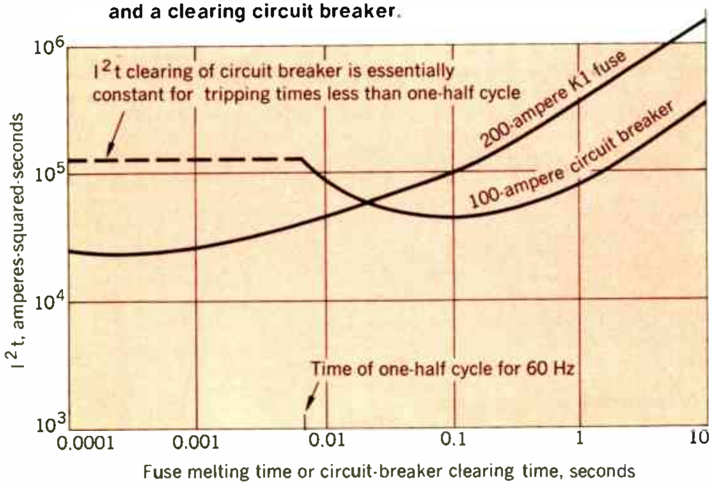
There are three subclasses of K fuses called K1, K5, and K9. The K1 fuse has the greatest current-limiting ability; the K9 has the least. The disadvantage of the class K fuses is that the less expensive class H fuse which is not current limiting can be substituted for it. Thus, any system that relies on the current-limiting ability of the class K fuse is vulnerable to defeat by improper replacement of the fuses. In recognition of this fact, paragraph 240-23(b) of the National Electrical Code states in part: "Fuseholders for current-limiting fuses shall not permit insertion of fuses which are not current-limiting." And UL does not permit the K fuses to be labeled "current limiting."

Classes G, J, and L fuses satisfy the noninterchangeability requirement of current-limiting fuses by having dimensions that prevent replacement by H fuses. Of these, the J fuse which is rated at 30–600 amperes and 600 volts or less is of interest here. The electrical characteristics of the J fuses are almost identical to the K1 fuses. For the experimental work that will be reported, K1 fuses were used to permit the use of standard, off-the-shelf panelboards. However, the conclusions reached as the result of the tests should be accepted as also true for J fuses.



[3] Comparison of fuse melting time and circuit-breaker clearing time. The fuse curve can be used (in conjunction with the circuit-breaker tripping characteristics shown by the dashed line) to determine that it will be spared from interrupting on normal overloads and will open in considerably less than one half cycle on all currents greater than the interrupting rating of the circuit breaker.

[4] Comparison of let-through energy, I^2t, for a melting fuse and a clearing circuit breaker.



A new class of fuse, the R (rejection) fuse, is presently in limited production. Its dimensions are the same as the H and K fuses but one end has a groove (0–60-ampere rating) or a slot (61–600-ampere rating) to enable fuseholders to be designed to accept class R fuses and reject class H fuses. The electrical characteristics of the class R fuse specified by UL when tested on short-circuit faults with 50 000 or 100 000 amperes available are identical to the class K5 fuse; that is, they are not as effective in limiting the fault current as class K1 fuses.

Picking the best bet

This broad menu of fuses raises the question whether or not a particular fuse will perform satisfactorily with a designated circuit breaker. In the absolute sense, this can only be decided by an extensive number of tests of fuse-breaker combinations. However, guidance for making selections of combinations with a high probability of success can be obtained from a study of the phenomena involved. It is, of course, important that the fuse and circuit-breaker combination perform satisfactorily over the whole spectrum of fault currents from slight overloads to bolted short circuits.

For a fuse to have current-limiting characteristics, the peak let-through current (I_p) and the maximum clearing I^2t (not to be confused with melting I^2t which is always shorter) must not exceed values specified by UL when the fuse is tested on circuits having values of available current between two specified points. These are the points where current-limiting operation begins and the 100 000-amperes point—or a value corresponding to the fuse's interrupting rating if it is less than 100 000 amperes. The I^2t is an especially important number. It not only represents the heat energy delivered to the fuse (or any other resistive element in the circuit) during the total clearing time, but it is also proportional to the change of momentum—i.e., the impulse, given to side-by-side, current-carrying parts.[8] Tests have substantiated the close correlation between the I^2t of the fault and the mechanical stress imposed upon the panelboard.

