Some Recent and Future Automotive Electronic Developments

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There have been many conferences and much has been published (*1, 2*) on the subject of automotive electronics, and now, with the introduction of a microprocessor to control the ignition timing of the 1977 Oldsmobile Toronado, a new age of automotive electronics has been unveiled. This first application of a microprocessor comes 25 years after the introduction of the first electronic control system on the automobile. This was the headlight control, which was introduced in 1952 and used the analog vacuum tube technology of the day. Over the past 25 years, 17 automotive electronic systems have been introduced, excluding communications and entertainment equipment. Sixteen of them remain and are shown in Table 1 in order of their introduction. This list excludes seat belt interlocks and traction control, which are no longer offered.

With the rapid advances being achieved in solid-state technology, increased packaging density, and lower cost and improved reliability of the systems, it is understandable why there is considerable interest in the application of this technology to the automobile. The stimulation provided by new technologies and the pressures of excessive and, at times, unnecessary governmental regulations have accelerated the automotive application of solid-state technology.

One measure of this increase in activity is the projected electronic content as a percentage of automobile cost. One source (*3*) predicts that by 1985, 10 percent of the cost of an automobile may be represented by electronics. That would represent a large electronic sales potential in excess of $10 billion annually, not including entertainment and communications equipment.

The size and complexity of an automobile electrical system makes it a prime candidate for the application of contemporary digital systems control technology. In addition to the 16 electronic subsystems previously mentioned (Table 1), an automobile can have 420 meters of cable and 83 switches which may be replaced in the future by solid-state devices. There can be 14 electric motors and 69 lamps. Also, there are 27 sensors and 27 fuses and breakers to protect the circuits, which are tied together with up to 108 connectors.

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Emissions and Fuel Economy

Two government regulations regarding emissions and fuel economy will have a significant impact on the continuing application of electronics to the automobile. Neither of these regulatory requirements can be satisfied with current technology. The 1978 statutory emission control standards (*4*) promulgated by the Environmental Protection Agency (EPA) require automobiles to be designed so that they do not exceed the exhaust emission values shown in Table 2 during the first 50,000 miles of vehicle operation (*5*). As emission standards become more stringent, a reduction in fuel economy may be anticipated. More stringent emission standards are in direct conflict with the intent of Public Law 94-163 (*6*), which requires each manufacturer to improve fuel economy and to have a production-weighted average fuel economy of 18 mile/gallon in 1978, 20 mile/gallon by 1980, and 27.5 mile/gallon by 1985.

Fuel economy improvements are being achieved first by making vehicles smaller and lighter, and second by improving engine and power train efficiency and performance. It is in the second area that electronics is expected to be applied; it is also in this area that strict attention must be paid to meeting the stringent emission standards.

Four electronic systems associated with engine control have been introduced or announced in the past 2 years. This is an addition to solid-state high-energy ignition systems which are essentially standard on American automobiles. Of the four, the most advanced to be introduced is the Delco-Remy MISAR system (microprocessed sensing and automatic regulation), which precisely controls spark timing for all conditions of load and speed consistent with drivability and emission control requirements (*7*). This system is being offered on the 1977 Oldsmobile Toronado and is particularly significant because it is believed to be the first application of a microprocessor to the automobile. A simplified diagram of the MISAR system is shown in Fig. 1. The input signals are crankshaft position, manifold vacuum, coolant temperature, and reference timing. The microprocessor is equipped with metal oxide semiconductors (MOS) and large-scale integration (LSI) technology and its read-only memory (ROM) has a capacity of 10,240 bits. The MISAR system can be readily expanded to other engine control functions because of unused ROM capacity. The system permits the engine to be tuned to improve fuel economy and drivability. It has improved the fuel economy on the Oldsmobile Toronado by approximately 10 percent while maintaining excellent drivability. Chrysler introduced a lean-burn spark timing control system utilizing analog technology on their large- and intermediate-size vehicles in 1976.

Electronic fuel injection (EFI) systems can provide improved starting and drivability in relation to carburetor systems. One such system is standard equipment on the Cadillac Seville. This was introduced in 1975 and is optional on other Cadillac models. The current EFI system is basically analog, but is a near-term candidate for the application of microprocessor technology.

