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The HSRI Part-Task Driving Simulator for Research in Vehicle Rear Lighting and Related Studies

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Report No. UM-HSRI-HF-72-12

Highway Safety Research Institute
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Contract UM 7101-C128
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ABSTRACT

This report describes the design, performance, and operation of a driving simulator for use in vehicle rear lighting and related studies. The results of two simulator validation studies are also described.

The purpose of the simulation was to represent a straight, two-lane road with a lead vehicle in the lane being driven. The test subject has accelerator and brake controls only, steering not being provided. Car-following tasks or overtaking without passing can be simulated, in day or night driving conditions. Approximations to rear vehicle acceleration and braking dynamics are used. Scaling and control of lamp intensity and color is achieved, with flexibility in varying rear lighting system display and operational characteristics. Lead car speed and signaling can be controlled manually or by magnetic tape records. The latter reproduces the speed-time history and signal actuations from a real vehicle under the highway and traffic conditions existing when the recordings were made. A digital computer interface provides system control, storage of rear lighting systems, and real time data acquisition and analysis.

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PART I: SIMULATOR DESIGN AND OPERATING CHARACTERISTICS

GENERAL DESCRIPTION

A schematic drawing and block diagram of the HSRI Rear Lighting Simulator (RLS) is shown in Figure 1. The roadway and lead car are simulated to 1/12th scale. A continuous loop rubberized conveyor belt is used to simulate just over 600 feet of straight and level two-lane roadway (Figure 2). The belt velocity is equal to the simulated following-car velocity and is controlled by the subject with accelerator and brake pedals. Accelerator displacement and brake pedal force are converted to electrical signals and applied as inputs to a vehicle dynamics simulator, provided by a special purpose analog computer circuit which can be programmed to simulate a variety of vehicle dynamic characteristics. The output of the dynamics simulator is the velocity command signal to a high torque velocity servo which drives the belt at a velocity proportional to the command signal and equal to the simulated following-car velocity. Seated at one end of the simulator the subject observes the road and the rear of the lead car model through a view port across a simulated car hood (Figure 3). The shape and size of the view port is made to give the impression of looking through a vehicle windshield. Since binocular vision aids in range discrimination at distances of less than about 50 feet, which is represented by about four feet on the simulator, a patch is placed over one of the subject's eyes to eliminate binocular cues in the simulator.

Control of the lead car velocity and the initiation of signals, such as brake and turn signals, originate from a stored program magnetic tape. This program has an analog voltage-time history of the desired lead car velocity on one channel, and binary (ON/OFF) time histories of the accelerator, brake, and

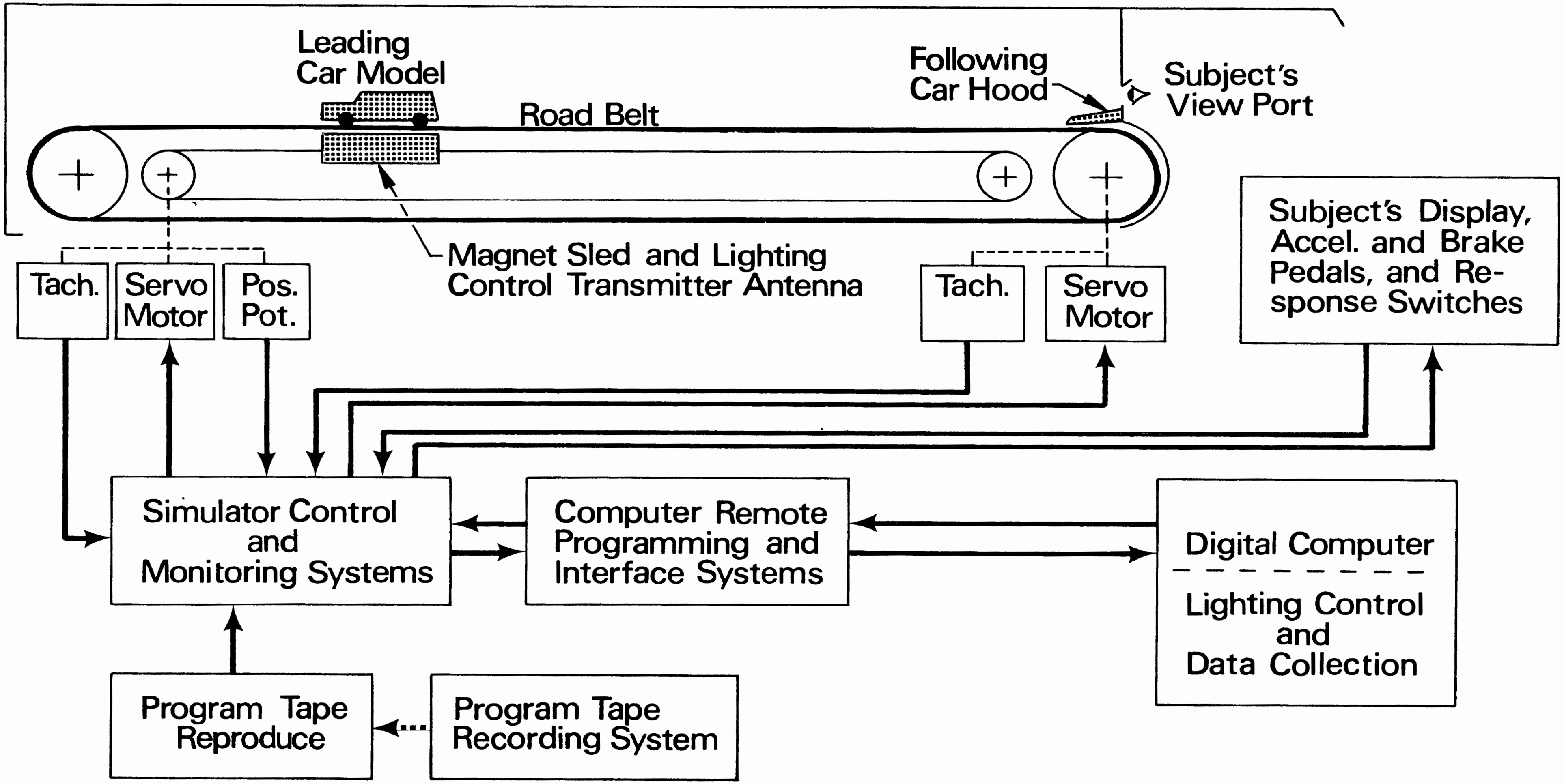

Figure 1. Rear lighting simulator system block diagram.

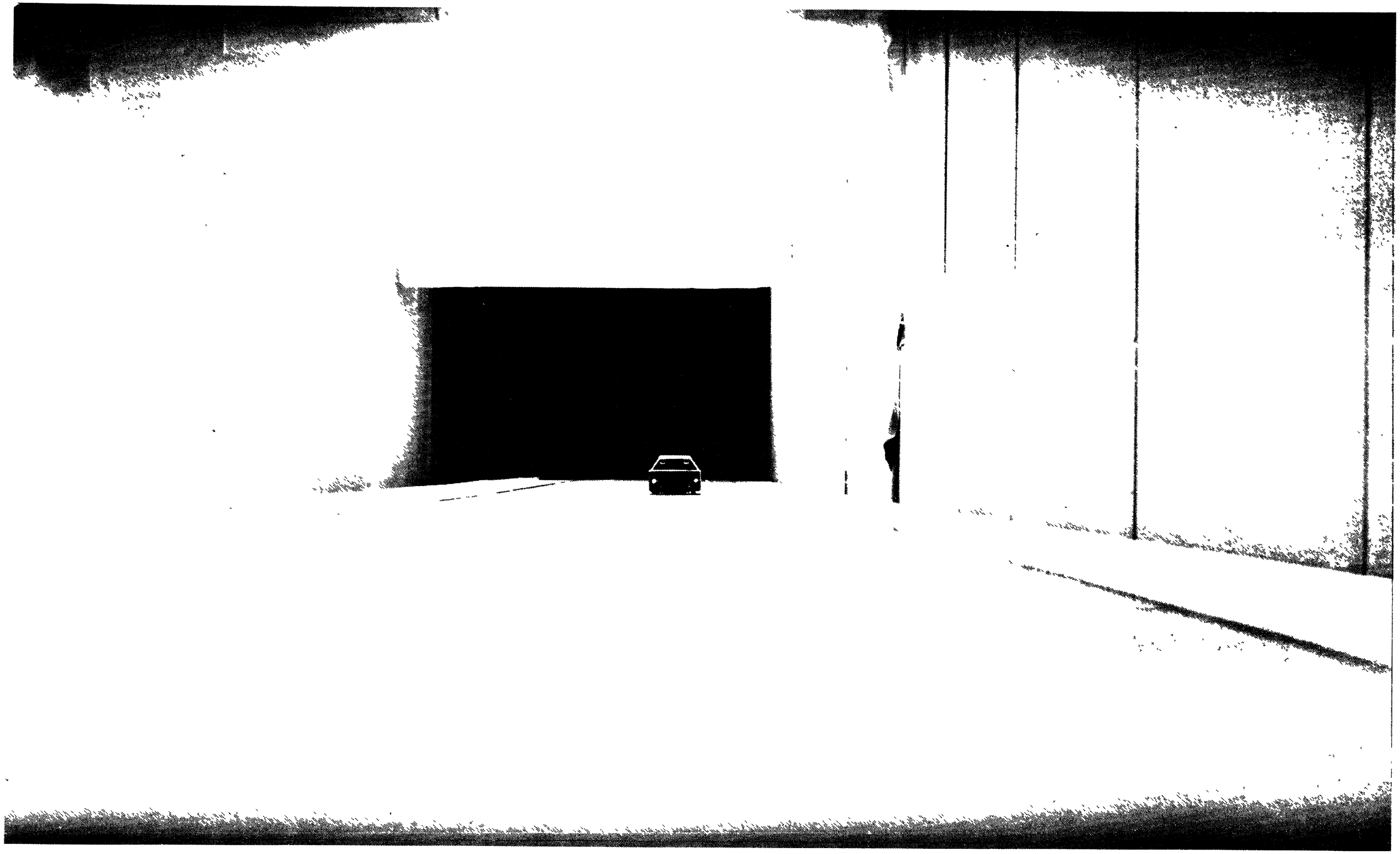

Figure 2. Photo of simulated roadway as seen by the subject.

Figure 3. Viewing station.

left/right turn signals on four other channels. It is generated by driving on real roads in an instrumented vehicle. Thus, the stored program contains a velocity profile with realistic vehicle dynamic characteristics and realistic relationships between velocity changes and the occurrence of coasting, brake, and turn signals, etc. A number of different programs can be stored and then played back for the same subject or for different subjects.

The model car rolls on its own wheels on the belt and follows the position of a sled, moving below the belt, by action of magnetic attraction between steel plates on the bottom of the car and strong permanent magnets on the sled. A position servo controls the movement of the magnet sled below the belt through a sprocket/chain drive. The position of the model car (lead car) on the roadway belt relative to the subject is equal to the simulated headway between the lead and following vehicles. Headway between two vehicles traveling colinear paths is equal to the initial headway plus the time integral of their velocity difference. Thus, the position command signal for the position servo is generated by integrating the difference between the programmed lead car velocity signal and the following car velocity signal derived from the belt velocity servo feedback tachometer.

The model car lighting control system design provides for individual control of intensity and the on-off cycle of up to 16 lamps on the lead car. Digital control signals generated in the IBM-1800 digital computer are transmitted through the roadway belt to the model car on a 10 MHz carrier via a coaxial cable, a transmitting coil antenna mounted on the magnet sled (Figure 4) and a receiving coil antenna mounted on the model car chassis. The coaxial cable is played out and taken up as the magnet sled moves along the simulator table by the reel mechanism shown in Figure 5. The digital signals transmitted

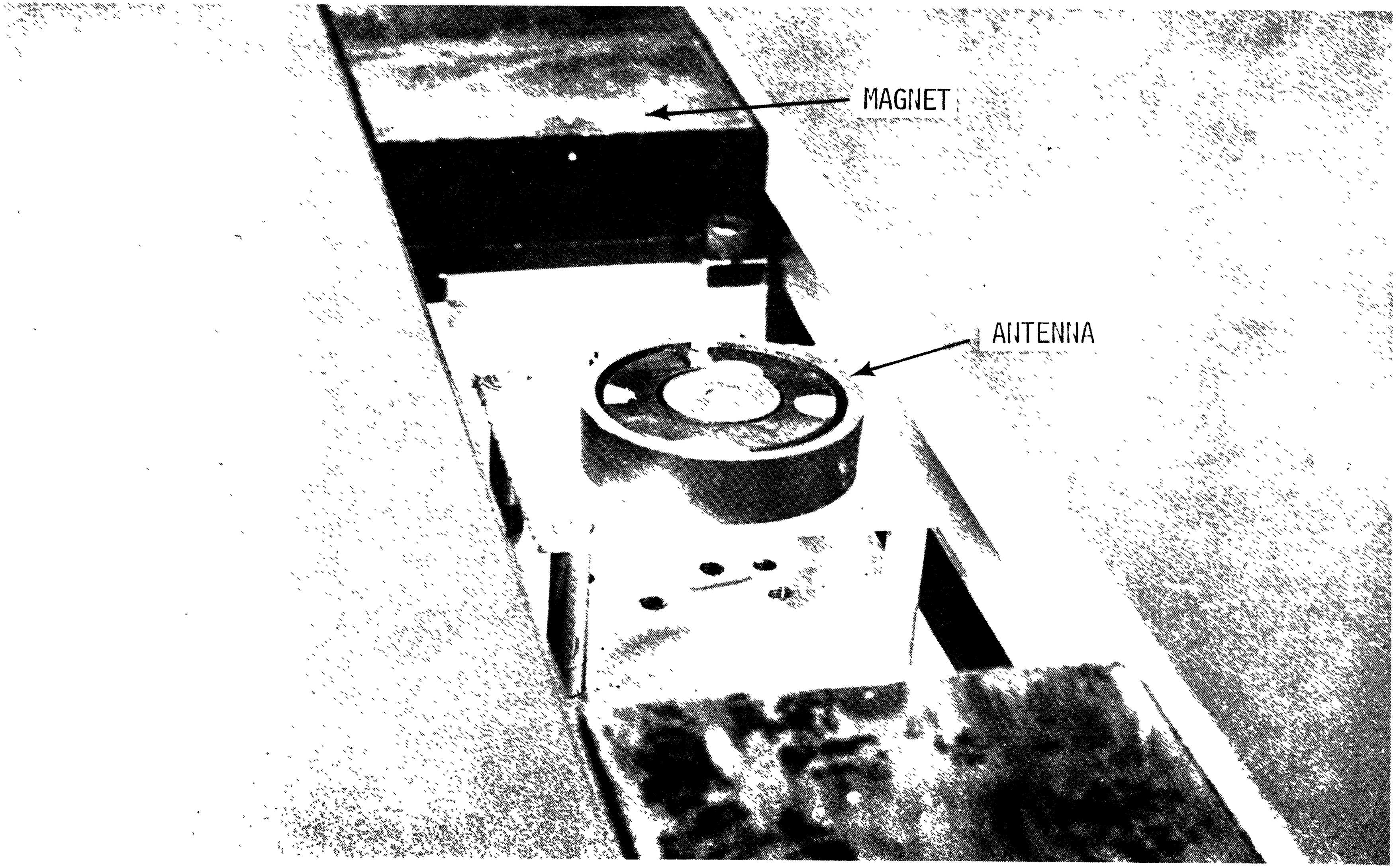

Figure 4. Antenna on magnet sled.

