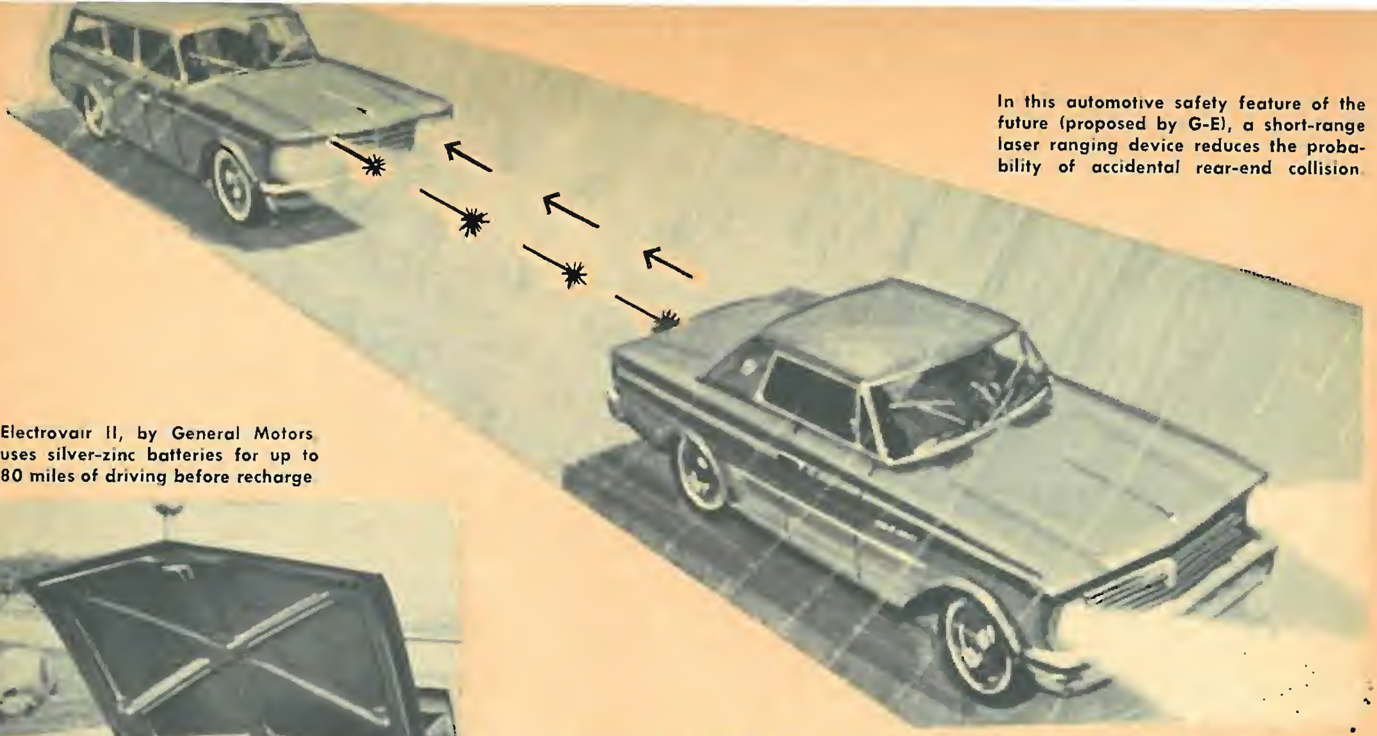


In this automotive safety feature of the future (proposed by G-E), a short-range laser ranging device reduces the probability of accidental rear-end collision.

Electrovair II, by General Motors uses silver-zinc batteries for up to 80 miles of driving before recharge

AUTOMOTIVE ELECTRONICS

By ROBERT M BROWN

Tomorrow's cars will lean heavily on electronics. For example, voltage regulators, fuel warning systems, anti-skid control, and a radar-like laser system to prevent rear-end collisions are among items proposed.

UNTIL quite recently, major developments in the automotive field seemed to be limited to such areas as better styling, improved gasoline consumption rates, and, lately, the feasibility of turbine-powered vehicles. Within recent months, however, electric and electronic equipment has moved to the forefront. To talk about transistorized car radios, automobile safety, and electric autos all in the same article might seem a rather disjointed method of approaching the status of automotive electronics, but these developments are all related and point to the fact that sweeping changes are indeed beginning to be felt in Detroit.

At this writing, it is still not known exactly which safety improvements will actually show up with the 1968 models, but if Dr. William Haddon, Jr., chief of the National Traffic Safety Agency, has his way, twenty stringently imposed features will debut this coming September.

Although most of the controversy has revolved around certain mechanical changes (such as better seat anchorages) and the auto manufacturer's leadtime requirements, considerable fallout has hit both the automotive accessory makers and the original equipment manufacturers (OEM) who now find themselves scurrying about for electronic devices designed to plug the more obvious safety loopholes in the American car. And since considerable Detroit funds have suddenly been diverted to meet Washington's new demands, a severe cutback is being felt by many standard component R & D companies now faced with the problem of economical and rapid production. The solution appears to be electronics.

Some Electronic Developments

Although we are all familiar with perhaps the first application of solid-state components in the family car—the transistorized radio—the most significant step forward was the use of the silicon diode in the alternator. This move represented a real risk for the automobile manufacturer because his use of these diodes affected both the safety aspect of the car and his costs, both initially and under warrantee. The success story of the alternator rectifier was so remarkable that the industry began to take a long, hard look at the electronic technology it had for so long ignored.

