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articles

departments

the cover

Symbolic of the article by Walter MacAdam, "Megawatts from municipal waste," p. 46, is this flaming assortment of household refuse collected and incinerated for the occasion by Art Director Herb Taylor.

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Troubleshooting with oscillographs

Classic in concept, the light-beam recording oscillograph preserves multichannel data for detailed examination

What's the most often used, most cost-effective piece of electronic test gear? Ask any veteran of hardware design, and chances are the oscilloscope gets the cigar every time. The scope's reputation as a troubleshooting tool has evolved to where no self-respecting electronics engineer would be without one. Today's high digital data rates and analog working frequencies only enhance the oscilloscope's importance because it is the one device that allows waveshape observation in "real time." But popularity aside, the standard oscilloscope does have some important, and often overlooked, limitations—limitations *not* shared by modern versions of the oscilloscope's predecessor, the light-beam recording oscillograph. Although they look (and operate) much like strip chart recorders, oscillographs have much wider bandwidths. Their low-mass galvanometers make real-time hard copy at 10 kHz practical, while strip charts commonly conk out below 100 Hz.

Where scopes come in second

Any finite display screen will exhibit limits in resolving power. With scopes, this is essentially a tradeoff between screen size and sweep speed. Often there is a need to look at a long stream of data and see each of the individual events as well as the entire train. For example, if 1000 events occur over a one-second interval and the entire train is displayed on a standard 12.7-cm screen, there will be 79 pulses per centimeter. With that density, it is extremely difficult to discern any individual event. Should some anomaly be suspected on the skirt of a pulse 100 counts downstream, and all are of equal amplitude, the problem is further compounded because a standard oscilloscope cannot trigger at the exact spot where a more detailed look is desired.

The need to monitor more than one point in time can also present a problem for the standard oscilloscope. Timing between events occurring at two or more points is usually critical in digital logic, as well as in any analog control system. Since points of interest may have repetition rates that are not harmonically related, a dual-channel scope must also have the ability to sweep simultaneously at two different speeds in order to capture the desired data. If the data are noncyclic in nature, a memory or storage-type oscilloscope—including a delayed trigger—will be required. Setup time can be long and frustrating.

Another limitation of the normal scope is channel capacity. By expanding the previous example to include *three* channels of data, each having a different time base, and with timing measurements to be made between events in all three channels, there is no way a standard scope can perform the desired task. (The data may be analog, digital, or a combination.)

Such snags can be overcome by an almost forgotten instrument—the light-beam recording oscillograph. And the oscillograph delivers a hard-copy record of the data as a bonus!

Then and now

Though used extensively by engineers during the early aerospace era for gathering data, the oscillograph's complexity prevented its use as a general-purpose lab tool. Perhaps the most serious operational difficulties engineers confronted were impedance matching and damping problems. The oscillograph's galvanometers had to be selected from a long list of sensitivity and frequency response specs that were in turn matched with the signal under investigation. One mistake or transient and the galvanometer was burned out. The writing medium was photosensitive paper or film requiring darkroom processing.

Recording oscillographs have come a long way since then. Today, oscillographs are as easy to operate as oscilloscopes. They have plug-in signal conditioners with front-panel controls calibrated in volts/cm of deflection and high input impedances compatible with most scope probes. Daylight-load direct-print papers allow the image to develop in normal room light.

Perhaps the best illustrations are applications that highlight oscillograph capabilities. Note that an oscilloscope *could* be used too, but in each case data collection would prove more difficult and time-consuming.

In each example, the requirement is to see more than two channels of information. The data consist of events occurring rapidly over a long period of time (relative to any individual event). It is important that each event be displayed in enough detail that pulse width, amplitude, and shape can be examined with respect to activity on the other channels occurring at the same time. These requirements, and the need to study an entire data train from beginning to end, seriously restrict the use of a scope.

However, note that an oscillograph is not intended for tracing faults to a particular circuit component. By displaying data sequences with respect to each other, and with respect to time, the presence, absence, or shape of a particular pulse is usually indicative of the overall problem. Its source may be found later with standard signal-tracing techniques.

Case of the crashing card reader

The first example involves an optical card reader system reading a dual-bar code and producing errors

Steven Krause Bell & Howell

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spectral lines

Judging the judges

Peer review, a subject of perennial interest to authors and editors, is once again in the headlines. This time the subject merited the interest of the U.S. Congress, which wondered if the National Science Foundation's use of the peer review process in helping award grants is fair and efficient. The premise of the Congressional look-see was that perhaps Congress itself should assume more of a role in the review process. Underlying the probe was the feeling that the peer review process is not perfect, that reviewers can be biased, that they may be in conflict of interest, or that they may misuse their anonymity. While all of these suppositions may, on occasion, be true, no one has yet proposed a clearly superior system. Harold Davis, editor of *Physics Today,* in commenting on the Congressional probe, puts the onus on the agency program officers to deal with the hazards of conflict and bias that may occasionally arise—a delegation of responsibility with which we must agree. (There is a clear parallel between refereeing papers and awarding grants—in neither case does the final decision rest with the reviewers.)

As editors, our parochial interests lie in the area of peer review for journal publication. Commenting on this process, Glenn Engen, a senior research scientist for NBS, asks some pointed questions about the concept itself—questions that echo the Congressmen's concerns: "Who determines the makeup of the 'peer' group? Is this wholly the prerogative of the editor? If so, what basis for selection does he use? Is it merely a list of those who have indicated a willingness to read certain papers? Supposing a member of the 'peer' group decides to write a paper, how is it going to be reviewed?" Dr. Engen goes on: "In a slowly evolving technology, there is perhaps a chance for a 'peer group' to become well defined. A major breakthrough, however, can completely upset the 'peer' relationships. Too often one barely has a chance to achieve 'peer' status before becoming technically obsolete."

Dr. Engen, who himself has served as an associate journal editor and member of an editorial review board, and who has authored some 30 published papers, observes that the existing review "system" is strongly oriented toward either resolving controversial ideas prior to publication or else rejecting the papers. This, he feels, is because most reviewers consider their approval for publication tantamount to personal endorsement of all ideas contained therein, standard disclaimers notwithstanding.

This is unfortunate, Engen feels, since most breakthroughs are likely to embrace elements of controversy. He recalls hearing a distinguished scientist tell of his problems in getting certain of his views in print because they took issue with those of an even more eminent scientist. All attempts to get the reviewers to identify the errors in his logic, or argue the case on its merits, were futile. The moral, says Engen, is that "in science, as well as religion, there are some who are much more concerned with defending their chosen authorities than in investigating the subject matter itself."

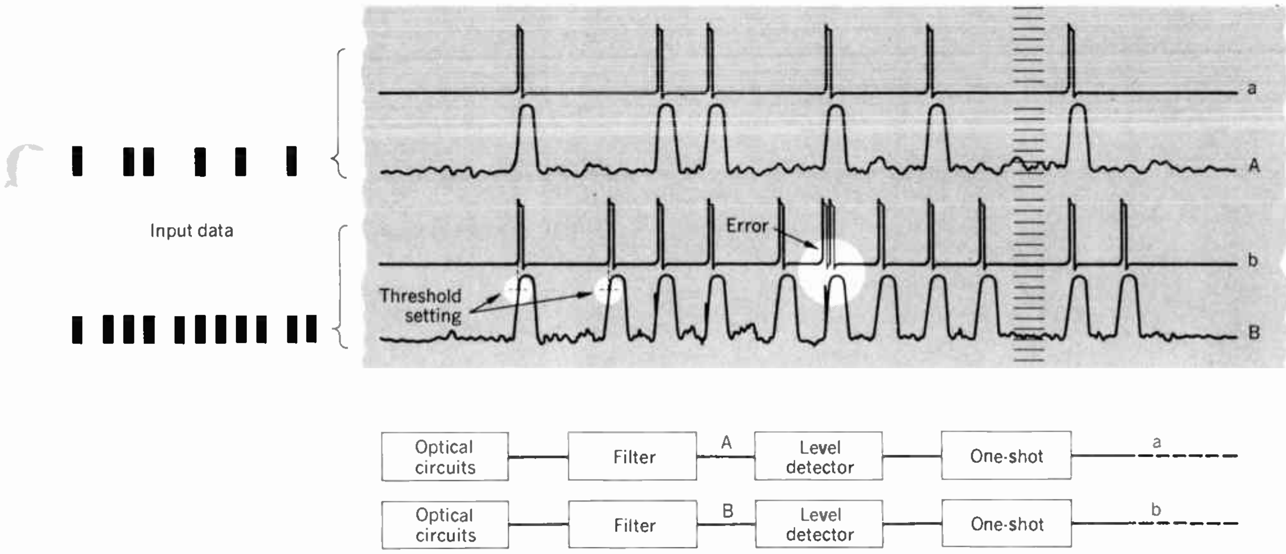
Addressing himself once again to the "breakthrough" paper, Engen observes: "If a paper calls for a reexamination of the existing practice, or tends to render it obsolete, the going can be tough. And if a paper truly represents a breakthrough, but requires some length for a proper exposition, it may be rejected on the basis of length considerations alone." Engen gives a bit of good advice when he suggests that if the author has reasons to believe that the publication of his paper may be at odds with other vested interests, he let the editor know before he assigns reviewers to it.

Anonymity of reviewers is another point for debate. Andrew Sekey of Tel-Aviv University proposes a campaign for the voluntary signature of reviews, believing that a referee who lives up to his obligation—that is, who prepares a thorough, fair, and constructive review—need have no misgivings about disclosing his identity even though he may recommend rejection. "Only the confirmed debunker, the ultraconservative, the notoriously lazy, or the like need be afraid of facing his 'victim' one day," Dr. Sekey observes. Yet even he would agree to foregoing the signature of a reviewer reviewing his boss's (or professor's) paper.

Because *Spectrum's* charter is significantly different from that of journals such as *Proceedings* and *Transactions* of the IEEE, the implications of peer review are somewhat different. For example, we are seldom, if ever, dealing with "first disclosure" or breakthrough papers. Thus, our peer reviewers are not burdened with the task of judging the merits of a claimed breakthrough, or searching for hidden ones.

Nevertheless, *Spectrum* can attest to the legitimacy of the concerns expressed by readers Engen and Sekey. For example, a surprising number of authors attack reviewers because of imagined lack of credentials ("the reviewer must be out-of-field," or "retired for several years," or "lacks industry experience"). Furthermore, an occasional author will maintain that a reviewer whose expertise is unchallenged was out-of-form the day he found fault with the author's own manuscript. As for reviewers, a disturbing number attack authors for failing to have the proper credentials, or at least for failing to reveal them. Some studiously avoid addressing the content of the manuscript itself, if, in their opinion, the author fails to pass the credentials test, a manifestation of elitism that is not always constructive.

So the selection of reviewers remains a sensitive art. The peer review system may be the best we have, but, in the perception of many authors, at least, the peer reviewer is seldom peerless. *Donald Christiansen, Editor*



[1] An oscillograph simultaneously monitoring two pairs of points in an optical card reader circuit can record the effects of unwanted noise. When spikes on the positive-going signal skirts (optical circuit output) exceed the level detector's threshold setting, an error pulse is produced by the one-shot. Amplitude reference gridlines on the chart paper are calibrated in volts/cm.

at its output (Fig. 1). For test purposes, standard scope probes connect the oscillograph to both the optical sensor outputs and the outputs of the one-shots triggered by the optical circuitry. Pulse widths are between 1 and 5 ms occurring at about 500 per second, and it is necessary to study this entire noncyclic pulse train, as well as individual pulses.

Initial oscillograph chart recordings indicated that the level detector thresholds were set too low. It is easy to find the initial threshold voltage settings because the time when the one-shots fire can be correlated to a particular point (voltage) on the input signal's positive-going slope. Readjusting the threshold level reduced the number of errors, but did not completely eliminate them.

A second record—run at a higher chart speed—showed that the one-shots were sometimes "triggering" twice on one input. The false trigger was coincident with noise appearing on the positive slope of pulses coming from the optical circuits. By redesigning the filter between the optical circuits and the level detectors, these errors were eliminated. Now the threshold voltage could be reset slightly above the normal background noise for even greater reliability.

Blocks blocked by self-acknowledge

Example 2 involves a remote-terminal mark-sense card reader transmitting data through a Bell 202C modem, half duplex, via telephone lines to a mainframe computer several hundred miles away (Fig. 2). The data rate was 1200 baud transmitted in blocks of 960 characters. After the first two blocks of data were transmitted, the time between blocks went from less than 2 seconds (normal condition) to 10 seconds or longer (abnormal condition).

An oscillograph was connected, via standard oscilloscope probes, to the terminal side of the modem. The four points monitored were "BA" (data transmission), "BB" (data received), "Carrier," and "Clear to Send" per RS 232 standards. A record was made from the time communication was first established with the computer until after the fourth block of data had been transmitted. Chart speed was kept low during this first test, since only the presence or absence of pulses was being determined.