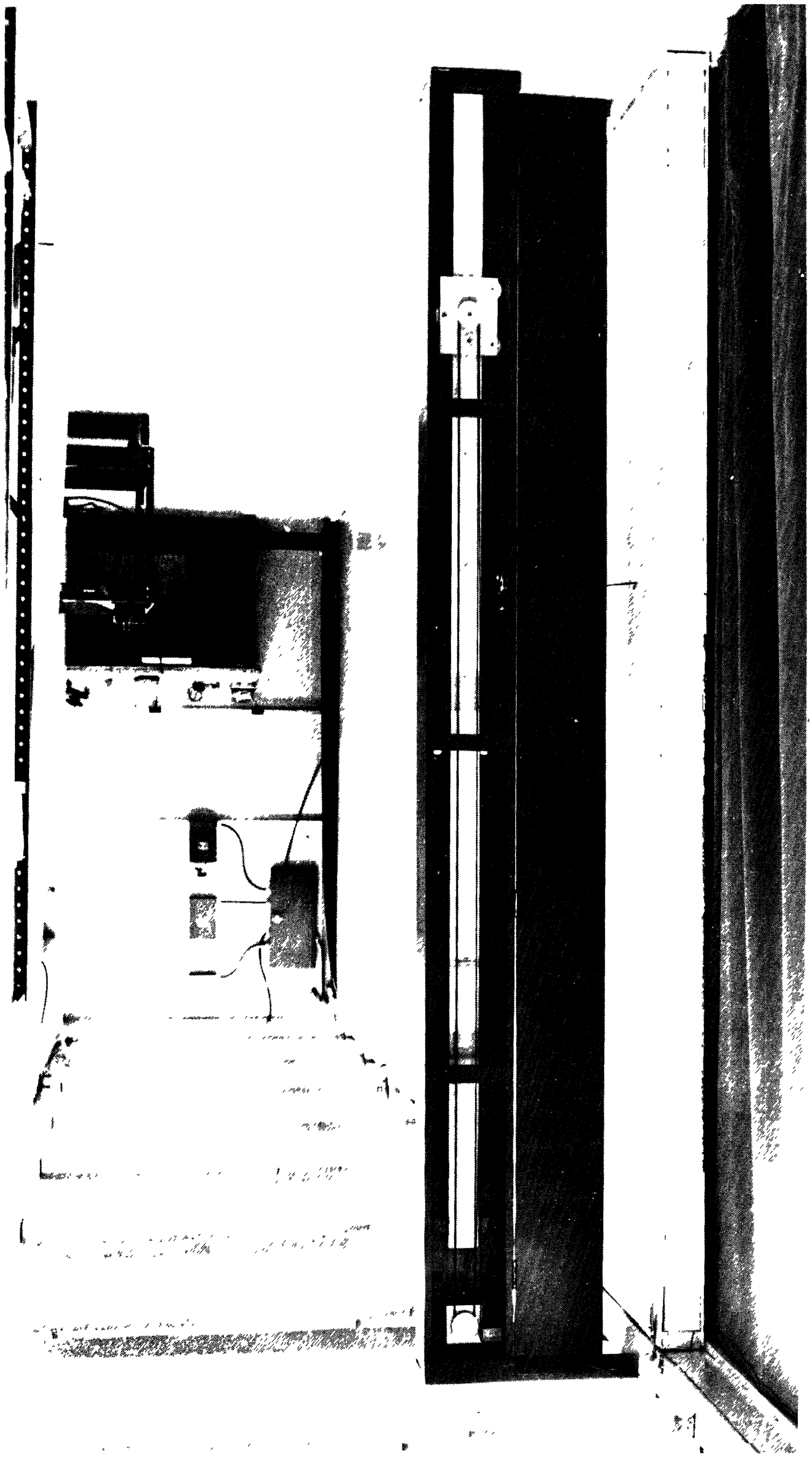

Figure 5. Antenna reel mechanism

into the model car are decoded by logic circuits which control the appropriate lamps through transistor lamp drivers. Computer output of the appropriate control signals for stop and turn signals are initiated through the computer interface circuits by the corresponding program tape output control signals. Lamps on the rear of the model car are mounted in a machined aluminum block along with focusing lenses. The machined block can be easily removed and replaced with others with different lamp arrangements (Figure 6). Lamp color is changed by clipping a color filter plate holding the desired color filter for each lamp over the back of the aluminum block.

In addition to the rear lighting control function described above the computer can be used on line for data collection and data reduction. For this purpose several data lines run from the simulator to the digital computer. Two digital input lines carry binary (ON/OFF) data from two subject response switches located at the subject station in the simulator. With these data the computer can measure, record, and accumulate subject response times after the onset of various light signals given on the lead car lighting and signaling system. Analog data lines carry the following data to the computer analog to digital converter (ADC) input terminals: lead car velocity (V_L), lead car acceleration (A_L), following car velocity (V_F), following car acceleration (A_F), headway (H), relative velocity (V_R), and relative acceleration (A_R). Sampling, analog to digital conversion and storage of these data are under digital computer control. Through computer programming a variety of data sampling procedures can be implemented. For example, the analog lines could be sampled at discrete intervals and the data stored on magnetic tape giving a time history of the signals which can be analyzed to provide various plots and tables to show the subject's per-

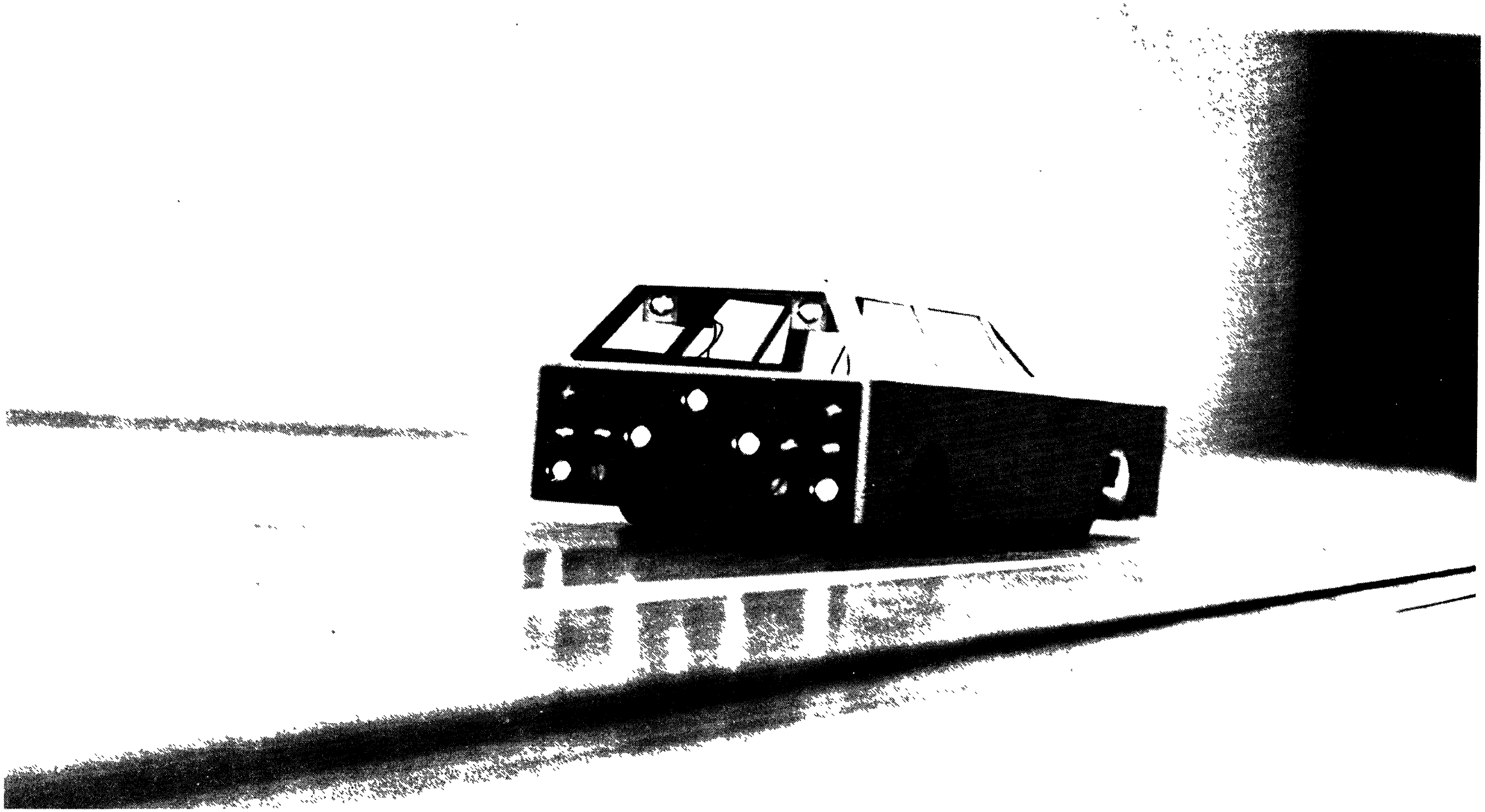

Figure 6. Mounting of lamps on rear of car model.

formance after a simulator run is completed; or data samples could be initiated only at certain times of special interest, such as when lead car coasting starts or lead car braking starts and when the subject responds to an observed change in headway or to the lead car's stop signal. Functional parameters of the simulator are given in Table 1.

SIMULATOR CONTROL AND MONITORING

Control and monitoring of the simulator and remote programming of the computer are handled by the operator through two control panels shown in Figure 7 (overall veiw of operator's station). All circuitry for control, calibration, simulator and computer interfacing, remote computer programming, etc. are contained on plug-in circuit cards in the chassis behind these control panels. Lighted pushbutton switches are used extensively to provide the operator with status and operation mode information. Most of the lamps on the computer remote programming panel are controlled by the computer through digital control lines.

OPERATOR CONTROL AND MONITORING CONSOLE. The simulator run or trial duration time can be controlled automatically or manually. These controls are in the upper left-hand corner of the control panel (Figure 8 - close up of simulator operator control panel). Alternate actuations of the AUTO switch, switches the system between automatic and manual modes. The trial starts when the operator actuates the START switch. In the automatic mode the trial stops when the timer completes its preset timing cycle which can be set anywhere from 30 seconds to 15 minutes. In the manual mode the trial continues until the operator actuates the STOP switch. The actual trial duration is recorded on the digital clock in minutes and seconds. The lead car rear lighting and signals, and computer data collection are enabled only during the trial "on" period.

Five illuminated pushbutton switches and two panel lamps

TABLE 1. Rear Lighting Simulator Functional Parameters.

Model Car:	
Simulated headway (model position)	6 feet to 648 feet
Simulated relative velocity (model velocity)	0 to 40 mph
Simulated relative acceleration (model accel.)	0 to ±2G
Maximum model acceleration (limited by magnetic attraction from magnet sled)	±4.0G
Lead Car:	
Simulated velocity	0 to 90 mph
Simulated acceleration	0 to ±1.0G
Following Car:	
Simulated velocity	0 to 80 mph
Simulated acceleration	0 to ±1.0G
Lead Car (Model) Rear Lighting Display:	
Number of independently controlled lamps	14
Simulated lamp area	≤18.8 sq inches
Lamp intensity (100 discrete steps)	≤100 cd/sq inch, white
Data Output:	
1. Subject response time	
2. Lead car velocity analog	
3. Lead car acceleration analog	
4. Following car velocity analog	
5. Following car acceleration analog	
6. Headway analog	
7. Relative velocity analog	
8. Relative acceleration analog	

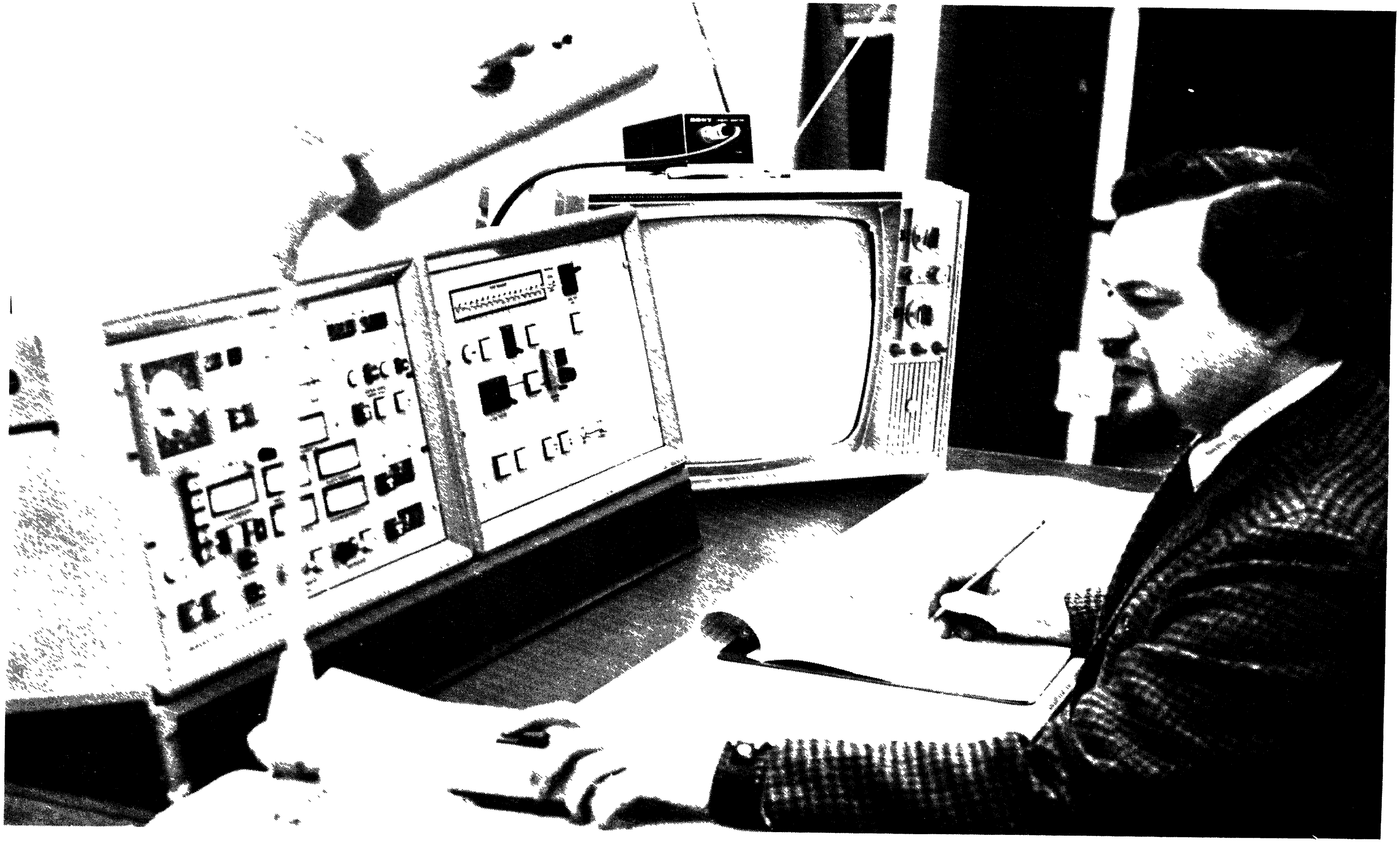

Figure 7. Operators station.