The next step was to see what could be done about the voltage regulator. It seemed logical that a transistor could be used for this purpose because a circuit could be designed to respond to the difference between battery voltage and a stable reference source, with this signal controlling the output of the alternator. Fig. 1A illustrates a simplified transistor-type regulator, while Fig. 1B shows an approach using an SCR. Several manufacturers (including *Motorola*) now have transistorized voltage regulators on the market, while *Ford Motor Company* has announced that it will be using

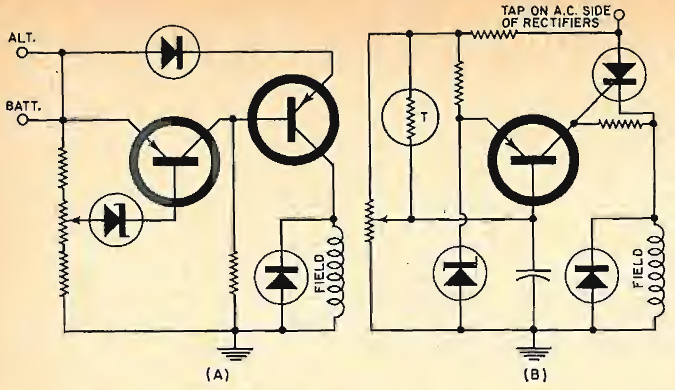


Fig. 1. (A) Simplified voltage regulator using a transistor. (B) Simplified SCR alternator voltage regulator.

some solid-state regulators in many of their 1968 models.

Although transistor ignition systems have been with us for some time, they are still undergoing further development. Of the several approaches commercially available, the capacitor-discharge system appears to be taking the lead, and some of the major auto manufacturers are already supplying such systems as an extra in some of their latest model cars.

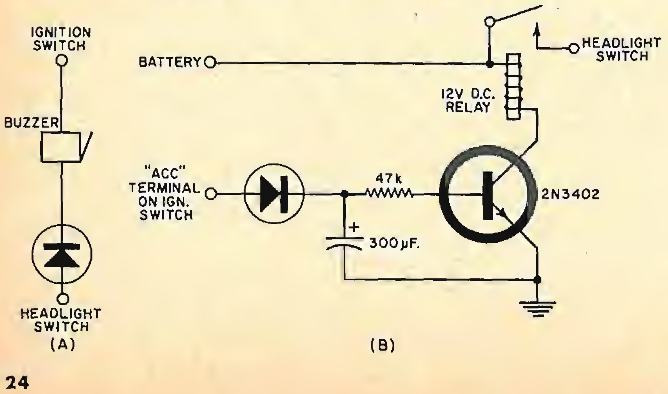
In some of the more advanced versions of the transistor ignition system, even the mechanical point contacts are being replaced by either a photoelectric or magnetic pickup, which, in turn, activates the ignition system.

As this latter approach reaches the customer, it then removes the last mechanical component that stands in the way of an all-electronic transistor ignition and voltage regulator system.

With the safety-equipment drive in full swing, renewed interest in the automatic headlight dimmer has arisen. Currently available in the top cars of the big three auto makers, this unit, in addition to turning the lights off after a predetermined delay, turns the headlights on and off according to ambient light. At present, there is considerable talk of using the same principle in dual-intensity tail lights—one brightness for daytime and a lower one for nighttime. This application has evolved from the problem of temporary "blindness" resulting from the increase in total light given off when a car is braked at night with four, five, or six bulbs across the back of the vehicle.

The day/night rear-view mirrors offered by the leading auto makers on certain models also show the extent to which solid-state circuitry is beginning to be used in safety apparatus. During night driving, if a following auto's headlights are on high beam, a photocell in the mirror sends a signal to a transistor amplifier, which in turn activates a miniature solenoid that flips the mirror to a different angle. This automatic action deflects the bright headlamp reflection away from the driver's field of vision. When the high-beam light disappears (or the following car switches to the low beam), the mirror flips back to its normal angle.

Fig. 2. (A) Headlight-on reminder buzzes when ignition is off and lights are on. (B) Headlight time delay automatically turns headlights off after a 60-90 second delay.



The acceptance of these devices is significant because it shows that both the automobile manufacturer and the owner are willing to trust certain control functions of the car to solid-state technology.

The Future

While it remains impossible to predict to just what extent the trend toward more and more electronics in the automobile will advance, startling work is currently being done on sophisticated safety device systems that may ultimately find their way into family vehicles. A number of firms (including *Bendix*) are presently conducting research into the possibility of an anti-skid control circuit, a design that will initially be tested on jet aircraft landing wheels. Since in many instances it is the sharp, prolonged application of pressure to the brakes that causes an automobile to veer into a skid and consequently go out of control, the suggested system would keep this from occurring by partially disengaging the pedal from the brakes while applying a moderate amount of braking by itself. The idea is simply to cause an automatic and *gradual* slowing down, regardless of how much frantic pumping the driver might exert.

This system will use four transistorized tachometers, one on each wheel, feeding an IC logic circuit which would compare each wheel revolution rate to the rest while at the same time using a fifth feed (consisting of any one of several proposed methods) for arriving at an actual vehicular motion reference (total car speed in relation to the roadway). The logic center would in turn be coupled to an electrical mechanism with override capability that would be attached to the conventional hydraulic brake system normally under driver control. When the IC control sensed a severe departure from the balanced rpm "norm" on any one or more of the wheels and also "felt" that over-all vehicle speed exceeded a safe level, it would apply moderate braking pressure to the wheels. This pressure would vary, depending upon the total motion factor and what was actually happening on that one wheel. Should the skid situation correct itself, full braking control would revert to the driver.

Although considerable research is now underway on just such a control circuit, it is felt in many circles that Detroit will never permit this much of a vehicle's mechanical system to be turned over to solid-state components. "Consider what would happen if the system failed!" is a frequently encountered remark. On the other hand, it is known that a similar system will soon be tested on aircraft grounding apparatus, and the ever-growing confidence in current automotive solid-state devices has far from reached a peak.