Analysis of the resultant record indicates that the first block of data was transmitted normally:

- Poll from computer
- Clear to send received
- Transmitted first 960-character block from terminal
- Computer acknowledged
- Clear to send received
- Terminal transmitted double EOT (end of transmission)

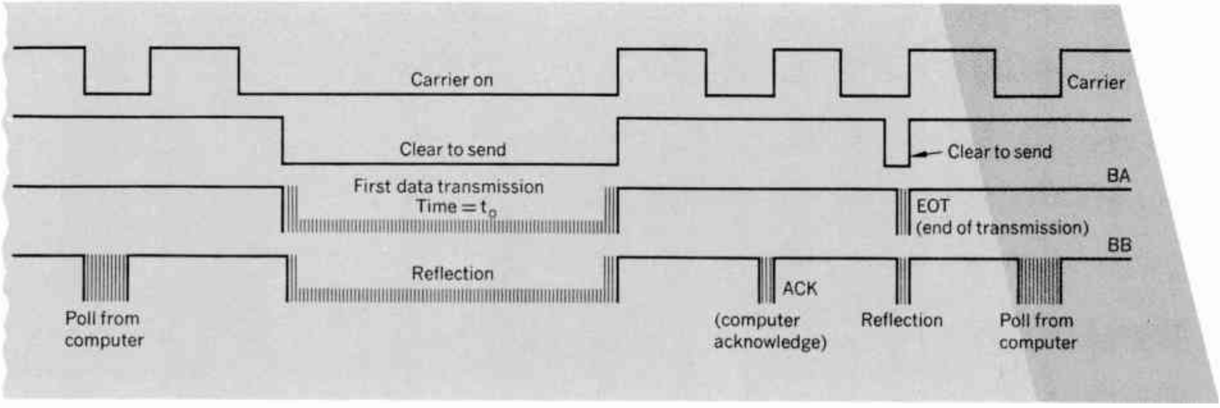
But the second block includes some serious deviations:

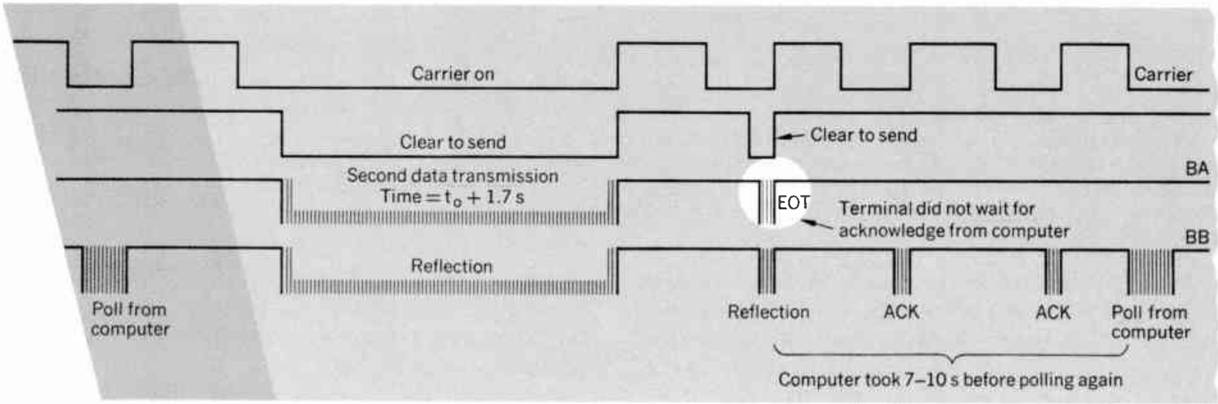
- Poll from computer
- Clear to send received
- Transmission of second 960-character block 1.7 seconds after the first block
- Clear to send received
- Transmitted double EOT *without waiting for computer acknowledgement*
- Computer acknowledged
- Computer acknowledged again
- Poll from computer after time lapse

The data transmitted to the computer were reflected down the BB line during transmission and loaded into the terminal receive buffer. A second oscillograph record run at 127 cm/s indicates that the last characters in the data transmission are the same as those the computer normally sends back to the terminal as an acknowledge signal.

Since the terminal was not clearing its receive registers at the end of each transmission, it appeared that an acknowledge signal had been received and the terminal proceeded with its routine (requesting to send and transmitting the double EOT). When the computer finally did acknowledge, the terminal was no longer looking for that signal and communication was temporarily broken. After about 10 seconds, the computer polled the terminal and the sequence began again.

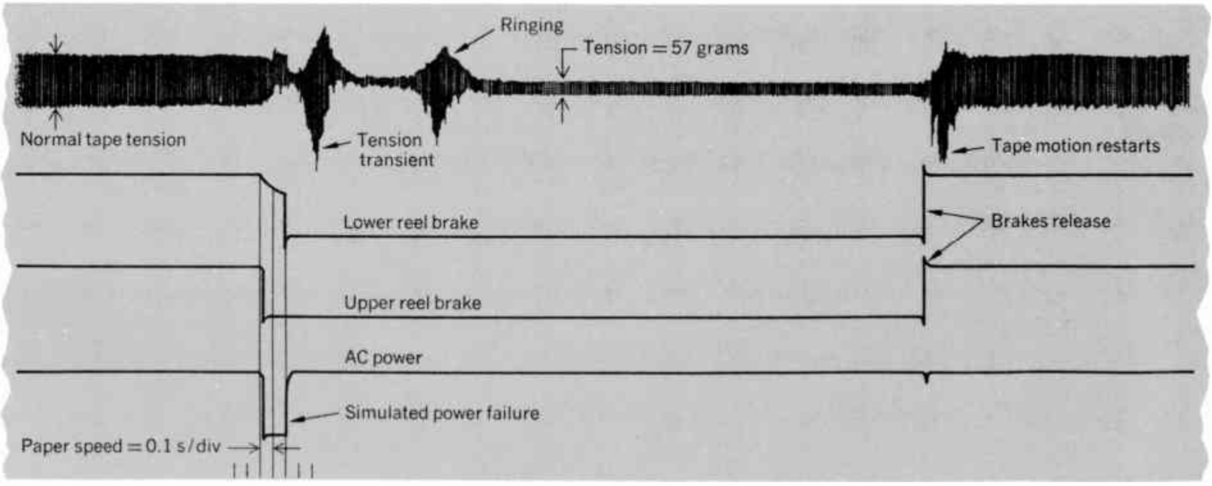
The mysterious delays were traced to the terminal,





[2] Delays in data transmission between a mark-sense card reader (remote terminal) and a mainframe computer are documented by the oscillograph. The problem was traced to the terminal's receive registers, which were not clearing at the end of each transmission.

[3] Tape tension transients encountered during a simulated power failure are monitored during the operation of an instrumentation tape recorder. The oscillograph record preserves key analog events—and the timing between each—from the moment of power interruption until tape motion returns to normal.



absolving the modem, phone lines, and mainframe. Modifications were made in the terminal receive registers so they would clear immediately after each transmission, eliminating the problem.

Smooth stops and data drops

Recording oscillographs are also useful in analyzing analog signals. Example 3 concerns a laboratory-grade instrumentation tape recorder required to operate during a 150-ms power failure. It was important to know how much data would be lost during that period, and that the tape would not suffer any damage due to excess tension.

Under normal conditions, the tape transport uses the upper-reel motor to supply constant holdback tension while the takeup reel pulls the tape forward. The

I. Availability of light-beam recording oscillographs

Manufacturer and Location	Model Number	Frequency Response at 5.08-Cm (2-in) Deflection Peak-to-Peak (kHz)	Number of Channels	Chart-Transport Transmission	Built-in Amplifiers	Number of Chart Speeds	Price of Basic Unit (No Galvanometers or Accessories)
B&F Instruments Cornwells Heights, Pa.	3006	Not spec'd	6 expandable to 12	Mechanical	No	8	$2410
Bell & Howell Pasadena, Calif.	5-134	13	18 not expandable	Servo	No	10	$2700
Bell & Howell Pasadena, Calif.	5-144	10	4 not expandable	Servo	Yes	10	$2570†
Hathaway Tulsa, Okla.	442	1	4 not expandable	Mechanical	Yes*	5	$900
Midwestern Instruments Tulsa, Okla.	LCR-1	2	3 not expandable	Not spec'd	Yes	8	$1300
Soltek (Japan) Encino, Calif.	5M21	1	6 not expandable	Mechanical	No	4	$1500

* Not isolated channel-to-channel
† Does include galvanometers and accessories

transport uses dynamic braking (controlled by the reel servos) and has a mechanical backup system held off by solenoids for use in a power failure.

Should power be interrupted, the upper-brake solenoid is immediately deenergized and the upper brake mechanically engages to provide holdback tension and prevent the transport from throwing a tape loop. The lower-brake solenoid, transport control electronics, and record electronics are held energized by capacitors in the power supply that slowly bleed off. Theoretically, if the upper brake is applied immediately upon power failure, the tape will continue to spool onto the takeup reel (inertia), and the entire transport will come to a smooth stop.

Important details about the braking during power loss can be revealed by a recording oscillograph. A tensiometer installed in the tape path senses tape tension throughout the test (Fig. 3). The tensiometer's output, the holding voltage for the upper- and lower-reel brake solenoids, and the recorder's ac power input are all monitored.

With the tape recorder running in the "record" mode, the ac input power was interrupted for 150 ms and a record made on the oscillograph. Several observations were made from that record:

Upon power interruption, the voltage energizing the upper-brake solenoid dropped to zero. The lower-brake hold-off solenoid remained energized, and the holding voltage decayed slowly as the power-supply capacitors bled off. The oscillograph record also indicates that shortly after power failure, tape tension dropped almost to zero followed by tension transients nearly four times above normal!

Further analysis showed that even though the upper-reel brake had been "electrically" energized immediately upon power failure, it was not until 50 ms later that mechanical braking was initiated. During the 50 ms without hold-back tension, the upper reel rapidly accelerated—much like a slingshot. When the brake finally engaged, a severe tension transient occurred, accompanied by mechanical ringing in the tape path.

Though the tape was not damaged, it was found that transients could be attenuated by reducing the delay between electrical actuation and actual braking. The amount of data lost or garbled during the outage was determined by recording the 60-Hz line voltage on tape and then monitoring that signal (oscillograph record) at the reproduce amplifier output with respect to the transport input power.

Guilty until proven innocent

Another extremely interesting application for oscillographs is problem isolation in the data communications field. Often several pieces of equipment from different manufacturers are part of the data loop—a teleprinter from one company, an acoustic coupler from another, and a modem from yet another. The system probably uses rented lines, courtesy of the telephone company, to talk (on a time-sharing basis) with a large computer miles away.

If trouble occurs, especially during initial system installation, finding and fixing it can be especially difficult. Often, faulty instruments work well on the bench, which results in all concerned blaming each other for the difficulties. An oscillograph record of the data in and out of every "black box" can isolate problems and save valuable time. Those suppliers whose equipment is no longer suspect are off the hook quickly. Finger-pointing is eliminated by a hard-copy record that can be filed, discarded, or used as proof of satisfactory operation.

True, the oscillograph will not replace the oscilloscope. It was never intended to. But certainly any piece of test gear that can add more light than heat to the endless argument over responsibility for technical performance deserves a broader understanding and the opportunity to prove its worth. ◆

Steven Krause is senior product specialist at Bell & Howell, where he is presently involved in marketing light-beam recording oscillographs, instrumentation amplifiers, and transducer signal conditions. Prior to joining Bell & Howell, he worked in instrumentation and data acquisition at North American Rockwell, Space Division, during the Apollo development program.

Electronic fuel injection: mileage boost, pollution squelch

Electronic controls are designed to activate injectors, air valves, and fuel pump to improve engine performance

If your car's engine stalls, stumbles, surges, backfires, diesels, idles roughly, or is hard to start, you may have carburetor problems. Ideally, in its role as a fuel-metering device, a carburetor maintains an air–fuel mixture that is neither too rich nor too lean for the prevailing engine needs. But when the carburetor performs less than optimally, any or all of these problems may occur. U.S. Government-mandated exhaust emission requirements aggravate the situation by setting limits on the amounts of nitrous oxides, hydrocarbons, and carbon monoxide that are permissible in exhaust emissions. To meet these standards, carburetors are usually adjusted to operate at 15.6:1 air–fuel ratios and catalytic converters are added or, alternatively, air–fuel ratios in excess of 16:1 are used in lean-burn emissions-control schemes. In either case, the carburetors may not always operate at the best air–fuel mixtures for maximum drivability.

Electronic fuel injection, or EFI, one alternative fuel metering or management system, can solve many of the problems associated with carburetors. EFI systems meter and atomize fuels to each cylinder in exact amounts determined by an electronic control unit. By reacting to inputs from sensors of such dynamic engine variables as engine speed and manifold absolute pressure, the control unit is able to improve engine performance and may assist the engine in meeting U.S. emission standards.

Why has EFI been a slow starter?

In 1974, you could not purchase a U.S.-manufactured automobile on which EFI was standard equipment. In 1975, you could get EFI as standard equipment on the Cadillac Seville and on the limited-edition Chevrolet Cosworth Vega, and, for $600, as an option on a few other Cadillac models. Yet, in 1975—and for many years prior to that—EFI was standard on many automobiles produced in Europe as well as on some built in Japan.