Fuse manufacturers usually publish curves of melting time of the fuse links versus current (Fig. 3). Such curves should be used first to determine (in conjunction with the circuit-breaker clearing characteristics shown by the dashed line) that the fuse will be spared from interrupting on normal overloads and will open in considerably less than one half cycle on all currents greater than the interrupting rating of the circuit breaker. This later condition is assured if the crossover point is at a time close to but greater than 0.0083 second. As a second step, the melting-I^2t-versus-time curve can be plotted from the data of Fig. 3. A typical result is as shown in Fig. 4. The important part of this curve is that portion for times less than 0.01 second since this represents approximately one-half cycle of 60-hertz current.

If the value of I^2t of the fuse in question as given by

It all started with Edison

Patent No. 227 226 issued May 4, 1880, to Thomas A. Edison states in part: "In other applications for patents made by me I have shown a safety device for preventing an abnormal flow of current through any branch. This safety device consists of a piece of very small conductor interposed in the main conductors of a house or in the derived circuit of a lamp . . . This small conductor has such a degree of conductivity as to readily allow the passage of the amount of current designed for its particular branch (wire) but no more. If, from any cause whatever, an abnormal amount of current . . . is diverted through a branch the small safety wire becomes heated and melts away breaking the overloaded branch circuit. It is desirable, however, that the few drops of hot molten metal resulting therefrom should not be allowed to fall upon carpets or furniture and also that the small safety conductor should be relieved of all tensile strain; hence I enclose the safety wire in a jacket or shell of non-conducting material . . ."

This patent is entitled "Safety Conductor for Electric Lights." The term "electric fuse," which in those days meant an electrically fired detonator, was not associated with the protective device until some time later.

The excerpt from Edison's patent tells with simplicity and clarity how a fuse is made, what it is supposed to do, and how it operates. Based upon this patent, upon his earlier use of a protective wire, and especially upon his vigorous continued development of the device, Edison is credited[1] with the invention of the safety fuse.

Early patent literature shows many designs that were forerunners of the circuit breaker. Automatic switches to disconnect the source of power in the event that an electric gas-lighter became grounded were the subjects of many patents in the early 1880s. However, on March 30, 1886, a patent entitled "Automatic Safety Circuit Controller" (338 752) was issued to O. F. Jonsson, a citizen of Sweden. As far as can be determined, this was the first circuit breaker developed expressly to protect branch circuit wires. The disclosure states: ". . . placed in a derived (branch) circuit in which are incandescent lamps in order to protect this circuit from destruction in the event of a short circuit." The mechanism was very simple: two leaf springs hooked together for closed-circuit operation were disengaged by an electromagnet upon occurrence of an overload.

The advantages of having protection for the distribution wires within a building were obvious to the pioneering engineers of the latter part of the nineteenth century. Intensive research and development followed the initial inventions so that by 1900 Joseph P. Sachs, who later was to become one of the most prolific inventors of American industry, was able to write a comprehensive article[2] about commercial fuses giving details of construction, operational characteristics, and comments on quality control. Listing by Underwriters' Laboratories[3] (UL) signals a recognized degree of maturity for a product. This event came surprisingly early. According to records now available at UL, fuses were tested and listed by that organization in 1898 and circuit breakers in 1901.

---

[1] Sachs, J., "The evolution of safe and accurate fuse and protective devices," *AIEE Trans.*, vol. XVII, pp. 131-203, 1900.

[2] Sachs, J., "The evolution of safe and accurate fuse and protective devices," *IEEE Trans.*, vol. XVII, pp. 131-203, 1900.

[3] Middendorf, W. H., "Standards—the evidence of concern," *IEEE Spectrum*, vol. 8, No. 8, pp. 70-74, August 1971.