General Electric is presently offering interested automobile accessory suppliers its ideas for an anti-tailgating device using a laser beam. The arrangement calls for use of a low-cost laser that would put out low-power pulses of light, coupled with an extremely sensitive solid-state sensor to pick up the light reflections. The laser device would mount on the front of the vehicle and "look" directly ahead for a distance of perhaps 300 to 400 feet, depending upon what range the driver is calling for at the moment. With the sensor feeding a transistor amplifier which in turn might activate a buzzer, lamp, or meter readout, the driver would know approximately how far he is behind the vehicle ahead even though that car might not be visible. Any number of sophisticated laser alerting systems could be developed. However, *G-E* feels that this system will probably make its debut as an anti-tailgating gadget designed primarily for use in heavy snow, sleet, and fog conditions where even radar is undependable. A spokesman for the company claims that such equipment could be mass-produced at "a very reasonable cost, although it must be stressed that the laser for passenger cars is still far from a reality."

Long before such exotic designs become standard equipment, a host of less complex yet still impressive gadgets will appear. In fact, many such devices are here now.

The Boom in Accessories

A quick glance at the "available equipment" chart (Table 1) confirms that solid-state components are presently playing a major role in many new products for the car. For example, let us take a look at what the photoelectric headlight dimmer has stirred up. Fig. 2A shows a simple way to remind the driver that he left his headlights on after he turned the ignition off. In operation, when both ignition and headlights are on, both sides of the device are at the same potential. If the ignition switch is off and the headlights are on, current flows through the diode, activating the buzzer. Fig. 2B illustrates one method of achieving automatic headlight-off 60- to 90-second time delay. This unit is really two devices in one.

(Continued on page 26)

D.C. MOTOR DRIVE FOR ELECTRIC CARS

By JOHN MUNGENAST
Electronic Components Div., General Electric Co.

That workhorse of the electric vehicle field, the fork lift truck, uses a d.c. motor control that has much to offer the electric car.

As we explore the electric drive for vehicles of the future, it is well to draw on the experience with solid-state drives presently being used on tens of thousands of vehicles throughout the world. The basic solid-state control system to be described is over six years old and has been in service in European delivery trucks, American golf carts, lift trucks, and personnel carriers as well as a complete German passenger train. The fundamental principle of a d.c. motor controlled by a solid-state "chopper" makes a natural starting point for discussions of future vehicle drive techniques. In addition, it should be noted that *Ford* research engineers claim they have in operation d.c. motors weighing only a quarter as much per unit power as the best now available and that these motors promise to be "low in cost and durable."

Essential vehicular drive requirements involve (1) the ability to reverse directions; (2) provision for dynamic braking; and (3) the ability to vary vehicle speed by lowering the voltage applied to the motor.

Categories (1) and (2) are generally provided by conventional methods of mechanical switching and the insertion of an appropriate armature resistance, which has been done conventionally for many years. The efficient reduction of battery voltage for speed control of the motor, however, poses a much more difficult problem.

While a variable resistor could do the job and indeed has been used in past electric vehicle controls, it has the disadvantages of lower efficiency, discernible control "steps," and poorer speed regulation (since the voltage drop changes with the motor current). Phase control, the answer to a.c. motor variation, is out of the question since the power source is a battery or other d.c. source. The power "chopper" mode of operation as shown in Fig. 1 seems like one answer. While this control method supplies the motor with power pulses, the motor responds to the *average* power level so that little sign of the pulsing is evident in operation.

A "chopper" is essentially a fast-acting switch, mechanical or solid-state, used to convert a d.c. level into a fluctuating waveshape for purposes of power control, subsequent amplification, etc. (Other "chopper" applications include vibrator power supplies, automotive ignition points, etc.)

The solid-state chopper can use either power transistors or an SCR, and each has certain advantages and disadvantages. But since the majority of high-current choppers use SCR's, this type will be discussed.

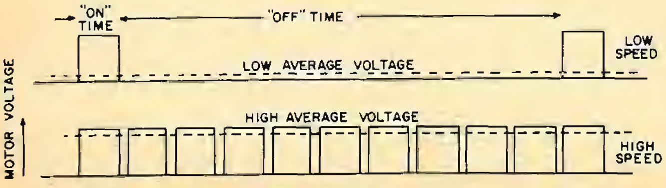
The advantage of latching-type operation, where a small momentary signal turns the device on, is offset to some extent by the difficulties in turning the SCR off when it operates from a d.c. source. To turn the SCR off it is necessary for the load current to be interrupted momentarily. The complete circuit for such an operation is shown in Fig. 2—actually an overgrown power flip-flop.

In operation, it functions as follows. *SCR1* is the main load-carrying SCR. When its gate is triggered on by unijunction transistor *Q1* circuit, current is allowed to flow through half the winding of *T3* and through the armature and field coil of the motor, which starts to run. The start of current flow induces a voltage into the other half of *T3* which charges up *C4*. This charge is held until the "off" SCR (*SCR2*) is triggered by unijunction transistor *Q2* circuit. The voltage across *SCR1* is then reversed and turned off. One of the advantages of this circuit is its ability to start reliably. Because of autotransformer *T3*, capacitor *C4* is always charged up whenever load (motor) current starts to flow; thus, commutation energy is always available. The main SCR is turned on again at an interval based on desired motor speed. Variation of motor speed is based on either varying pulse width or pulse frequency, or a combination of both.

A typical control, built by the Industry Control Department of *General Electric*, is now in use in thousands of electric fork trucks and is shown in the photo below. The SCR's, heatsinks, and commutating capacitor are mounted on the large board with the firing circuit board held in the hand.

The control potentiometer (not shown) is connected to the accelerator pedal. Bypass switch *S1* (Fig. 2) is usually energized at the end of accelerator travel, providing direct drive from battery to motor for maximum speed. ▲

Fig. 1. In a power chopper circuit, the average voltage applied to a motor is a function of pulse "on-off" time.