Why have U.S. automobile manufacturers been less receptive to EFI than their counterparts in other countries? The answer to this question lies not only in the manufacturers' decisions as to how they want to spend their money but also in whether or not they want to take advantage of certain features of EFI. For example, most U.S. cars have large displacement engines, whereas most non-U.S. cars have small displacement, four-cylinder engines. From the non-U.S. automobile manufacturers' point of view, EFI makes it possible to use a small engine and develop more horsepower (usually about 5 percent more) than could be developed from that engine with a carburetor. And, as an added bonus, EFI-equipped engines can develop more torque at low r/min.

As an example of the horsepower/torque benefits that can be derived from EFI, the 1975 special-edition Opel Manta, equipped with the Robert Bosch GmbH L-Jetronic fuel injection system, develops 81 hp at 5000 r/min from its single overhead cam engine. The same engine with a carburetor develops only 75 hp at 4800 r/min. The EFI-equipped engine also develops 96 lb-ft of torque at 2200 r/min instead of 92 at 2800. The differences may not seem large but, as *Motor Trend* magazine puts it, they translate into real performance improvement. And the lower r/min at which peak torque occurs translates into improved fuel economy (about 3 miles per gallon better than carbureted versions of the same engine).

The high cost of EFI is perhaps the main reason for its slow acceptance in the U.S. automotive marketplace. Integrated circuits and other technological advances have brought costs down considerably from what they were in the 1960s, but EFI is still at least 2.5 to 5 times more expensive than a carburetor fuel-management system. The cost factor is why EFI has found only limited application in the top models of some U.S. automobiles, because they could bear the additional cost, or as an expensive option.

The principles of EFI have been known for about 20 years and the basic patent (U.S. Patent No. 2 980 090) was granted to The Bendix Corporation in 1961. As evidence of the uphill battle for acceptance of EFI, Bendix shelved its EFI program in 1961—after having invested more than $1 million in it—because it seemed to hold little promise as a viable product for the corporation. EFI's poor cost–benefit ratio, and its apparent inability to survive in the harsh automotive environment, were major reasons for that decision. It wasn't until several years later, when demand for a more accurate method of metering fuel to reduce exhaust pollutants and the development of technological advances in electronic circuits and related hardware came about, that Bendix reestablished its developmental program.

In the meantime, Robert Bosch GmbH in Germany, a Bendix licensee, had made considerable progress in what is called the D-Jetronic fuel-injection system. Bendix, of course, once it reinstated its EFI program, was able to take advantage of the work already done at Bosch.

How EFI works

An EFI system meters fuel into an engine in the proper proportions with air to achieve optimum vehi-

Ronald K. Jurgen Managing Editor

cle performance, good fuel economy, and low exhaust emissions. It does so with solenoid-actuated fuel-injection valves, one for each cylinder. The fuel-injection valves are located in the engine intake manifold air induction runners.

When the engine is running, sensors located on or near the engine monitor the prevailing engine conditions. In response to inputs from these sensors, the electronic controller operates the fuel injectors according to a predetermined program. The duration of injector valve opening depends primarily on the amount of air taken into the cylinder. The injector valves are fired in select groups at specific times in each engine cycle. For most EFI systems, the fuel pressure is maintained at a high pressure differential (e.g., 39 lbf/in^2) across the injector valve. The amount of fuel delivered to any cylinder is then determined only by the pulse width of each command signal. The pulse width is set by the electronic controller at an optimum value for the prevailing engine operating condition. Figure 1 shows both open- and closed-loop inputs to the electronic controller.

In closed-loop EFI, such as the Bosch L-Jetronic system mentioned earlier, the desired air–fuel ratio is set as a voltage level inside the electronic control unit. It processes the signal from the air–fuel sensor, Fig. 1, and then commands the fuel-injection valves, Fig. 2, to feed sufficient fuel to the cylinders to maintain the desired air–fuel ratio.

Closed-loop EFI can compensate for such variables as barometric changes, altitude effects, fuel composition, fuel density, fuel temperature, exhaust gas recirculation, bore and stroke, valve lash, fuel control system tolerances, and volumetric efficiency. Each of these variables attempts to change the operating air–fuel ratio. An oxygen sensor (zirconium dioxide), located in the exhaust manifold between the engine and the catalytic converter, detects any change in air–fuel mixture and inputs a signal to the electronic controller so that it can adjust automatically the amount of fuel to be mixed with the available air mass.

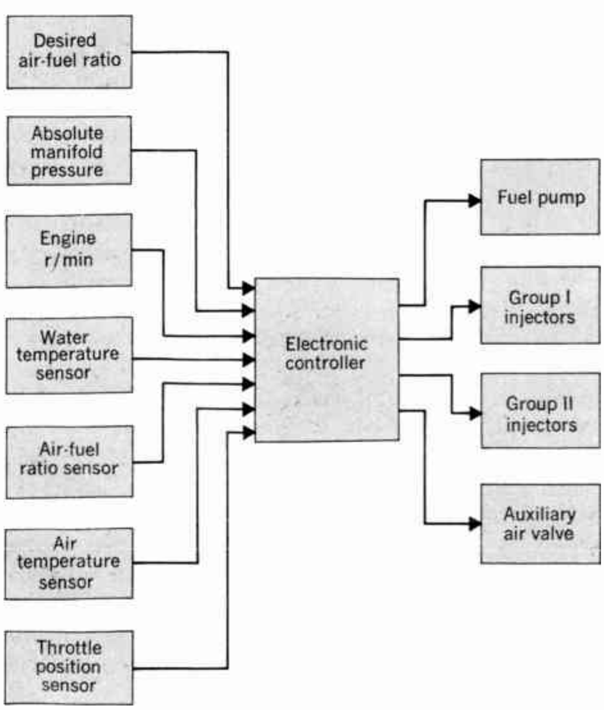
Alternatives to EFI

When a single carburetor feeds a number of cylinders, the fuel may be distributed unevenly. Certain cylinders are apt to get more fuel droplets than others. The difference in air–fuel ratio among the cylinders can be as much as 15 percent. EFI minimizes this problem by direct injection of fuel into the intake port in the vicinity of the intake valve.

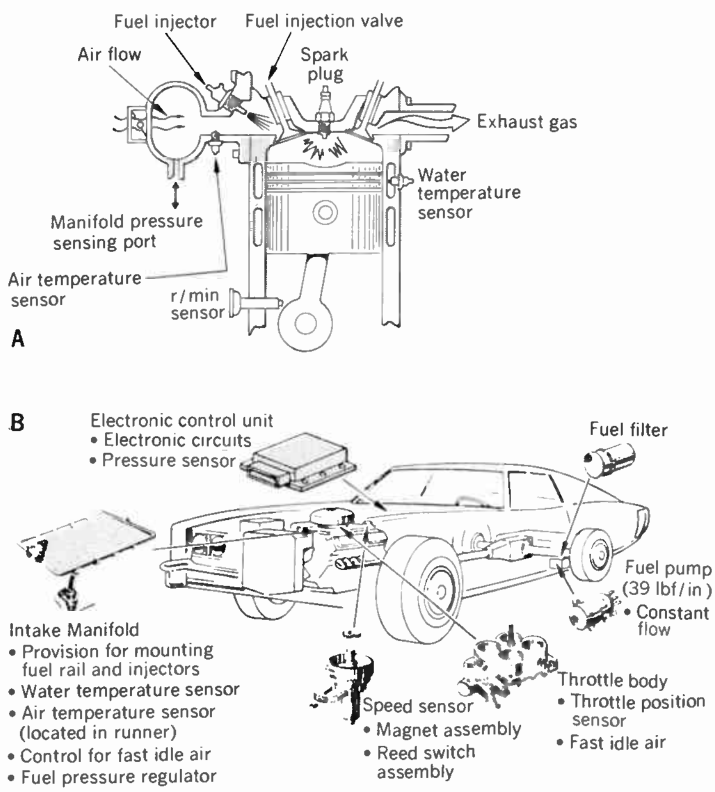
A less-expensive approach than EFI to this aspect of the total fuel-metering problem is the use of ultrasonic energy to obtain fine atomization of the fuel. Autotronic Controls Corporation of El Paso, Tex., for example, markets what is called the Electrosonic Type V fuel-induction system. It measures the air going into the engine and electronically meters the correct amount of fuel, then ultrasonically atomizes and mixes the fuel and air completely. All of the components mount in one housing that replaces the carburetor.

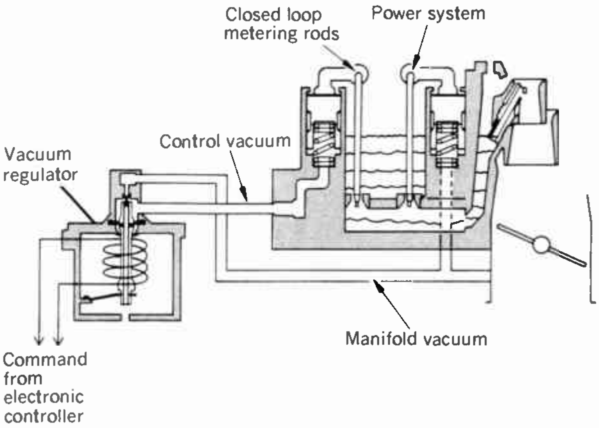
General Motors Corporation has been experimenting with a closed-loop carburetor emission-control system. It uses a venturi carburetor with a special set of metering rods in the primary main circuit of a four-barrel carburetor, as shown in Fig. 3. The carburetor is used in a system with exhaust-gas sensors, a three-way catalytic converter (a converter capable of reducing NO_x as well as oxidizing HC and CO), and an

[1] The electronic controller in an EFI system is fed both open- and closed-loop inputs upon which it acts to feed output signals to the fuel pump and valve injectors. The design of an electronic controller consists, typically, of four custom bipolar integrated circuits and a custom power hybrid module to control the injector current.



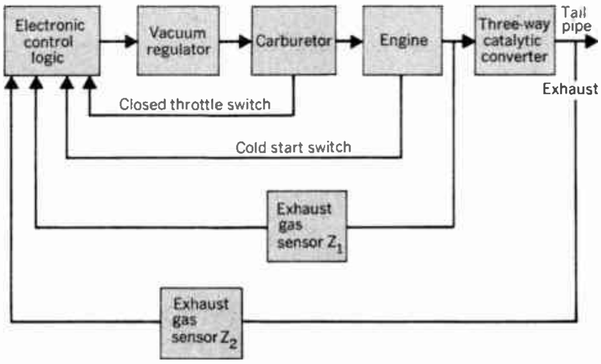
[2] In an electronic fuel-injection system, solenoid-operated fuel-injection valves feed fuel to the cylinders (A). Other major components of the system are shown in (B).





[3] A closed-loop carburetor mechanism has the components shown. When manifold vacuum is greater than about 6 in of Hg, the power system is in its full lean position, and only the movements of the closed-loop metering rods affect the quantity of fuel delivered for a given venturi signal. The vacuum regulator can position the closed-loop metering rods to any desired point between rich and lean.

[4] Closed-loop system diagram for the electronic carburetor. One of the objectives of the system is to minimize production of HC, CO, and NO_x in the tail-pipe exhaust by operating the engine at the air–fuel ratio that produces the highest mutual conversion efficiencies in the converter.



electronic control unit. The converter is the same as that used in closed-loop EFI systems.

One exhaust-gas sensor samples tail-pipe exhaust gas at the converter outlet; the other samples the engine-out exhaust at the exhaust manifold. The carburetor includes a vacuum regulator to provide the mechanism for varying the air–fuel ratio in response to command signals from the electronic control unit. A closed throttle switch on the carburetor assembly provides for one of several open-loop functions and a cold start switch senses engine coolant temperature for another open-loop function.

One fuel-metering circuit provides closed-loop control of the air–fuel ratio for part-throttle, warmed-up driving conditions. The other fuel-metering circuits provide conventional precalibrated, or open-loop, control of fuel for additional driving conditions, including wide-open throttle, closed throttle, cold start, and rapid throttle openings. The closed-loop system diagram is shown in Fig. 4.

Emission levels with the electronic carburetor system have not yet met 1978 standards but they are said to be sufficiently low to conclude that the venturi carburetor can be considered as a possible means for accomplishing fuel metering in a closed-loop emission system.

In Great Britain, the Zenith Carburetor Company is developing a sensing carburetor that uses an oxygen sensor in the exhaust manifold to detect the percentage of oxygen in the exhaust gas. The signals from this sensor, after amplification, drive a small stepping motor that controls an air-bleed orifice. The air-bleed orifice, in turn, controls the fuel-metering orifice.

What's next in fuel management?

The use of sensors and electronic controls in a closed-loop system is a prime candidate for giving a fuel management system the ability to control the air–fuel ratio accurately enough to meet 1978 emission standards (if three-way catalysts are improved considerably). Without a closed-loop electronic system, such as in simple carbureted systems and mechanical fuel-injection systems, such accuracy of control may not be attainable.

