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HEADWAY SEPARATION ASSURANCE SUBSYSTEM (HSAS)

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FINAL REPORT

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16. Abstract

The design, fabrication, test and evaluation of a Headway Separation Assurance Subsystem (HSAS) operated at 8-1/3 seconds headway on a 9-3/4 mph guideway is presented. Included hardware and software packages are applicable, with minimum modification, to any PRT system, allowing economical full scale installation.

System design studies and guideway tests show the HSAS capability of operation at 2-1/2 seconds headway on a 30 mph guideway.

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PREFACE

A development program was conducted by Alden Self-Transit Systems Corporation in which the Alden Headway Separation Assurance Subsystem (HSAS) was designed, tested, and evaluated on an operating prototype Personal Rapid Transit (PRT) system at the company test track at Bedford, Massachusetts. The end results were a HSAS capable of operation at 2-1/2 seconds headway on a 30 mph guideway, and the production of prototype equipment which advanced the component/subsystem base available for improved overall operation of PRT systems.

CONTENTS

CONTENTS (CONT'D)

CONTENTS (CONT'D)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF TABLES

GLOSSARY OF ABBREVIATIONS

CCIU (Control Computer Interface Unit: An interface to both the Control Computer and the Headway/Safety Computer whose primary functions are:

1. Generation of Track Timing
2. Generation of LGU Chain Control Signals
3. Interfacing of Control Signals and Data Returns to/from LGU Chains
4. Storage of Track Data in Memory for use by both Control and Headway/Safety Computers.

HLU (Headway Logic Unit): The portion of the CCIU which verifies vehicle position. In addition, it monitors total vehicle system count to protect against beacon failure, recognizes LGU counter/interface circuit failures, and monitors merge points to determine possible collisions.

HSAS (Headway Separation Assurance Subsystem): The total hardware and software required to continuously monitor the position of all vehicles on the guideway, immediately recognize any headway violation, and effect appropriate action to maintain safe vehicle operation. It includes the CCIU, all LGUs, and associated track hardware and interface circuits. The HSAS operates independently from the control computer.

LGU (Local Guideway Unit): A wayside signal conditioning and data acquisition unit, consisting of a local logic unit, receiver, selector switch, and loops attached to the switch. An LGU covers a length of track equal to the headway distance, so that only one car will be in the range of a given unit at a given time.

SSM (System State Map): A uniform data structure which describes the present and future status of guideway (both mainline and in station) and vehicles. The SSM weaves into a single unified whole most of the information needed to control a transit system.

1. HEADWAY SEPARATION ASSURANCE SUBSYSTEM (HSAS)

1.1 SUMMARY

This report discusses the design, fabrication, test and evaluation of a Headway Separation Assurance Subsystem (HSAS) capable of reliable, failsafe performance in PRT systems. The items designed included both hardware and software packages. These packages are applicable, with minimum modification, to any PRT system, and are designed to allow economical full-scale installation. Supported by an "in-place" prototype control system, the demonstrations and tests took place on the Alden test track, where the interactions of the HSAS with vehicles, control computers and vehicle guideways were evaluated. Tests were performed at 9-3/4 mph with 8-1/3 seconds headway. The system design studies, as considered in an interim report (Reference 1), and the tests performed at the track show that the HSAS has the capability of operating at 2-1/2 seconds headway on a 30 mph guideway.

1.1.1 Basic Concept

The HSAS is based on the use of an onboard transmitter inductively coupled to position sensing pickup loops located on the guideway (Figure 1-1). To minimize the cost of the wayside signal conditioning and data acquisition equipment, several loops are connected through a selector switch to a single receiver and local logic unit. A sampling technique is then used to examine each loop for vehicle presence.