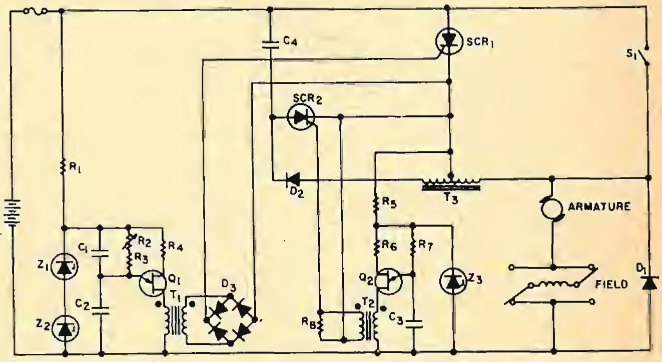
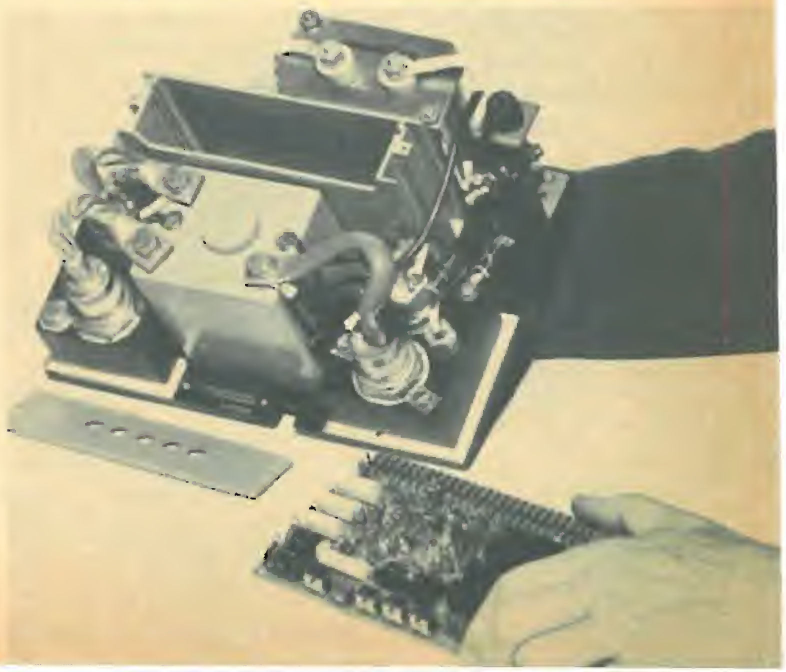


Fig. 2. SCR chopper circuit used for controlling a variety of battery-operated, d.c.-motor-driven electric vehicles.

Large SCR's and commutating capacitors on rear board, with firing circuit located on the smaller board. This system has been used for many years on electric fork lift trucks.



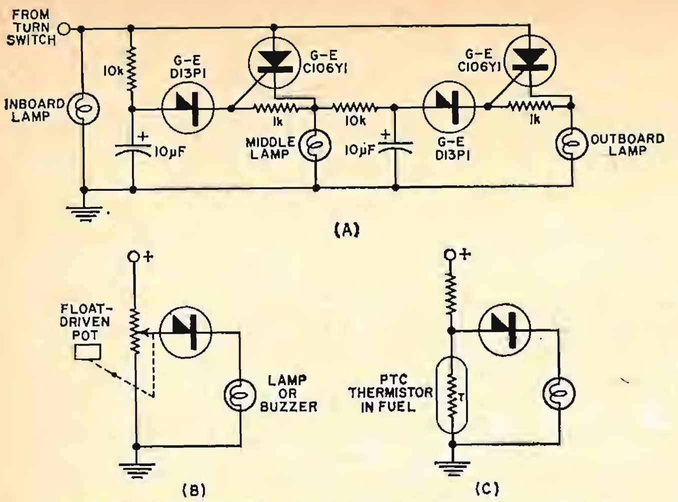


Fig. 3. (A) A system for creating sequential tail-light flashing. (B) Low fuel warning system using float. (C) Low fuel warning system using a self-heated thermistor.

It will delay the light-off signal to illuminate the way down the driveway or automatically turn headlights off should the driver forget.

Several manufacturers are introducing a solid-state module to produce the dazzling sequential tail-light effect now seen on certain cars. One way to do this is shown in Fig. 3A. These systems use SCR's to control the lamps and a conventional thermal flasher to open the circuit and reset the SCR's. A heavy-duty variable load flasher will not work with this system because it has a heater in parallel with the contacts and never really opens the circuit to shut off the SCR's. The breakdown diodes in the schematic are four-layer diodes which breakover (essentially short circuit) at a specific voltage (6 to 10 volts), thus triggering on the associated SCR. These diodes are well suited to such applications as level sensing. For example, one way that a manufacturer might indicate a low fuel supply is shown in Fig. 3B. In this circuit, as the float drops due to lowering of the fuel level in the tank, the potentiometer arm approaches the battery voltage until the diode fires, operating the buzzer or lamp. Fig 3C shows a method of employing a self-heated thermistor that uses the fuel liquid as a heat sink to achieve the same low-level sensing. When the fuel level goes below the thermistor level, the thermistor heats up, raising its resistance, until the diode voltage is sufficient to cause breakover.

Semiconductors have also been finding their way into products related to service and performance, although permanent auto equipment applications are still being watched very carefully because of the undetermined reliability factor. *Delco-Remy* has introduced a capacitive-discharge ignition system which uses a magnetic arrangement to eliminate the points. This system requires a switch signal amplifier, a transistorized inverter to produce a high voltage for charging a capacitor, and an SCR to switch the capacitor charge through the ignition coil in step with the switch signal.

Three English firms have been demonstrating a fuel-injection system that uses electronics to provide metering information and to control solenoid valves at each cylinder.

The Car of Tomorrow

Arthur E. Fury, a specialist in market development for *G-E's* Semiconductor Products Division, has some interesting thoughts on the dream car of the future. He visualizes an electronic speedometer used to drive an electroluminescent numeric readout as well as to provide information to the car's system. A laser range finder (an expansion of the proposed anti-tailgating system) supplies information about the distance and relative velocity of other vehicles. An accelerometer measures acceleration and deceleration, while a tachometer measures engine rpm.