The next step forward with any EFI or electronic carburetor system may be its incorporation as a subsystem in a computer-controlled automobile. In that event, the fuel-metering system could conceivably use a central computer in a time-sharing mode or multiplexing arrangement together with other electronic subsystems. This arrangement, however, could cause reliability problems. In aircraft, for example, engine functions are never time-shared or multiplexed with other on-board, computer-controlled functions. But a central computer could serve in a monitoring mode to determine whether or not air–fuel or emission requirements were being met. ◆

For further reading

Detailed descriptions of the Bendix approach to EFI can be found in the following papers:

Rachel, T. L., "Automotive electronic fuel injection—essential design considerations," *IEEE Trans. Vehicular Technology,* vol. VT-23, pp. 25–33, May 1974.

Rivard, J. G., "Electronic fuel injection in the U.S.A.," paper presented at the SAE-IEEE International Colloquium on Automotive Electronic Technology, Oct. 28–30, 1974.

Rachel, T. L., and Gunda, R., "Electronic fuel injection utilizing feedback techniques," Sess. 36 preprint, 1974 IEEE INTERCON.

Gyorki, J., "Fundamentals of electronic fuel injection," paper no. 740020, SAE annual meeting, Feb. 1974.

Technical descriptions of the Bosch D-Jetronic and L-Jetronic EFI systems can be found in these two papers:

Eisele, H., "Application of electronics to fuel management and emission systems: electronic fuel injection in Europe," paper presented at the SAE–IEEE International Colloquium on Automatic Electronic Technology, Oct. 28–30, 1974.

Gorille, I., Rittmannsberger, N., and Werner, P., "Bosch electronic fuel injection with closed loop control," paper no. 750368 presented at SAE annual meeting, Feb. 1975.

A thorough description of Chevrolet's closed-loop carburetor is contained in the paper:

Spilski, R. A., and Creps, W. D., "Closed loop carburetor emission control system," paper no. 750371 presented at SAE annual meeting, Feb. 1975.

Power semiconductors

Thyristors, rectifiers, and transistors offer 'super' characteristics as a result of device design advances

The present crop of new power semiconductor devices is characterized by high switching speeds, higher voltage and current ratings, greater reliability, and lower prices than its predecessor.

Today's multikiloampere and -kilovolt silicon-controlled rectifiers (SCRs) with switching speeds of many kilohertz are a far cry from the first ones invented back in 1957. They are the end product of two decades of a quiet evolution in power semiconductors that has vastly improved not only SCRs but other thyristors, such as triacs, as well as rectifiers and power transistors. As a result, applications for power semiconductor devices are growing rapidly.

Power devices are defined—for the purposes of this article—as thyristor, rectifier, and transistor components that dissipate enough power in normal operation (usually 1 watt or more at room temperature) to make that power dissipation a limiting factor in their application.

New device developments

Thanks to newer types of power semiconductors, designers now have a wider choice of devices and hence greater flexibility in design. Some advanced thyristor and transistor devices already are competing for the same applications. Such device developments over the last one to two years include:

- Newer thyristors such as low-gate-level gate-turn-off switches (GTOs), blocking-diode thyristors, and high-speed asymmetrical SCRs (ASCRs). High-power SCRs for industrial applications (Fig. 1) have increased dramatically in current and voltage ratings.
- Newer transistors such as high-current-gain and high-speed Darlington pairs (even three- and four-stage Darlingtons), and high-voltage fast-switching transistors.
- Newer rectifiers such as high-speed Schottky-barrier devices and high-power-handling varistors.

Bigger and better thyristors

Larger-diameter (and hence higher-power-handling) thyristors—up to 77 mm (3 in) in diameter—are becoming available for the high-power industrial applications. Such devices handle thousands of amperes and volts. Switching speeds for lower-voltage and lower-current devices are increasing to 10 kHz. Except for some special devices, the technology limits for commercially available high-power devices (thyristors and rectifiers) are at about 5000 volts of peak reverse voltage (PRV) and 3000 amperes of forward rms current, from 77-mm-diameter silicon wafers. The highest voltage and current ratings are necessarily mutually exclusive, with the highest-voltage devices having lower current ratings, and vice versa; and it can be expected that the higher the voltage rating, the larger the forward voltage drop. As for switching speeds, thyristor and rectifier devices are available to be used at up to 10 kHz for 50- to 100-kVA devices.

Advances in high-power-device performance can be typified by International Rectifier's new 600-volt 500-ampere SCR that can switch at 10 kHz and has a forward voltage drop of just 1.3 volts. It is part of a line of SCRs that includes devices handling 1200 volts and 500 amperes at 5 kHz.

A big factor in obtaining higher switching speeds (higher *di/dt* and *dv/dt* ratings) in SCRs is the geometry of the gate structure. Modern interdigitated gate designs for large-diameter (greater than 15–20-mm) SCRs have provided substantial performance improvements over conventional dynamic gate designs. The three major types of gate geometries in use today as employed by the "big three" makers of large-volume high-power devices are the involute structure (General Electric), the divergence structure (International Rectifier), and the dual-ring structure (Westinghouse), all of which have helped increase SCR *dv/dt* and *di/dt*

(Continued on page 40)

[1] This 53-mm-diameter SCR (foreground) from General Electric's Semiconductor Division is capable of handling 2000 amperes of rms current at up to 1800 volts. The Press Pak type of package utilized is used for circuit mounting with a pressure clamp (background) for proper thermal contact and heat removal. The clamping force for such a clamp can be nearly 3 tonnes.

Roger Allan Associate Editor

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(Continued from page 37)

ratings. National Electronics makes use of a regenerative gate design in its line of power devices.

Another device that has become important during the last few years is the GTO thyristor. This device allows low gate turn-on and turn-off voltages and currents. It is similar in operation to a conventional SCR in that it is turned ON by a positive voltage pulse to the gate. The big difference is that the GTO can be turned OFF by a negative voltage pulse. No expensive commutating circuitry is needed to break the power-supply line as in conventional SCRs.

GTO techniques are used in power thyristors across the power-level spectrum—from thyristors that handle a few watts to the large "Press Pak" or "Hockey Puck" SCRs that handle thousands of amperes at megawatts of power dissipation.

The reverse-blocking thyristor from Westinghouse Semiconductor is a new two-terminal device for pulse-modulator radar applications. It is switched to the conduction state from the blocking state by the application of a fast-rising voltage pulse, a task formerly accomplished with more expensive ignitron or thyratron vacuum tubes requiring plate and filament power supplies. Westinghouse's RSR (Model T40R) is rated at 1200 amperes peak pulse, 2000 A μs *di/dt*, and a blocking voltage of 1000 volts at +125°C. Turn-on time is 100 ns at +25°C.

Sometimes a device's performance can be too good. For example, some advanced sensitive-gate SCRs are so sensitive that they can be triggered ON from nearly any small signal, such as a stray transient, leading to erratic operation. In such cases, it may be better for the user to specify a less sensitive SCR and learn to live with tougher SCR drive requirements.

Fast, high-voltage transistors

In power transistors, it is necessary to obtain increased output currents at relatively high output voltages for power applications in television sets, audio amplifiers, automobile ignitions, motor control, and switching power supplies. The Darlington-pair configuration with its inherent high gain and low driving signal is proving to be an answer to this need.

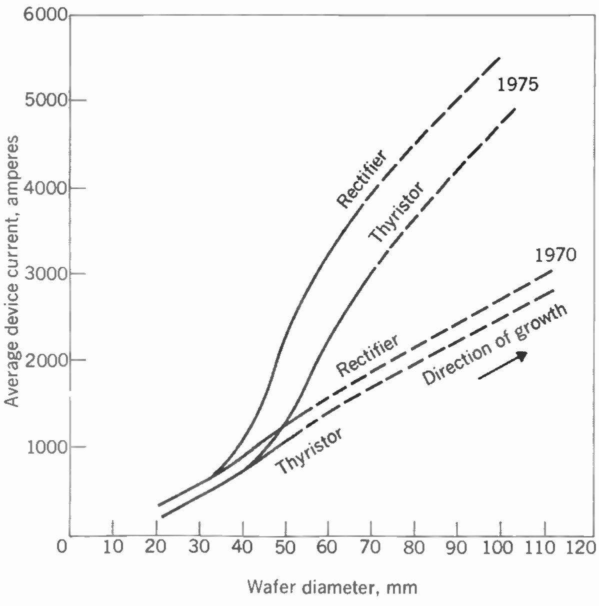
Triple- and four-stage Darlingtons are in the offing. In fact, RCA has developmental samples of a triple Darlington power device with ratings of 10 amperes and 1000 volts, a switching time of 1.5 μs, and current

Applications span a wide spectrum

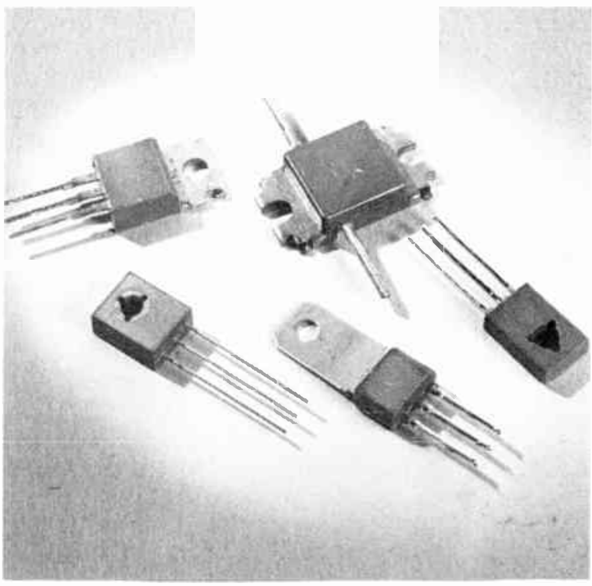
There is hardly any area where low-signal-level ICs or electromechanical components are used in which power semiconductors are not applied. Present and future applications can be broken down into three major areas (with some overlap) by power level:

- High- to very-high-power industrial applications, such as electric power generation and distribution, railroad and electric-car transportation, dc and ac motor drives (elevators, machine tools, forklifts, cranes, hoists, and electric golf carts), uninterruptible power supplies (UPS) for large computer backup power, and processing equipment (welders, platers, heat treaters, induction heaters, and metal hardeners and melters). Power-dissipation levels are typically in the range of hundreds to thousands of watts.
- Medium-power industrial and commercial applications, as in solid-state ballasting, switching-regulator power supplies, servoamplifiers, and automotive solid-state ignition and voltage regulators. Here, applications require power-dissipation levels ranging from tens to hundreds of watts.
- Low- to medium-power commercial and consumer applications (potentially the largest market for power semiconductors), such as television sets, stereo amplifiers, automotive electronics (dashboard displays, antiskid controls, windshield wipers, and fuel-injection systems), light dimmers, and home appliances (washing machines, ovens, ranges, toasters, and blenders). Power-dissipation levels range from a few to about 100 watts.

[2] Power-device currents are on the increase, and go up in magnitude with increasing silicon-wafer diameter. Note that estimates of 1970 device trends were exceeded. These curves are for low-frequency, low-voltage (less than 600 volts) conditions.



[3] Plastic packages for power devices are becoming more popular due to increases in hermetic performance, thanks to better passivation and metallization techniques. Shown are "Versawatt" TO-5 and TO-126 plastic packages from RCA Solid State Div.



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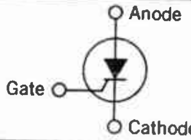
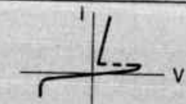
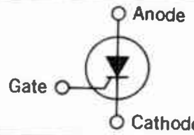
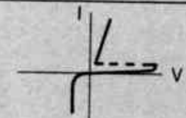
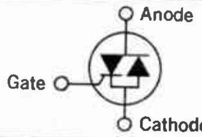
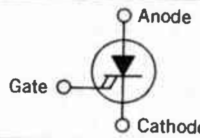
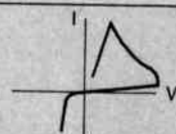
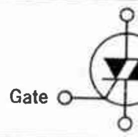
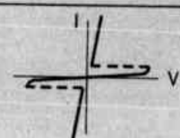
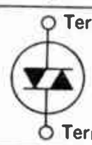
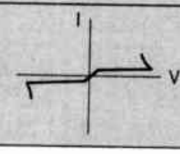
Thyristor and rectifier characteristics

Device	Symbol	V-I characteristics	Comment
Silicon-controlled rectifier (SCR)	 Anode, Gate, Cathode	 I, V	Unidirectional switching Requires commutating circuits Fast devices—4–10 μs switching Average devices—20–35 μs switching Phase-control devices—100–200 μs switching
Asymmetrical silicon-controlled rectifier (ASCR)	 Anode, Gate, Cathode	 I, V	Unidirectional switching Low reverse blocking Typical turn-off time—2–6 μs Typical turn-on time—200 ns Useful for 20 kHz–50 kHz switching
Integrated thyristor rectifier (ITR)	 Anode, Gate, Cathode	 I, V	Unidirectional switching Reverse current conduction Typically faster than conventional SCRs Typical Turn-off time–2–6 μs High-volume usage in TV deflection
Gate-turnoff silicon-controlled rectifier (GTO SCR)	 Anode, Gate, Cathode	 I, V	Unidirectional switching Controlled turn-off from the gate with negative gate pulse Ideal for high-voltage transistor-type circuits Inrush-to-steady-state ratios of 10 typical
Triac	 Main terminal 2, Gate, Main terminal 1	 I, V	Bidirectional switching Ideal for 60-Hz ac controls Selection suitable for 400-Hz operation Surge-to-average current ratios of 10 typical
Diac	 Terminal 1, Terminal 2	 I, V	Bidirectional switching

gain of about 500. RCA also expects to introduce a two-stage, 500-volt, 6-ampere Darlington for auto ignitions that features a gain of 500 and microsecond switching. Darlington-pair devices are available from several manufacturers for handling voltages of a few hundred to more than 1000 volts at output currents up to 50–100 amperes and switching times of approximately 1 μs.