Ford Motor Company recently announced (*8*) an electronically controlled dual displacement engine (DDE). The engine will be introduced in the next 2 years on light trucks, and it is expected to improve fuel economy by at least 10 percent and perhaps up to 20 percent. This improvement is achieved by deactivating half the cylinders when the vehicle speed exceeds 45 mile/hour or when it is decelerating to 25 mile/hour. Upon acceleration, all cylinders are activated. The electronic engine control system computes commands based upon engine temperature, transmission gear, engine vacuum and speed, and throttle opening.

A closed-loop knock-limiting system was developed by General Motors in 1976 which may allow improvements in fuel economy while permitting an engine to operate at acceptable knock levels on current 91 octane fuels. The system was designed to control ignition timing only under knocking conditions so that optimum timing may be used under all other conditions to improve fuel economy while satisfying exhaust emission constraints.

A sensor determines engine knock and provides information to an electronic logic system which retards timing to acceptable knock levels. An acceptable system must control knock under all operating conditions of speed, load, temperature, humidity, or altitude without significant degradation in economy, drivability, performance, or emission levels. A low-cost device to sense knock at trace levels in all cylinders without mechanical or electrical interference is required.

Catalysis is the only known method of achieving the 1978 statutory emission standards; however, the technology has not matured sufficiently to meet the statutory standard for 50,000 miles, and a change in the law is essential if the industry is to continue to produce acceptable automobiles. Systems which simultaneously control hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxide (NOX) emissions with a single catalyst require the air and fuel mixture to be precisely controlled to the stoichiometric ratio (14.6 : 1), at which point good catalyst efficiency is obtained (Fig. 2) for the three regulated by-products of combustion. This level of control is achieved with a system in which the oxygen level in the engine exhaust is used as the sensing parameter. The oxygen transducer is essentially a battery comprised of a solid electrolyte of zirconium dioxide with platinum-plated electrodes on either side. At the stoichiometric ratio and at exhaust gas temperatures, the zirconia sensor provides excellent signal characteristics (Fig. 2) which coincide with the optimum catalyst efficiency for the three constituents of interest. A simplified block diagram of the closed-loop system is shown in Fig. 3. Closed-loop emission control systems may be used on both EFI and carbureted engines if a three-way catalyst is used, and considerable effort is being expended by the automobile industry to develop such systems.

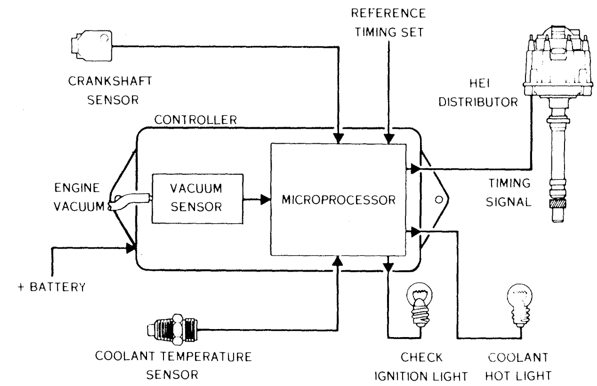


Fig. 1. The Delco-Remy MISAR system which controls spark timing for all conditions of load and speed.

Table 1. Contemporary automotive electronic subsystems.

Headlight control	Wheel-lock control
Alternator rectifier	Clock
Voltage regulator	Intrusion alarm
Tachometer	Air-cushion control
Cruise control	Electronic fuel injection
Electronic ignition	Lamp timing control
Climate control	Spark timing control
Windshield wiper control	Electronic digital displays

Table 2. The exhaust emission values that must not be exceeded during the first 50,000 miles of vehicle operation, according to the 1978 statutory emission control standards (*4*).

	Emissions (g/mile)		
	HC	CO	NOX
	1978 Standards		
Federal	0.41	3.4	0.4
	1977 Standards		
Federal	1.5	15	2.0
California	0.41	9	1.5

Alternative power plants, such as the Stirling cycle engine, gas turbine engine, and electric engine, are post-1980 developments (*9*).