Additional solid-state devices? "Thermistors, photocells, and silicon strain gages are placed about the car to measure ambient light, engine temperature, inside temperature, coolant level, gas level, oil level, oil pressure, tire pressure, and so on. Fuel flow is measured by two thermistors in the gas line, and exhaust emission is checked electrostatically. We add a two-way radio, and presto! we have a car that could be driven onto a superhighway and controlled either manually or by autopilot."

How would it work? A driver with such equipment would now have information about his speed condition, efficiency of the car, and road conditions. When it gets dark, his lights

Table 1. Three categories of automotive safety devices divided into electric, non-electric, and electronic divisions.

PERFORMANCE/EFFICIENCY

ELECTRIC

Tandem fuel pumps that deliver 70 gallons per hour

Fuel flowmeters that read out engine consumption in gallons per hour

ELECTRONIC

Alternator/generators, SCR

Transistorized tachometers

Solid-state voltage regulators

Exhaust gas analyzers that measure combustion efficiency and fuel-air ratio for correct carburetor settings

Electronic superchargers

Transistorized ignition systems

Capacitive discharge ignition systems

SAFETY/WARNING

NON-ELECTRIC

Magnets that pick up stray bits of metal in engine blocks

Fiber-optic tubes carrying light from outside lamps to warn of malfunctions

ELECTRIC

"Lights on," "Door not closed," etc., warning lights

Trunk and door locks

Transmission lock in "Park"

Windshield wipers

Cornering lights, activated by turn signal

ELECTRONIC

Transistorized 4-way emergency flashers

Photoelectric headlight activators and dimmers

Delay circuits to keep lights on 90 seconds after ignition is off

Siren/flashers for police vehicles

Transistorized burglar alarms

Overspeed warning devices

Flip-flop rear-view mirror using photocells, transistors, solenoids

LUXURY/EXTRAS

ELECTRIC

Push-button door openers

Motorized seats, antennas, windows, etc.

ELECTRONIC

Power inverters for powering electric shavers, etc.

Transistorized AM/FM/short-wave receivers, often with reverb.

Transistorized in-car stereo playback systems

Converters for h.f. and v.h.f. reception on AM car radios

Two-way mobile communications equipment (CB, etc.)

Sequential tail-light systems for high-style rippling effect

Electronic throttle and speed controls

Automatic climate controls using thermistors and transistor amplifiers to activate outside air flow, heater, air conditioner, etc.

would go on automatically and the brake lights would be set to a dimmer degree. Should he go too fast, a buzzer would warn him and then some automatic counterpressure would be applied to the gas pedal. If he approaches the car in front too rapidly, the laser would control his brakes and accelerator. Should he panic, an anti-skid circuit would take over. Dashlights would tell if the gas is low, etc., and a major failure of something such as oil pressure would tell the computer to stop the car. (See "Integrated Circuits and the Automobile" in the February, 1967 issue of this magazine.)

Too way out? Probably, but the publicity over the HELP (Highway Emergency Locating Plan) program two years ago has already given way to *GM's* DAIR (Driver Aid, Information, and Routing) system now being tested in Detroit. It utilizes a basic CB set in an advanced-design configuration (Fig. 4) which affords the driver the following basic aids:

1. It provides reception of voice messages pertinent to traffic conditions and the road ahead.
2. It provides a display panel on the dashboard which reproduces roadside traffic signs by lights and readout tubes through its reactions to magnetic traps in the roadbed (see Fig. 5).
3. It provides illuminated instructions (turn left, make right, etc.) over a predetermined route, eliminating the necessity for map reference.
4. It provides a facility for tone-coded or voice communications between driver and a service center (on the CB band), permitting the motorist to summon aid or get road information when traveling on non-magnetic highways.

The Phenomenon of the Electric Car

Detroit's 1966 electric car revelation has perhaps more than any other factor been responsible for hastening the transition to solid state in the family vehicle. With the mass media supplying the public with daily reports of electric car R & D progress, potential customers are becoming increasingly aware that if anything truly revolutionary is ever to emerge from the automotive scene, a high degree of ultimate reliance on electronic components is essential. Mechanically inclined teenagers are poring over auto magazines bristling with facts about fuel cells and sodium-sulfur batteries while their parents skeptically await the first production-line electric car. Behind the open "can-it-be-done?" controversy, however, there lies a feverish undercurrent of activity felt not only by the auto makers but indeed by their suppliers and substantially influential segments of the electronics industry.

The reason for much of this is the inherent competitiveness associated with the American auto manufacturing business, well exemplified last fall when *Chrysler, Ford,* and *GM* made public for the first time their research into better storage cells. These announcements were made within a week or so of each other. In spite of the massive *GM* work which seemed to culminate in its "Electrovan" and "Electrovair" experimentals, one factor that has kept this entire business from simply becoming relegated to the status of a publicity stunt was *Ford's* public statement that perhaps "within five years we will have a production-line electric car" that would utilize the company's new sodium-sulfur batteries, "good for the life of the vehicle." While *Ford* talked about small two-passenger runabouts and the rest of the industry concentrated on competing with existing gasoline types, electronics engineers were developing improved drive systems utilizing sophisticated SCR control apparatus and IC logic units. Since October, 1966 the over-all size and prototype costs for one such high-voltage system (necessary for the a.c.-motored types *GM* and *Chrysler* envision) have been nearly halved.