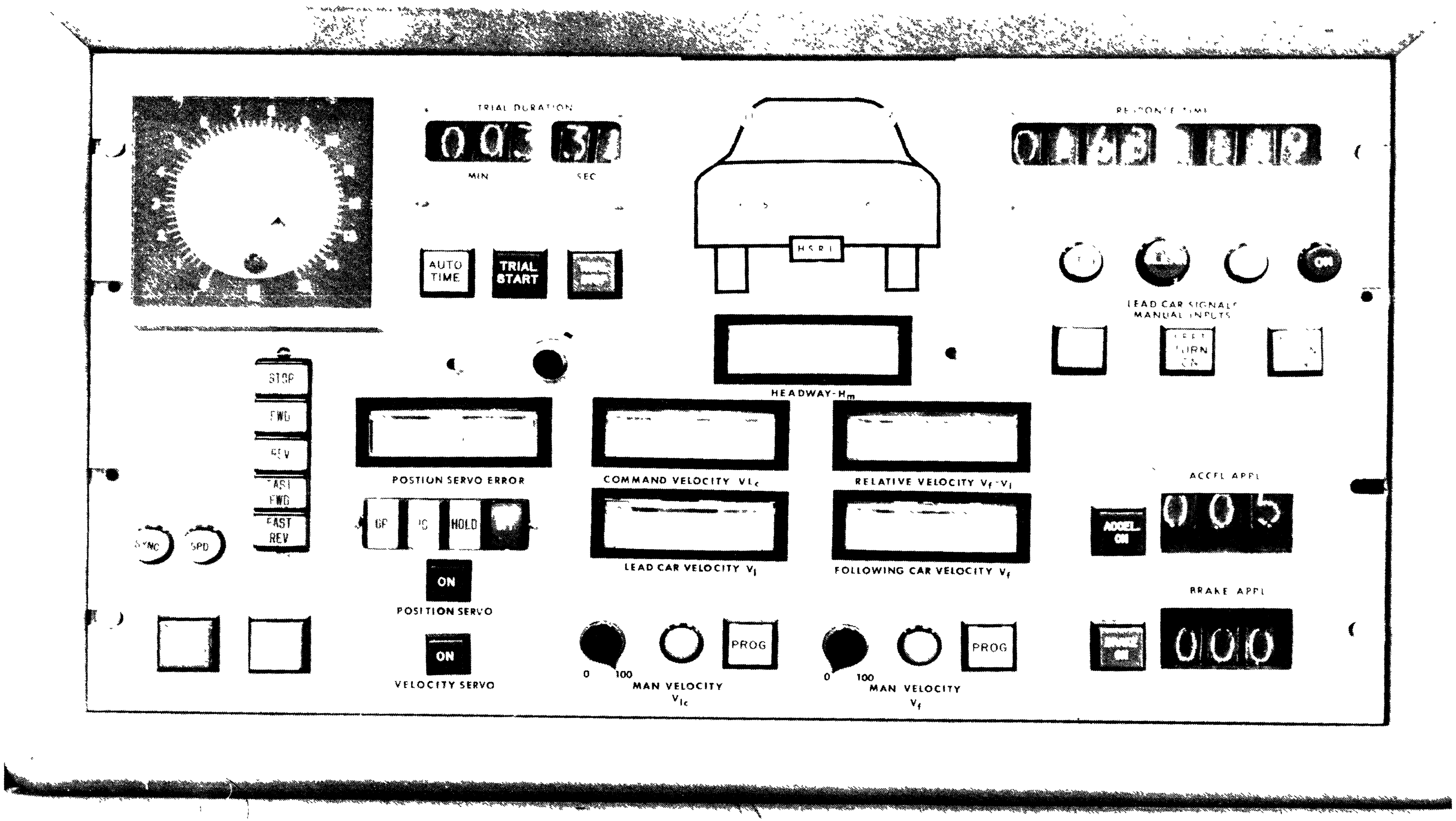

Figure 8. Simulator control panel.

at left center of the panel are remote controls and indicators for the program tape reproduce machine which is located about 100 feet from the simulator in the computer room. The operator has remote control of five tape reproduce machine modes: stop, forward, reverse, fast forward, and fast reverse. One indicator lamp shows the operator that the tape reproduce speed is set correctly to $1\frac{7}{8}$ inches per second and the second shows the operator when the tape reproduce speed servo is in synchronization for proper data reproduction in the forward mode. Program number and tape footage are recorded on the magnetic tape voice track and reproduced on a speaker below the control panel so that the operator can locate any point desired on the tape.

The switches at the left bottom of the control panel are prime power on/off and servo amplifier power on/off controls.

The left meter (servo error meter) and the controls immediately above and directly below this meter are belt velocity servo and model car position servo controls.

In the case of the velocity servo there is only a velocity servo ON/OFF lighted pushbutton switch, but the position servo controls and indicator requirements are more demanding in order to keep the model car under control. Four interlocked, lighted pushbutton switches plus a momentary pushbutton ON switch control and the position servo operating mode. Besides ON and OFF the modes are operate (OP switch), initial condition (IC switch) and hold (HOLD switch). When the position servo is turned on, the servo error, i.e., the difference between the position command and the actual position of the model car, must be near zero or the magnet sled will accelerate rapidly toward the commanded position and possibly throw the model car loose from the hold of the magnets. Thus, after turning on system power the operator switches to the IC mode, adjusts the position command with the IC potentiometer located just above the servo error meter to obtain approximately zero error indication on the meter, and then pushes the position servo ON switch to actuate the position servo. With the position servo ON the operator can position the model car to a starting position anywhere along the simulated roadway with the IC potentiometer.

Five meters in the center of the control panel give the operator a continuous indication of lead car velocity command (V_{LC}), lead car velocity (V_L), headway (H), relative velocity (V_F-V_L), and following car velocity (V_F). Both lead car velocity command and lead car velocity, the latter obtained from the position servo feedback tachometer, are displayed so the operator can see that the simulated velocity is indeed a reproduction of the recorded program velocity.

The controls immediately below the meters allow the operator to select MANual or PROGram control of the simulator. In the manual control mode the operator controls the lead car velocity command and/or the following car velocity command with the potentiometers on the control panel. In the program mode velocity commands are derived from the program tape and from the subject controls. In either mode, before switching the position servo system from IC to OP, the operator must check that the lead and following car velocity commands are about equal or both zero as indicated on the meters. In the manual mode the operator accomplishes this by adjusting the manual velocity controls to obtain equal readings on the lead car velocity command meter and following car velocity meter or by turning both controls full counterclockwise to zero. In the program mode the subject is instructed via an intercom to maintain zero following car velocity (brake on) while the operator runs the program tape to the start of a program and starts the tape. The start of each stored program contains a section of zero lead car velocity command during which time the operator switches to the OPerate mode.

The position servo HOLD mode is designed primarily to protect the simulator if the subject does not maintain reasonable relative velocity (model car velocity) between the lead and following cars particularly near the ends of the simulator table. If the relative velocity exceeds a preset threshold, which is 40 mph (simulated) over the central 44 feet of the table and decreases linearly to zero mph in the last five feet at either end of the table, the position servo automatically switches to HOLD and the model car is brought to a controlled (4G's simulated) stop. The model is held at the stop position until the subject brings the relative velocity back into a safe region. If desired the operator can switch the position servo to hold manually by pushing the HOLD switch, in which case the OPerate switch must be pressed again to return to the operate mode.

LIGHTING SYSTEM MONITOR DISPLAY. An interchangeable panel at the top center of the control panel contains a lamp array identical to the array on the rear of the model car providing the operator with a continuous display of the lead car lighting and signaling. The lamps in this display are controlled by decoding and lamp driver circuits identical to those in the model car. System errors generated before the decoder circuitry, will appear on the operator's lead car lighting display as well as on the model car and may be detected by the operator.

DRIVER REACTION TIMERS AND ACCELERATOR/BRAKE APPLICATION COUNTERS. Two 0-99.99 seconds timers located in the upper right corner of the control panel may be used by the operator to collect subject response time data independently of the digital computer. One timer displays subject response time to brake signals and the other displays subject response time to left or right turn signals. The timers clear automatically at the start of each trial when the operator actuates the trial start button.

After recording a response time reading the operator can clear the response timers or the response time can be left to accumulate giving the total response time for the complete trial. If the subject fails to respond the timer may be stopped by the operator with the switches just below the timers.

Three lighted pushbutton switches just below the response timers may be used by the operator to generate stop, left and right turn signals independently of the program tape. Alternate actuations of the switches turn the signals on and off. The switches remain lighted while the corresponding stop or turn signal is on, either from manual or program tape actuation of the signal.

Two three-digit counters in the lower right corner of the control panel accumulate counts of the subject's accelerator and brake pedal applications. The indicator lamps at the left of each counter are lighted while the accelerator or brake pedal is actuated by the subject. The brake on indicator lamp is also an alternate action switch which, when actuated by the operator, overrides the subject's brake control and applies a constant braking deceleration of about 0.4G to the roadway belt bringing the belt to a controlled stop.

COMPUTER REMOTE PROGRAMMING CONSOLE. Communication from the RLS operator to the digital computer is carried on via the various switches and controls on the computer remote programming control panel (Figure 9), and communication from the computer to the RLS operator is via the indicator lamps and lighted switches on the panel. The range of communications and the communication lines are preset through computer software (programming) and computer interface wiring.

By means of the remote programming console the operator can program new rear lighting and signaling patterns or call out pro-

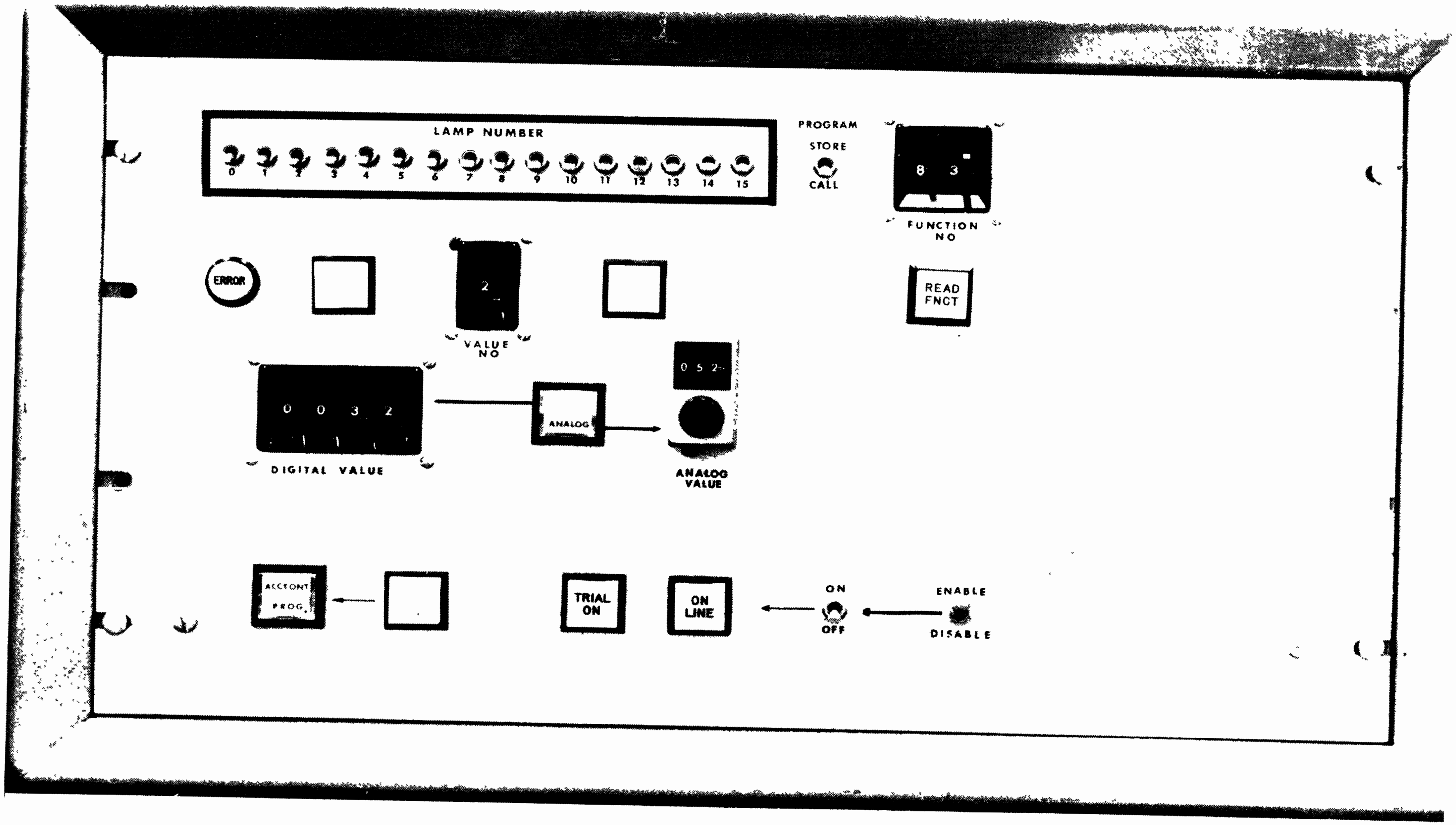

Figure 9. Computer remote control panel.

grams previously designated and stored in the computer. Any one or more of fourteen lamps numbered 0-13 on the rear of the model may be assigned one or more of the available functions, i.e. presence light, stop light, etc. Lamps fourteen and fifteen are wired as headlamps. Four functions presently available in the computer software are: presence lamp, stop lamp, left turn lamp, and right turn lamp. Each function is assigned a number and can be called by placing this number on the FUNCTION NO. thumbwell switch in the upper left corner of the program panel and pressing the READ FUNCTION switch below the thumbwell switch. The lamps assigned a designated function are selected by placing the appropriate toggle switches, at the top left of the console, in the up position before pressing the READ FUNCTION switch. After receiving this information the computer extinguishes the READ FUNCTION light and lights the READ VALUE and SET VALUE lamps. Each function has one or more parameter values, i.e. intensity, turn signal on and off times (flashing cycle), etc. The operator enters the parameter value on the DIGITAL VALUE thumbwell switches and presses the READ VALUE switch to enter the parameter value in the computer. When all parameter values for a given function have been entered, the computer relights the READ FUNCTION light and the operator repeats the procedure for all functions required. Any errors in the program sequence will be detected by the computer and signaled to the operator on the ERROR light at the left side of the panel.

In some cases values can be entered in the computer via the analog value potentiometer, in which case the split face, alternate action DIGITAL/ANALOG switch in the center of the panel is pressed to light the ANALOG section of the illuminated switch plate, and the value is set on the analog value dial.

When the operator has completed a program it may be stored for future recall by placing the PROGRAM STORE/CALL switch to

STORE, setting the FUNCTION NO. switch to any number between 81 and 98, and pressing the READ FUNCTION switch. To recall the program the program number is set on the FUNCTION NO. switch, the PROGRAM STORE/CALL switch is set to CALL and the READ FUNCTION switch is pressed. A change from one stored program to another can be made in about 60 seconds. A new program can be set up and stored in about five minutes.

From the above discussion it will be noted that the computer is used in two modes of operation, a program (PROG) mode in which the operator sets up the lighting pattern desired and an acquisition and control (ACQ/CONT) mode in which the computer acquires data and controls the lead car lighting. To change from one mode to the other the operator presses the split face ACQ/CONT-PROG button at the bottom left of the panel and then presses the adjacent MODE INT switch. The computer immediately lights the appropriate half of the ACQ/CONT-PROG button and a few seconds later lights the READ FUNCTION button if in PROG mode or the TRIAL ON lamp (bottom center of panel) if in the ACQ/CONT mode.

The two toggle switches and lighted pushbutton switch at the bottom right of the control panel are used by the operator to place the computer on or off line to the simulator. When the computer is on line it lights the ON LINE indicator lamp.