Truck Systems

There have been three recent applications or announcements of electronic systems for trucks. Government standards (*10*) for buses, trucks, and trailers with air brakes were sufficiently stringent that manufacturers resorted to the use of wheel-lock control systems in order to meet the performance levels specified. The basic problem was that initial requirements were too stringent, and insufficient development time was allowed for by the government regulators in spite of substantial and continuing pleas on the part of the vehicle manufacturers. The resulting unacceptable reliability of bus wheel-lock control systems prompted the government to suspend stopping-distance requirements for these vehicles. The wheel-lock control systems offered today are all analog in nature, and a microprocessor will no doubt be used for the control unit in the future.

Ferranti announced (*11*) the development of a flexible load-weighing system for trucks. The system derives weight data from a strain gauge attached to each axle. The load on each axle is computed and displayed as is the total vehicle load. The system can detect inadvertent overloads which can result in higher maintenance cost and possible fines, and can indicate underload situations which, if corrected, can improve the economics of hauling.

General Motors has developed a low tire pressure warning system for trucks, tractors, trailers, and buses. The system consists of four major components: a temperature-compensated pressure switch, an actuator-sender that replaces one wheel mounting bolt, a stationary

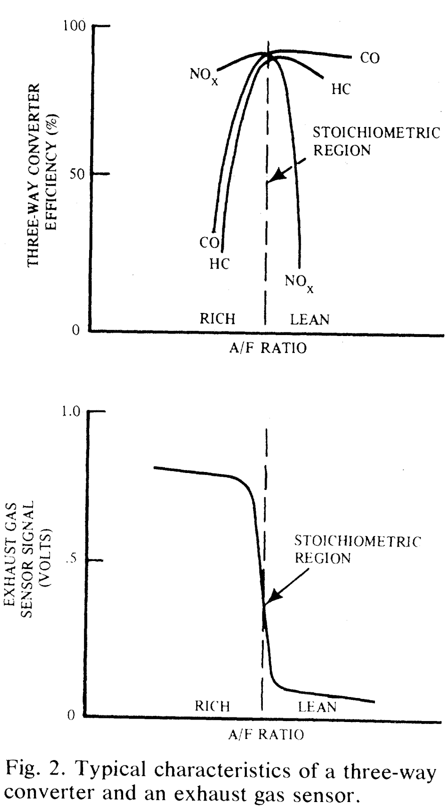


Fig. 2. Typical characteristics of a three-way converter and an exhaust gas sensor.

sensor behind the mounting bolt, and a display panel. Low tire pressure lights a panel indicator and a "pop-up" button in the wheel actuator provides out-of-cab detection. The warning continues until the tire has been inflated and the "pop-up" button reset. The low tire pressure warning system maximizes tire life and fuel economy in addition to improving safety and reducing maintenance inspection time.

Displays

With the start of the 1977 model year, General Motors introduced electronic displays integral with an automobile AM/FM radio. The four-digit, seven-segment light-emitting diode (LED) displays four functions on command, namely, date, time of day, elapsed time, and radio station frequency. In addition to LED's, electronic display technology under development around the world includes gas discharge, liquid crystal, electrochromic, and electroluminescence. Cost and demonstrated life continues to present major barriers to expanded use of electronic displays. However, it is anticipated that future automobile instrument clusters will be generated from a single mask by means of these technologies. Prototype d-c electroluminescence instrument clusters have been manufactured from a single mask and demonstrated in vehicles (*2*). This system displayed both digital and analog data.

Multiplex Systems

As electrical and electronic systems are added to the automobile, it becomes progressively more difficult to meet reliability objectives because of multiple connectors. Multiplex systems have the potential to improve reliability and reduce weight, and they can be designed to be immune to noise. It appears that adequate technology would be available for the use of such systems if their cost were more competitive with current wiring systems. An additional advantage of such a system is the relative ease of introducing diagnostic routines, provided low-cost transducers are available.

An interesting development is the application of fiber optics to automotive multiplexing systems. Advances in fiber-optic control systems during the past 2 years include more efficient infrared light sources, low noise photo diodes, and rugged, efficient fiber-optic cables, many of which are now available off the shelf.

Lightweight, interference-free fiber-optic cables are replacing heavy, complex copper wire bundles aboard military aircraft and ships. Underground communication cables are being replaced with light pipes capable of transmitting conversations over many kilometers. Current fiber-optic technology for data lines can provide a weight advantage of up to 100 : 1 and a cost advantage of 30 : 1 compared to copper lines.