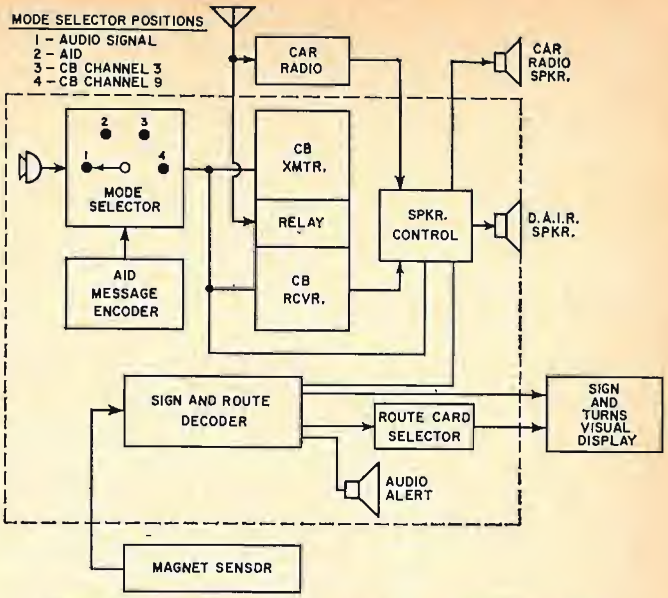


Fig. 4. Basic arrangement of General Motor's DAIR (Driver Aid, Information, and Routing) system now being tested.

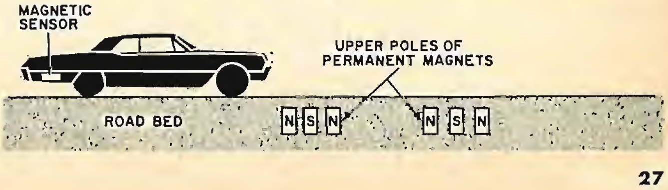
Ford, on the other hand, is holding to its simple, low-voltage d.c. drive concept which appears to be gaining steadily in industrial acceptance. A recent Gallup poll confirmed that the public, too, would be interested in seeing *Ford's* scaled-down motorcar. Temporarily compromising for the sake of competition, *Ford* has promised to deliver from its British factory "the first prototype"—using conventional lead-acid storage batteries—"to be shipped to the United States in June." Walter Hayes, a British *Ford* official, admits that "this is going to be no Batmobile . . . but a bigger version could take a minimum of 10 years to get on the road in the U.S." *GM* and *Chrysler* seem to agree but on the surface appear to be sticking to their "average-sized car" battleguns. Rumblings from the OEM camp and certain segments of the solid-state industry, however, indicate quite the opposite. It remains to be seen just what will eventually emerge from Detroit, but it is quite clear that a considerable amount of auto maker R & D funds is being spent on exploration of various types of electronic car control systems.

However, not all this money is coming from Detroit. The Edison Electric Institute (a trade association of power companies) has earmarked over $1 million for 1967-68 work on "battery-fuel cell development." Obviously, associated solid-state systems research also falls into this category. U.S. Senator Magnuson's pending bill would grant huge sums of Federal aid to electric car development, and two quite similar bills are currently awaiting action in both houses of Congress. The U.S. Post Office is now test-driving four battery-powered trucks in various sections of the East. *Lear-Siegler* has developed a six-motor electric-driven test bed vehicle for the Army. Since 1964, teams of researchers from the General Atomic Division of *General Dynamics* have been exploring diverse facets of electric cars. And the list goes on and on.

The Role of Solid State

Recurrent off-the-cuff remarks by electronics firms largely dependent upon Detroit contracts would have one believe that all the talk about future scarcity of gasoline, traffic

Fig. 5. In the DAIR system, the magnetic poles are sensed and decoded as programmed vehicle speed. Other magnetic arrangements are used to supply further control commands.



noise, reduced electrical costs, and air pollution is just so much nonsense. This viewpoint has been given momentum by *American Motors'* announcement in February of its intention to market a small combustion-type passenger car which would openly compete with the Volkswagen.

Coupled with the near reality of *Ford's* electric car for city driving, this makes a pretty good argument for those with vested interests in d.c. drive configurations controlled by SCR choppers. Again, though, it is becoming apparent that regardless of the a.c.-d.c. controversy, solid-state components will be used as the "heart" of the vehicular drive system.

If fuel cells are employed in mass-production cars, thermistors, transistor amplifiers, and in some cases IC's will be required to maintain required temperature control. The widely publicized hydrogen-oxygen cells require a cooling level between −279°F and −423°F. Most of the experimental motors now in use must be constantly temperature-compensated, using circulating oil as a coolant.

A host of new solid-state safety devices is also imminent,

A.C. MOTOR DRIVE FOR ELECTRIC CARS

PUBLIC excitement over Detroit's sensational electric car disclosures last year was somewhat dampened by the apparent impracticality of available batteries. In the wave of disappointment which followed, one major point was all but overlooked—the fact that a lightweight, a.c. electric-drive system had proven itself in a passenger car, turning in a performance comparable to that of any current internal combustion engine. Not that a.c. electric motors are new by any stretch of the imagination, but the fact that their first trial with an electronic control system in an automobile achieved such satisfactory performance is nonetheless startling. Particularly as employed in cars where the maximum weight area must be allotted to batteries, the a.c. drive system holds much promise for the future.

Squirrel-cage a.c. induction motors have traditionally been used as single-speed machine power sources in applications demanding high rpm action. To supply the motor adequately, it is only necessary to feed it a constant voltage, at a constant frequency, consistent with the requirements of the motor. This consistency depends upon "slip" frequency—the difference between the actual mechanical rotor speed and the rotating stator field speed. (The rotor actually runs a bit behind the field.) Since the "slip" is plainly evident at a constant speed, a prescribed frequency requirement is met with the feed current. Hence, to attain variable speed operation, both the voltage and the frequency would have to be varied. To further complicate matters, the percentage of "slip" may be as little as 1% or as much as 10%, depending upon motor design and operating parameters.