DESCRIPTION OF SIMULATOR SUBSYSTEMS

The block diagram in Figure 10 shows the interconnections and signal paths between the various RLS subsystems. Signal paths between the control and monitoring systems console and the servo actuators, program tape reproduce machine, subject's controls and display, etc. are descriptively labeled. Digital control and analog data signals flow between the control console and the computer interface console and then to the computer via

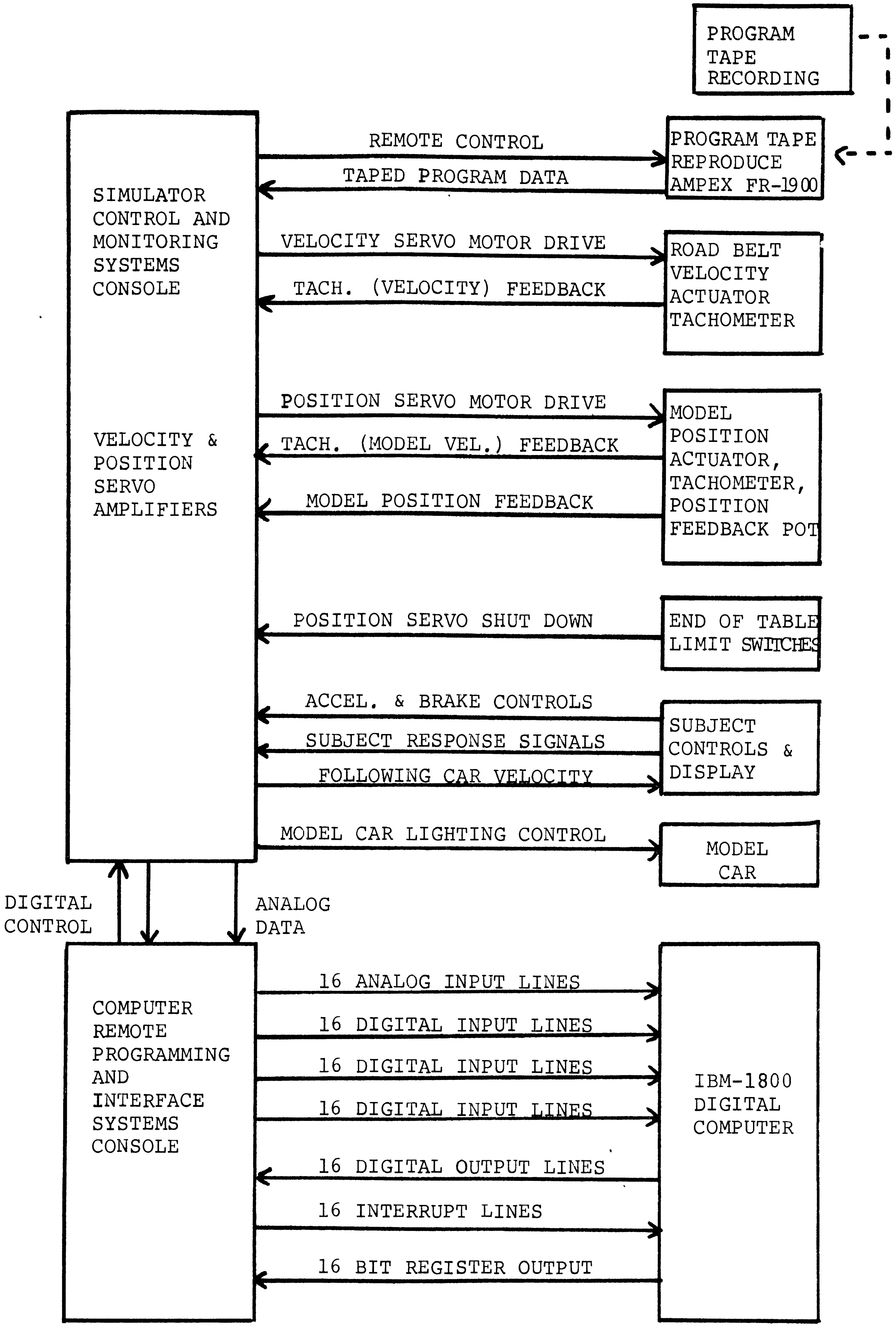

Figure 10. Block diagram of simulator subsystems.

7 sets of 16 interface lines. The signals assigned to each line are listed in the following tables. All 16 lines of each group are not used but they were wired since the inputs are available on the computer and thus are made readily available for future use if needed. Analog data from the simulator is sent to the computer via the 16 analog input lines. The three sets of 16 digital input lines carry remote computer programming data and digital control signals from the simulator to the computer. Indicator lamps on the computer remote programming console are controlled by the computer through the 16 digital output lines. Computer action, i.e. data collection, lead car signaling, etc. is initiated by "interrupt" signals on the 16 interrupt lines. The 16 bit output register lines carry the computer generated words which are converted from parallel to serial form in the computer interface console and then transmitted to the model car for control of the lamps in the rear lighting display. In some cases the lines serve different functions in the PROGram mode and ACQuisition and CONtrol mode as indicated in the tables.

TAPED PROGRAM RECORDING SYSTEM. A simplified block diagram of the system used to generate and record the lead car stored program control data is shown in Figure 11. Five signals are recorded on the stored program magnetic tape. These are:

1. Velocity	-1.5 to +1.5 volts	0 to 90 mph
2. Right Turn	OFF = 0 volts	ON = 1.5 volts
3. Left Turn	OFF = 0 volts	ON = 1.5 volts
4. Brake	OFF = 0 volts	ON = 1.5 volts
5. Accelerator	OFF = 0 volts	ON = 1.5 volts

Velocity is obtained from a DC tachometer driven from a tee in the vehicle's speedometer drive cable. The other signals are generated by switches coupled to the turn signal lever, the brake pedal linkage and the accelerator linkage. The tachometer and switches interface with the tape recorder via signal conditioning

TABLE 2. Analog Input

Line No.	Input	Scaling
0	V_L, lead car velocity	0 to +5 volts; 20 mph/volt
1	A_L, lead car acceleration	-5 to +5 volts; 0.2 G/volt
2	V_F, following car velocity	0 to +5 volts; 20 mph/volt
3	A_F, following car acceleration	-5 to +5 volts; 0.2 G/volt
4	H , headway (model car position)	0 to +5 volts; 120 ft/volt
5	V_R, relative velocity (model velocity)	-5 to +5 volts; 20 mph/volt
6	A_R, relative acceleration	-5 to +5 volts; 0.2 G/volt
7	Unused	
8	"	
9	"	
10	"	
11	"	
12	"	
13	"	
14	"	
15	Analog Value Input	-5 to +5 volts

TABLE 3. Digital Input I

Line No.	Input	
	Program Mode	Acquisition/Control Mode
0	Lamp No. 0 selected	Following car accelerator ON/OFF
1	" " 1 "	Following car brake ON/OFF
2	" " 2 "	Subject response switch #1 ON/OFF
3	" " 3 "	Subject response switch #2 ON/OFF
4	" " 4 "	Lead car left turn signal ON/OFF
5	" " 5 "	Lead car right turn signal ON/OFF
6	" " 6 "	Lead car brake signal ON/OFF
7	" " 7 "	Trial ON/OFF
8	" " 8 "	Lead car accelerator ON/OFF
9	" " 9 "	Unused
10	" " 10 "	Unused
11	" " 11 "	Unused
12	" " 12 "	Unused
13	" " 13 "	Unused
14	" " 14 "	Unused
15	" " 15 "	Unused

TABLE 4. Digital Input II

Line No.	Input					
0	Function Number, Decimal			10's	BCD	8's
1	"	"	"	10's	"	4's
2	"	"	"	10's	"	2's
3	"	"	"	10's	"	1's
4	"	"	"	1's	"	8's
5	"	"	"	1's	"	4's
6	"	"	"	1's	"	2's
7	"	"	"	1's	"	1's
8	Argument Number, Decimal			1's	"	8's
9	"	"	"	1's	"	4's
10	"	"	"	1's	"	2's
11	"	"	"	1's	"	1's
12	Value Input - DIGITAL/ANALOG					(0/1)
13	ON/OFF Line					(1/0)
14	Program - STORE/CALL					(1/0)
15	MODE - ACQ-CONT/PROG					(0/1)

TABLE 5. Digital Input III

Line No.	Input
0	Digital Argument Value, Decimal 1000's BCD 8's
1	" " " " 1000's " 4's
2	" " " " 1000's " 2's
3	" " " " 1000's " 1's
4	" " " " 100's " 8's
5	" " " " 100's " 4's
6	" " " " 100's " 2's
7	" " " " 100's " 1's
8	" " " " 10's " 8's
9	" " " " 10's " 4's
10	" " " " 10's " 2's
11	" " " " 10's " 1's
12	" " " " 1's " 8's
13	" " " " 1's " 4's
14	" " " " 1's " 2's
15	" " " " 1's " 1's

TABLE 6. Process Interrupt

Line No.	Function		
0	Following car accelerator	ON & OFF	Interrupt line enabled only in ACQ/CONT mode and Test ON. Disable in PROG mode or during Trial OFF
1	Following car brake	ON & OFF	
2	Subject Response #1	ON	
3	" " #2	ON	
4	Lead car left turn	ON & OFF	
5	Lead car right turn	ON & OFF	
6	Lead car brake	ON & OFF	
7	ACQ-CONT/PROG mode interrupt (disable during trial ON)		
8	Lead car accelerator ON & OFF		
9	Unused		
10	Unused		
11	Unused		
12	ON & OFF line	(disabled during trial ON)	
13	Read function	(disabled when in ACQ-CONT mode)	
14	Read value	(disabled when in ACQ-CONT mode)	
15	Trial ON & OFF	(disabled when in PROG mode)	

TABLE 7. Register Output

Bit No.	Bit Function	
0	Sync pulse	Always 1
1	ON/OFF pulse	ON-1, OFF-0
2	BCD lamp address	8's
3	" " "	4's
4	" " "	2's
5	" " "	1's
6	Operate time	Always 0
7	Clear time	Always 0
8	Sync pulse	Always 1
9	ON/OFF pulse	ON-1, OFF-0
10	BCD lamp address	8's
11	" " "	4's
12	" " "	2's
13	" " "	1's
14	Operate time	Always 0
15	Clear time	Always 0

TABLE 8. Digital Output

Line No.	Function
0	ON LINE lamp
1	READ FUNCTION lamp
2	READ VALUE lamp
3	SET VALUE lamp
4	ERROR lamp
5	MODE INTERRUPT lamp
6	Unused
7	PROG mode lamp
8	ACQ-CONT mode lamp
9	TRIAL ON lamp
10	Unused
11	Unused
12	Unused
13	Unused
14	Unused
15	Unused

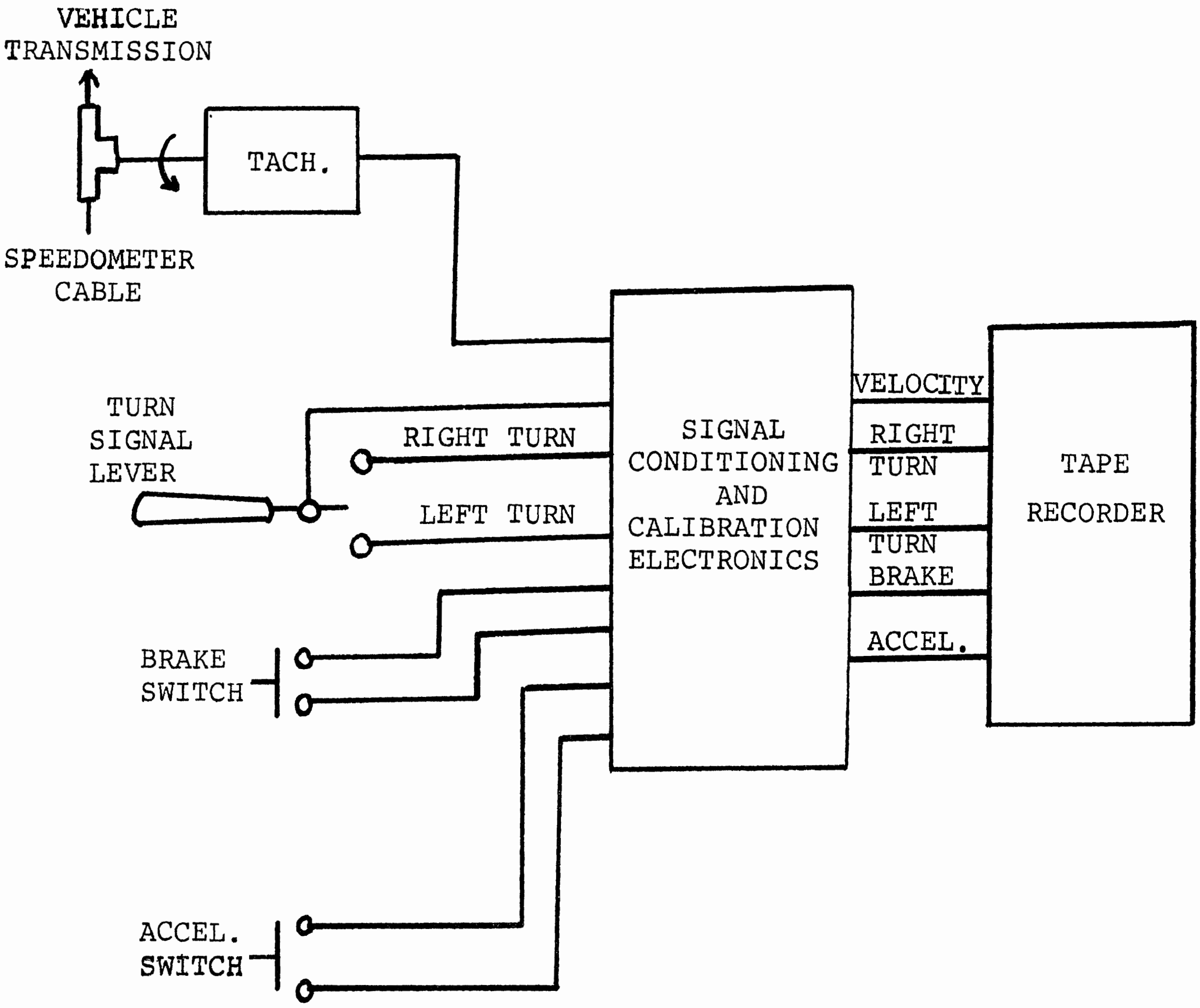

Figure 11. Tape program recording system.

and calibration electronics which include low pass filtering of the tachometer signal and gain and offset adjustments to set appropriate input levels to the recorder. Data are recorded on a Lockheed 417A 7-channel, 1/2 inch IRIG recorder in the car. The data are retaped and voice annotation added in the laboratory on one inch tape with an Ampex 1900 magnetic tape recorder. Data reproduction is also done with the Ampex 1900.

ROADWAY BELT VELOCITY CONTROL SYSTEM. The belt velocity control system includes the subject's accelerator and brake controls, a following vehicle dynamics simulator, a servo amplifier and motor, and a belt velocity feedback tachometer. A simplified block diagram of this subsystem is shown in Figure 12.

The vehicle dynamics simulator is a special purpose analog computer circuit which solves the equation of motion:

$$F=ma-kv^2-f$$

where:

F=force applied to control the vehicle
m=mass of the vehicle
a=vehicle acceleration
v=vehicle velocity
kv^2=air drag on vehicle, assumed proportional to v^2
f=a constant friction drag component

F is the sum of an acceleration force F_A and a braking force $-F_B$. F_A is assumed proportional to the accelerator displacement and its voltage analog is obtained from a potentiometer geared to the subject's accelerator pedal. F_B is assumed proportional to brake line pressure. The analog of F_B is obtained from a potentiometric type pressure transducer in a simulated brake line connected to the subject's brake pedal. Gain A_1 sets the maximum acceleration force at full accelerator displacement and A_2 sets the brake deceleration-pedal force gain. F_A and $-F_B$ are summed to obtain F.