There also has been rapid development of high-voltage switching transistors, with voltage ratings climbing up to 2 kV (2–3 kV for some European and Japanese devices) at microsecond switching speeds. The basic applications for the high-voltage switching transistor include television horizontal-sweep circuits, auto-ignition circuits, and switching power-supply circuits. With these mass markets in sight, more activity is taking place in high-voltage transistors than in any other semiconductor power-device field.

Some notable high-voltage transistor products include 1400-volt, 5-ampere units from Delco and Motorola at switching speeds of about 1 μs. Texas Instruments claims to have similar devices with 2000-volt capabilities. For fast switching with large current-carrying performance, Power Tech of Clifton, N.J., offers 80-volt transistors that can handle 500 amperes peak, and 100 amperes continuous, at 400 volts. Switching speeds are under 1 μs. Solitron Devices of Riviera Beach, Fla., also has power transistors that can handle up to 500 amperes and 1600 volts. Dozens of U.S. and overseas manufacturers sell power transistors with collector-voltage ratings between 500 and 1000 volts at currents from 50 to 100 amperes, at microsecond switching speeds. RCA expects to have a low-cost TO-3 metal-case (plastic later) power transistor (the TA8767) for switching-power-supply applications that can handle 400–600 volts of collector voltage and 4 amperes, at a switching speed of 200–400 ns. This developmental device should be ready by late 1975. Motorola and Solid State Devices also expect to have similar power transistors by late 1975.

Rectifiers go up in speed

In rectifiers, high efficiency in converting ac to dc power is of critical importance. To that end, newer rectifiers using Schottky-barrier technology and ion-implanted rectifiers are offering designers the lowest forward voltage drops at fast recovery times.

Some advanced fast-recovery rectifiers sacrifice forward voltage drop for even higher speeds—as fast as 30 ns. Devices such as those available from Semtech, Newbury Park, Calif., make use of many individual silicon junctions stacked together and fused, to switch tens of kV in 100 to 200 ns.

An improved power device that has contributed heavily to power-circuit performance is the Zener-diode metal-oxide–varistor combination, used for surge suppression and clamping. These devices, such as those available from General Electric, Motorola, Fairchild, and Semtech, are increasingly being used in power equipment of all types to relieve the duty and stresses on other components. One can only appreciate their usefulness in power-device protection when it is

[4] Power by the pellet. These glass-passivated power-semiconductor chips (foreground) from General Electric's Semiconductor Division include SCRs, triacs, and rectifiers in various configurations, for direct use by a designer in a circuit. Lower cost and smaller physical size are just two advantages. In the background are the devices in packages.

isolation exists, the insulator is dispensed with and the pellet can be soldered directly to the heat sink, which is generally smaller than one for a packaged device, thereby effecting further savings.

Heat removal is important

Increases in power-device performance levels have meant corresponding increases in heat generation. After all, power implies heat. And the name of the game in power semiconductor devices is faster heat removal from the chip, a task that gets more complex with increases in power-dissipation levels.

In addition to heat sinking, water and forced-air cooling are employed to remove heat from high-power devices. Newer techniques under study include the use of integral supercooled liquids within the device package, and the use of heat pipes. New contact systems for better heat removal are also under study.

For devices that can dissipate so much power that forced-air or liquid cooling is a must, mechanical unreliability problems (due to fans, blowers, water pumps, switches, etc.) are added to the system in which they are used, and there must be additional fusing and heat-sensing circuitry as well. When a water-cooled SCR handling a few thousand amperes of current loses its water supply, or gets insufficient cooling due to a drop in water pressure, the result for an unprotected system can be more than just a burned-out device. Often, the entire circuit can melt from such high welding-level currents.

Proper heat removal implies proper mounting forces for pressure-mounted devices, and such forces can be quite high. For example, the clamping pressure on a 53-mm-diameter Press Pak device for proper operation through heat removal is nearly 3 tons!

When power semiconductor devices fail prematurely due to excessive temperatures (and excessive voltages), the primary wear-out mechanism is usually thermal fatigue, a problem to which the semiconductor device manufacturers are addressing themselves by investigating newer chip-to-outside-world contact systems with lower thermal stresses.

Separating fact from fiction

Power semiconductor devices are expected to operate at high temperatures. In fact, hotter devices mean less heat sinking and more economical operation, provided they don't fail due to overheating. Unfortunately, many device manufacturers do not completely characterize their products. The result is that the user is left to operate a power device somewhat in the dark, courting premature failures. Manufacturers of low- and medium-power devices often tend to overspecify power handling in a device, assuming infinite heat sinks. Safe operating area and secondary breakdown characteristics are two key types of data that manufacturers don't always spell out completely.

One method of gaining user confidence is to provide device thermal-fatigue ratings. Pioneered by RCA, such ratings provide a measure of a device's life under operating conditions by indicating the maximum number of cycles such a device can handle during operation for a given temperature swing within the device (from self-heating).

For self-protection, some large power-device users have instituted stringent in-house testing and qualifying criteria. The result in many cases has been the increased exchange, between user and manufacturer, of the type of information that can lead to better devices through redesign based on user feedback.

Sometimes, the only way a power-device manufacturer can be completely confident in a product is to have the intended user apply it in a design, and then wait for the user's feedback. Regardless of how complex and thorough in-plant testing may be, it quite often cannot duplicate actual conditions. For example, one power-supply user specified a 450-volt, 3.5-ampere switching power transistor at a current gain of 10, a 1-μs maximum fall time, and a case-junction temperature of +125°C. Several manufacturers were chosen as suppliers; their data sheets had such parameters conservatively rated, yet all the transistors would not perform satisfactorily at +125°C. The power-supply designer eventually consulted with the device manufacturers and found that he should derate the device temperature for his application. In fact, this designer claims that available +125°C Schottky diodes for power-supply switching applications (the present state of the art) are insufficient for many designs, and that +150°C diodes are needed.

Another user of power transistors had premature device failures at less than maximum rated currents. Individual transistors consisting of four chip sections each were rated for 20-ampere operation (5 amperes per chip) yet kept opening up at the bonded leads under total circuit currents of 7 to 8 amperes. A detailed analysis by the user (not every user is equipped to do this) led the manufacturer to solve this problem by redesign of the bonded-lead structure. ◆

Information for this article came from many sources. Major contributors were: Finas Gentry, Forest Golden, John Hey, and Raymond Kidner, General Electric; Robert Baily, Motorola Semiconductor; Michael Craft, National Semiconductor; Dale Baugher, Richard Denning, Thomas McNulty, and James Miller, RCA; and Raymond Freuler, Joseph Johnson, Daniel Muss, and James Ramsay, Westinghouse Semiconductor.

Megawatts from municipal waste

European cities have the edge in refuse-energy recovery, but U.S. communities now take 'trash power' seriously, too

An unwanted by-product of civilization, refuse is now emerging as the "Cinderella" fuel—the result of rising fossil-fuel costs and strong social and environmental pressure for clean waste disposal. On the East Coast of the United States, for example, as well as in some West Coast areas, where there is predominant dependence on oil or low-sulfur coal, it is now generally economical to generate electricity from refuse and charge only reasonable disposal fees. Such generation can be accomplished by electric utilities, by private firms selling the power to the utilities at mutually advantageous rates, or by local municipalities themselves.

The concept of refuse as a potential energy source has been developed extensively in Europe over the past 20 years, and more recently in Japan, Australia, and Canada (see *Spectrum*, September 1974, pp. 83–87). Springing from a late start in the United States, the combination of refuse disposal and environmentally sound recovery of energy and other resources now has become an important consideration in the nation's community planning and management. Not only has this involved an application of updated and refined combustion processes developed in Europe, it has also produced an explosion of new techniques and systems involving refuse-derived solid fuel and the production of gas or oil from municipal solid waste. The attractive possibilities of power generation have stimulated further improvements in combustion efficiency and boiler designs for systems firing unprocessed refuse exclusively, permitting more efficient superheated steam production at the higher temperatures and pressures suitable for power production.

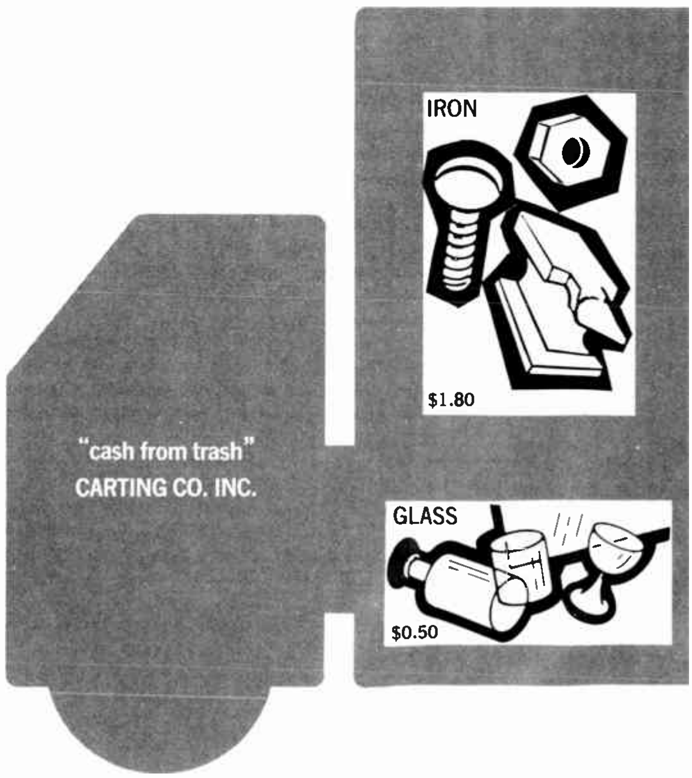
And surprisingly, considering the past limited application of the concept in the U.S., New York City was the site of one of the world's first trash-fired generators—put into operation in 1905! It burned hand-picked refuse as boiler fuel for a steam-driven generator powering arc lights on the Williamsburgh Bridge. But for economic and environmental reasons, this type of system never flourished.

Europe takes the initiative

Until very recently, harnessing "trash power" on a large scale had been confined to European countries. In view of the distribution of land and population in Europe, this is not unusual. Historically, open land near municipalities has been scarce, expensive, or nonexistent. Compared with the U.S., fuel costs have been consistently higher and the greater population density has drawn earlier attention to the undesirable environmental aspects of refuse dumps. Incinerators have been in use for at least a century, although the first extensive employment of full-scale refuse-energy systems dates back a little more than two decades.

Characteristic of the first successful systems is the Van Roll-designed plant in Bern, Switzerland, constructed in 1954 with a capacity of 200 tonnes a day. Still in continuous operation, this plant produces steam, heated water, and electricity—for hospitals, schools, apartments, a railroad station, and a chocolate factory. Inspired by the success of the Bern plant, the idea was soon accepted by other cities—and today almost every major European population center has its refuse-energy plant. The "refuse-to-energy" concept next spread to Australia and Japan, where fuel costs are also high. In Canada, the Montreal 1080-tonne facility was built in 1969 and a 900-tonne system was completed in Quebec City in 1974, providing energy to a nearby paper pulp plant.

The emergence of full-scale refuse-energy systems in the U.S. during the past few years has primarily been limited to two general areas: (1) refuse-fired steam-generating systems delivering low- or moderate-pressure steam to nearby industrial plants, and (2) a



Walter K. MacAdam Wheelabrator-Frye

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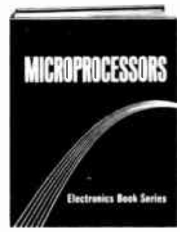

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few pilot plant applications using shredded refuse as fuel (the paper and light plastic components). The shredded material is either fired as a 10–20-percent (heat value) supplement to coal in a modified boiler, or it is converted to gas or oil in a pyrolysis process (to be described later). Typical of these applications are full-scale energy-producing systems in Norfolk, Va.; Oceanside, N.Y.; St. Louis, Mo.; Baltimore, Md.; and Saugus, Mass. Others are on the drawing boards, or under construction, giving promise of increasing recognition of the value of energy and materials resources in refuse (see "For further reading," p. 49).

