A Design for an Experimental Route Guidance System

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This paper describes an experimental route guidance system (ERGS) designed by General Motors Corporation under contract (No. FH-11-6626) to the Federal Highway Administration, Bureau of Public Roads.

The objective of the design was to develop an electronic system which would automatically provide drivers with routing instructions at decision points in the road network along the way to their respective destinations. System hardware consists of both mobile and fixed elements, which automatically establish two-way digital communication between moving vehicles and antennas embedded in the roadway.

The system is destination oriented. At the beginning of his trip, the driver enters a code word representing the address of his destination into the unit in his car. As his vehicle approaches each instrumented intersection, the destination code is transmitted to the roadside equipment, where it is decoded in accordance with a stored program. An appropriate maneuver instruction is calculated, returned to the vehicle, and displayed to the driver in the length of time necessary for the vehicle to travel a distance of approximately five feet at Interstate Highway driving speeds.

•THE system design described in this paper was developed by General Motors Research Laboratories and Delco Radio Division, General Motors Corporation, under contract (No. FH-11-6626) to the Federal Highway Administration, Bureau of Public Roads (1). The paper describes a hardware system design to implement an experimental route guidance system (ERGS).

The primary objective of ERGS is to automatically provide drivers with routing instructions at decision points in the road network. These instructions successively guide the vehicle along the "best route" to its destination.

The system design requires the installation of electronic equipment in each vehicle which is to receive routing instructions and the installation of roadside equipment at each intersection which is to supply routing instructions. This road and vehicle equipment (Figs. 1 and 2) establishes a two-way digital communication link between every equipped vehicle in the traffic stream and the roadside. It also provides the logic systems needed to process the road-vehicle digital communications.

The ERGS system is destination oriented and makes use of a coding system which is designed to uniquely identify all intersections in the continental United States (2). A driver may address any intersection in the country as a destination by entering the assigned code word for this specific destination into the vehicle equipment. Then, as his vehicle approaches each instrumented intersection, this code word is communicated on command to the roadside equipment which determines how the vehicle should leave the intersection to best reach its destination, encodes the appropriate routing maneuver instruction and then communicates it back to the vehicle.

Paper sponsored by Special Committee on Electronic Research in the Highway Field and Committee on Traffic Control Devices and presented at the 48th Annual Meeting.

Figure 1. Vehicle Equipment—the communication antenna (not shown) is located under the rear of the vehicle.

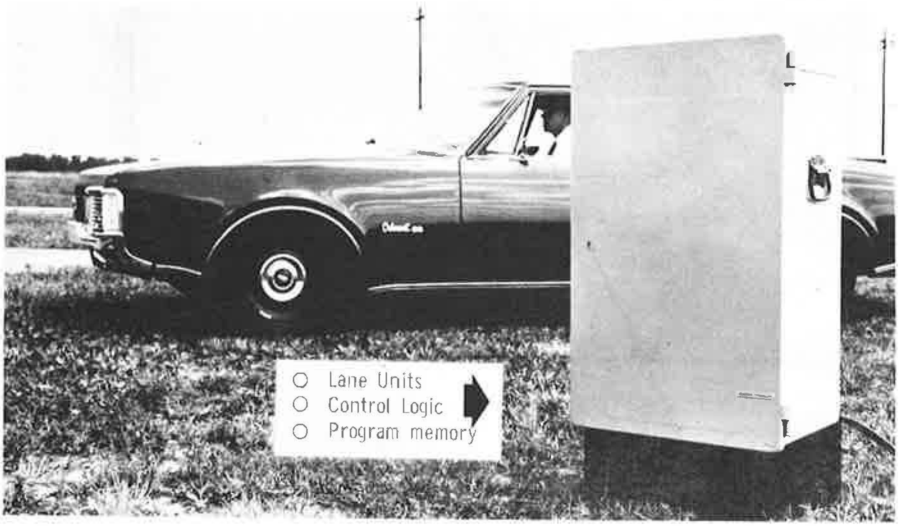

Figure 2. Roadside Equipment—the communication antennas (not shown) are deployed in each in-bound traffic lane of the intersection.

The best-route instructions which the driver receives are derived from a stored program in the roadside equipment. The program for each intersection equipment is generated according to a best-route criterion, such as minimum trip time, from road network data and then written in the roadside memory unit by means of punched tape.