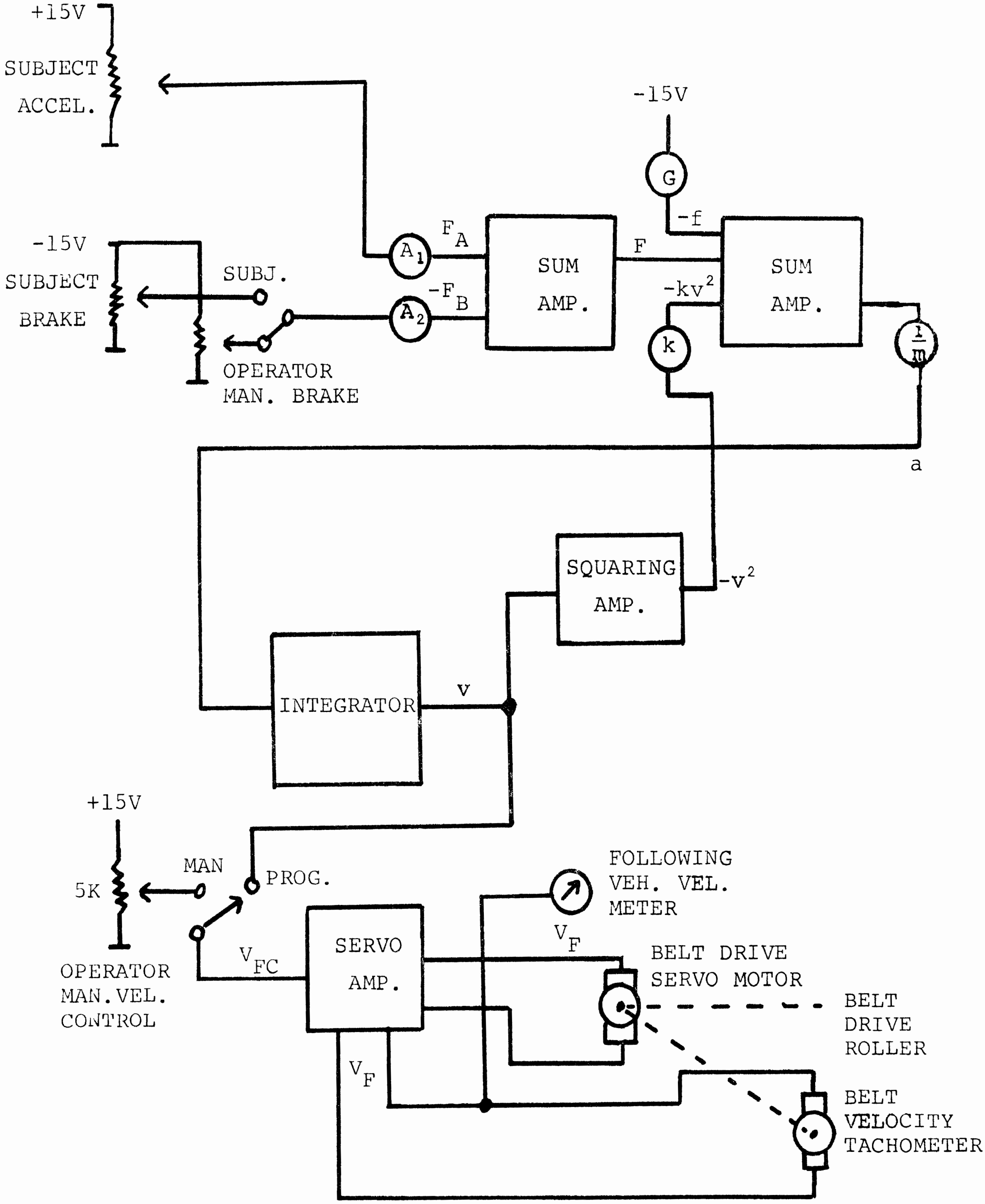

Figure 12. Roadway belt velocity control system.

F, $-kv^2$, and $-f$ are summed to obtain $ma=F-kv^2-f$, the acceleration is integrated to obtain velocity, and v^2 is formed by a squaring amplifier as indicated in Figure 12.

The belt velocity (following car) servo input command signal, V_{FC}, is taken from the output of the integrator in the simulator program mode and from the operator manual velocity potentiometer in the manual mode.

A tachometer coupled directly to the servo motor shaft generates the following-car velocity feedback for the servo amplifier. The tachometer output, V_F, is also applied to the operator's and subject's following-car velocity display meters and routed to the digital computer through analog data lines.

Lorig-Aligner, Type II, self-centering rollers, 10 inches in diameter, are used for the belt drive and idle rollers. This is a rubber covered roller with grooves slanted toward the transverse center of the roll cut into its surface. Deformation of the grooved roll surface under load produces centering forces on the belt. The drive roller is driven through a 1.6:1 pulley reduction ratio by an Inland model TT-5746 torque motor rated at 17 ft-lb continuous torque.

The roadway belt is a 3-ply cotton fiber rubber coated conveyer belt, 113.5 feet long, spliced to form a continuous loop. It weighs about 160 lbs. The model running surface of the belt is supported by a slider table surfaced with teflon impregnated aluminum plates to minimize friction. The wheels of the model car straddle a 3-inch wide slot, cut in the slider table, in which the magnet sled travels just beneath the belt. At the scale of 1:12 the 54 feet of useful model running surface gives a simulated roadway length of 648 feet.

The simulated roadway is enclosed and illuminated from above by 114, 40-watt and 60-watt incandescent lamps. Illumination is controlled by a 6000-watt SCR dimmer control which provides an adjustment range from 0 to over 10 ft candles at the road surface.

MODEL CAR POSITION CONTROL SYSTEM. The model car position control system (Figure 13) circuits generate a position command voltage, H_C, by integrating the difference between the lead car velocity command, V_{LC}, and the following car velocity V_F. The servo[1] positions the lead car at the computed headway. Circuits also provide for initial positioning of the model at the start of a test and automatic-stop and hold when the model exceeds preset velocity limits. The latter is particularly important near the end of the track. A simplified block diagram of this subsystem is shown in Figure 14.

Either the taped program or the operator's manual control potentiometer can be selected as the source of V_{LC}, the lead car velocity command. The following-car velocity, obtained from the belt velocity feedback tachometer, is subtracted from V_{LC} to obtain V_{RC}. With the OP/HOLD relay in the OPerate position and the IC/OP switch in the OPerate position, V_{RC} is low pass filtered and then integrated to obtain the lead car position command signal, H_C, which is the input to the lead car position servo. A 10-turn position feedback pot. is coupled to the servo motor shaft through a 4:1 gear reduction. The servo motor turns to maintain the position feedback voltage equal to the position command voltage and drives the magnet sled and model car along the table through a chain and sprocket drive coupled directly to the servo motor shaft. Headway (model position), measured by the position feedback poten-

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[1] The servo motor is a Printed Circuit Motors, Inc. Model 16M4T torque motor, with integral tachometer, rated at 1.6ft-lb continuous torque.

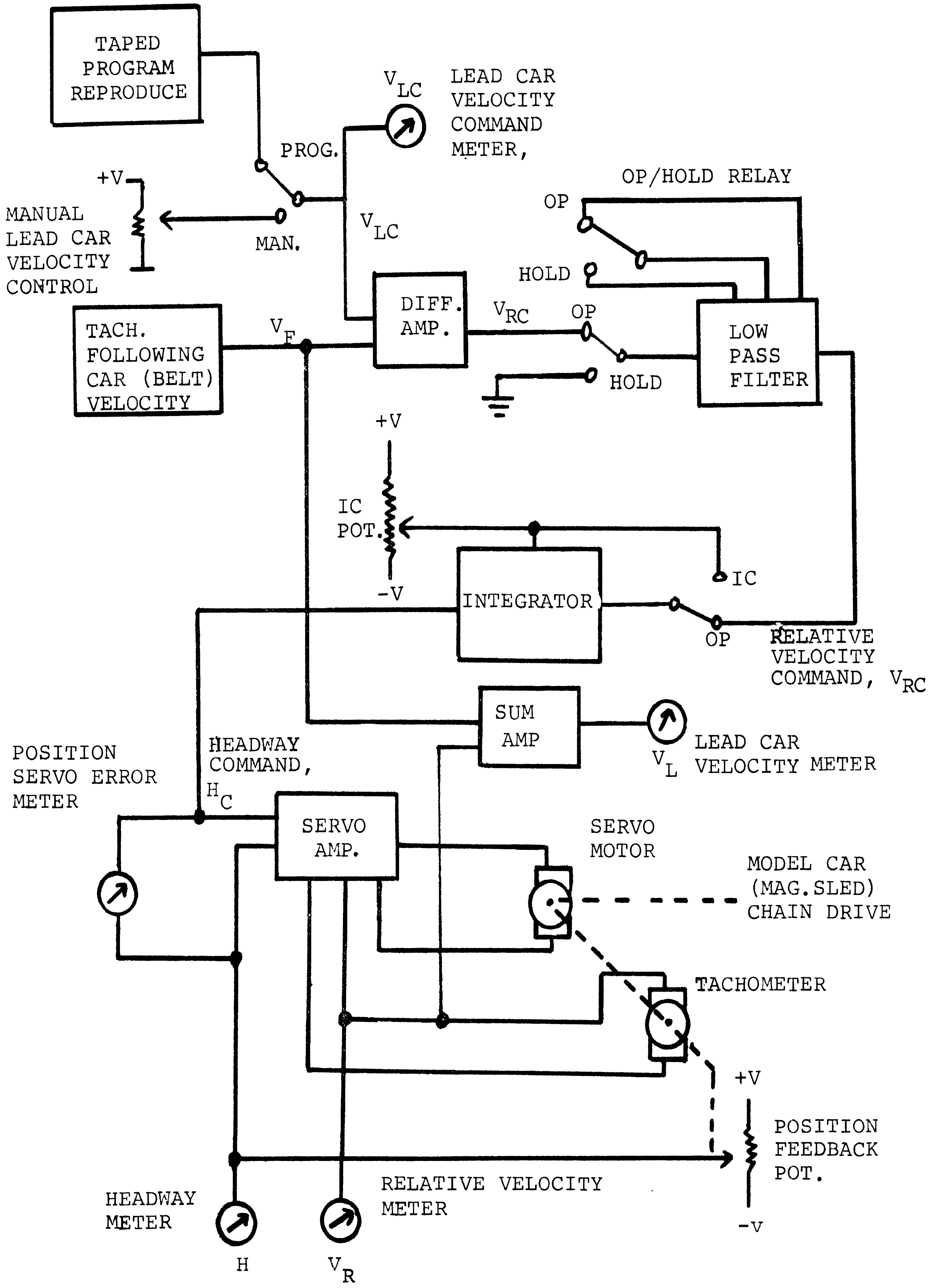

Figure 13. Model car position control system

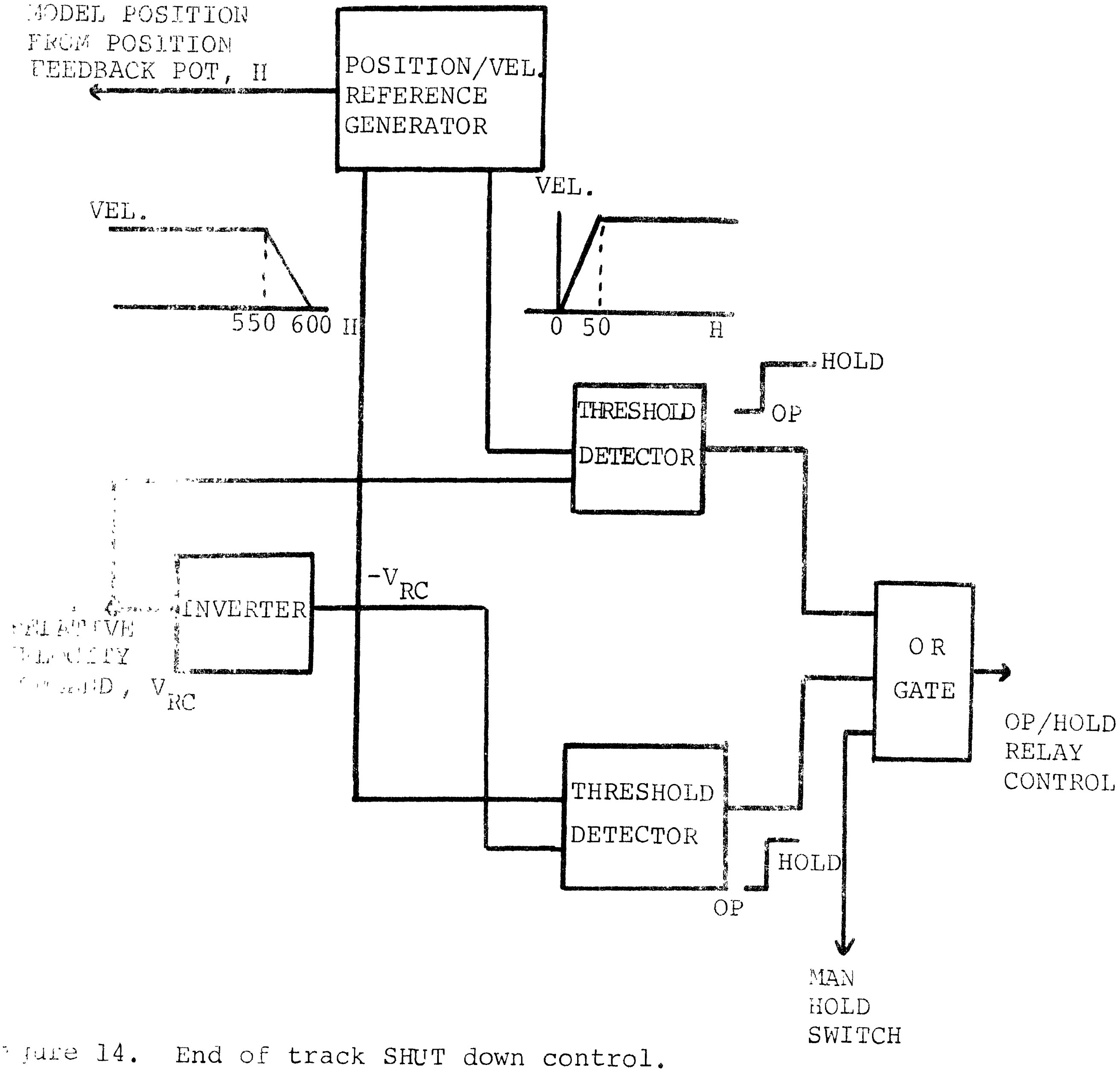

Figure 14. End of track SHUT down control.

tiometer, is displayed on a control panel meter and sent to the computer on an analog line. Relative velocity, obtained from a tachometer coupled to the position servo motor shaft, is displayed on a control panel meter and sent to the computer.

With the IC/OP switch in the Initial Condition position the integrator output voltage is set by the IC potentiometer. Before the position servo is turned on, the servo error indicated on the servo error meter is adjusted to near zero with the IC potentiometer, and after the servo is turned on the model position is adjusted to its test start position with the IC potentiometer.

The OP/HOLD relay functions to place the system in HOLD stopping the car when it reaches the end of the track. A position velocity reference generator receives the model position signal from the position feedback potentiometer and generates two velocity threshold voltages as a function of the model position as shown in Figure 14. In the middle 44 feet of the roadway table the velocity threshold is 40 mph and the threshold decreases linearly to zero in the last five feet at either end of the table. Plus and minus V_{RC}, the relative velocity command signal, are compared with the velocity references in two threshold detectors such that a hold voltage control level is generated when the model velocity exceeds the reference velocity. Outputs from the two threshold detectors are OR'ed with the output from the manual HOLD switch and the output from the OR gate controls the OP/HOLD relay. When the relay switches to HOLD position the input to the low pass filter is grounded and a larger time constant is switched into the filter such that the filter output decreases to zero at a rate that brings the model car to a stop with maximum deceleration of about 4 G's (simulated). The system automatically switches back to operate when the subject changes the following car velocity, V_F, so as to reverse the polarity of the relative velocity command.

Lead car velocity, V_L, is obtained by summing the following car velocity from the belt velocity servo tachometer and the relative velocity from the lead car position servo tachometer. V_L is displayed on a control panel meter and sent to the computer on an analog line.

MODEL CAR LIGHTING CONTROL SYSTEM. A digital control scheme is used to control the intensity and on/off cycle of up to 16 lamps on the lead car model. Each lamp is switched on and off at approximately 50 Hz with intensity controlled by changing the on-duty cycle from 0 to 100% in 100 discrete steps. Thus, each lamp is instructed to turn on or off 5000 times per second. For example, a lamp operating at 70% duty cycle receives 70 "on" commands followed by 30 "off" commands 50 times each second. Calling an individual on or off command to a lamp a word, 5000 words per second are transmitted to each lamp. For 16 lamps the transmission rate is 80,000 words per second.