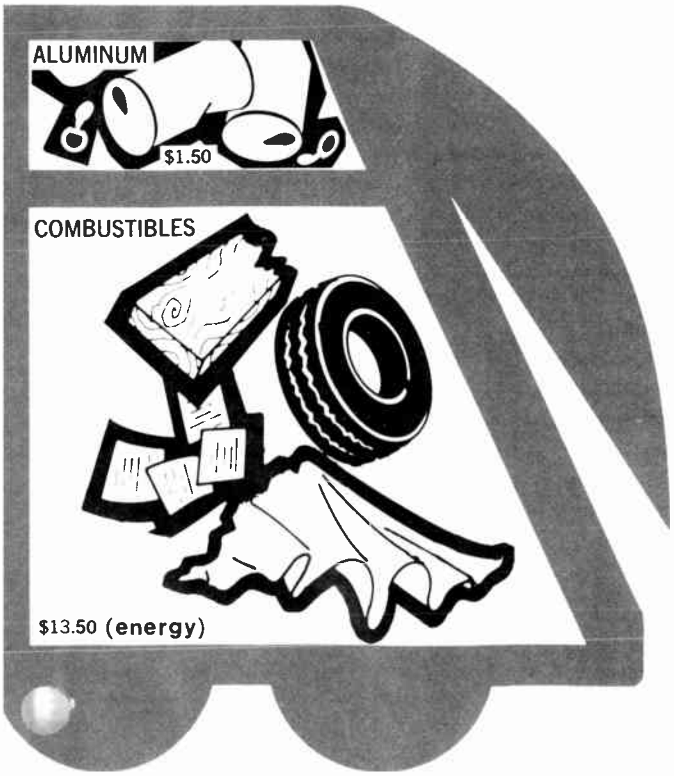
Originally, most refuse–energy systems concentrated on selling steam or heated, pressurized water to industrial facilities or community heating distribution networks. Although electricity was produced by some plants in "topping" turbines to absorb any excess energy, with few exceptions, such electric generation received secondary emphasis. The principal reason for these priorities in the early systems came from the need to control boiler tube corrosion in metalwork exposed to burning refuse or high flue gas temperatures. This required operation at relatively low steam temperatures and pressures, a detriment to economical electric power generation.

Economics takes over

However, circumstances have changed. Demonstrated technical advances, environmental pressures, worldwide inflation, and the Mideast oil embargo of 1973 have combined to favor refuse-fueled electricity generation over the past two years. Six key factors underly the new situation:

- Utility fossil-fuel costs increased substantially in relation to refuse-plant processing costs.
- Refuse-fired boiler design refinements and corrosion-control measures, based on European experience, demonstrated reliable operation at increased steam temperatures and pressures, with consequent improvement in power generation efficiency. Electric generation yielded about 540 kilowatthours per input tonne of "as-is" municipal waste compared with just 270–360 kWh/tonne obtained a few years earlier.
- Advances in refuse boiler design minimized tube-surface cleaning problems and substantially increased on-line availability.
- A pilot plant constructed in St. Louis, Mo., successfully burned the lighter fraction of air-classified shredded refuse (refuse particles sorted by weight using forced air and gravity) as a 15-percent fuel value supplement to pulverized coal in a utility boiler.
- Dwindling landfill sites near urban settlements and growing concern for ground contamination meant communities seeking clean refuse disposal were willing to pay increased hauling charges to bring trash to incinerator/generator plants.
- The emergence of transfer compactor substations permitted tractor–trailer or rail delivery of compacted refuse, reducing road traffic and permitting larger, more efficient processing installations.

Urban refuse contains several components of significant cash value. Examined on a dollars-per-tonne basis, combustible material is the primary concern, yielding almost 80 percent of the profit, with recoverable metals and glass a distant second and third. Besides such salable material, municipal waste also contains water and miscellaneous solids.



There are also important side benefits associated with wide deployment of refuse-powered electric generators. For example, inputs to a power transmission grid can be established at many alternate locations, eliminating the previous requirements that a refuse-powered boiler be adjacent to a steam user. This simplifies siting problems and significantly expands the field for recovering usable energy. And since refuse-generated power is a small fraction of a given utility's generating capacity, costly backup generation facilities are not required. (When corrosion problems are under control, refuse boiler availability is comparable to that of fossil-fuel utility boilers.)

Direct combustion of unprocessed municipal refuse at the higher temperatures needed for efficient generator operation depends on several recent design modifications. Air jets placed above the burning refuse minimize boiler tube corrosion that can occur in the presence of carbon monoxide (reducing atmosphere). These air jets also limit slag build-up along the furnace walls. Additional air introduced under stepped-grate systems provides increased gas turbulence, minimizing "hot spots" on furnace walls and boiler tubes. And new automatic temperature-regulating systems deliver uniform steam flow at full plant capacity (without exceeding temperature limits), independent of the refuse supply's variable heat content.

Moving grates . . . suspension . . . pyrolysis!

Refuse energy-extraction technology is concentrated in three general areas: combustion on moving grates using 100-percent refuse (temperature optimized for steam generation); suspension firing of air classified, shredded refuse (usually burned as a supplement fuel in a coal-fired boiler); and pyrolysis systems involving destructive distillation of refuse and extraction of oil or gas for subsequent firing in a nearby furnace boiler.

From the standpoint of demonstrated performance, the moving-grate system developed over the past two decades represents a mature process for producing high-temperature steam (Fig. 1). Described in greater detail in the September 1974 *Spectrum*, it consists of a refuse-fired steam-generating boiler equipped with reciprocating grates arranged in steps over which the burning refuse tumbles to provide complete combustion. Air is introduced under and over the grates, raising the firing temperatures and producing gases of 800–1000°C. Boiler tubes in the furnace walls and convection section thereby produce superheated steam for driving a turbine generator. After further processing, the sterile residue yields iron particles, aggregate (for road sub-base material), and landfill. Typically, the ash aggregate with the iron extracted represents about 6 percent of the original unburned volume.

The suspension firing of refuse fuel in a utility boiler has been successfully demonstrated as a supplement to pulverized coal and—subject to further experience—should prove worthwhile where the needed modifications to existing fossil-fuel boilers are economically justified (Fig. 2). This system first passes incoming refuse through one or more large shredders, and then extracts ferrous metal with a magnetic separator. The remaining material is conveyed to a classifier that separates the particles into light and heavy components with a forced-air current. The lighter fraction (primarily paper and plastic) can be blown into a utility boiler, typically as a 15-percent fuel supplement to the pulverized coal introduced through separate burners. The heavy fraction (wood, glass, and dirt) is usually sent to landfill.

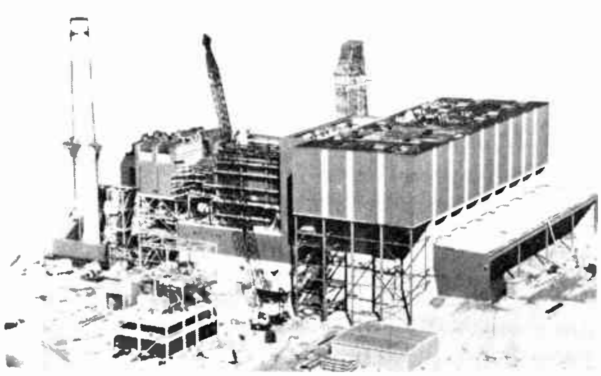
Oil- and/or gas-producing pyrolysis systems are still in the pilot plant or laboratory stage, but appear to have a promising future (Fig. 3). As is the case with shredded-refuse fuel facilities, pyrolysis also involves preshredding and magnetic separation, followed, in some cases, by air classification. The shredded-refuse fuel is then introduced into the top of a vertical shaft furnace where it is subject to high-temperature destructive distillation in an oxygen-deficient atmosphere. This produces carbon monoxide, hydrogen, and oil that are drawn off for combustion in a separate furnace. Heat for the pyrolysis process is produced at the bottom of the shaft where the char remaining from the pyrolytic action is burned in the presence of air or oxygen at about 1700°C. Glass and other incombustibles are drawn off in molten form.

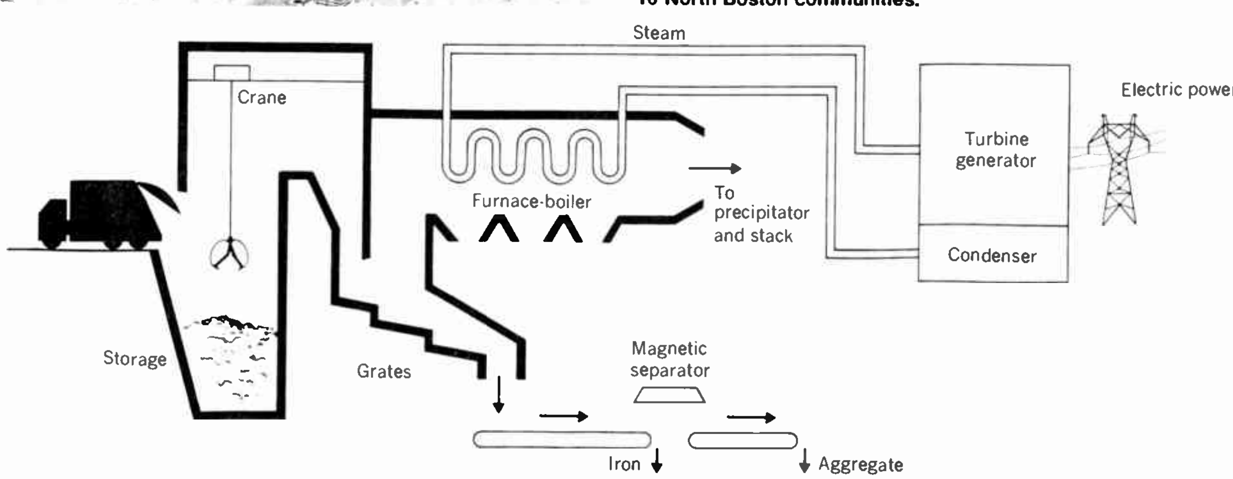
Boilers, bids, and the bottom line

The chief advantages of the refuse-fired boiler burning unprocessed waste are demonstrated reliability and mature technology coupled with good efficiency and low operating cost. Its main drawback is the high initial capital expenditure required even though this is largely offset by low-cost operation. The shredded-refuse system offers an opportunity to supplement existing high-temperature, high-pressure utility boilers directly with air-classified trash. It entails a lower first cost for boiler modifications, but usually a higher total operating cost and shorter service life than a refuse boiler firing unprocessed refuse. Since it has been demonstrated only as a pilot plant, its reliability and resistance to corrosion must still be proved in full-scale operation. Pyrolysis systems are still mostly in an early stage of development, but promise to be useful where oil or gas is the desired fuel. Because of its relatively low heat value, pyrolysis gas does not appear economical to compress and transmit over long distances unless combined with richer natural or synthetic products.

The reality of these technical alternatives and the comparative economics are evidenced by some recent actions of private enterprise:

• Two long-term sales contracts have been consummated with U.S. East Coast utilities for refuse-generated electric power at a minimum charge in the range





[1] No "prior processing" is required to burn waste in a typical moving-grate combustion boiler. The 1080-tonne-per-day Weelabrator-Frye refuse-energy plant shown here went online in September 1975, sending steam to General Electric's Lynn River (Mass.) Works. This is the first privately owned and operated refuse-energy plant in the U.S., and it will serve 16 North Boston communities.

For further reading

Communities everywhere are finding themselves in a crisis situation with exhausted landfills and limited acceptable alternatives. Utilities once served by sulfur-tainted coal or oil are forced to shift to cleaner, more expensive fuels. Governments and industries worldwide are attacking refuse-disposal problems and rising energy costs by improving existing recycling/recovery technologies and developing new ones. Several recent papers are illustrative of the success being attained with various refuse-energy recovery systems.

A summary report on municipal refuse characteristics, and estimates of the quantities available, can be obtained from the U.S. Environmental Protection Agency, Washington, D.C. Entitled "Second report to Congress: resource recovery and source reduction," the document also examines the means for recovering energy and materials from waste, and makes broad estimates of the economics and future potential.

Appearing in the February 1975 issue of *Power Magazine*, a special report, "Power from waste" by R. G. Schweiger, reviews the various systems used to recover energy from refuse and the problems associated with each process.

More details on the Wheelabrator-Frye facility in Boston (see Fig. 1 in this article) will appear soon in *Chemical Engineering Progress*, published by the American Institute of Chemical Engineers. Entitled "Energy and materials from unpreprocessed municipal solid waste—the Boston North shore facility," the report is authored by Walter K. MacAdam.

Further discussion of the St. Louis pilot plant (see Fig. 2 in this article) burning shredded refuse with coal is available in the 1973 *Proceedings* of the American Power Conference. Authored by G. E. Dreifke, D. L. Klumb, and J. D. Smith, it is entitled "Solid waste as a utility fuel."