The destination-oriented approach to route guidance offers the driver two distinct advantages over a route-oriented system. First, the driver is independent of any route programming source. The only information he requires is knowledge of the code word for his specific destination. This does not mean that the driver is without control over the route he will take. He may program his own route by successively addressing intermediate destinations which lie on the route he wishes to take to his final destination. The ERGS roadside equipment will instruct him on best routes to these intermediate destinations. The second advantage of the destination-oriented approach to route guidance is that the driver cannot get lost in the network. If, for any reason,

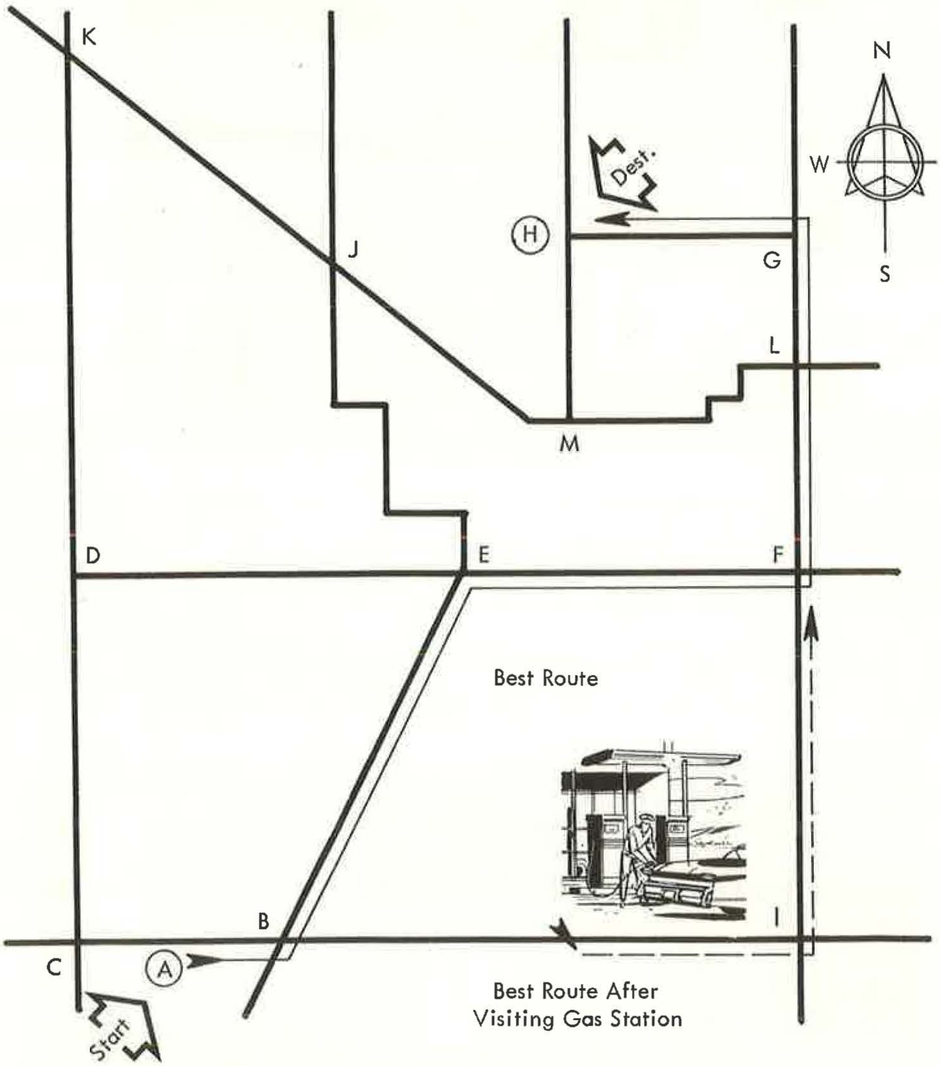

Figure 3. Instrumented Road Network—the paths show the routes of vehicles bound for intersection H from two origins in the network. Routing instructions are received in the vehicle as it approaches each instrumented intersection.

he does not follow the instruction at an intersection, the next instrumented intersection he approaches will direct him to his specified destination from that point.

To describe the overall operation of the system, let us follow an equipped vehicle on a short trip through the instrumented network shown in Figure 3.

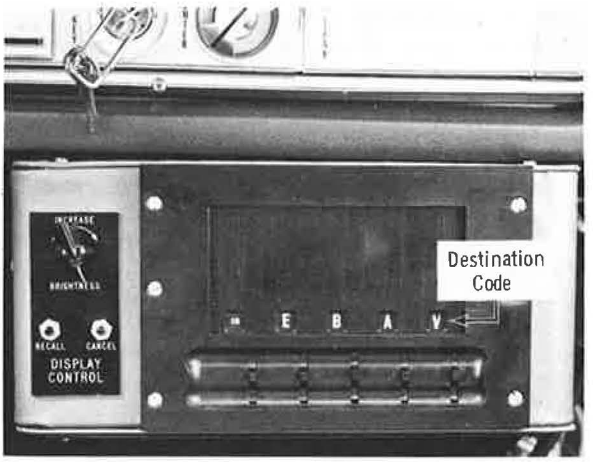

Figure 4. Destination Encoder—the driver enters the code word for his destination at the start of each trip.

Assume that the vehicle starts from point A, and its destination is node H. Before starting the trip, the driver consults a destination code source (which could resemble a postal zip-code book), from which he obtains the route guidance code word for node H. Alternatively, if he intended to stop at a motel or other commercial establishment located at node H, he might obtain the destination code from their literature or advertisement. To inform the route guidance system of his desired destination, he enters the code word into the encoder on the front panel of his vehicular unit by turning the five thumbwheel coding switches until the desired code word appears in the encoder windows (Fig. 4). Thus set, the destination code word remains in view throughout the entire trip, providing visual verification of the preset destination.