Each word consists of 8 bits. The first bit is always a 1 which is used to synchronize the decoding circuit. The second bit is the ON/OFF command, a 1 is an "on" command and a 0 is an "off" command. The next 4 bits contain the Binary Coded Decimal, BCD, address of one of the 16 lamps, and the last two bits are always 0. During the last two bit times the lamp addressed is switched on or off and the decoding circuits are cleared to be ready to receive the next word. Word bits are transmitted into the model car in serial form so that only one data channel into the car is required. Pulse width modulation on a 10 MHz carrier is used. A "0" bit is transmitted as a 0.2 μ sec pulse and a "1" bit is a 1.0 μ sec pulse. A bit period or clock period is 1.5 μ sec. Words are generated in the digital computer and transferred to the RLS control circuits, two words (16 bits) at a time, via the computer's 16-bit output register. Simplified block diagrams of the modulator/transmitter circuit and the receiver/decoder circuit are shown in Figures 15 and 16, respectively. A timing diagram for both circuits is shown in Figure 17.

System timing is controlled by the 666.6 KHz free-running clock. The clock output is a square wave with period of about 1.5 µ sec. When the computer has a 16-bit word loaded into its output register it raises the READY line and clock pulses are passed through the AND gate to the JK flip-flop. Once in every 16 clock pulses the divide-by-16 (see Figure 15) circuit changes state for one clock period and the rising edge of the next clock pulse toggles the JK flip-flop output (MODE CONTROL) high for one clock period. While the MODE CONTROL is high the falling edge of the next clock pulse transfers the 16 bits from the computer output register into the shift register. The falling edge of the JK flip-flop output triggers the 10 µ sec one shot which sends a "SYNC" pulse to the computer. Upon receiving the sync pulse the computer drops the ready line, loads a new set of 16 bits into its output register and again raises the ready line in less than 10 µ sec.

The falling edge of each clock pulse triggers both the 1.0 µ sec and the 0.2 µ sec one shots and shifts the next bit to the shift register output and into the pulse selector. If a "0" is on the register output the 0.2 µ sec pulse is passed to the modulator and if a "1" is on the register output a 1.0 µ sec pulse is passed to the modulator. Thus, the digital lamp control words are transmitted as a series of short and wide pulses, "0's" and "1's", into the model car via the transmitting and receiving antennas.

The output of the receiver (Figure 16) is a replica of the pulses applied to the modulator. The leading edge of each pulse, wide or narrow, triggers the 0.75 µ sec one shot thus regener-

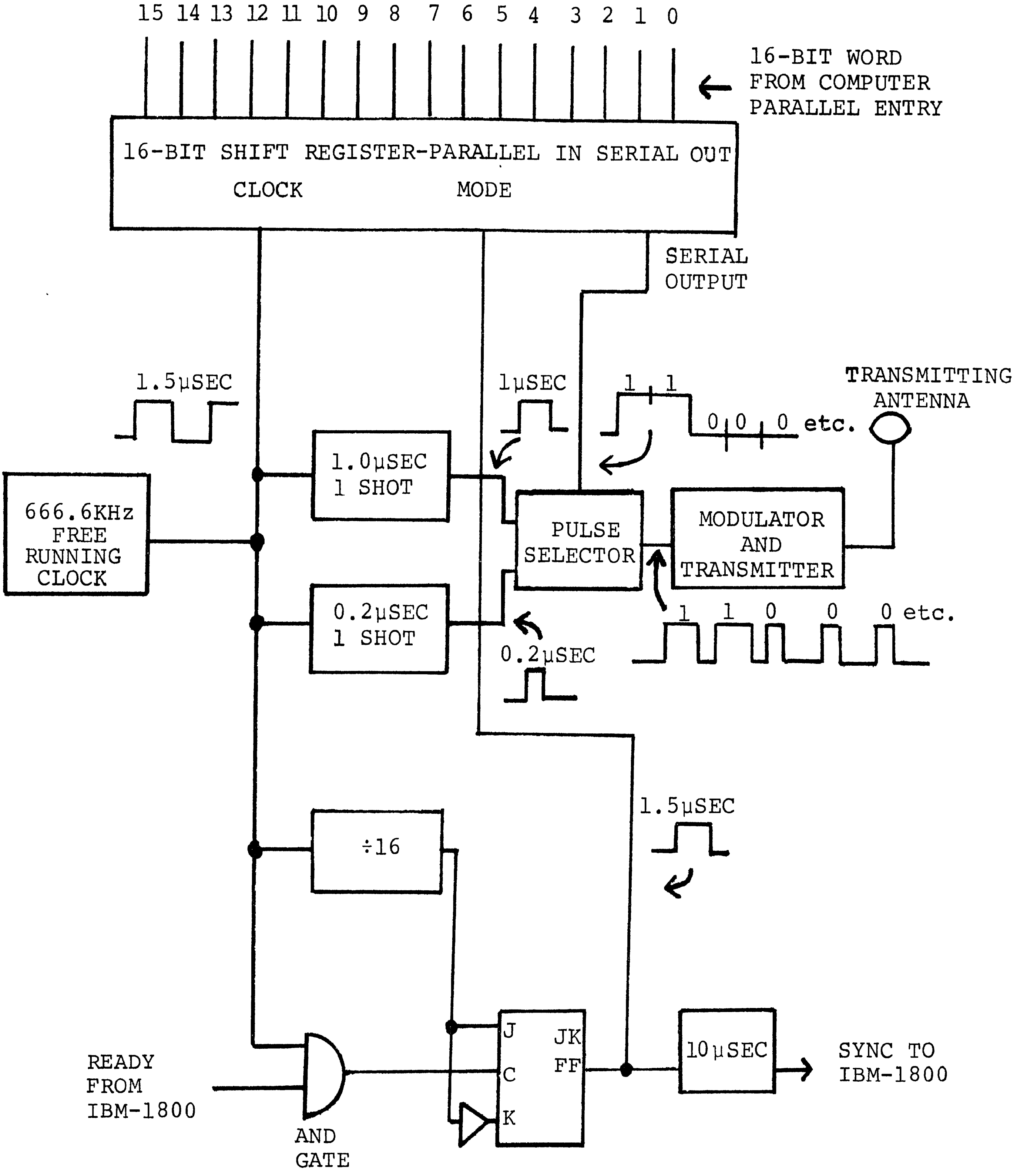

Figure 15. Simplified block diagram of lamp control modulator/transmitter.

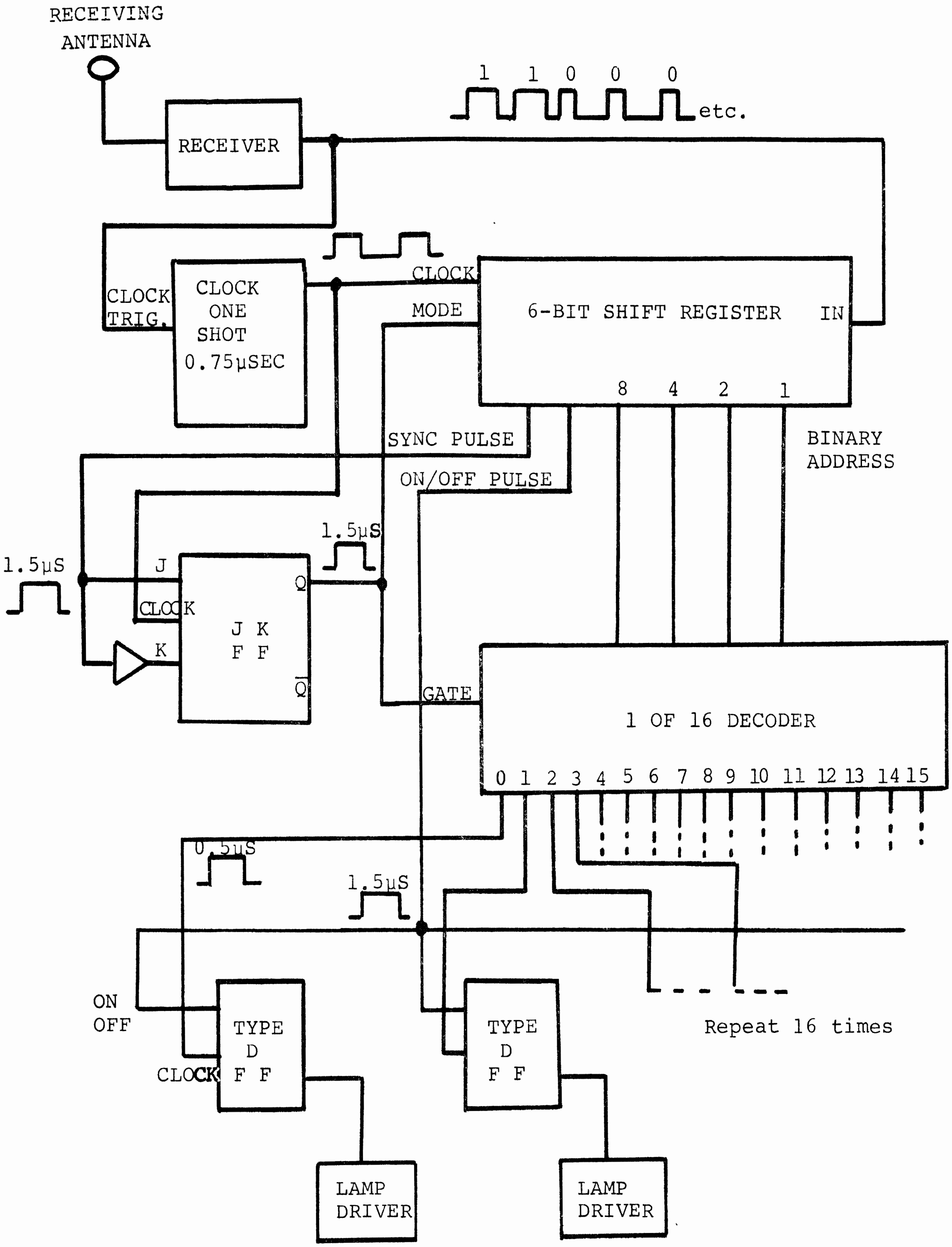

Figure 16. Simplified block diagram of lamp control receiver decoder.

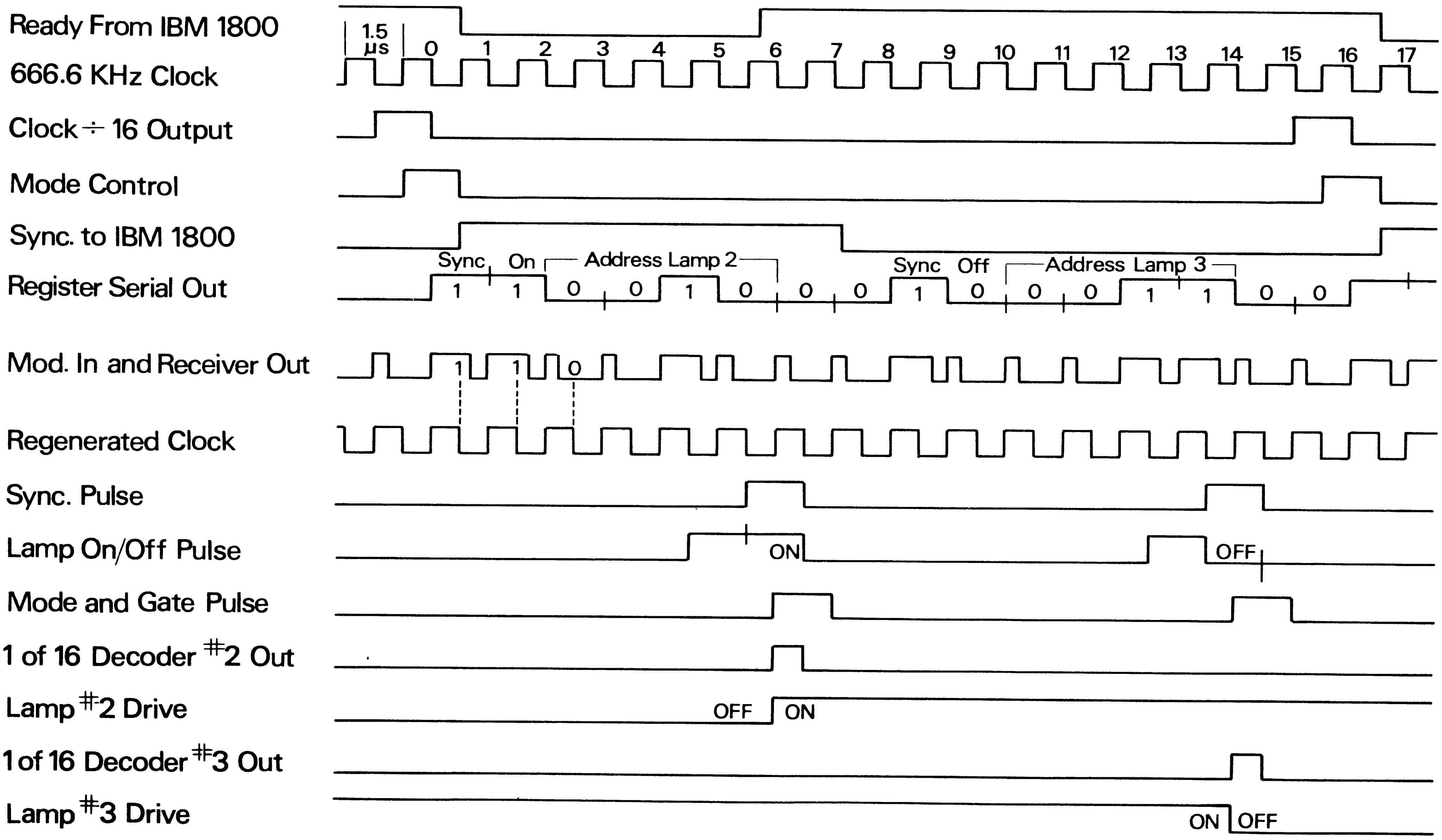

Figure 17. Lamp control system timing diagram.

ating the clock in the model car circuit. The voltage level at the shift register input coincident with the falling edge of each clock pulse is high "1" for a wide pulse and low "0" for a narrow pulse. Thus, the required "1's" and "0's" shift into the shift register on the falling edge of the clock pulses. When the SYNC pulse, the first bit of the 8-bit word, enters the sixth bit position in the register the BCD lamp address is in the first 4-bit positions which are connected to the 1 of 16 decoder inputs, and the ON/OFF bit is in the fifth bit position of the shift register and connected to the D input of all 16 Type D flip-flops. With the SYNC pulse and inverted SYNC pulse on the J and K inputs of the JK flip-flop the rising edge of the next clock pulse sets the output of the JK flip-flop high. The JK output gates the 1 of 16 decoder output and the line addressed goes high applying a pulse to the clock input of the corresponding Type D flip-flop, thus transferring the ON/OFF command at the D input to the output and then to the lamp driver of the lamp addressed. The JK output also is applied to the MODE input of the shift register and the falling edge of the next clock pulse clears the shift register. With the SYNC pulse line returned to low, or "0", the rising edge of the next clock pulse resets the JK flip-flop output low and the decoder is ready to start receiving the next 8-bit word. Words transfer through the decoder in 12 μ sec per word. Thus, all 16 lamps are addressed once during each 192 μ sec period.

PART II: SIMULATOR VALIDATION STUDIES

An important consideration affecting the usefulness of a simulation procedure is to determine how well data obtained using such a device would provide the same or comparable information as obtained in the operational situation which is being simulated. Although many part-task driving simulators and aircraft simulators have been constructed there has been practically no effort made to attempt to validate these testing devices. This is due to a number of reasons. Sometimes it is too expensive to conduct the operational test for the purpose of obtaining the performance measurements, and on other occasions it is impossible to do so until the mission actually takes place, such as is true of the simulation of space flights. Even part-task driving simulators are difficult to validate because of the costs and complexity involved in conducting vehicular tests. However, this does not reduce the importance of attempting to obtain validating information.

The first studies using the HSRI rear lighting research simulator were aimed at gathering validation data. Since we have previously conducted a considerable amount of road testing of driver performance in the evaluation of various rear lighting displays, it was determined that two of these tests should be repeated using the simulator. In this way correspondence between the findings obtained in the road and simulator tests could be observed, and used to determine the extent to which similarities in results become available using the simulator.