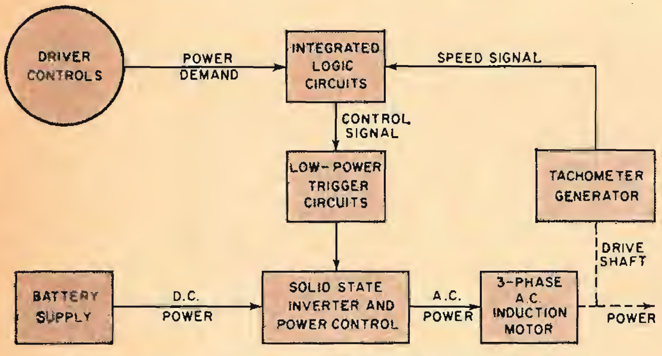
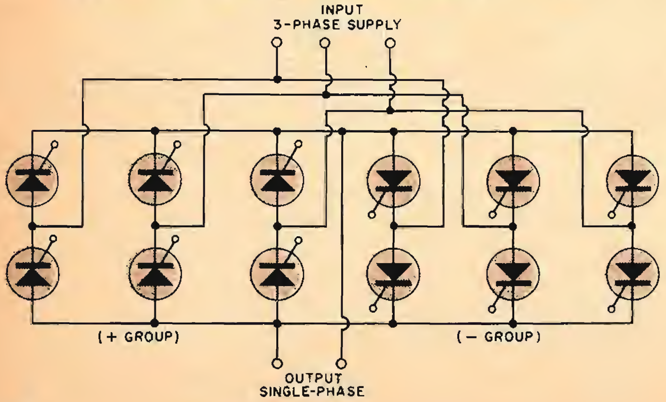


Fig. 1. Loop system of a.c. drive used by General Motors.

Fig. 2. Basic SCR unit of Lear-Siegler changes three-phase power from gas-engine-driven alternator to single-phase a.c. output. Logic circuits control the conversion.



These obstacles are somewhat diminished when it is considered that this apparatus can also take care of reverse action and braking, while the resultant high rpm will eliminate the necessity for bulky three- or four-speed transmissions. Existing 4:1 gears and differentials can be employed for the sake of expediency.

Several approaches can be taken. The *Henney* "Kilowatt" (a refitted *Renault* "Dauphine") employs electric relays for closing magnetic switches in sequence as the accelerator is pressed to provide six power levels. Yet accelerator technique is tricky and frequently results in blown fuses. Critics also call attention to "uneven acceleration". Electronic switching could be achieved using thyratrons or ignitrons. However, these outdated elements, in addition to being ungainly and heavy, do not solve the "slip" frequency problem.

The Loop A.C. Drive System—GM

Using integrated circuitry and SCR choppers, the "modulating inverter" has been devised to cope with a.c. induction motors. This, in effect, varies both the voltage and frequency in accordance with motor slip requirements and the driver's acceleration. Known as a "loop" control system (Fig. 1), *General Motors* is banking on it for all future electric car research and production, although engineers on the "Electrovair" and "Electrovan" estimate 1966 costs at about $5000. Part of this expenditure was due to the use of 400-ampere, 1200-volt SCR's which have to be series- and parallel-connected in the inverter. It is hoped that within a few years inexpensive 500-A, 2000-V versions will lower this cost appreciably.

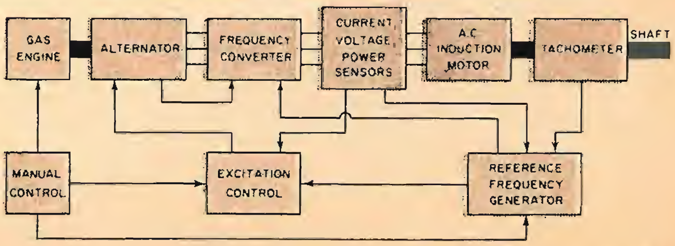
In the loop system, a voltage proportional to motor speed is obtained by a tachometer/generator on the drive motor shaft. This signal is passed to an IC logic circuit where it is compared with a preset voltage (derived from a potentiometer coupled to the accelerator) to produce the frequency for switching the solid-state inverter and power control (SCR's) on and off. Since the inverter *reduces* the average voltage to the motor by supplying it with power pulses, the ratio of on-to-off time of the pulse determines motor voltage. Varying the ratio of the on-to-off time of the pulse while keeping the pulse frequency constant, accomplished by varying the frequency of repetition of a constant-width pulse, renders a combination of pulse-width and pulse-frequency modulation. This combination has been found to produce excellent variable speed operation of an a.c. induction motor. To change motor speed, the driver alters the value of the preset voltage by depressing the accelerator (connected to a potentiometer). A switch turns the system off each time the accelerator is released.

The Loop Drive System—Lear Siegler

With many organizations attempting to develop high-performance a.c. motor-drive systems simultaneously, it is logical that different approaches would be tried.

Thinking more in terms of heavy-duty truck-type vehicles or applications for railroad transportation (and even drive systems

Fig. 3. Lear-Siegler's motor loop system fabricates the variable frequency drive from portions of a.c. supply.



since reliability will again become a major area of concern (power could lock on, motor could overspeed, control lever could slip from forward to reverse, etc.). New warning lights and failure-compensating circuitry will be required. If the *GM* concept is accepted, adequate safeguards against SCR overheat and over-all system shorting will have to be developed, as well as safeguards against possible danger to the driver as a result of 400-volt, 400-ampere currents, particularly in the event of severe physical vibration or collision with another automobile. Even the low-voltage *Ford* approach will ultimately necessitate a means of driver-monitored performance, optional automatic speed-reduction circuits to optimize battery life, and wherever feasible over-all substitution of solid-state components for present mechanical counterparts to achieve the absolute minimum drain on the already overworked storage cells.

Even if electric cars fail to materialize to the degree anticipated, at least the controversy will have left the automotive electronics industry many years ahead of where it might have been without it. ▲

How some companies plan to use an a.c. source as power for their cars. Unique among them is a drive motor mounted within the wheel.