Upon entering the highway system at point A, the driver must proceed to the first instrumented node before receiving the first routing instruction. Let us assume that he knows his destination lies generally northeast of his starting point, and accordingly starts east toward node B. As he approaches node B, he crosses a road antenna embedded in the surface of the pavement, initiating the following sequence, which transpires in less than the time required for the car to cross the antenna.

1. His vehicular unit receives a trigger signal from the road antenna, causing it to transmit the preset destination code word to the road antenna.
2. The destination code is received and processed by the roadside decoder, and an appropriate instruction message is returned to the vehicle.
3. Within the vehicle, the received instruction is visually presented on a driver display panel (Fig. 5) until either extinguished at the end of a preset time period or replaced with a fresh message at the next instrumented node.
4. Display of the routing instruction is accomplished by a momentary audible tone to inform the driver that an instruction has been received.

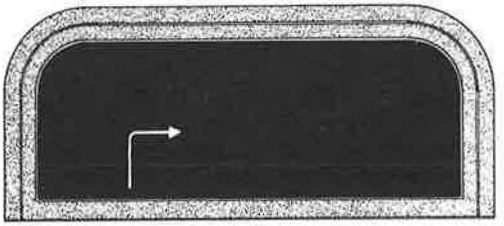

Figure 5. Driver Instruction Display—the display shows the symbol used to instruct the driver to make a simple right-turn maneuver.

In this example, a symbol indicating TURN LEFT will be presented to the driver at node B. As he continues his trip, following each instruction presented to him, he will subsequently receive a TURN RIGHT instruction at node E, TURN LEFT at F, STRAIGHT THROUGH at L, and TURN LEFT at G, and END at H, his destination.

Since ERGS is a destination-oriented guidance system, each instrumented node will direct him from the point toward his destination, regardless of the path he has followed in arriving there. From this, it follows that a driver within a fully deployed

portion of an ERGS network cannot lose his way for more than a short period of time even if he ignores or fails to follow a routing instruction. For example, returning to Figure 3 and assuming the driver is again starting from point A with node H as his destination, let us examine the response of the route guidance system if upon arriving at node B and receiving a TURN LEFT instruction, he had chosen instead to go to the gas station which he saw east of node B. After leaving the gas station and returning to node B, he then appeared to the node B roadside unit as a westbound driver requesting the route to node H, and accordingly, received this time a TURN RIGHT message. Had he instead continued east to node I after leaving the gas station, the best route from that point to node H would have been via link I-F, and the ERGS unit at node I would have presented a TURN LEFT instruction, followed by STRAIGHT THROUGH at node F.

Thus, each time he approaches a node, an independent, new routing message, based on his present position in the road network, is selected for him. Although the ERGS unit in his vehicle remembers his destination throughout the entire trip, each individual roadside decoder retains this destination code only long enough to process it and return an appropriate routing instruction to the vehicle.

DIGITAL COMMUNICATIONS LINK

The communication link is critical to successful operation of the ERGS system and required the consideration of several major factors before details of the design were undertaken.

An important requirement for the ERGS communication link was that it conform to Federal Communications Commission regulations. Any system which interferes with existing communications or requires reallocation of a large segment of the frequency spectrum would not likely be considered in the public interest. Therefore, in the ERGS design careful attention was given to bandwidth and frequency requirements.

Economic considerations also affect the design of the communications system. The ratio of automobiles to intersections (estimated at 20/1) dictates that system complexity be transferred from vehicular equipment to roadside equipment in order to minimize total system costs.

Communication errors would rapidly destroy user confidence and consequently could limit effective utilization of ERGS; therefore, system reliability is essential. This affects the communication link in two ways: first, the vehicle portion of the communication equipment should be as simple and reliable as possible, since maintenance of this equipment is the vehicle owner's responsibility and servicemen capable of repairing complex equipment may not be readily available to him; second, the communication link should provide a high degree of immunity to interference from other ERGS transmitters, lightning, automotive ignition systems, and other sources of noise.

The choice of two-way rather than one-way communication of information between road and vehicle was an easy decision to make. The marked reduction in transmitted data made possible by two-way communication sharply decreases the time-bandwidth requirement of the communication link and eliminates the need for the decoding of information in the vehicle.

In addition, one-way communication, from the road to the vehicle, would preclude the possibility of the road system receiving useful information from the vehicle, e.g., the vehicle's destination, its classification and its identification. Information such as this may be important in the future to urban traffic control and urban transportation planning.

The reduction in the information handling problem made possible by the decision to use two-way road-vehicle communications, made practical the consideration of a low frequency (30-300 KHz) near-field link or a narrow bandwidth far-field link.

If a far-field system were employed, many frequencies would have to be used to avoid transmitter interference problems between adjacent ERGS units. These extra frequencies would not only add to the bandwidth requirements and drastically increase the vehicle receiver cost, but also introduce the problem of setting the vehicular receiver to the required frequency channel.

