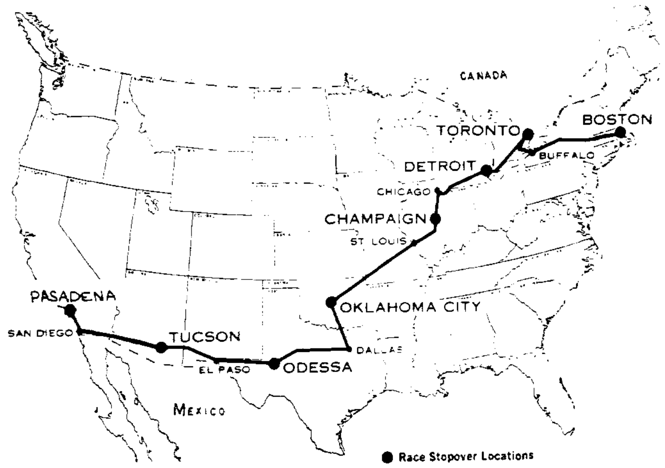

Fig. 9. Route of the 1970 Clean Air Car Race.

Act, also known as the Muskie bill because of Maine Democratic Senator Edmund Muskie's sponsorship. The bill includes stringent provisions for the enforcement of air pollution standards—provisions that the Nixon administration had regarded as too tough on the auto industry. The most controversial of these requires 1975 model cars to be equipped with emission controls roughly 90 percent more effective than those on 1971 models. Under a previous law, this goal had been set for 1980. In addition to retaining the 1975 deadline, the bill requires that the auto manufacturer seeking an extension must indicate that he has availed himself of the best emission control technology, even if developed outside the industry. Also set forth in the Muskie bill are ambient air standards that states and cities will have to meet regardless of the state of the art of emission controls.

Fig. 10. WPI hybrid crosses the finish line at Caltech.

The effectiveness of this legislation is anyone's guess at this point; however, if Detroit continues to publicize its inability to develop control technology within five years, we can probably expect a student demonstration that lacks the good intentions and humor of the Clean Air Car Race.

Dual SCR Chopper as a Motor Controller for an Electric Car

WALLY E. RIPPEL, MEMBER, IEEE

Abstract—**Despite recent advances in solid-state controls for electric cars, chopper-induced problems still exist: commutation and ac losses are significantly high, the chopping action induces losses within the power source, and large ripple components in the chopper output cause increased rms losses at the motor. The author's dual chopper, two conventional choppers in parallel, reduces these problems. The duty cycle generated by the firing circuit is feedback controlled so that the load current remains proportional to control output. The dual chopper operates in a three-in-one system: in the first mode, the batteries charge at high rates; the second mode controls the amount of power flowing from battery to motor; and in the third or regenerative braking mode, the chopper transfers energy from the motor to the battery.**

GOVERNMENT figures attribute approximately 60 percent of U.S. air pollution to emissions from the internal combustion engine. Of all the alternatives to the gas engine, electric propulsion is by far the least polluting. Unfortunately, electric propulsion technology has an oversize share of obstacles that must be conquered before electricity can replace gasoline. The power source is still the main problem, but considerable work is also needed in the area of solid-state speed and charging control.

A number of industries, including some of the largest electrical component manufacturers, are presently drawing up plans and building prototype electrics. Indications are that the first generation of these vehicles, scheduled to appear in the early seventies, will use lead acid or modified lead-acid batteries in conjunction with brush-type dc traction motors.

Despite recent advances in solid-state control technology, many of these vehicles will use conventional relay controllers. While solid-state controls are modern and provide glass-smooth acceleration, they do have some drawbacks, which we will examine. We will also look at an improved scheme—the dual chopper—not as a final answer to the dc power control problem, but as a step in the right direction.