The extensive advantages of this technology include the immunity of the fibers to electromagnetic interference (EMI) and to oil, grease, dirt, and acids, and high-speed information transmission. These advantages are of considerable importance to the automobile engineer. The advent of lower cost components, coupled with the inherent performance advantages of this technology, make it an ideal means of reducing vehicle harness weight and providing EMI-immune systems.

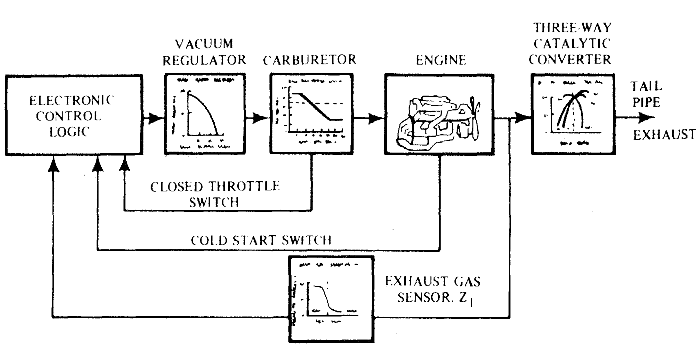
A multiplexed control system with a single fiber-optic cable (see Fig. 4), has been developed to replace the multiwire harness, connectors, and printed circuitry required to interconnect steering column switching functions with vehicle power actuators and lights.

An encoder module, located at the top of the steering column, interprets the following switching commands and digitally multiplexes each command signal: windshield wiper, turn signal, hazard flashers, key reminder, horn, headlamp controls, cruise control. These signals are transmitted as light pulses through the fiber-optic cable to a decoder module located at the base of the steering column. This module decodes individual switch commands and sends a signal to the appropriate power actuator, for example, the windshield wiper motor, horn relay, or lights.

An inexpensive LED on the encoder chip is electrically pulsed. The 32-bit digital words are converted by the LED to light pulses which are transmitted down the cable. A photo diode on the decoder chip receives the light pulses as

Table 3. A list of proposed electronic systems for the automobile. Prototypes of many of these systems have already been made.

Automatic cruise control	Vehicle locator
Automatic brakes	Emergency location transmitter
Radar crash sensors	Multiplex wiring systems
Crash recorders	Low tire pressure indicators
Electrocardiograms	Vehicle load weighing systems
Sleep detectors	Ultrasonic fuel injectors
Alcohol ignition interlocks	Engine knock limiting control
Automatic vehicle guidance	Dual displacement engine control
Road coefficient detector	Closed-loop engine control
Controlled exhaust gas regulation	Electronic displays
Automatic diagnostic systems	Current drain protection
Vehicle blind spot detectors	



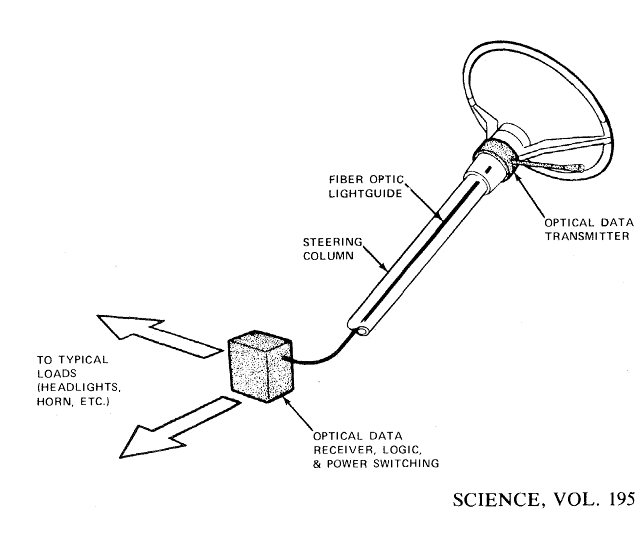
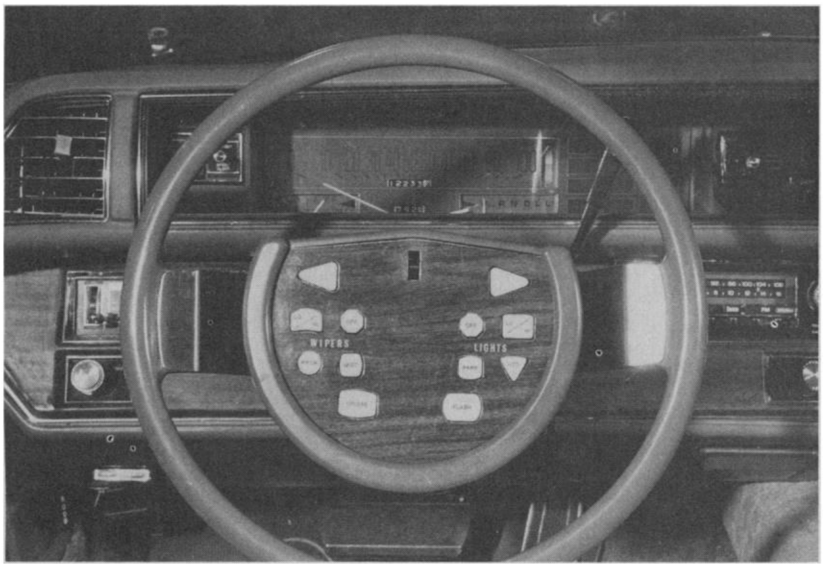