The channel selection problem and the problem of obtaining a frequency allocation for routing purposes were greatly reduced by using a near-field link in which the transmitting and receiving antennas are in such close proximity that the effective field is confined to a single vehicle.

Furthermore, near-field RF meets the system requirement that the communication link selectively address each car which requests a routing instruction, in order to return the proper instruction to the car which requested it.

Finally, due to the proximity of the transmitter and receiver in such a system, the number and severity of external noise problems are greatly reduced. For these reasons, the near-field radios should have substantially reduced complexity, lower cost, and better reliability than their far-field counterparts.

The elements of the communications link are identified in a system block diagram (Fig. 6). The system design requires deployment of a road antenna in each inbound traffic lane of the intersection. When antennas must be placed in adjacent lanes, they are staggered longitudinally to provide a minimum of seven feet separation. This constraint is imposed to eliminate interfering cross-talk between adjacent road antennas,

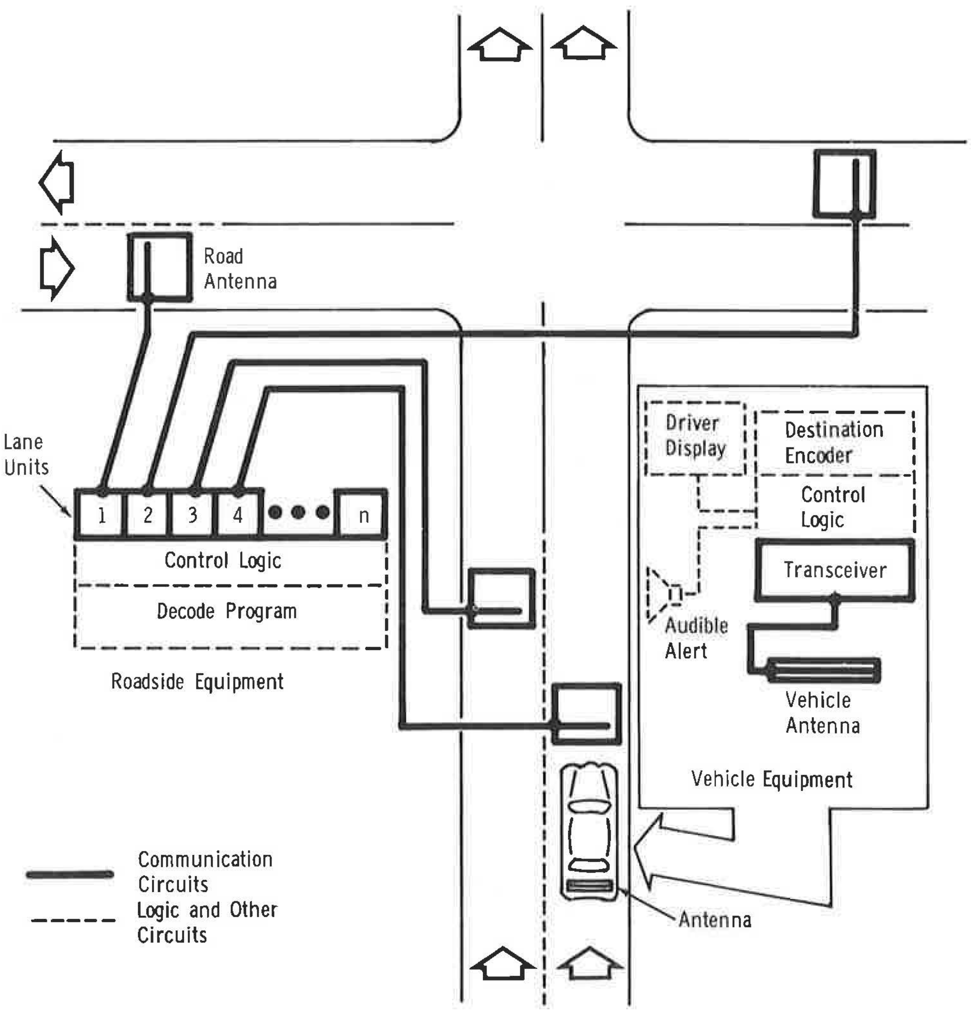

Figure 6. Block diagram of ERGS road and vehicle equipment, showing deployment of equipment at an intersection.

which might otherwise introduce communication errors. Each road antenna is connected to its own terminal equipment (lane unit). Each lane unit is serviced by one processing logic which is common to all lane units at that intersection.

Communication of information from the vehicle to the road is not initiated until the vehicle antenna is inside of the area bounded by the road antenna. Processing of the vehicle destination code and return of the routing instruction to the vehicle is completed before the vehicle leaves this area. The road antennas, communication rate and central data processing rate are designed to handle up to 16 lanes of 75-mph traffic under worst case load; that is, 16 vehicles simultaneously requesting routing information.