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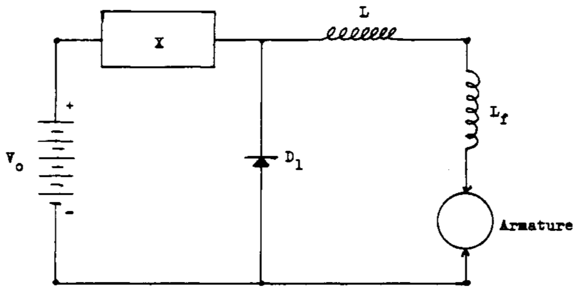
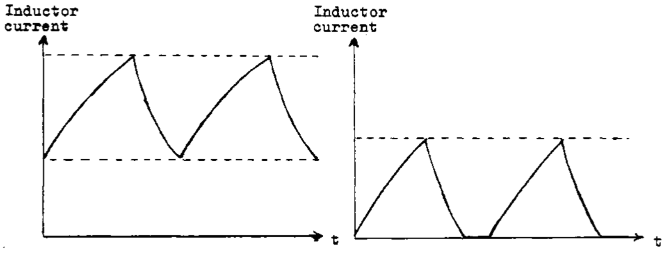


Fig. 1. Basic chopper circuit with battery source and series motor load.



(a) (b)

Fig. 2. (a) Current through L during overcritical operation. (b) Current through L during undercritical operation.

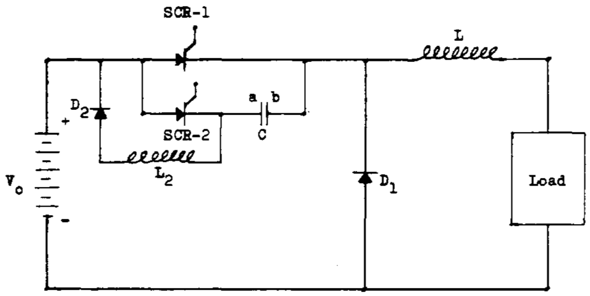


Fig. 3. A conventional SCR chopper circuit.

ELEMENTARY CHOPPER

Fig. 1 depicts the basic chopper circuit. Box X is an electronic switch such as a power transistor or a commutated SCR. Power is controlled by regulating the percentage of time during which X conducts. The free-wheel diode D_1 conducts when X is off and serves as a low-loss path for load currents that are kept in motion as a result of inductance. Inductance L is added in series with the load to reduce ripple components of the load current.

When the product of the switching frequency and the average load current is sufficiently high, current flows through L and the load over an entire cycle of operation, and operation is said to be *overcritical* [Fig. 2(a)]. During overcritical operation, the average output voltage is equal to the input voltage times the duty cycle of X. As might be guessed, the average output current is equal to the average input current times the reciprocal of the duty cycle. In these respects, the elementary chopper acts something like a step-down dc transformer, with turns ratio equal to the duty cycle.

For smaller products of load current and switching frequencies, the load current goes to zero during a finite portion of the cycle and operation is said to be *undercritical*. During undercritical operation the chopper still acts as a step-down transformer, except that the average output voltage is now a function of the load current.

Fig. 3 shows an actual SCR chopper circuit of conventional design. Operation is as follows. Capacitor C is initially charged, with side b positive, an amount V_0 with respect to side a. The cycle starts with the firing of SCR_1. A short time later, when turn off is desired, SCR_2 is fired, which effectively shunts C around SCR_1, causing SCR_1 to momentarily reverse bias, while C discharges through the load. If C is sufficiently large, SCR_1 will remain reverse biased long enough for recovery and will remain in the off state until refired. During the commutation process, C gains a reverse charge, with side a positive, an amount V_0 with respect to side b. When SCR_1 is refired, the charge on C will reverse by resonant action of L_2 and D_2 and prepare the circuit for another cycle of operation.

As indicated earlier, energy flow from power source to load is controlled by regulating the duty cycle. In the case of Fig. 3, the duty cycle is equal to the interval between the firing of SCR_1 and the firing of SCR_2 divided by the total cycle time.