Fig. 3 (left). Diagram of a closed-loop system for use in controlling the air and fuel mixture. Fig. 4 (right). A multiplexed control system with a single fiber-optic cable.



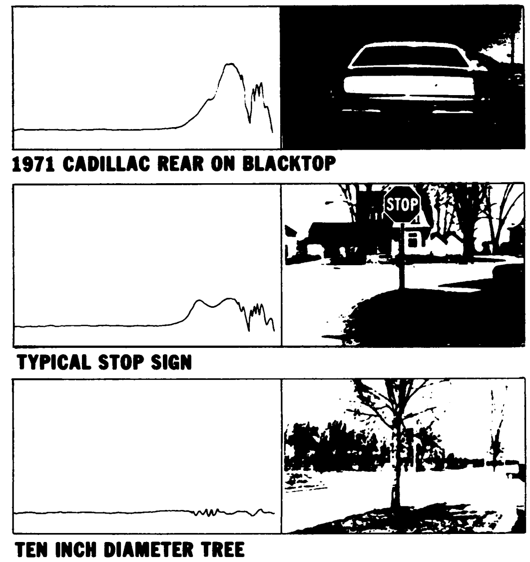


Fig. 5. Steering wheel control panel. The main switches are on a nonrotating platform in the center of the wheel.

Fig. 6. X-band radar signatures.

they emerge from the cable and reconverts them to electrical signals which are recognized by the decoder on individual switch commands.

A 1975 Buick Electra was equipped with a fiber-optic multiplexed steering column system (Fig. 5). Design flexibility was demonstrated by placing major vehicle switching functions on a nonrotating platform in the center of the steering wheel. Small switches located on the platform, or anywhere on the instrument panel and door panels, can replace larger, high-current carrying switches required with conventional systems. This feature provides considerable design flexibility. For instance, a citizen's band (CB) microphone could be mounted in the center of the platform to carry voice signals down the fiber-optic cable to the CB transmitter unit.

Systems of this type are not without problems, however. Several major engineering hurdles must be overcome before optical multiplex systems are applied to an automobile. A low-cost solid-state switch capable of converting low-current switching commands from the decoder module to high-current power drive signals is required. These developments further emphasize the need for automotive systems to be cost-effective.

Long-Range Systems

A list of proposed electronic systems for the automobile would be extensive and exceed 100 items in addition to the current systems shown in Table 1. Some of the advance systems which have been proposed are shown in Table 3. Many of these systems have the potential to become standard or optional automotive equipment in the next decade; several of them are under active consideration and may be seen on automobiles within this decade. In general, the near-term systems suffer from poor cost-effectiveness, generally because of the high cost of the transducers and actuators. While the utility of many of the longer-range systems can be justifiably challenged, the universal need for effective transducers and low-cost actuators cannot. Two of these longer-range systems are of particular interest: alcohol ignition interlocks and automatic radar brakes. If these systems could be successfully developed, they could have a significant impact on improving highway safety. Their implementation would, however, depend on an acceptable level of cost-effectiveness being achieved.