The combination of a local logic unit, receiver, selector switch, and the loops attached to the switch are referred to as a local guideway unit (LGU). The LGUs cover a length of track equal to the headway distance, so that only one car will be in range of a given unit at a given time. Each unit contains a phaselock receiver which locks onto the loop excited by the transmitter beacon. The location of the locked-on loop is stored. When the cars are due on the centers of the loops, the Headway Logic Unit requests the locations of the locked-on loops. They are read, through the Interface, into the Headway Data Memory. It stores the locations of all of the locked-on loops and serves as a communications link between the Local Control Computer and the Headway Logic Unit (HLU). If the car is not within the proper loop

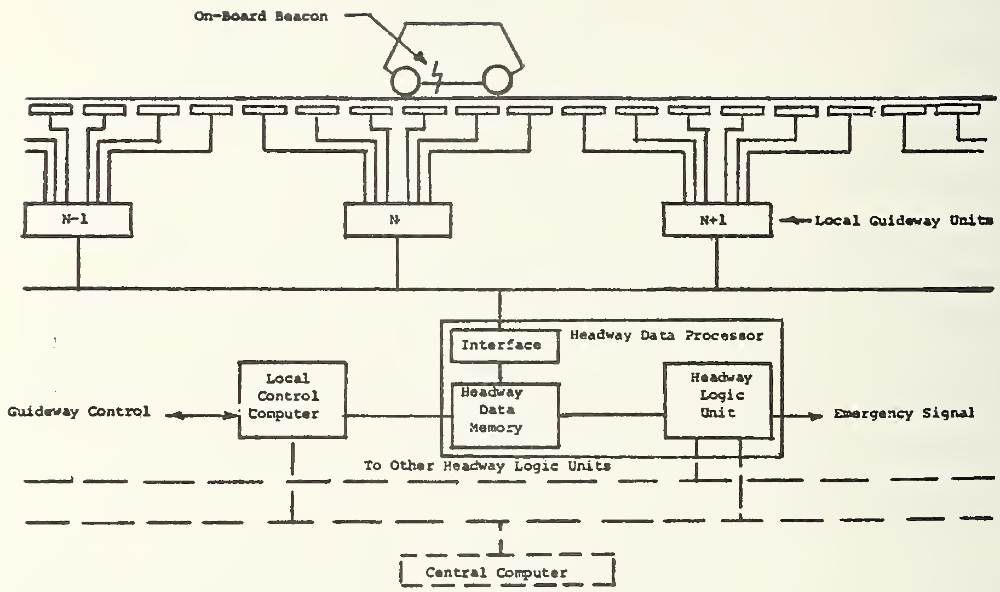


Figure 1-1. Headway Separation Assurance Subsystem

(in a synchronous system), an emergency is indicated. An asynchronous system would require additional HSAS software to determine vehicle separations for evaluation of emergency conditions. Since a car must be within the loop to be considered safe, the loop length defines the allowable position tolerance. Data are read out of the Headway Data Memory by the Local Control Computer.

The Local Computer is responsible for the actual control of the car. This computer is the highest level of control on the test track. A larger system would have a central computer responsible for dispatching, managing empty cars, etc., and each Local Control Computer and Headway Logic Unit would be responsible for only one section of the guideway.

1.1.2 Design Studies

A computer program was developed and used to design the HSAS system for the Alden test track. It was used to determine the safe relationships among speed, loop length, headway, and system parameters. The program considers:

1. Acceleration and deceleration transitions;
2. Unexpected stop and overspeed hazards;
3. Periodic initial position deviation from nominal trajectory; and
4. Velocity transitions of arbitrary (non-trapezoidal) shape.

The critical hazard on the main guideway was found to be unexpected stop of a preceding car; on a station entry deceleration ramp it was overspeed of a following car. It was also observed that deceleration ramp headways were much more sensitive to system parameters than the main guideway headways.

1.1.3 Test Results

All LGUs were bench tested prior to installation at the test track to determine that all components performed as designed. Tests performed at the track revealed:

1. The HSAS was not susceptible to malfunction from electrical noise although more protection against high voltage transients is required.

2. Tracking was not continuous through all loops. (This difficulty was not due to HSAS logical design but due to loop and test track hardware problems.)

3. Typical Lock/Unlock intervals of 0.3 to 2.0 msec.

4. Beam widths less than 0.6 feet.

5. Vehicle controllability to be equal to that used in headway calculations (with modification to deceleration ramp timing).

6. Sufficiently short response time of HSAS to conditions of overspeed, underspeed, and beacon failure, for safe system shutdown.

2. SYSTEM DESIGN

2.1 DERIVATION OF THE CONCEPT

Automated transit systems require close spacing between vehicles to provide high guideway throughput (capacity). In particular, this requirement for close vehicle spacing leads to the companion requirement for a reliable, failsafe, Headway Separation Assurance Subsystem (HSAS). This system should continuously monitor the position of all vehicles on the guideway in order that any headway violation may be immediately recognized and the appropriate action taken to maintain safe operations.