EXPERIMENT I: EFFECT OF BINOCULAR AND MONOCULAR VIEWING ON CHANGE IN HEADWAY DETECTION

The first study that was carried out with the rear lighting research simulator was one to confirm theoretical considerations affecting the use of binocular and monocular vision in the simulator. It would be supposed that monocular vision should be used, since artificial cues to closure with a lead vehicle would be produced by the use of binocular vision in the simulation. This is because binocular vision provides binocular desparity cues at distances of less than about 50 ft (Woodworth and Schlosberg, 1954). Since most driving conditions involve car-following at greater than this distance, binocular cues would not be of great importance in actual car driving. However, the simulator has a maximum length of just over 50 ft and binocular cues could introduce stimuli, useful to headway estimation and change in headway detection, that would not be found in real driving.

METHOD

Subjects. Three subjects were used in this test each of whom had some previous experience in the simulator.

Procedure. A test program tape was made wherein a real car was driven at 54 mph and, at various time intervals, began to coast when the driver disengaged the cruise control and released the accelerator. A number of such trials were run and subsequently played back as the forcing function for the lead car on the simulator. A low ambient level daytime driving situation was simulated by turning on the overhead lights to full power, providing about 10 ft-candles of illumination on the roadway. The simulator trial began when both the following car and the lead car were traveling at 54 mph and the initial headway was set at either 150 ft or 300 ft. At some point in time the lead car would begin to coast, at the instant that the real car began to coast when the program tape was made. The subject's task was to detect the onset of coasting, and respond by depressing a switch with his right hand. Each subject received a total of 24 trials, half with the initial headway at 150 ft and the other half at

300 ft, and half were carried out with binocular vision and the other half with monocular vision.

RESULTS. The mean change in headway, that occurred prior to detection of coasting, at 150 ft and 300 ft, for binocular and monocular viewing was computed, and shown in Table 9. It will be noted that for binocular vision the values are the same for both the initial headway conditions, whereas in monocular viewing the change in headway is larger at the larger initial headway distance. The table also shows the values of ΔH/H for both conditions. This indicates that in monocular vision the driver's sensitivity and headway change detection remains fairly constant, whereas this is not true in binocular vision.

TABLE 9. Mean Change in Headway (ΔH) and ΔH/H as a Function of Initial Headway for Binocular and Monocular Viewing. Data for 3 Subjects.

Viewing Mode	ΔH		ΔH/H	
	150'	300'	150'	300'
Binocular	34'	35'	.22	.11
Monocular	33'	53'	.22	.18

CONCLUSIONS. The data show that the initial distance had no effect on coasting detection, as measured by the mean change in headway, when binocular vision was used. Previous field studies have shown (Mortimer, 1970, 1971b) that the change in headway prior to detection of coasting is a function of the initial headway at the start of coasting. The simulated distances of 150 ft and 300 ft, at 1/12 scale, represent 12.5 ft and 25 ft of real distance in which binocular cues would be of value, as found in the experiment. Monocular viewing produced different headway change distances at the 150 ft and 300 ft simulated initial headways, and similar values of the ratio ΔH/H, thus showing the behavior exhibited by drivers on the road.

Therefore, monocular viewing is the proper mode in the simulator. It is obtained quite simply by having the subject wear spectacles with an opaque glass covering the non-dominant eye, or an opaque attachment is placed over the non-dominant eye of subjects who wear spectacles for far vision.

EXPERIMENT II: THE DETECTABILITY OF STOP AND TURN SIGNALS AS A FUNCTION OF REAR LIGHTING SYSTEM CONFIGURATION

The first study was concerned with an evaluation of five rear lighting system configurations as measured by the driver's ability to detect stop and turn signals. The five rear lighting systems shown in Figure 18 were used. System 1 represents that which is current practice on U.S. automobiles and uses two red lamps, each of which provide presence (tail), stop and turn signals. In system 2, the red presence and turn lamps are separated from the red stop signal lamps. In system 3, complete functional separation is used, so that each signal is given by a separate red lamp. System 4 is identical to system 2 except that the presence and turn signals are given by a green-blue lamp and the stop signal by separate red lamps. System 5 uses complete functional separation and a different color for each signal, with presence lamps being green-blue, turn signal lamps being amber, and stop signal lamps being red. In all systems, the presence lamps were operated at a luminance of 0.25 candelas/sq in. and stop or turn signals at 3.22 candelas/sq in. These luminances would translate into intensities of 7 cd and 91 cd, respectively, for actual presence and signal lamps of 6 in. diameter, which is the lamp diameter that was scaled (1/12 scale, i.e., 1/2" dia.) for the lead car. The intensity ratio between signal and presence lamps is therefore about 13:1. These intensities are the same as were used in some previous road tests (Mortimer, 1970).

An instrumented test car was used to generate a test program tape by driving the vehicle on local roads, within the normal traffic stream, and recording on magnetic tape the speed of the vehicle, brake, and left and right turn signals. The signal modes used were: stop signal, left or right turn signal, stop signal followed by left or right turn signal, and left or right turn signal followed by stop signal. Each sequence, consisting of four

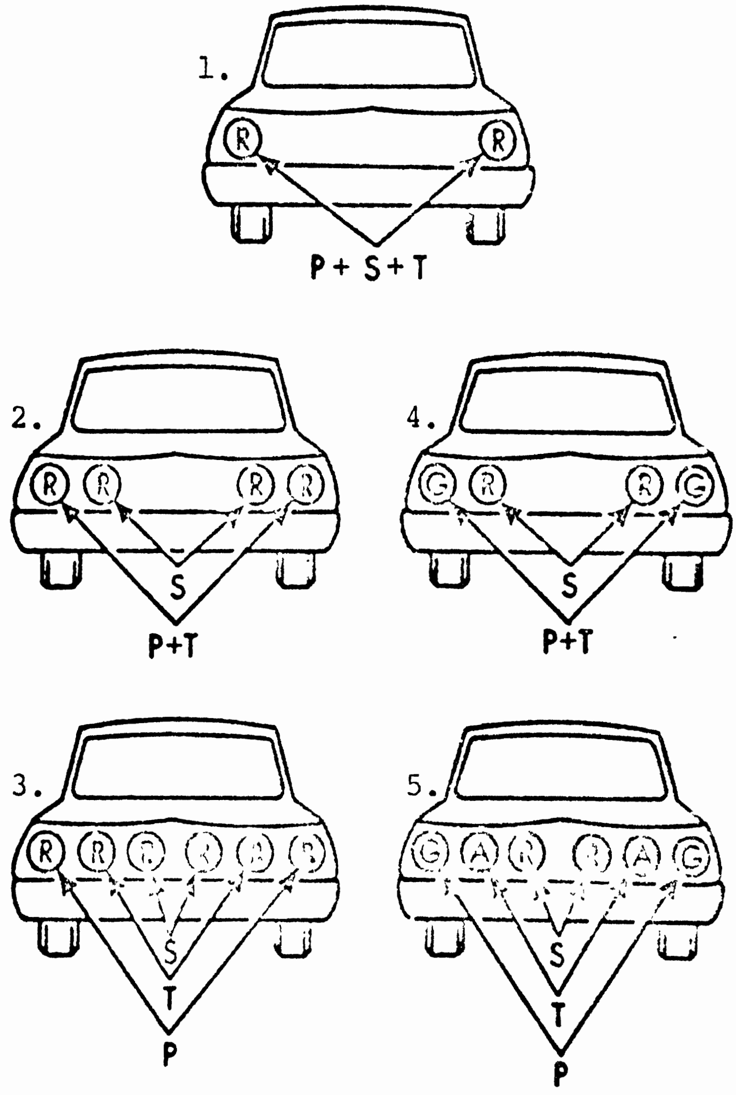

Figure 18. The lighting configurations. P=Presence (tail light), S=Stop, T=Turn, R=Red, A=Amber, G=Green-Blue.

signals of each type (for a total of 16 signals), required approximately ten minutes of driving time. Five such sequences were made up under these actual driving conditions. As already explained in Part I, this program tape is used to generate the inputs to the lead car to designate its velocity and the occurrence of the signals.

Each simulator trial was begun with the lead car positioned 150 ft (simulated) ahead of the subject's car, with both vehicles stationary. The lead vehicle then received a speed command from the tape forcing function and began to accelerate, just as the actual vehicle had done when the tape was made. The subject, who drove the "following car," was instructed to maintain a distance of about 150 ft behind the lead car throughout the test by modulating the speed of his vehicle by means of an accelerator and brake pedal, to fulfill this requirement as well as possible. Each subject was given one practice run in order to familiarize himself with this procedure using the conventional rear lighting system (system 1). By means of a two-way intercom, the experimenter was able to communicate with the subject, and periodically provide him with information concerning how well he was maintaining the 150 ft headway. This forced the subject to pay attention to this aspect of the driving task. The subject was also instructed to respond as quickly as possible to stop signals, by depressing a foot switch on which he continuously rested his left foot, and to left or right turn signals by depressing one of two hand-operated switches conveniently located at the front of the right arm rest.

INDEPENDENT VARIABLES. The variables of interest in this study were:

1. The lighting configurations: systems 1-5.
2. The signal modes: stop, turn, stop→turn, and turn→stop.

DEPENDENT VARIABLES. The measurements taken to evaluate the subject's performance were:

1. Reaction time to correctly identify the signals presented.
2. Missed signals.
3. Frequency of accelerator releases and brake applications.

RESULTS. Each reaction time, of the 18 subjects used in the experiment, was transformed to natural log form and an unweighted means analysis of variance carried out on these data. Significant differences were found ($p \leq .01$) for the main effect of the rear lighting system and the signal mode, and for the mode x system interaction.

The geometric mean response times to each of the four signal modes for each of the five signal systems used are shown in Table 10, which also indicates the corresponding data obtained in

TABLE 10. Geometric Mean Reaction Times for Each Signal Mode for Each System, in Simulator and Road Tests. Data for 18 Subjects.

Signal Mode	System									
	1		2		3		4		5	
	Sim.	Road	Sim.	Road	Sim.	Road	Sim.	Road	Sim.	Road
Stop	0.97	0.92	1.08	0.95	0.96	0.93	0.96	0.91	0.93	0.89
Turn	0.90	1.08	0.96	1.16	1.07	1.10	0.83	1.09	0.85	1.01
T→S*	1.44	0.99	1.01	0.87	0.00	0.92	0.86	0.81	0.85	0.81
S→T*	2.05	1.94	1.51	1.31	1.08	1.03	1.00	1.09	0.89	0.97
Mean	1.17	1.17	1.05	1.05	1.02	0.99	0.90	0.96	0.89	0.92

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*The reaction times shown are for the signal underlined.

the road tests. These data are also shown in Figure 19. It will be noted that there are some clear-cut differences between the response times obtained among the systems, particularly when a stop or turn signal is preceded by the other.

A Newman-Keuls test was conducted within each signal mode to show the existence of significant differences between rear lighting signal systems. Table 11 shows the results of these tests for the simulator and the road experiments. It will be noted that no significant differences were found in the simulator between systems on the stop signal, whereas system 5 had a lower response time than system 2 in the road test. For the turn signal systems 4 and 5 had lower response times than system 3 in the simulator,

TABLE 11. Newman-Keuls Test on the Geometric Mean Reaction Times to Signal in Each Signal Mode for Each System, in Simulator and Road Tests. Data for 18 Subjects.

Mode	Simulator		Road	
	Mean RT For System	Sig.* Less Than System	Mean RT For System	Sig. Less Than System
In, Stop Mode	No Sig. Differences		5	2
Turn Mode	4, 5	3	5	4,3,2,1
$T \rightarrow \underline{S}$** Mode	5,4,3,2	1	5,4,2	3,1
			5,4	2
$S \rightarrow \underline{T}$** Mode	5,4,3,2	1	5,4,3,2	1
	5,4,3	2	5,4,3	2
			5	4,3

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*$p \leq .01$

**The comparison is for the mean response time of the signal underlined.

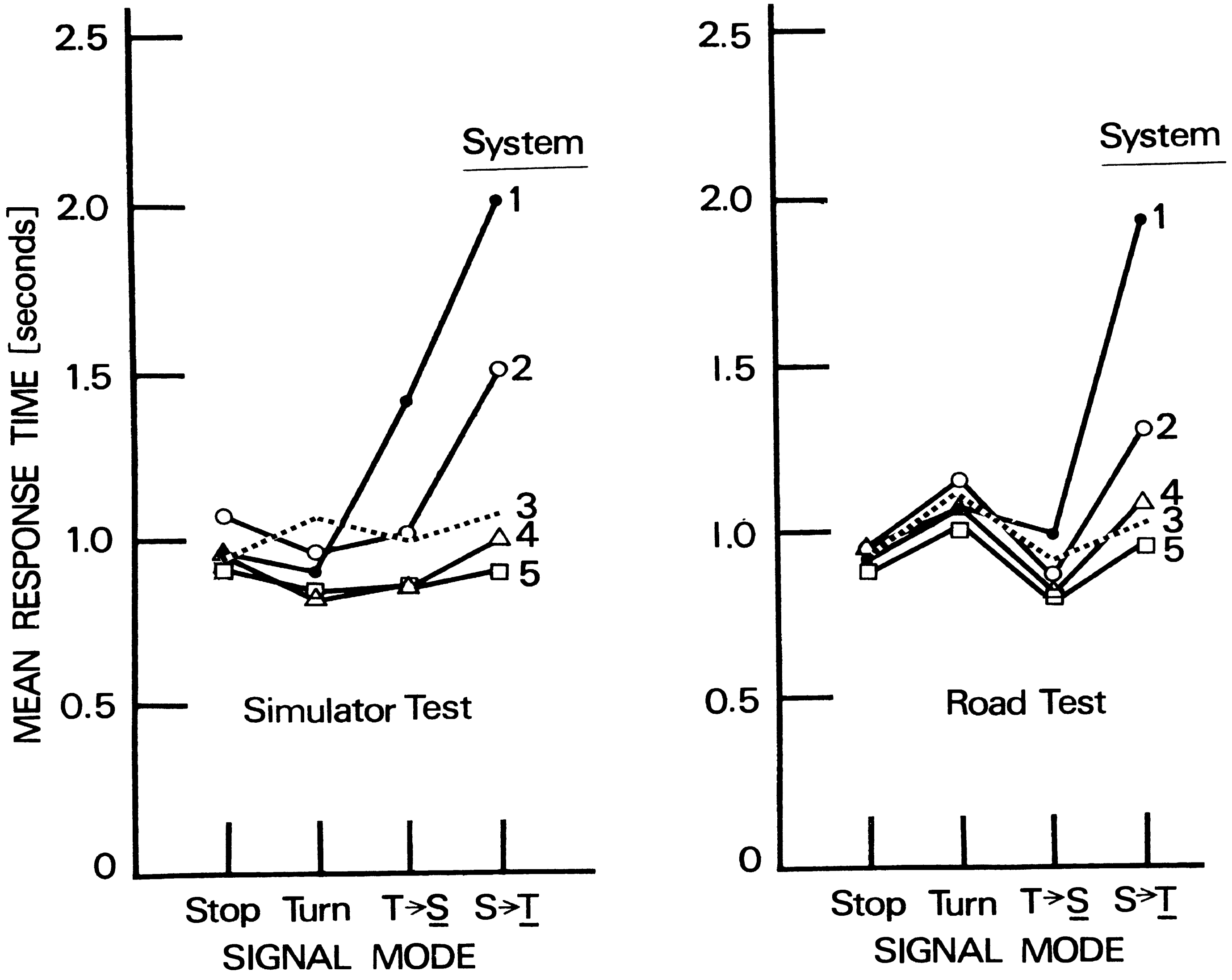

Figure 19. Mean response time to signals for each system, in simulator and road tests. (T→S, S→T denotes turn followed by stop and vice versa, with the response time being that for the second signal.)

whereas system 5 had lower response times than the other systems in the road test. The response times to the stop signal when it was preceded by a turn signal were found to be significantly lower for systems 5, 4, 3 and 2 than system 1 in the simulator, whereas in the road test systems 5, 4 and 2 had lower response times than 3 and 1, and systems 5 and 4 had lower response times than system 2. The analysis of the data for the case where the turn signal response time was measured when it was preceded by a stop signal showed, for the simulator, that systems 5, 4, 3 and 2 had significantly shorter response times than system 1, and 5, 4, 3 than system 2; whereas in the field test systems 5, 4, 3 and 2 had significantly shorter response times than system 1, systems 5, 4 and 3 than system 2, and system 5 than 4 and 3.