Government studies (*12*) continue to show that the driver is the major contributor to the cause of over 80 percent of vehicle highway accidents. Alcohol continues to be a major cause of highway accidents. Over 50 percent of highway fatalities are due in part to alcohol consumption, and this percentage is expected to rise because of the projected increase in per capita alcohol consumption (*13*). Drivers continue to run into the rear of other vehicles. In another government study (*14*) of rear-end collisions, 45 percent of the drivers in the striking vehicle claimed they never saw the vehicle struck until after the accident. Because of these conditions, it is expected that research will continue in areas aimed at reducing the driver-caused accident, with specific emphasis on research directed toward the ultimate goal of inhibiting the operation of an automobile by an intoxicated or otherwise impaired driver, and toward automatic brakes.

Experiments have been conducted with electronic devices which will prevent a drunk individual from starting his car. The first device developed by General Motors was the Phystester (*15*), which rejected approximately 50 percent of potential drivers with a blood alcohol concentration of 0.1 percent. This led to the development of a critical task tracker (*16*), which gave a rejection rate of 75 percent. We are still seeking a device which would be 100 percent effective.

Accidents caused by driver inattention to vehicles stopping or slowing ahead indicate that radar-augmented braking systems may have potential for preventing highway accidents (*17*). The major barrier to designing an acceptable system is the inability of the system to conduct a hazard analysis of potential obstacles. Figure 6 shows X-band radar signatures of three obstacles which are frequently involved in highway collisions. As can be seen, the small stop sign has a signal amplitude considerably higher than that for the 10-inch-diameter tree (*5*). If the system detection threshold were set to include all three obstacles, a large number of false alarms might result which would be unacceptable to the driver.

With the reduced cost of memories, such as charge-coupled devices and bubble memories, the potential exists to store sufficient radar signatures to support a high-speed hazard analysis. The initial application of radar to the automobile is expected to be as part of a cruise control or station-keeping system. If this is successful, it could lead to fully automatic braking systems.

Radar crash sensors for air-cushion restraint systems have been discussed (*18*) in the past. In this application, the severest hazard analysis situation exists because of the unacceptability of inadvertent or false inflations of the air cushion.

Summary

The automotive industry continues to examine new electronic technologies for their applicability to the automobile. Today, 16 electronic systems can be found on the automobile, and future engine and emission control systems will soon be added. Truck systems of interest include wheel-lock control, vehicle weighing systems, and tire pressure warning devices. Digital electronic displays and multiplex wiring systems are expected to be near-term developments and, on a longer-range basis, it is expected that automatic radar brakes and intoxicated-driver interlocks will receive considerable attention.