Pyrolysis using a rotating kiln with supplementary oil firing is the subject of E. T. Bielski's and A. C. J. Ellenberger's "Landgard for solid waste," appearing in the *Proceedings* of the ASME National Incinerator Conference, 1974. Figure 3 in this article outlines the basic pyrolysis process.

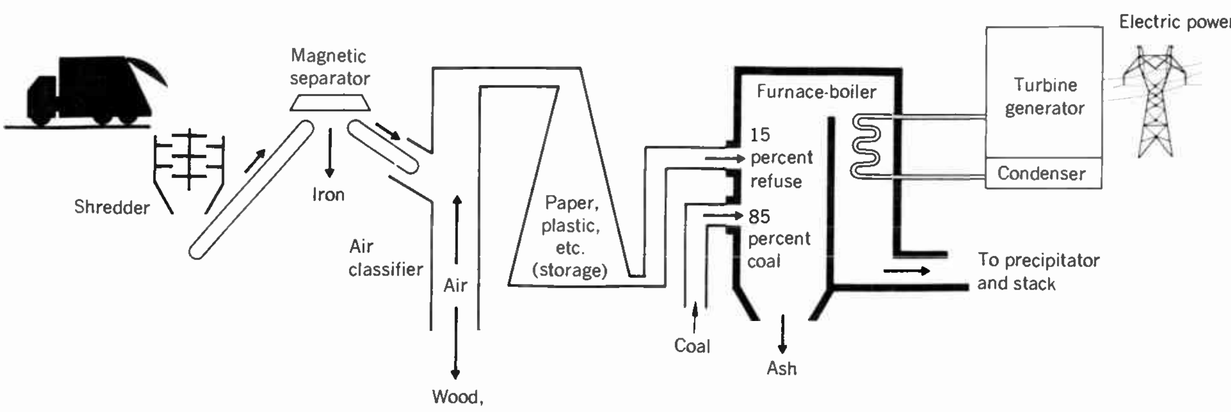
of 24 mills ($0.024) per kilowatthour and with escalation based on fuel cost.

- A recent competitive proposal request by a major U.S. municipality produced three bids by industry to generate electric power from refuse, with tentative prices in the 17–25-mills/kWh range. Disposal charges to the municipality were proposed at levels below $10 a tonne.
- Private industry has been willing—in selected situations—to take an equity interest and be responsible for all financing of refuse-energy plants that can generate electricity, for sale to utilities, and recover valuable solid materials. Such plants can pay local taxes and equity ownership is a vote of confidence in long-term, reliable performance and economic viability.

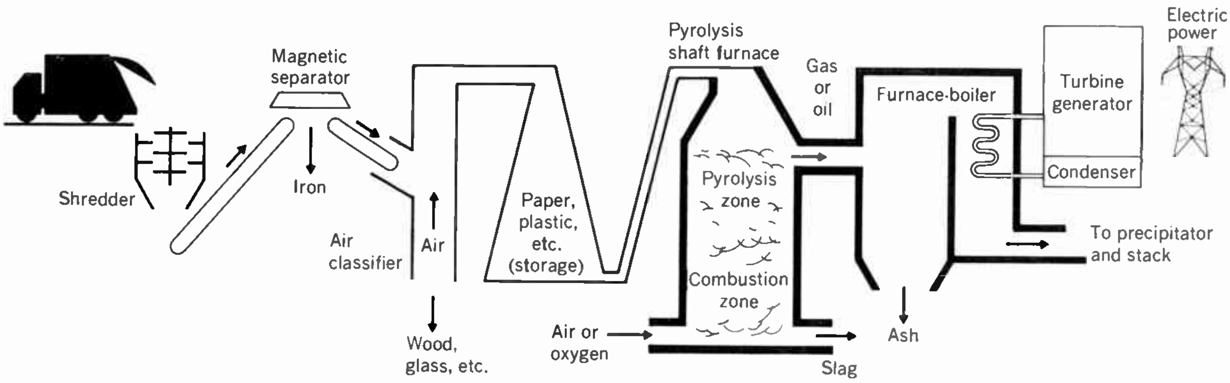
In considering the appropriate selling price of this electricity to utilities, it is important to recognize that refuse power is produced essentially on a continuous basis. It is not related to high-cost power delivered during peak-load periods. Because of this capability as a long-term continuous power supplement, it bears a close relation to a utility's total average generating costs and *not* merely the cost of the fuel and operating component. This average total generating cost has been the basis of current contracts with East Coast utilities and accounts for prices of approximately 24 mills/kWh.

Private industry can and, in fact, is playing an important role in the planning and implementation of

[2] Supplementing coal with shredded-refuse fuel has been demonstrated in a prototype plant built and operated jointly by the city of St. Louis, Mo., the Union Electric Co., and the U.S. Environmental Protection Agency. A major feature of this system, the air classifier, can be clearly seen in the center of the photo.



[3] **By heating light-fraction refuse in an oxygen-deficient atmosphere, gas or oil can be produced (pyrolysis). The plant shown here, which was recently completed by Monsanto, features a rotary kiln in place of the vertical shaft furnace depicted in the diagram. Rated at 900 tonnes per day, the facility furnishes steam to Baltimore, Md., for electric generation.**



refuse disposal and energy extraction. This is more than coincidental. There are numerous situations where private initiative can become a catalyst in developing a refuse–energy system:

- When multiple communities are involved, a single firm can take the initiative for a large-scale project that would be unattractive or difficult for a single small community to undertake.
- A private owner is more inclined to design for optimum lifetime costs even if this requires a large initial capital expenditure. Many communities find it difficult to budget large amounts in a single year.
- Marketing effectiveness is enhanced for energy and materials if the owner–operator has a bottom-line cost center responsibility.
- Private ownership encourages efficient operation with an appropriate level of preventative maintenance by skilled operators.
- Financing is simplified if the private owner takes full financing responsibility and no economic burden is placed on the taxpayer. Bond interest costs of a privately financed plant can be equal to or even lower than the cost of municipal general obligation bonds since tax-exempt industrial revenue bonds can usually be employed and other tax credits are available to private owners.
- The payment by the owner of local real estate taxes encourages community acceptance.

Career power too!

For electrical engineers in the power field, the expanding area of refuse-derived energy is providing an exciting and challenging area of operation. As an example, the involvement of IEEE's Energy Committee in promoting a search for alternate energy sources—including refuse—is indicative of the top priority being given the subject in conjunction with other societies and organizations. Participation by individual members and organizational units is demonstrated by technical papers and panel discussions at important IEEE-sponsored meetings such as the 1974 Earth Environment and Resources Conference held in Philadelphia Pa.

Of major significance in 1975 is IEEE's cosponsorship and full support of the First International Conference on the Conversion of Refuse to Energy, being held this month in Montreux, Switzerland. Out of about 90 papers from Europe, Japan, Australia, Canada, and the U.S., more than a dozen presentations are devoted to new opportunities for electric generation from refuse. In addition to reporting advances in the technology, discussions will cover comparative economics, financing, and community involvement.

Looking to the future, all indications point to increased economic attractiveness of refuse-fired electric generation. Delays experienced in developing nuclear power mean that numerous utilities will remain dependent on increasingly expensive fossil fuels for many years to come. Here, all reasonable alternative energy sources must be explored, including the socially desirable and economically attractive option of recovering electric energy through the clean disposal of municipal solid waste. ◆

Walter K. MacAdam (F), the senior engineering consultant at Wheelabrator-Frye Inc., in Hampton, N.H., is actively engaged in developing energy-generation-from-refuse technology and is serving as U.S. program chairman for the First International Conference on Conversion of Refuse to Energy being held this month in Montreux, Switzerland. He also has authored numerous technical papers in the refuse-energy field, with particular emphasis on sound economic planning. A Past President of IEEE and a former vice president of AT&T, Mr. MacAdam is a registered professional engineer and holds a master-of-science degree from the Massachusetts Institute of Technology.

EWS: Germany's answer to ESS

Stored-program control is at the heart of the Deutsche Bundespost's electronic telephone switching system

In the West German Federal Republic, as in most European countries, the telephone system is the responsibility of the same Government agency that operates the postal service—in West Germany, the Deutsche Bundespost. With 18 million subscriber stations in the Federal Republic, only the U.S., Japan, and Great Britain have more telephones. However, there are only 29 telephones per 100 inhabitants, which places the Federal Republic down at number 14 on the per-capita world list.

When the Bundespost decided in the early 1960s that it needed electronic switching equipment, several different manufacturers were asked to produce prototype switching offices to demonstrate the new technology. Four of these prototype offices were actually cut over into trial operation—the first in 1962, and the last in 1967. Each was designed and built by a different telecommunications manufacturer. Despite the appearances, there was little real intercompany competition in this situation. All the prototype offices were funded by the Bundespost, and the various manufacturers were asked to work together toward a single unified design. The EWS switching system that resulted is described in the article that follows.

Like the EMD electromechanical telephone switching system that was previously used by the Bundespost, EWS is largely the brainchild of Siemens Aktiengesellschaft. Siemens, a large company plentifully endowed with technical and political know-how, has long dominated telephone equipment design and manufacturing in West Germany. In addition, Siemens is the major West German manufacturer of heavy electric equipment and computers, and of other electric and electronic products as well.

EWS is built around large centralized service computers—Siemens uses its 4004 computer system for this application. In addition, the EWS system is designed to bring its new technology into older switching installations through the use of remotely controlled switching equipment.

Helping to meet international switching needs, EWS includes a feature that has become feasible with the use of electronic switching equipment: separate data and speech paths. This separation is the new standard for all international telephone links.

—Howard Falk

An electronic telephone switching system (EWS) is slated to replace existing electromechanical systems in the Federal Republic of Germany during a changeover period that is expected to last several decades. When the first EWS local switching center was cut over in Munchen-Perlach on August 29, 1974, the era of stored-program computer control for the West German telephone system had officially started.

At the touch of a button

For the subscriber, the EWS system offers a number of attractive features, many of which can be initiated and controlled from the subscriber's own dial or push-button telephone. For example, incoming calls can be temporarily blocked, and redirected to recorded announcements. For an automatic wake-up service, the subscriber feeds in the desired date and time of day. Connection to frequently called numbers can be made by one- or two-digit dialing codes that are set up by the subscriber. A tone can be automatically supplied during a call to notify the subscriber that another call is waiting. Telephones can be blocked, at the subscriber's option, from use for certain classes of call, such as long-distance or international calls. In addition, the system includes such features as identification of malicious calls by automatic printout of the calling party's telephone number, and direct inward dialing to PABXs. Independent number allocations for equipment allow subscriber lines to be relocated without changing the subscribers' directory numbers.

The system is designed to permit access to individual subscriber-related data and to allow flexible modification of existing features as well as addition of new ones. For example, features that are latent in the system include in-call suffix dialing and conference calls.

The EWS system also offers a number of technical features and advantages that were not available in previous systems. For example, with EWS the range of the lines between the subscriber and the local switching center has been increased. Small-diameter subscriber lines (0.4 mm) can now be used over distances of more than 6 km since loop resistance of up to 1800 ohms is permitted. To relieve cable-availability problems, concentrators are to be used to merge groups of 20, and also 100–150, subscriber lines into fewer conductors. Automatic alternative routing is provided at the originating switching center.

In existing switching centers, EWS allows the use of concentrators to supply added capacity; new small switching center additions can be remotely controlled by computers at larger EWS switching centers.

Automatic test and maintenance techniques are extensively used in the system. These derive much of

Heinz Kunze Deutsche Bundespost

their effectiveness from computer-based methods of fault monitoring, identification, and isolation.

Computer-routed local switching

The basic EWS local switching center, designated EWSO1, is diagrammed in the center of the illustration to the right. Peripheral circuits in EWSO1 handle the incoming and outgoing lines. Thus, each subscriber line is fed from a subscriber circuit, dialing digits are handled by digit-input circuits, and connections to other switching centers are handled by peripheral switching circuits.

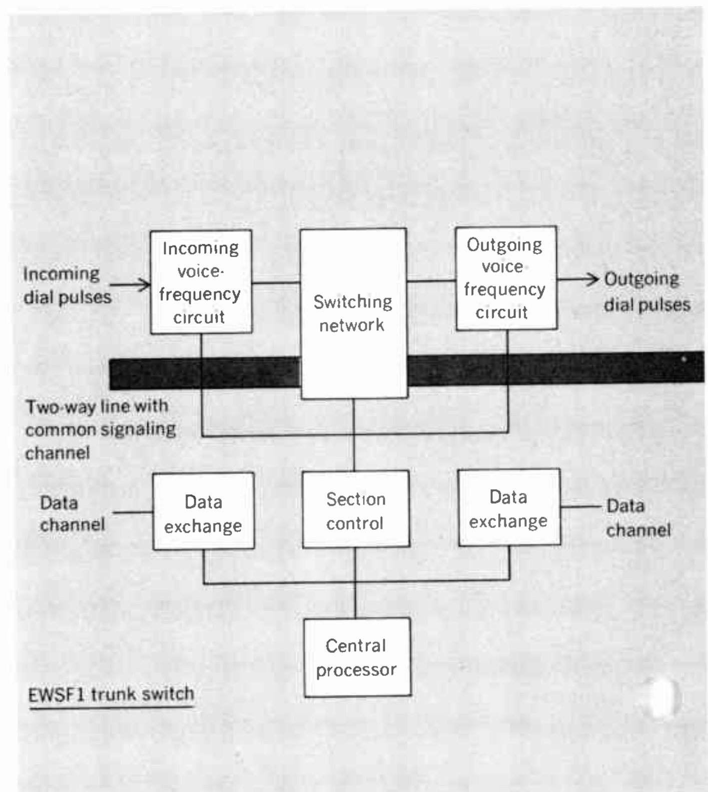
The EWS switching network itself is made up of banks of small bistable relays, mounted on boards and interconnected with printed wiring. The network uses a reversed trunking scheme that permits full equipment availability. Two wires—the ones that actually carry the subscriber's telephone message—are connected through this network for each incoming call. All selection of the necessary connection paths through the network is controlled by the switching center computer.