The only constraint placed on the traffic stream is that vehicles must be within the lane boundary to receive routing instructions; no provision is made in the present system design to communicate with straddle-lane vehicles.

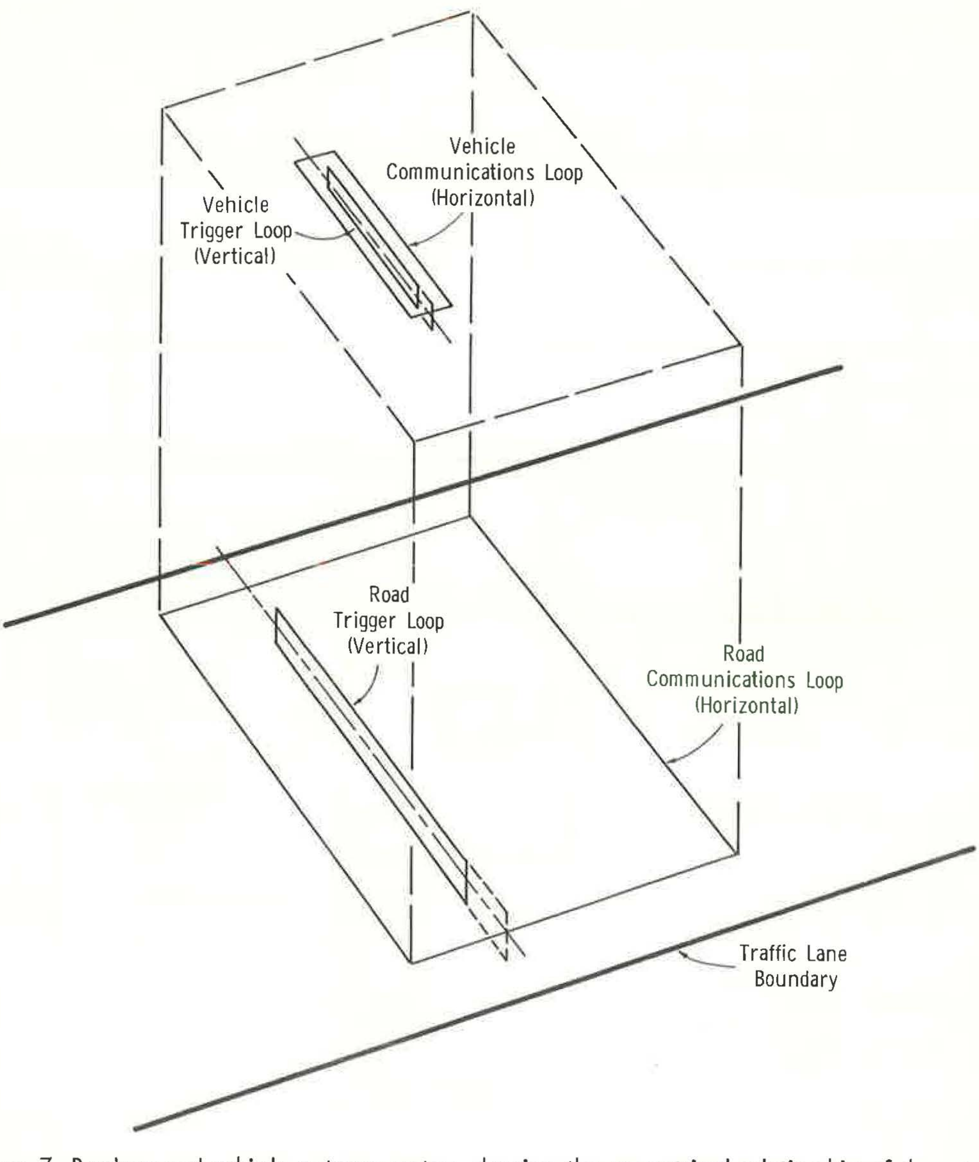

Figure 7. Roadway and vehicle antenna system, showing the geometrical relationship of the antenna loops during communication.

The road and vehicle antennas are electrically and mechanically similar. Each consists of two loops set in quadrature with respect to each other (Fig. 7). The larger road and vehicular antennas are located in horizontal planes. When the vehicle antenna is located over the road loop, these planes are separated by about 14 inches and provide for the communication of information between the road and vehicle through mutual coupling of magnetic fields. During the transmission of the vehicle destination code to the lane unit, the vehicular antenna is electrically energized and produces a magnetic field which induces a voltage in the road antenna. During the transmission of the driver instruction code, from the road to the vehicle, the road antenna is driven and a voltage is induced in the vehicular antenna.

The smaller, vertically oriented road and vehicular antennas are used to provide the trigger function which initiates transmission of the vehicle destination code to the roadside. To perform this function, the road trigger loop is the driven element and the voltage induced in the vehicular trigger loop initiates transmission of data.

The trigger antennas are only one inch high in the vertical plane and are linked by the horizontal component of field. Both road and vehicle antennas are tuned to parallel resonance at their loop terminals.