References and Notes

1. See, for example, Society of Automotive Engineers, *Automot. Electron.* SAE Publ. No. SP-388 (January 1974); *Convergence 74, International Colloquium on Automotive Electronic Technology* SAE Publ. No. P-57 (Society of Automotive Engineers, Warrendale, Pa., 1974), p. 57; *Convergence 76, International Conference on Automotive Electronics and Electric Vehicles*, SAE Publ. No. P-68 (September 1976); *Automot. Electron.* SAE Publ. No. SP-417 (February 1977); *Automot. Electron. II* SAE Publ. No. SP-393 (February 1975).
2. Institution of Electrical Engineers, *Automob. Electron.* IEE Conference Publ. No. 141 (July 1976).
3. G. F. Villa, in *Proceedings of Convergence 74, International Colloquium on Automotive Electronic Technology* SAE Publ. No. P-57 (Society of Automotive Engineers, Warrendale, Pa., 1974), p. 149.
4. Clean Air Act of 1970, Title 42, U.S. Code Emission Standards for Moving Sources, Chapter 2, Section 202 (Government Printing Office, Publ. 0-445-880, Washington, D.C., 1971).
5. The metric equivalents for units used in the text are as follows: 1 mile = 1.6 km; 1 gallon = 3.7 liters; 1 inch = 2.5 cm.
6. Energy and Policy Conservation Act, PL 94–163 Title 5, "Improving Automotive Efficiency" (Government Printing Office, Washington, D.C., 1976).
7. D. J. Simanaitis, *Automot. Eng.* **85**, 24 (1977).
8. Vehicular Technology Group, *IEEE Vehicular Technol. Group Newsl.*, p. 6 (November 1976).
9. J. J. Brogan, in *Proceedings of Convergence 76, International Conference on Automotive Electronics and Electric Vehicles* SAE Publ. No. P-68 (IEEE, New York, 1976), p. 24.
10. Federal Motor Vehicle Safety Standard 121, "Air Brake Systems" (National Highway Traffic Safety Administration, Department of Transportation, Washington, D.C.).
11. H. F. Dickinson, *Automob. Electron.* IEE Conference Publ. No. 141, p. 33 (July 1976).
12. Institute for Research in Public Safety, "Tri-Level Study of the Cause of Traffic Accidents," Contractor's Report No. DOT-HS-034-3-535-TAC (National Technical Information Service, Springfield, Va., October 1974).
13. Department of Transportation, "The National Highway Safety Forecast and Assessment (A 1985 Traffic Safety Setting)" (National Highway Traffic Safety Administration, Department of Transportation, Washington, D.C., 1975).
14. "Problems of Linear Closure at Urban Intersections," Contract No. CPR-11-4201, Second Quarterly Progress Report (National Highway Traffic Safety Administration, Department of Transportation, Washington, D.C., 1966).
15. T. O. Jones and J. A. Tennant, "Alcohol Impairment Detection by the Phystester—Evaluation Summary," SAE Paper 730093 (Society of Automotive Engineers, New York, January 1973).
16. J. A. Tennant, in *Proceedings of Automotive Safety Engineering Seminar* (General Motors Corporation, Warren, Mich., June 1973), p. 95.
17. D. M. Grimes and T. O. Jones, *Proc. IEEE* **62**, 804 (1974).
18. T. O. Jones, D. M. Grimes, R. A. Dork, "A Critical Review of Radar as a Predictive Crash Sensor," SAE Paper 720424 (Society of Automotive Engineers, New York, May 1972).

Electronic Mail

Electronic communication of information is more rapid than conventional transportation of documents.

Robert J. Potter

The concept of an organized mail system is believed to have emerged in about 400 B.C. in the Persian Empire. Queen Elizabeth I issued a proclamation in 1591, which prohibited carrying of mail to and from England except by messengers authorized by the Master of the Posts. In America, the first postal system was authorized by the colonial legislature of Massachusetts in 1639.

Efficiency was gained by faster transmission and, subsequently, by faster distribution at the terminals of the system. The pony express increased the extent of the postal system. Airmail reduced the time of transit. And now our society is in the midst of a revolution, the electronic revolution, which makes the delay in transmission of information negligible.

The term "mail" has come to mean the ordinary physical transport of a document, from one location to another in a sealed and addressed envelope. The electronic revolution has made it possible to replace the transportation of the document with the electronic communication of its information—"electronic mail." The decision to use an electronic mail system is primarily sociopolitical and economic. Today's technology can provide a cost-effective electronic mail system under many conditions.

An interesting analogy can be drawn between the evolution of the telephone (from manual switchboards, to electromechanical switching, and now to electronic switching) and mail systems, which also started with manual sorting and human transportation and delivery; they have progressed to automated electromechanical sorting, rapid air transportation, optical character recognition, and have now begun to use electronics for many of their operations.

Several systems on the market today use electronics for communication of information, that is, forms of electronic mail. The telegraph and the telegram (though fading rapidly because of the newer and more advanced forms of electronic communication) were early means of transmitting information electrically. Teleprinter systems, telex/twx, and mailgram, more modern forms of electronic mail, are now used throughout the world. Mailroom and point-to-point facsimile are becoming widely accepted electronic systems for inter- and intracompany mail service. Large interconnected computer centers are used to transmit messages to and from computer terminals. The use of communicating typewriters, word processors, various keyboard terminals, and other electronic devices is predicted to grow rapidly because of their high efficiency in transmitting alphanumeric characters.

Kinds of Mail

The mail can be divided into five major types: (i) transactions, (ii) advertising, (iii) correspondence, (iv) magazines and newspapers, and (v) merchandise in order of decreasing volume (*1*). Much mail contains financial transactions such as

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