By ROBERT M. BROWN

for large parabolic antennas), *Lear Siegler* (*LSI*) took a somewhat more complex approach to the problem. However, the fallout from this research represents still another possibility for a.c. electric passenger vehicles.

Lear Siegler's theory for varying squirrel-cage motor speed is basic. Using fast electronic-switching techniques, a variable-frequency, single-phase input to the motor is created from selected portions of a fixed-frequency, three-phase supply. Originally this was attempted in the post-World War I period with the "cycloconverter," a mercury-arc system that proved a bit too massive and expensive to be practical at the time. Today, however, the company has revived its interest in this dormant concept because of the availability of suitable SCR's.

The result is an all-a.c. system that can be powered from a commercial three-phase, 60-Hz power source; a battery-powered three-phase inverter source; or an engine-driven, three-phase alternator, probably the most practical of the group.

Lear Siegler's solid-state "cycloconverter" is a step-down frequency device comprising a number of "choppers" interposed between the power source and load. When actuated, the load is selectively coupled to the power source in such a manner that the current to the load is at a lower frequency than the source power frequency. The output is thus "fabricated" from small bits of the input.

The basic module in the frequency converter is a 12-SCR, three-phase-in/one-phase-out unit. Each single-phase module (Fig. 2) uses two groups of three-phase, full-wave rectifying bridges. This permits power from each of the input phases to supply power to the single-phase output.

Using seven integrated-circuit modules in the logic unit, the basic 3-to-1 converter module successively selects the appropriate portions of the supply-voltage waves which will closely approximate a desired waveform for the induction motor. At this point, suitable filtering is introduced to smooth out the waveform so that it is acceptable, although the inherent inductance of the squirrel-cage motor is sufficient, when the motor is used at varying speeds, to cause the current to be almost perfectly smooth to begin with.

Since more segments of the input power waveform are available for fabrication of the output waveform as the frequency ratio is accelerated, it is necessary to limit the minimum input-to-output ratio of the frequency converter to 2 (no limit on the maximum). For example, a conventional 60-Hz alternator produces a 30-Hz output frequency to the motor, which results in a drive motor speed of 1800 rpm, according to *LSI*. For a higher speed, it would be necessary to supply more than 60 Hz to the converter (which could be accomplished by driving a high-frequency alternator by a 60-Hz induction motor).

The balance of the system is much the same as that previously explored, employing the tachometer/generator at the motor shaft, etc. (See Fig. 3.)

But what about speed? Although *LSI's* experiments have not been primarily concerned with this factor, the company has developed an Army vehicle which employs an oil-cooled motor that rotates at 16,000 rpm at a vehicle speed of 50 mph. However, this approach uses the vehicle's conventional 6-cylinder gasoline engine to drive a rotary alternator which serves as the prime power source.

Motor Placement

Depending upon application, the a.c. squirrel-cage motors can be placed almost anywhere. *LSI's* Army test bed vehicle uses six powered wheels, each one capable of 16,000 rpm as indicated above. For the most part, the motor is inside the wheel with planetary reduction gearing just outside, less than two inches from the wheel itself. This arrangement is shown in Fig. 4. The gear mechanism is bolted to the outside of the vehicle frame, with the SCR frequency converter box located with others toward the rear center of the chassis. The result is a compact power wheel that at first glance looks much the same as conventional types. Fig. 5 shows the electrical arrangement.

An English firm, *Telearchics, Ltd.*, has a prototype of a small three-wheeled electric car that is driven by a single motor on the front wheel. With batteries in the rear, the "Winn City" car can maneuver a right-angle turn at 40 mph (its top speed).

General Motor's experimental "Electrovair" and "Electrovan" make optimum use of available equipment, placing a single a.c. induction motor where the conventional combustion engine would normally be situated and employing a standard differential to achieve rear two-wheel drive. The cooling system is a six-quart-capacity circulating-oil type that also serves to cool the SCR modulating inverter (total cooling system weight is 80 pounds).

It becomes apparent that location of the motor is not at all critical except where engineers must work with specific existing designs. Indeed, the electric car of the future may well be a combination of both approaches, perhaps using two rear *LSI*-type powered wheels with *GM's* simplified motor-loop concept. ▲

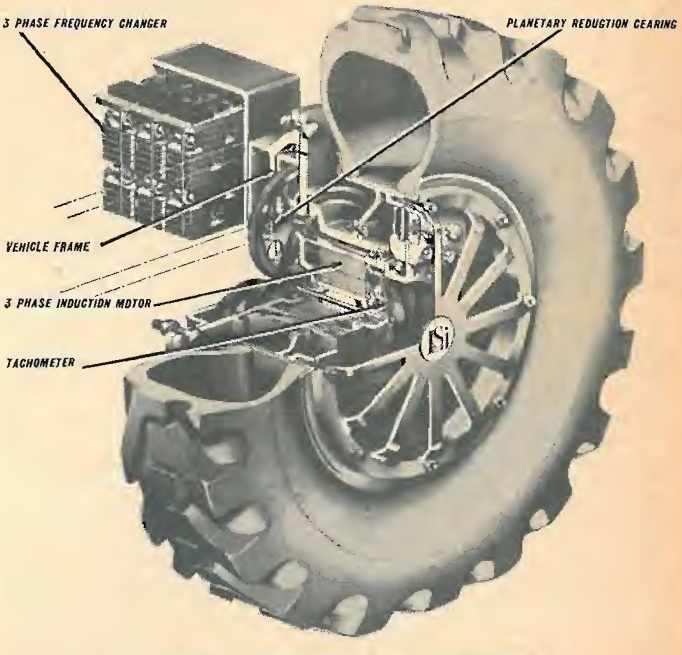


Fig. 4. In the powered wheel, the drive motor and its associated gearing is located within the drive wheel itself.

Fig. 5. Drive layout for the experimental military vehicle.