The road loops are installed by cutting slots in the pavement and 2-in. diameter holes at the loop terminals to accommodate the tuning capacitors. Additional slots are cut in the pavement to run the feedlines back to the lane units.

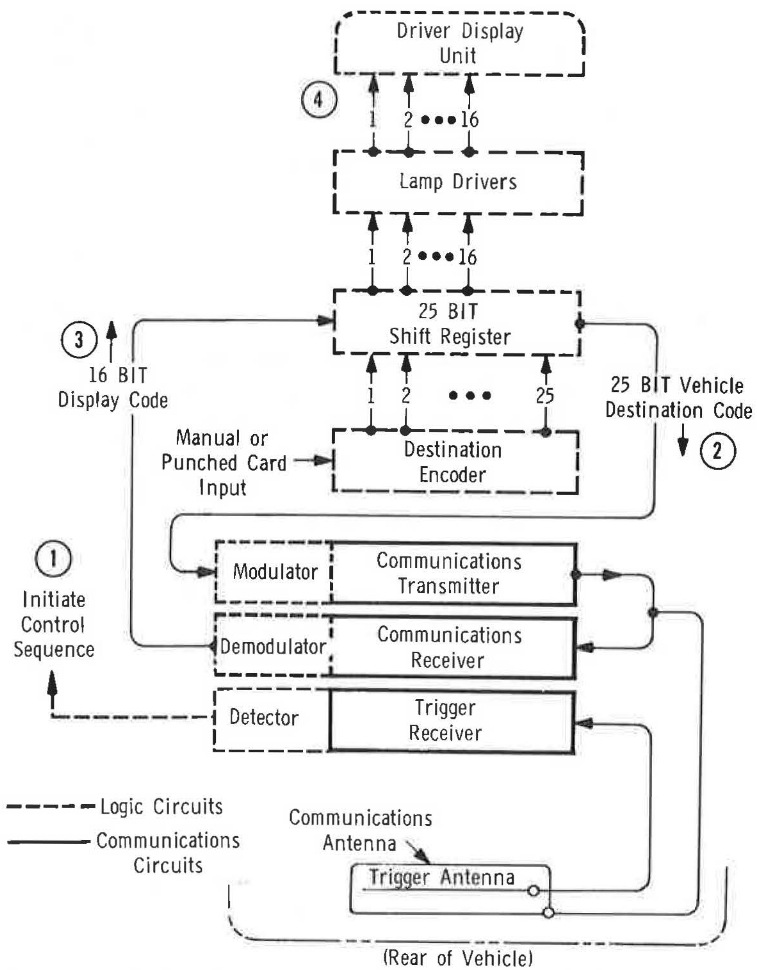

Figure 8. Block diagram of vehicular equipment, showing the flow of information in the vehicular unit.

The operation of the vehicle and road communication link is explained with the aid of Figures 8 and 9. The road trigger transmitter supplies a continuous 230 KHz carrier to the trigger antenna. When this field is intercepted by the vehicle antenna and detected by the vehicle trigger receiver, a command to transmit the vehicle destination code is generated. The destination code is stored as 25 bits of binary data in the vehicle shift register. The transmit command causes the vehicle communication transmitter to be modulated by the destination code stored in the register, serially transmitting the data to the lane-unit antenna where it is detected and stored in the lane-unit register. The communication transmitter operates on a carrier frequency of 170 KHz with a digital modulation rate of 2 kbps.

After the destination code has been stored in the lane-unit buffer it is processed by the central logic which selects from its memory the appropriate driver instruction display code. The display code is then stored in the lane-unit register in the form of 16 bits of binary data which are then serially transmitted back to the vehicle by the lane-unit communication transmitter. The display code is received by the vehicle communication receiver and stored in the vehicle register. After the 16 data bits have been stored they are used to energize the appropriate display elements thereby presenting