While circuits of this type have found practical application, operation is far from ideal. Not only are there problems directly associated with the chopper itself, but there are also what may be called *chopper-induced* problems.

Consider first the problems peculiar to the chopper.

1) *Commutation Limit:* Analysis shows that if a peak current of I_p is to be successfully commutated using a main SCR (SCR_1) with recovery turn-off time of T_{off}, capacitor C must have a minimum capacitance of $T_{\mathrm{off}} I_p / V_0$. Typically, a capacitor rated this way costs about as much as the main SCR itself.

2) *Commutation Losses:* Due to the finite Q of L_2 (usually less than 10), a portion of the capacitor's energy is lost each cycle. These losses account for a significant fraction of the total power lost in the chopper itself.

3) *AC Losses:* Considerable levels of ac current components flow through the various branches of the Fig. 3 circuit. These components, while they do not contribute to net energy transfer, do nonetheless add to the rms losses within the chopper.

In many cases, the chopper-induced losses are of even greater effect than the direct losses. On one hand, the chopping action induces losses within the power source. In the case of a battery-operated vehicle, this means additional battery heating and decreased usable battery output, which in turn means decreased range and decreased performance. On the other hand, the presence of large ripple components in the chopper output causes increased rms losses at the motor, compounded by eddy and hysteresis losses. The induced motor losses are particularly bad because motors used with such choppers must be derated in an attempt to prevent excessive heating.

DUAL CHOPPER

A circuit was developed by the author that significantly reduces the problems just mentioned (Fig. 6). In Fig. 4, the dual chopper is simply two conventional choppers in

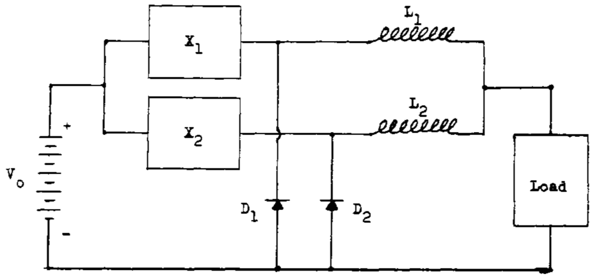
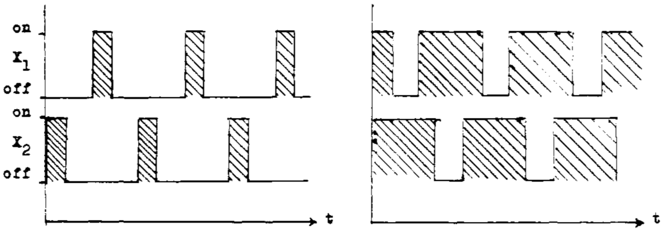


Fig. 4. Block diagram of the dual chopper.



(a) (b)

Fig. 5. (a) Conduction intervals for dual chopper: small-duty cycle. (b) Conduction intervals for dual chopper: large-duty cycle.

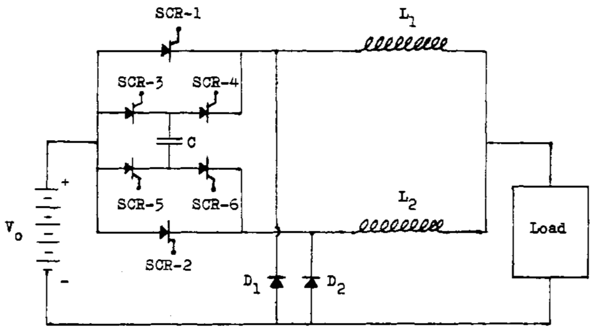


Fig. 6. SCR version of dual chopper.