Table 10 also shows the overall mean response times to each system, across the signal modes, for the simulator and road experiments, showing that there is a very close correspondence between the values obtained.

Another way of looking at the findings is to show the rank orders of the mean response times in each of the signal modes for each system for the simulator and road tests. These data are shown in Table 12. Correspondence between simulator and road

TABLE 12. Rank Orders of Mean Response Times in Each Signal Mode for Each System, in Simulator and Road Tests.

Signal Mode	System									
	1		2		3		4		5	
	Sim.	Road	Sim.	Road	Sim.	Road	Sim.	Road	Sim.	Road
Stop	4	3	5	5	2	4	2	2	1	1
Turn	3	2	4	5	5	4	1	3	2	1
$T\rightarrow\underline{S}$ *	5	5	4	3	3	4	2	2	1	1
$S\rightarrow\underline{T}$ *	5	5	4	4	3	2	2	3	1	1
Mean	5	5	4	4	3	3	2	2	1	1

---

*The rank order is based on the mean response time of the signal underlined.

tests would be indicated by similar rank order values for the corresponding cells in the table.

Since there were only 6 signals missed in the whole experiment, no further analyses were made with those data.

The mean frequency of accelerator releases and brake applications per run for each system are shown in Table 13. This indicates slightly fewer accelerator releases on system 1 than the others, with the most frequent accelerator releases occurring on system 5. Brake application frequencies were essentially the same for all systems.

TABLE 13. Mean Accelerator Release and Brake Application Frequencies for Each System.

Control Mode	System				
	1	2	3	4	5
Accel. Release	27	30	31	29	34
Brake Application	11	12	12	11	12

DISCUSSION. The findings of the simulator study can be seen to be quite similar to those in the road test. The mean reaction times to the five systems are ranked, overall, the same in both the simulator and road tests. There is also a good deal of similarity among the comparisons within each of the signal modes in each system. The simulator study showed that the current system (system 1) was considerably less effective than some of the experimental systems in the response times to a stop signal when preceded by a turn signal and the converse case when the turn signal is preceded by a stop signal. The concept of system 2, involving the separation of stop lamps from combined presence and turn lamp, yielded some advantage particularly in the dual mode signals compared to system 1. Thus, this relatively simple change in the rear lighting display would appear to result in some benefits in terms of driver performance. The data of both studies again show that the greatest gain will be obtained by a separation of function and the use of color coding, as demonstrated by the generally superior performance of systems 4 and 5 in both the simulator and the field tests.

EXPERIMENT III: THE EFFECT OF PRESENCE LAMP ARRAYS ON HEADWAY CHANGE DETECTION

The purpose of this study was to measure the sensitivity of subjects in the simulator in their ability to detect changes in headway distance of a vehicle they are following. In addition, the effects of two presence lamp arrays were evaluated. This procedure is a replication of an earlier road study (Mortimer, 1970) in which headway change detection was measured for a number of different rear lighting arrays, in night driving.

METHOD.

Subjects. Thirteen male and female subjects, each holding a valid driver's license, were used in this study. They all had some previous exposure on the simulator.

Procedure. A test program tape was made by driving an actual vehicle on an expressway at two speeds, 54 mph and 74 mph. The vehicle was driven at one of these speeds, using a cruise control, for a period of not less than half a minute nor more than one and a half minutes before the cruise control was disengaged and the vehicle allowed to coast down for about 15 seconds before the speed was resumed. Four runs of this type were made at each speed before changing to the other speed at which four similar runs were made. A number of sections of tape, each containing eight runs of this type involving coasting down from 54 and 74 mph, were made. Between each of the sections of eight trials, the test vehicle came to rest for about two minutes.

This tape was then used as the input to the lead car in the simulator test. In the simulator, each session began by accelerating the lead car and the subject's car to the desired initial speed, as obtained from the program tape, and then holding that speed constant at the predetermined headway distance. After a random interval of 30-90 seconds the lead car began to coast, at the time that coasting occurred when the program tape was made. In the simulator two initial headways were used in this test, 150 ft and 300 ft. The subject did not have control of the accelerator or brake pedals. The headways were set up by the experimenter controlling the speed of the following car until the desired spacing was obtained. At that instant both the lead vehicle and the following vehicle were traveling at the same speed. The task of the subject was to depress a switch as soon as he could detect that the lead vehicle had begun to coast. The reduction in headway which occurred, from the start of coasting to the instant the subject detected it, was measured. The lead car was then accelerated up to the speed to be used in the next trial and set at the appropriate headway, and the procedure repeated. In two of the sessions the rear lighting consisted of two presence lamps and in the other two sessions four presence lamps were used on the lead car as shown in Figure 20.

Independent Variables. Three independent variables were used in this test, as mentioned above:

1. Presence lamp array: two-lamp, four-lamp.
2. Initial headway at start of coasting: 150 ft, 300 ft.
3. Initial velocity at start of coasting: 54 mph, 74 mph.

Dependent Variable. The dependent variable was the change in headway which occurred prior to the detection of coasting.

RESULTS. For each subject there were four runs, each consisting of eight coasting events, four at 54 mph and four at 74 mph initial velocity. Half the trials at each speed commenced

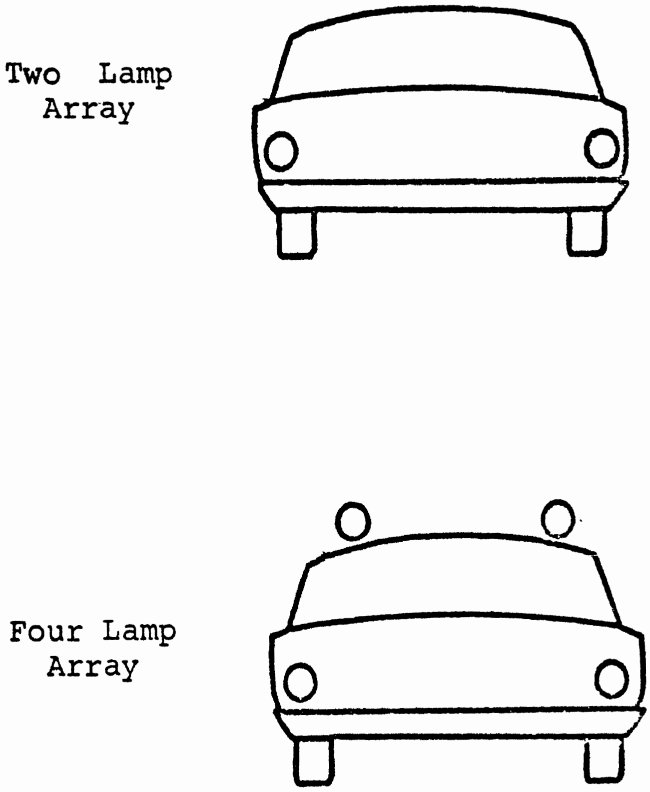

Figure 20. The presence lamp arrays used in the simulator (Experiment III) and road tests of headway change detection.

at an initial headway of 150 ft and the other half at 300 ft. Thus, each subject made 32 judgments of the onset of coasting during this experiment. An analysis of variance on the headway change data showed that the main effects of the initial headway and the lighting array were significant ($p \leq .01$).

Table 14 shows the coasting detection thresholds both in absolute terms (ΔH) and as a proportion of the initial headways ($\Delta H/H$).

TABLE 14. Minimum Detectable Headway Change, in Scale Feet (ΔH) and as a Proportion of Initial Headway ($\Delta H/H$), for Each Array, Initial Velocity, and Initial Headway. Data for 13 Subjects.

	ΔH	$\Delta H/H$
Initial Headway (scale feet)		
150	13.59	.0906
300	26.34	.0878
Initial Velocity (scale mph)		
54	18.44	.0815
74	21.50	.0970
Array Type (number of lamps)		
2	22.71	.1004
4	17.22	.0781

DISCUSSION. The ratio, $\Delta H/H$, provides a measure of the driver's sensitivity in detecting coasting or closure with a vehicle ahead of him. These values, shown in Figure 21, are fairly consistent within each lamp array, indicating that drivers can detect closure with another vehicle when the just noticeable change in the headway reaches a fixed proportion of the initial headway. A road test, not concerned with presence lamp arrays,

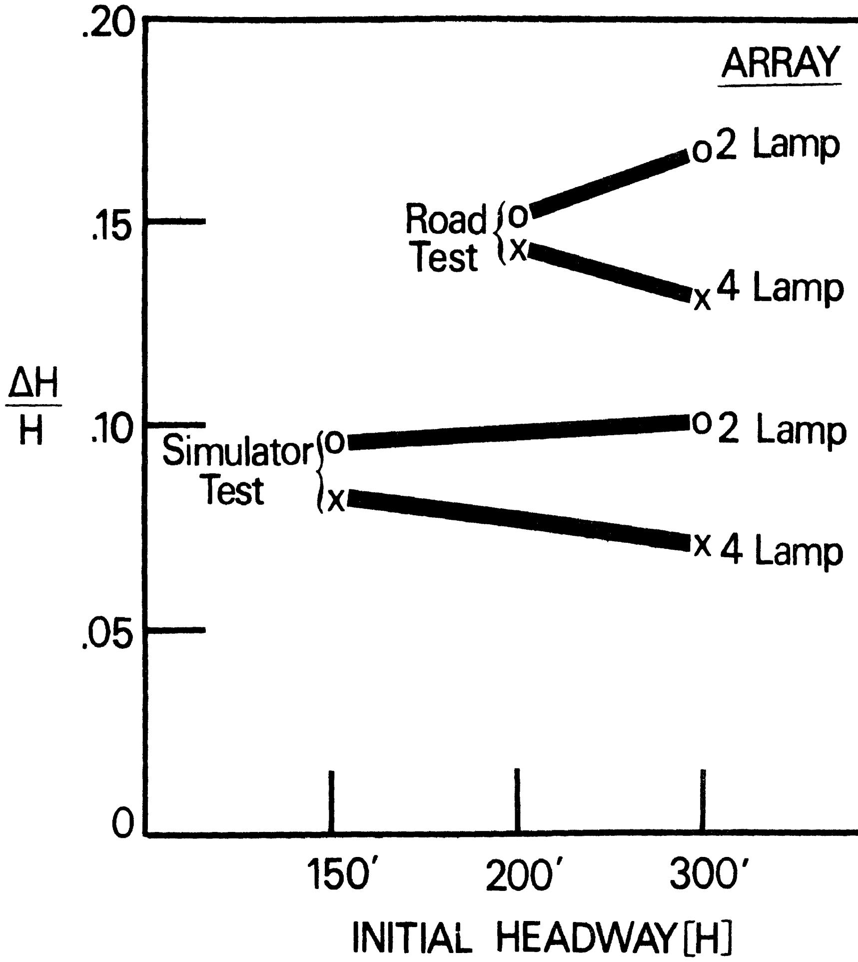

Figure 21. Weber ratios for detecting headway change for two- and four-lamp arrays, in simulator and road studies.

found a median value of 0.12 for this ratio (Mortimer, 1971b) at night and in daytime. The simulator provided greater driver sensitivity, with ratios of about 0.10 for the two-lamp array than the value of 0.12 reported above or the value of about 0.16 for the two-lamp array in the road tests shown in Figure 21. This could be expected because the simulator does not involve steering, whereas the drivers in the road tests not only steered the vehicle but also had to carry out a demanding side-task. If a side-task had been introduced in the simulator it is possible that the detection sensitivity would have decreased, thereby raising the values of $\Delta H/H$ in the simulator test closer to those found in the road test.

The important comparison for the purpose of validating the simulator lies in the differences found between the lamp arrays. Both the road study and the simulator study found that the four-lamp array provided better driver sensitivity, as shown by lower $\Delta H/H$ values. There also appears to be a trend in both studies that the four-lamp array provides a somewhat greater benefit at 300 ft than 100 ft in the simulator and at 300 ft than 200 ft in the road test. This suggests that, as the visual angles subtended by the lamps in a two-lamp array become small, there is a particular benefit to be derived from adding two additional lamps in the vertical to give an increase in the overall visual angle subtended at the following driver's eye.

Overall, the four-lamp array offered about a 20% improvement in sensitivity in detection of headway change compared to the two-lamp array in the simulator, and about 13% in the field test, for comparable initial headways.

CONCLUSIONS

Both experiments II and III have found quite similar results to those attained in field tests conducted previously. The second study was concerned with the detectability of signals given by rear lighting systems, and it was found that basically the same conclusions would be reached using the simulator data as using the road test data. This is encouraging not only because of the similarity in results but also because only 18 subjects were used in the simulator compared with 40 subjects in the road test, which was a lengthy and much more costly test to run.

In the third study, a measure related to car-following performance was used and it was found that quite similar results again were obtained in the evaluation of the presence lamp arrays, and the same model was applicable to describe the manner in which coasting was detected. Both the simulator and the field test data were sufficiently sensitive to reveal differences in the performance with the interpretation from both studies leading to the same conclusion. Since the overall sensitivity of the subjects in the simulator test was greater than in the road test, it would suggest that in future tests a side-task be used to provide additional perceptual loading on the subjects in the simulator to give similar levels of sensitivity as were found in the driving tests.

Some further corroborative data for the fidelity of the simulation was obtained in the initial pilot study concerned with monocular and binocular vision, by showing that monocular vision provides appropriate results in the simulator, as was theoretically expected.

Thus, the studies that have been described suggest quite strongly that the simulator should generate data which are transferable to the road test situation for studies involving driver response in detecting and interpreting signals of rear lighting systems and in measurements of car-following performance. Since these are the important behavioral data which it was intended the simulator should be capable of obtaining and from which interpretations of the effectiveness of driver performance could be made, it appears that a useful device has been developed for use in rear lighting systems research and for other studies in car-following under dynamic conditions.

OTHER RESEARCH APPLICATIONS

The studies that have been reported in the preceding sections were concerned with providing information of the validity of the device, in terms of generalizing the data from the simulation to actual driving situations. The simulator will be used for additional studies directed at evaluating desirable aspects of vehicle rear lighting and signaling systems.

Some of these studies will be concerned with utilizing the simulator as a means of obtaining information concerning the driver's behavior in car-following or in the less tightly coupled situation wherein a driver is approaching another vehicle from the rear at some large distance, before car-following can be said to be taking place. In both of these situations it is important to learn more about the driver's response, particularly to changes in rear lighting systems. An obvious advantage of the simulation approach is that accident-producing situations can be evaluated, which is difficult if not impossible to do with actual vehicles. Since this is the thrust of the safety-related research in vehicle marking and signaling it is evident that the simulator offers an opportunity for providing important data.

The simulator will also have a capability of providing information of the microscopic behavior of drivers in these kinds of situations for use in the development of computer simulation models, which can then be used as alternative means of evaluating the likely collision reduction of different marking and signaling systems.

A considerable body of knowledge is lacking concerned with fundamental aspects of driver behavior, such as headway and relative velocity judgments, and the manner in which drivers respond to different relationships of these two variables and the occurrence of signals on a vehicle ahead of them. If such behavior can be measured it can be introduced in a mathematical model, as indicated above, for systems evaluation.

Apart from the evaluation of the information required by drivers to safely perform car-following tasks or those in which relative velocities between vehicles exist, it may also be possible to evaluate the effectiveness of semi-automatic or automatic systems that may be suggested to aid the driver. One potential system is that involving a "radar brake," which could be used in a semi-automatic mode to indicate status on a display within the vehicle to a following driver or to automatically regulate the speed of a following vehicle by modulating the accelerator or brakes. Numerous questions concerning the application of such systems readily become apparent as they relate to the driver's behavior and their overall effectiveness in reducing collisions.

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