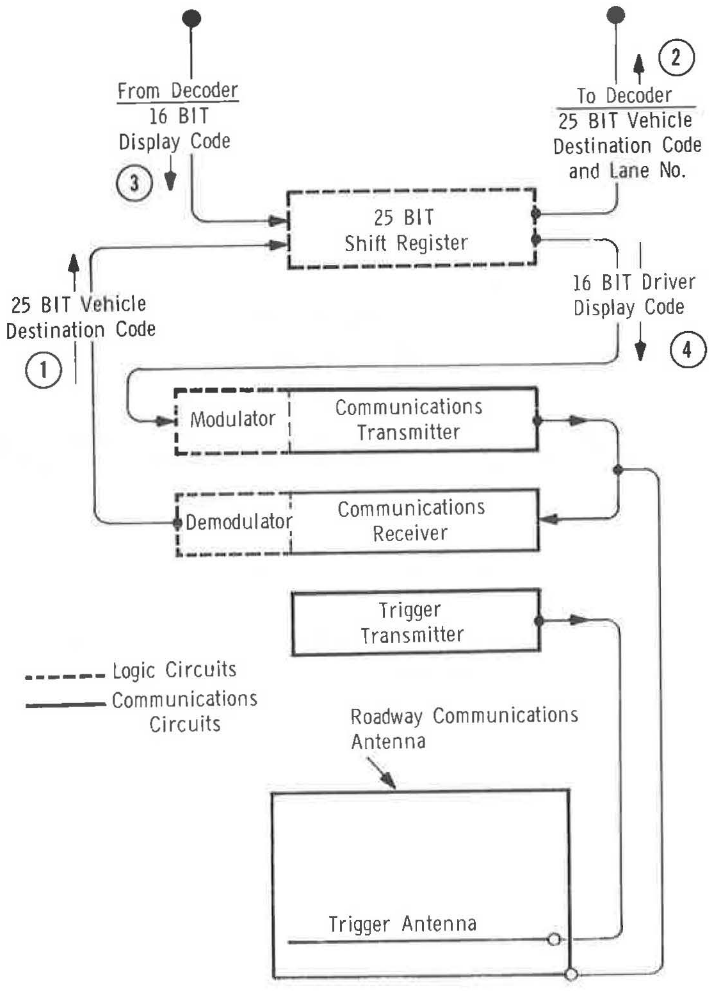

Figure 9. Block diagram of lane equipment, showing the flow of information in the roadside lane unit.

the routing maneuver to the driver. The entire process requires between 21 and 24.5 ms, depending on the lane unit loading of the central processor.

ROADSIDE LOGIC

The flow of information in the roadside central processor is shown in Figure 10. All lane-unit registers are serviced by a lane-unit register control. This control sequentially scans each lane-unit register until it detects a register loaded with a vehicle destination code. The control then stops scanning and transfers the code into the destination decoder, where it is decoded character-by-character according to the stored decode program. The decoding process is completed when an exit-path number is obtained.

In the simplest case an exit-path number specifies the branch road by which the vehicle is to leave the intersection. This is the case when the branch road has only one outbound traffic lane. In the general case, there are as many exit-path numbers as there are different ways for vehicles to leave the intersection. Figure 11 shows an intersection with an assignment of 12 exit-path numbers, whereas, there are only 4 exit branches.

The concept of exit paths is important if drivers are to receive high-quality routing instructions. For example, exit-path 4 or 6 would be specified for vehicles required to make a left or right turn at the next intersection (A). They make it possible to assign vehicles to particular exit lanes in preparation for their next maneuver. Without this ability, a driver may find himself in a traffic lane from which he cannot safely or legally be given the best routing to his destination.

Along with the exit-path number, the inbound lane-identification number is supplied to the driver instruction selector. Sufficient information (inbound and outbound states) is now available to select the appropriate maneuvering instruction (instruction number). The selected instruction number is then encoded in the form of a 16-bit display code for transmission back to the vehicle.

Each bit of the display code controls one element in the driver display unit. This method of coding makes it unnecessary to provide display decoding circuits in the cost sensitive vehicle equipment.

Destination decoding, instruction selection and encoding are all programmed into the roadside equipment. The data are stored in a 1024 word, 8 bits per word core memory.

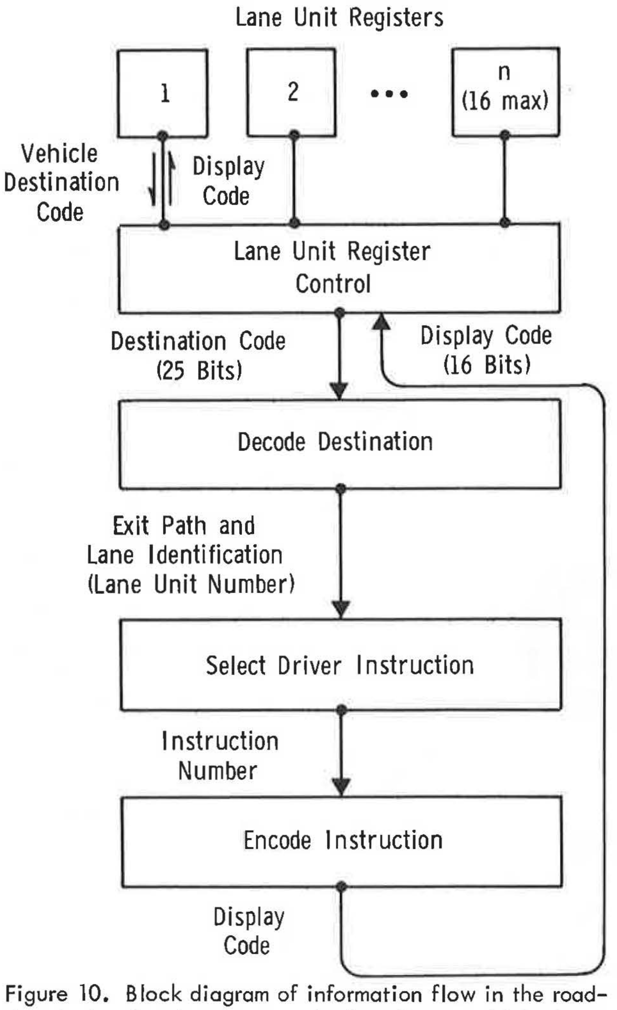

Figure 10. Block diagram of information flow in the roadside logic, showing the steps in decoding a vehicle destination code and the selection of a maneuvering instruction (display code) to be returned to the vehicle.