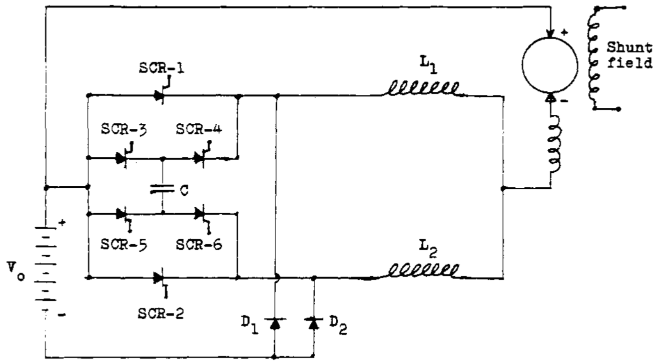


Fig. 7. Dual chopper connected in regenerative brake mode. Energy is transferred from motor to battery.

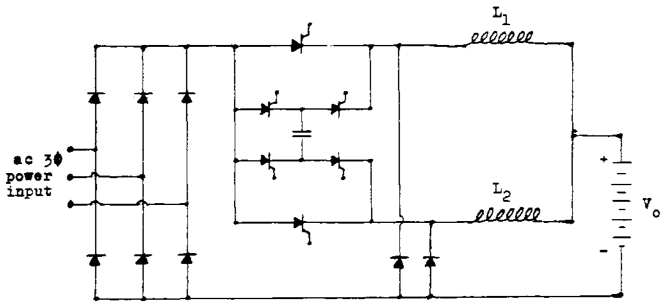


Fig. 8. Dual chopper connected in recharge mode.

parallel. If the turn-on and turn-off times of X_1 and X_2 were identical, the circuits of Figs. 4 and 6 would behave like the basic circuit of Fig. 1. If, however, the X_2 switching times lag the X_1 switching times by exactly one half-period, as shown in Fig. 5, all of the even-load current harmonics are eliminated while odd-load harmonics are significantly reduced. In a like manner, both even and odd harmonics are reduced at the chopper input, which enables the power source to run more efficiently.

Operation of the Fig. 6 version of the dual chopper is as follows. Capacitor C is initially charged by simultaneously firing SCR_3 and SCR_6; charging current flows through the load. With C charged, SCR_1 may be fired. The simultaneous firing of SCR_4 and SCR_5 turns off SCR_1. Current flows through SCR_4 and SCR_5 until C attains a reverse voltage equal to V_0. Having successfully commutated SCR_1, the capacitor is now ready to commutate SCR_2 upon the simultaneous firing of SCR_3 and SCR_6. After doing this, C has its initial charge and the circuit is ready for the next cycle of operation. Power flow is controlled simply by varying the time interval over which SCR_1 and SCR_2 are allowed to conduct.

The Fig. 6 circuit, in addition to having the advantages already discussed, features a bridge-type commutation circuit that is of inherent high efficiency. Furthermore, for a given kVA rating, the dual chopper requires only slightly more than half the capacitance used in conventional SCR choppers. Accordingly, there is a corresponding cost and weight savings. While the dual chopper uses a total of six SCRs and two free-wheel diodes, these components, because of their reduced current ratings, typically cost less than the two or three SCRs and one or two diodes used in conventional systems.

DUAL CHOPPER USED IN A THREE-IN-ONE SYSTEM

In the actual system developed, the duty cycle generated by the firing circuit is feedback controlled so that the load current remains proportional to a control input. Accordingly, the dual chopper, when connected to a power source, functions as a current source rather than as a voltage source.

As a speed control, the dual chopper is connected between battery and motor with the control input connected to the accelerator pedal. Accordingly, motor current, and hence motor torque, is proportional to the accelerator depression.

Depressing the brake pedal activates the regenerative brake mode in which the chopper acts as a step-up transformer and transfers energy from the motor (now acting as a generator) to the battery. In the brake mode, the chopper is connected via relays (Fig. 7). The chopper control input is transferred to the brake pedal and a shunt field on the motor is excited so that compound generator action results.