Abbreviated UL 489 tests for UL listing (all tests are performed in sequence)

Circuit breakers

1. *200-percent calibration.* Circuit breakers rated 0–30 amperes must trip in 2 minutes; 31–50 amperes in 4 minutes; 51–100 amperes in 6 minutes, etc.
2. *125-percent calibration.* Circuit breakers rated 0–50 amperes must trip in 1 hour; higher ratings in 2 hours.
3. *Overload.* Circuit breaker is opened and closed 50 times with 600-percent current (not less than 150 amperes) and 0.45 to 0.50 power factor.
4. *Temperature and 100-percent calibration.* Circuit breaker terminals shall not rise in temperature more than 50°C when carrying rated current continuously, and shall not trip. This test is performed without an enclosure.
5. *Endurance.* Circuit breakers rated 100 amperes or less are operated 6000 times at rated current and 0.75–0.80 power factor; and 4000 times with no load. Similar tests are performed on higher-rated circuit breakers.
6. *200-percent calibration.* Repeat test 1.
7. *125-percent calibration.* Repeat test 2.
8. *Short circuit.* This most-important test is performed with the circuit breaker mounted in the smallest enclosure it is to be used in and connected to the electrical supply with commercially available insulated conductors of corresponding rating. A cotton pad is placed immediately in front of the operating handle and a cheesecloth in the enclosure. A minimum of three short circuits are initiated at 5000 amperes for circuit breakers rated 0–100 amperes and 10 000 amperes for ones rated 101–800 amperes. Supplementary tests can be run to qualify a circuit breaker for various higher interrupting ratings. Molded-case circuit breakers used in residential panelboards are available with interrupting ratings to 65 000 amperes. Any mechanical or electrical failure, conductor-insulation damage, arc to ground, or igniting of the cotton pad or cheesecloth either during or after this short-circuit test constitutes a failure of this test.
9. *Trip-out.* Circuit breaker must operate successfully on 200 percent of rated current.
10. *Dielectric potential.* Circuit breaker must withstand twice the rated voltage plus 1000 volts between line and load terminals while open; as well as between terminals of opposite polarity and between live parts and ground while closed.

Fuses

1. *Temperature and 100-percent calibration.*
2. *135-percent calibration.*
3. *200-percent calibration.*
4. *Short circuit.* These tests are equivalent to the corresponding circuit-breaker tests except for the fact that each test is performed on a separate fuse (the fuse link is destroyed each time a test is performed). Short-circuit tests are performed over ratings of 10 000 to 200 000 amperes.

a curve similar to Fig. 4 is substantially less than the I^2t experienced by the circuit breaker on the UL short-circuit test, the fuse-breaker series combination will probably withstand the short circuit. To get an easy number to remember, 4000 amperes rms for one half cycle gives an I^2t of 125×10^3 amperes-squared-seconds.

Some factor of safety should be considered since the fuse data of Figs. 3 and 4 are for melting time and not for total clearing time. Also, the I^2t obtained from UL tests on molded-case circuit breakers occurs over a duration of one half cycle whereas for a current-limiting fuse operating within the limiting region, the pulse duration is less. On the other hand, a circuit breaker can undoubtedly survive faults of higher I^2t than experienced during the UL tests. Moreover, the current-limiting fuse and circuit breaker acting together to produce a double break in the circuit gain an advantage similar to that previously mentioned for the 22 000-AIC main circuit breaker and 5000-AIC branch circuit-breaker systems.

Verification tests were run to substantiate the theoretical considerations given above. The first series involved panelboards having commercially available 100–200-ampere K1 fuses for main protection and 15–100-ampere 5000-AIC circuit breakers for branch protection. The current available at the panelboard line terminals was 50 000 amperes. The expected peak currents for the 100- and 200-ampere fuses were 11 000 and 13 000 amperes, respectively, and both had an expected melting I^2t of about 50 000 amperes-squared-seconds. This information was obtained from catalog data.

The results were excellent. For each test, the total clearing I^2t was much lower than the 125×10^3 amperes-squared-seconds associated with the short-circuit test of the typical circuit breaker and, in fact, was lower than the expected melting I^2t—from 23.5×10^3 amperes-squared-seconds for the 100/15-ampere fuse/breaker combination to 38.2×10^3 amperes-squared-seconds for the 200/100-ampere fuse/breaker combination. This is at least partially due to the impedance of the circuit breaker, the panelboard, and the four-foot test leads whose size corresponds to the rating of the branch circuit breaker. The absence of a loud report of expanding gas and the slight flash of visible light indicated that the mechanical and thermal stresses on the branch circuit breakers during these tests were considerably less than during the standard UL 5000-ampere short-circuit test.