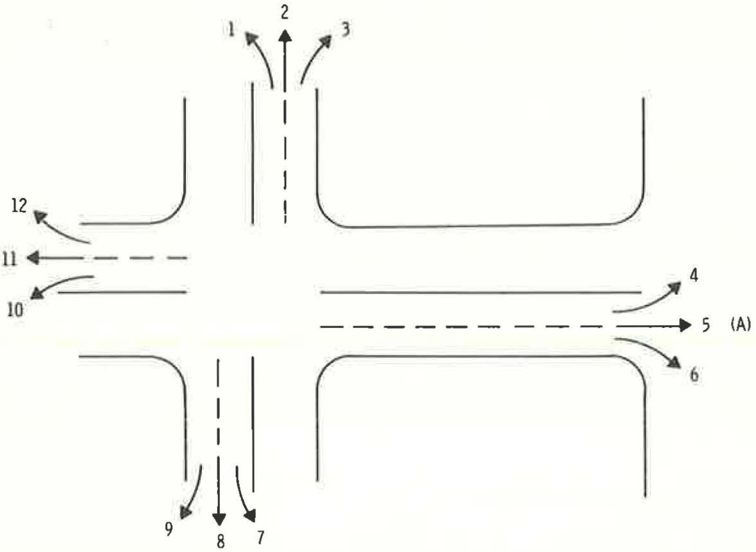

Figure 11. Assignment of exit-path numbers to an intersection; exit-path numbers permit vehicles to be assigned to particular lanes of outbound branch roads.

Provisions have been made in the program logic to insure compatibility with time variant intersection traffic control, such as no-left-turn constraints during morning and evening peak loads. This is accomplished by selecting a programmed alternate instruction number when the traffic constraint is in effect. The result is a legally acceptable maneuver but one which may no longer provide the driver with a best route to his destination. To insure drivers best routes under time variant traffic control conditions would require altering part or all of the destination decode program stored in the roadside unit. This would be the first step in the direction toward a dynamic route guidance program.

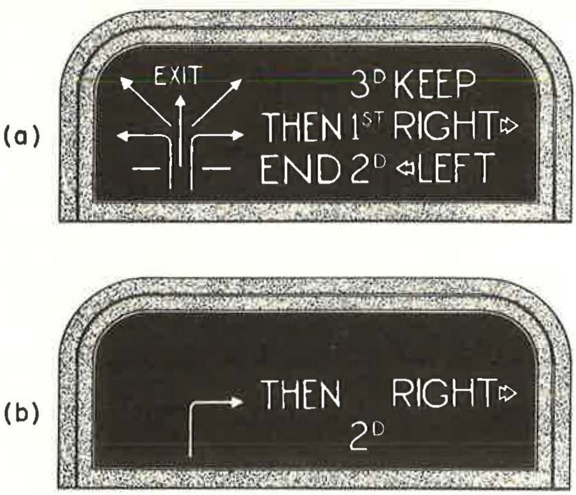

Figure 12. Driver instruction display, consisting of 16 back-lighted elements (a). Instructions are formed by lighting combinations of these elements (b).

Although the ERGS system design is intended to be a static routing system, the decoder design is expandable to dynamic operation in which a central computer, operating in real time, updates the program stored in the memory of each roadside unit as necessary to reflect changes in best routes under varying conditions of traffic loading. The decoder is designed to time-share the program loading operation in between communication with vehicles; therefore, the stored program may be altered without interruption of service. This could be accomplished, for example, by means of a wired Dataphone link from a central information processing facility.

DRIVER DISPLAY

The driver display, designed as part of this equipment, is a trans-illuminated unit which presents

routing instructions in the form of sixteen graphic and verbal symbols (Fig. 12). The graphic symbols are presented when the required maneuver is simple and no ambiguity is encountered in its use. For more complex instructions the verbal symbols and combinations of graphic and verbal symbols may be used (Fig. 12b).

The display is capable of generating approximately 100 different maneuvering instructions that are useful in guiding drivers through the maze of intersections found in the present road network.

ACKNOWLEDGMENTS

The work described in this paper is the result of the efforts of a project team whose members were: (at GM Research Laboratories) J. M. Farrell, D. N. Pocock, R. W. Rothery, S. M. Rubin, J. E. Stevens, R. R. Thompson, L. M. Troxel, C. R. von Buseck; (at Delco Radio Division) W. R. Kearney, S. M. Neal, L. E. Noble, and J. A. Rodaer.

Factual information and many helpful suggestions were provided by Bureau of Public Roads personnel, particularly W. L. Gibbs, F. J. Mammano, D. A. Rosen, and B. W. Stephens.

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