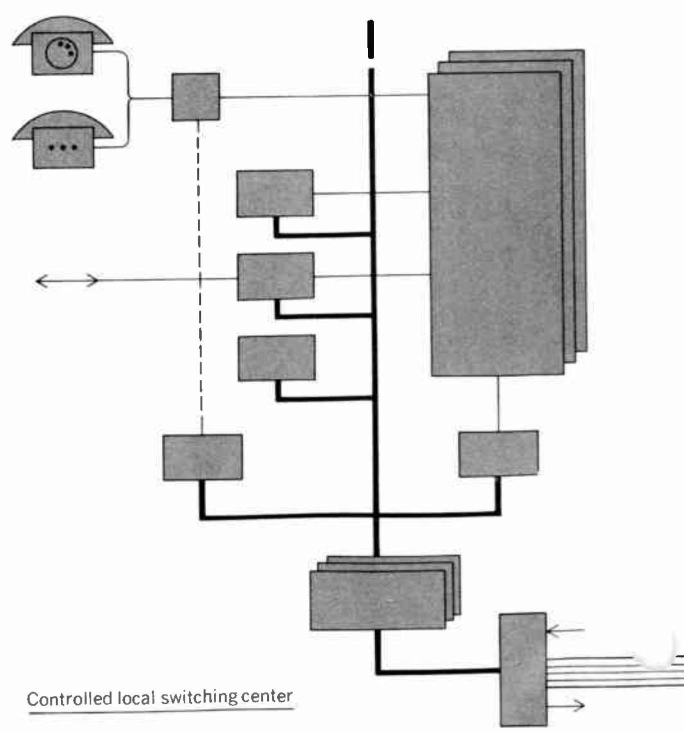
The EWS system is structurally divided into three levels. The central processor, with its program and data stores, belongs to the first level and is designed to operate around the clock. With its memory stores, this processor acts as a process control computer that carries out switching tasks on a real-time basis. To insure reliable operation, it actually has two processing units, microsynchronized to each other, that constantly perform identical operations in parallel.

The first level is linked to a second, intermediate-control-equipment level via a central bus system. Intermediate-control equipment includes a group of section control units, which constitute the interface between the central processor and the switching network. The number of these units needed for a center depends on the size of its switching network; each unit serves about 4000 subscribers. Section control units find and connect peripheral functional devices. The control units also translate parallel data signals from the local computer, or from other centers, into serial formats that can be used by the local switching network and its associated equipment. Information headed in the opposite direction, from the switching network to the computer, is likewise formatted in the control units. Message storage and any necessary conversion of voltage and power levels are also performed by the control units. Switching network crosspoint relays selected by the computer are actually driven by the marker controller unit.

The third level consists of the switching network itself and the associated peripheral system. This system connects the subscriber line circuits to the section control unit and also provides access to a number of special service circuits, such as those used for testing. Most of the system test procedures are implemented by a service computer, located in a separate computer center that serves a number of local switching centers, but an operator's console connected to the central bus system allows some local maintenance via the switching center computer.

An identifier circuit monitors the subscriber lines as calls are processed, and provides the address data needed to handle such functions as billing and the interception of malicious calls. Subscriber charges are





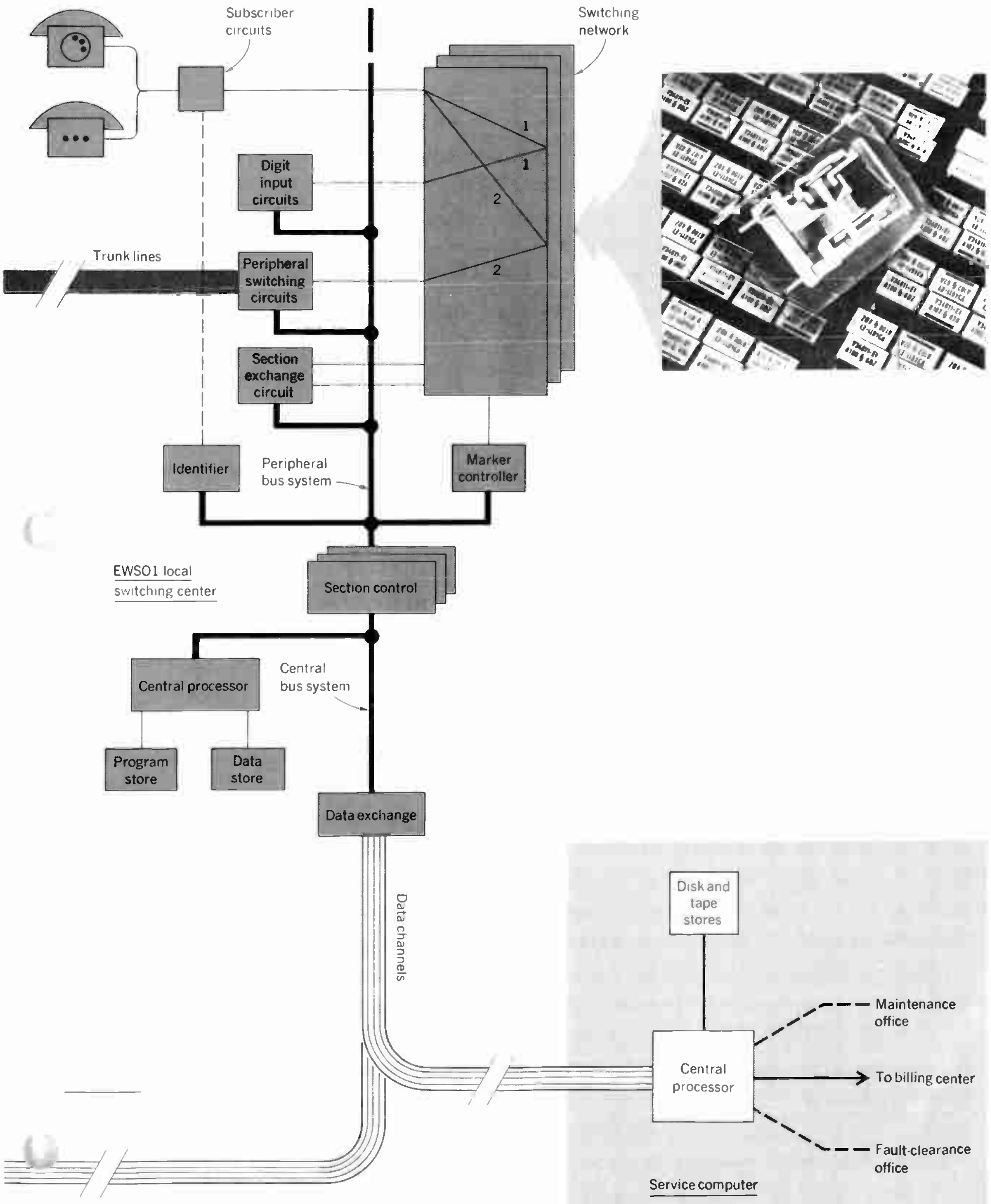
At the center of this overall view of EWS system equipment is an EWSO1 local switching center. Long-distance lines connect to an EWSF1 trunk switching center at the left. From the EWSO1 data exchange unit, data channels link its computer to another, computerless, local center, which is thus remotely controlled. Data channels also link the EWSO1 to a service computer that provides fault location, collects charges, and performs special services.

automatically registered throughout the invoicing process.

From one switching center to another

Data channels link local EWS switching centers and other switching centers. A local data exchange unit formats and routes data exchanged between centers. Data bytes for a single message are transmitted simultaneously, in parallel, over available lines, and incoming bytes are reassembled into complete messages. Transmission rates are 1200–4800 b/s.

Portions of the EWSO1 switching network can be remotely located, while remaining under the control of the local switching center computer. As a prerequisite for remote control, signals are preprocessed in the peripheral circuits. This frees the central processor from time-consuming dynamic processing procedures, and at the same time relieves internal data links of some



heavy data traffic. Several remote configurations are possible. For example, portions of a switching network can serve as a remote line concentrator to handle traffic in areas where there is rapid growth of telephone service. It is also possible to use computerless EWS local switching units to expand the capacity of older switching centers. These units are placed at the older centers and controlled—via 64 message trunks and two control channels—from the local EWSO1 center.

A computer-controlled trunk switching center called the EWSF1 serves to route long-distance traffic. It differs from the EWSO1 mainly at the third or peripheral level, and in the software associated with this level. The EWSF1 switching network, like that of the EWSO1, uses bistable relays at its crosspoints, but speech wires are connected through on a four-wire basis. Incoming and outgoing speech paths are crossed as needed for two-way transmission. This takes place at the switching network input.

To permit its use for international telephone interconnections, the EWSF1 contains all the circuits needed to meet all CCITT (International Telegraph and Telephone Consultative Committee) requirements. In addition, this trunk switch is designed to accept inputs from pre-EWS switching centers, and to transmit to these older centers as needed.

A basic EWSF1 switching unit has 768 four-wire terminations, and up to 17 of these units can be interconnected to form a network with 13 056 terminations.

There is also a digital trunk switching system, EWSD1, with a switching network constructed of integrated semiconductor circuits, and pulse-code-modulation (PCM) transmission links. In the future, exclusive use of PCM signals is expected on both local and long-distance trunks. It will then be possible to set up a video switching network. PCM promises equipment space-saving of over 50 percent as compared with existing systems.

Automatic test equipment for the switching network and peripheral circuits is a part of all EWS system versions. Using internationally recommended testing methods, the resistance of designated paths through the switching network is checked to locate faulty crosspoint relays. The computer then excludes use of these relays until they are replaced. Line circuits are accessed for testing using a ring line, whose connection is controlled by the EWS computer.

Servicing a switching area

Up to 20 EWS local switching centers form a service area that may cover 200 000 to 300 000 subscribers. Each such area has a service computer, which functions as a link to other processing equipment for telecommunication data and also performs technical service operations. As a centralized data processing system, the service computer has two essential tasks to perform. It acts as a computing and storage aid for the EWS system, and it also handles individual telecommunication office tasks such as maintenance, fault clearance, and customer and intercept services.

To locate faults in the system, the service computer uses evaluation and diagnosis programs designed to narrow the location of the fault down to a specific plug-in module in a specific switching center. The results are shown on a data-display console at the service computer. Information to and from the service computer travels over the system's data channels.

Billing information is automatically collected from the various switching centers in the service area. At the service center, all charges are collated into individual call-number accounts. This information is then used by the system's accounting computers for customer billing and for checking customer accounts as needed.

Special services in which the service computer plays a role include wake-up alarm and telephone-answering services for subscribers. Subscriber listings for information inquiries are kept up to date at the service center. In addition, the center performs a number of interval system functions, such as traffic monitoring and maintenance of data on equipment locations and cable routes.

A program for every task

As in any telecommunications system controlled by stored-program computers, EWS software performs many of the most vital system functions. For example, a set of safeguarding programs act to monitor and locate system malfunctions. Fault signals indicating malfunctions may result from program-controlled routine monitoring or directly from system equipment. These signals are recognized and interpreted by a fault-report program while a fault-location program pinpoints the component responsible for the malfunction. A changeover-to-standby program then puts the affected component temporarily out of service, and operating personnel are alerted to correct the malfunction.

Another group of programs performs the short-lived but vital tasks of start-up and expansion of switching center operations. These programs include off-line test sequences that set up precise, step-by-step connection of subscriber exchanges and peripheral devices at start-up. For expansion of switching facilities, the programs provide for such changes as addition of new trunk-group connections, and the large-scale memory address changes that are often necessary as expansion forces the use of larger areas of data storage.

There is a specific program for every device connected to the switching center peripheral bus system. These use a set of subroutines to perform recurring, device-independent tasks. User-service programs perform traffic measurements, execute readouts of data on customer charges, and handle record-keeping operations.

A central test installation is dedicated to software maintenance. Here, program changes are introduced and, when these changes are released, magnetic tapes of the new programs are distributed to those EWS switching computer installations that require the changes. ◆

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