More-extensive tests were run by the Dayton Power and Light Company. These involved 100 and 200-ampere panelboards from several manufacturers. Available symmetrical currents of 12 950, 15 760, and 25 620 amperes were used. The test rig allowed a removable cover of the main switch, which acts as the fuseholder, and disconnecting means to be inserted but not retained. This was meant to determine whether or not the cover would be expelled by expanding gas during the current fault. The rig also allowed the removable cover to be inserted in a hesitating fashion (jiggle test) to determine if lack of skill in inserting the pull cover would result in undue damage. In all tests, the K1 main fuses and the 5000-AIC circuit breakers performed excellently. On the other hand, similar tests conducted using H fuses left no doubt that these fuses must not be used on circuits where the available current exceeds the 10 000 amperes for which they are rated.

Tests were also run with class R main-fuse-branch-circuit-breaker systems having 15 000, 25 000 and 50 000 amperes available at the panelboard terminals. The class R-fuse-breaker system did not operate as well as systems using K1 fuses. This is to be expected in view of class R fuses having less current-limiting ability than class K1 fuses. Considerable expansion of gas and flashing resulted with class R fuses in the system, but there was no major destruction.

The above tests show that technology is available to produce main-fuse/branch-circuit-breaker protective systems that will give excellent protection to residential installations against high-current faults.

There is strong indication, based on testing, that K1 (or J) fuses perform excellently and that R fuses can be satisfactory as current-limiting main fuses with molded-case branch circuit breakers, even when used on circuits with higher available fault currents than are likely to be encountered in residential installations.

Today, many installations are well within the 5000- and 10 000-ampere limits of available current readily covered by the "standard" all-circuit-breaker panel. Furthermore, some utilities have stated the policy of limiting the available current at single-family residences to 10 000 amperes; however, others have not and the fact remains that policies can be changed. It is prudent to make the new installations capable of meeting possible future requirements, if this can be done without significant economic disadvantage. Indications are that it can be.

REFERENCES

1. *Short Circuit Characteristics of Insulated Cables.* Belmont, Mass.: Insulated Power Cable Engineers Association, pp. 32–382.

2. Lewis, A. D., "Head resistance characteristics of primary wire insulation," Automotive Engineering Congress, Detroit, Mich., January 11–15, 1971. SAE Paper 710094.

3. Doyle, C. D., WADD Technical Report 60-283, Aeronautical Systems Division, Wright Patterson AFB, Ohio, 1960.

4. Bear, E. (Ed.), *Engineering Design for Plastics.* New York: Reinhold, 1964.

5. Goldenberg, H., "Calculation of transient heating in single-core cable dielectric," *The Engineer*, vol. 197, pp. 779–80, May 28, 1954.

6. Jacobs, P. C., "Current-limiting fuses: their characteristics and applications," *AIEE Trans.*, Pt. III, vol. 75, pp. 988–993, 1956.

7. Carlson, M. S. and Edmunds, W. H., "Coordination of current-limiting fuses and low-voltage air circuit breakers," *AIEE Trans.* Pt. III, vol. 75, pp. 1038–48, Oct. 1956.

8. Kaufmann, R. H. "The magic of I^2t," *IEEE Trans. Industry and General Applications, vol. IGA-2, pp. 384–392, Sept.*/Oct. 1966.

William H. Middendorf (F) is a consultant and director of engineering and research for the Wadsworth Electric Manufacturing Company. A member of the teaching staff at the University of Cincinnati since 1948, Professor Middendorf's principal areas of interest are design methodology and engineering management. In addition, he is a member of the General Engineering Committee of the Low-Voltage Distribution Section of NEMA and a member of three of UL's Industry Advisory Councils.

Dr. Middendorf received the B.E.E. degree from the University of Virginia in 1946, the M.S. degree from the University of Cincinnati in 1948, and the Ph.D. degree from the Ohio State University in 1960. He holds 26 patents, has published numerous papers, and is the author of three books.