Finally, the dual chopper serves as the control link in a high-power recharge mode (Fig. 8). Mode switching is again carried out by relays. The chopper control input is switched to the output of a circuit that senses charging current, battery voltage, and gas evolution rate. Accordingly, the chopper controls the recharge current so that limits on the above parameters are not exceeded.

The dual chopper charger is neither frequency nor phase rotation sensitive. The circuit of Fig. 8 operates successfully over a wide range of input and battery voltages by virtue of the feedback loop in the firing circuit. Furthermore, because of the chopper's excellent input form factor, the recharge mode power factor is quite high.

It is hoped the author's research will encourage others to take steps of their own. If enough advances are made in electric vehicle technology, the gasoline engine and its polluting emissions may become things of the past.

Analysis of an Electronic Fence Element for a Vehicle Location System

GERALD S. KAPLAN, MEMBER, IEEE

Abstract—At the present time there is much interest in vehicle location systems [1]–[3]. For certain applications [4]–[7] precise location of the vehicle is not needed and determination that the vehicle is within a zonal area of the city is sufficient. This paper considers a vehicle location system in which an array of transmitters forms an "electronic fence" along the zone boundaries. As it passes through the electronic fence a suitably equipped vehicle receives and stores the zonal location information. This information is sent by the vehicle to a central location via a separate radio channel after receiving an interrogation message.

The analysis of the communication performance of the short-range communications link between the zonal transmitters and the vehicle is the concern of this paper. Design curves and formulas are presented that allow performance calculations to be made. The implications of this predicted communication performance to a vehicle locator system are then considered.

Most of the results obtained are directly applicable to a general class of vehicle location systems, which utilize the proximity of a vehicle to some coded electronic signpost to determine the vehicle's location. The electronic fence is a special case of the proximity-type system.

I. Introduction

USE OF a vehicle location and tracking system enables effective and efficient utilization of mobile vehicles [1]–[3]. For certain applications such as a dispersed array communications system [4]–[7], precise location of the vehicle is not needed and determination that the vehicle is within a zonal area of the city is sufficient. There are many approaches that could be used to implement a vehicle locator system, but one realization suited to the zonal location requirement would be an "electronic fence" around each zone. The electronic fence consists of an array of transmitters placed along the zone boundaries. These transmitters continuously emit digitally coded messages (identifying the zone), which are received and stored in the vehicle. Upon interrogation from a central location, the vehicle responds with the last stored message corresponding to the zone presently occupied. This paper is concerned with analyzing the communication performance of the short-range communication link, which can be used to enable the vehicle to receive the location information from the short-range zonal transmitters. The implications of communication performance to a vehicle locator system are considered. The system is then described in more detail.

II. System Description

As shown in Fig. 1, the city is divided into a number of zones; these are shown as squares in the figure, but this is not a requirement. An array of transmitters is placed along the zonal boundaries such that all vehicles traversing the boundary must pass through the electronic fence. The identity of the zone is received at the vehicle and the last received message corresponding to the presently occupied zone is stored. A separate interrogation link is used for acquisition of the vehicle's current location. The vehicular receiver (shown in Fig. 2) is basically a binary frequency-shift keying (FSK) noncoherent threshold decision receiver. The incoming FSK signal is first passed through the mark-space bandpass filters, then is envelope detected with the low-pass filtered outputs applied to a comparator that chooses the larger of the two outputs at the sampling instant. The sampling instant is determined by the clock, which is turned on when the first bit of the N-bit message exceeds a preset threshold. In addition to being applied to the comparator, the filtered envelope detector outputs are applied to threshold detectors. At the receiver, each bit is examined to determine if a preset threshold has been exceeded on one of the envelope detector outputs. If the signal strength has not been high enough to exceed the threshold on each of the N bits comprising the message, the message is rejected and the previous message retained. This ensures that weak signals will be ignored and only reliable messages based on strong signals can be received. In addition, a parity check is made after the N bits have been received. Failure of the parity check also causes the message

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