Reviewed now are:

1. HSAS Requirements
2. Background in HSAS Development
3. Synchronous System Operation
   - Synchronous Addressing
   - Loop Multiplexing
4. Incorporating Communications
5. Extension to Asynchronous Operation

2.1.1 HSAS Requirements

The HSAS requires that all cars have an onboard active transmitter (beacon), whose signals are inductively coupled to short receiving loops arrayed along the edge of the guideway. The position of those loops receiving signals is monitored by local guideway units and the information is delivered to a headway data processor to determine if the track is safe.

The HSAS must operate independently from the control computer, and should protect against overspeed or unexpected stop emergencies, on both the main guideway and acceleration/deceleration ramps. Other conditions which it must monitor in order to initiate emergency shutdown are:

1. Lost Car -- More/fewer vehicles in system than expected.
2. Transmitter Out -- Vehicle transmitter malfunction
3. Return of unreliable data from LGUs
4. Merge Violation -- Collision imminent at merge point (track location where acceleration
5. Control Computer Inoperative -- Control computer not answering.

Other functions which the HSAS must perform are:

1. Switch Position Verifications
2. Launch Inhibit -- Prohibit launches into the system at times in which it might be unsafe.

The HSAS must be capable of reliable, failsafe performance of the aforementioned operations in PRT systems operating at 30 mph with 2.5 seconds headway.

2.1.2 Alden Background

Alden's original concept for an HSAS involved no active elements onboard the vehicle. Instead, a figure-eight pickup loop in the guideway surface was inductively coupled to a transmitting antenna mounted along the guideway wall. The loop was so arranged that in the absence of a vehicle, the voltages induced in the two halves of the loop were of equal magnitude and 180 degrees out of phase causing zero voltage to appear at the loop terminals. However, a vehicle traversing the loop would cause an imbalance in the coupling from the antenna to the loop and a voltage would appear at the loop terminals indicating vehicle presence.

This system was installed and tested at the Alden test track. It was found that although the system could be made to work as conceived, it was very "site sensitive" and considerable effort had to be spent in installing and adjusting the loops.

To reduce this sensitivity, it was decided to put the active antenna onboard the vehicle with no change in the other system components. Adequate performance was obtained, but the procedure for detecting headway violations, which involved detecting vehicle presence in supposedly unoccupied loops, did not protect against onboard transmitter failure. More positive tracking schemes were developed and implemented in computer software which required that the actual position of each vehicle be monitored and compared with its commanded trajectory. Beacon failure could then be detected when the vehicle "disappeared" from surveillance.

Although the method was adequate for an installation the size of the test track, the limitations placed on the system by computer response time (and the cost of handling the loops individually) seriously increased the attainable headways.

The HSAS described in this report overcomes these limitations by locating the tracking function on the guideway (Local Guideway Units) and by making extensive use of multiplexing to reduce system costs.

2.1.3 Synchronous System Operation

The pacing subsystem in the Alden PRT development has been the control and communication subsystem which includes elements on the vehicle, guideway, in the stations, and at a central control complex. Alden has chosen to base this system on a synchronous control law, using point-follower vehicle control for ease of implementation.

Conceptually a synchronous vehicle control system may be regarded as a set of slots, circulating around a guideway, into which a vehicle may be inserted and carried from origin to destination as shown in Figure 2-1. The vehicle slots circulate continuously on the guideway, always separated by the headway time interval. Since headway is fixed throughout the system, the distance between slots is proportional to the velocity. Thus in the constant velocity zone (B), slots are evenly spaced, but farther apart than they are in zone (A), where the speed is lower. In transition zones, such as entering or leaving a station, the space between slots is constantly changing.

A car operating on the test track's synchronous guideway will follow a fixed trajectory from one station to the other by following a computer-generated point which moves with one of the slots. The headway protection system as installed on the Alden test track is thus simply implemented. It merely determines when a car deviates too far from its fixed trajectory. There must be sufficient headway between trajectories to discover a car out of position, in the worst case, and bring cars to an emergency stop without colliding. What is sufficient depends on the parameters of the whole system, such as guideway speed, allowable accelerations and control accuracies and on the parameters of the headway protection system, such as time delay and position measurement resolution.

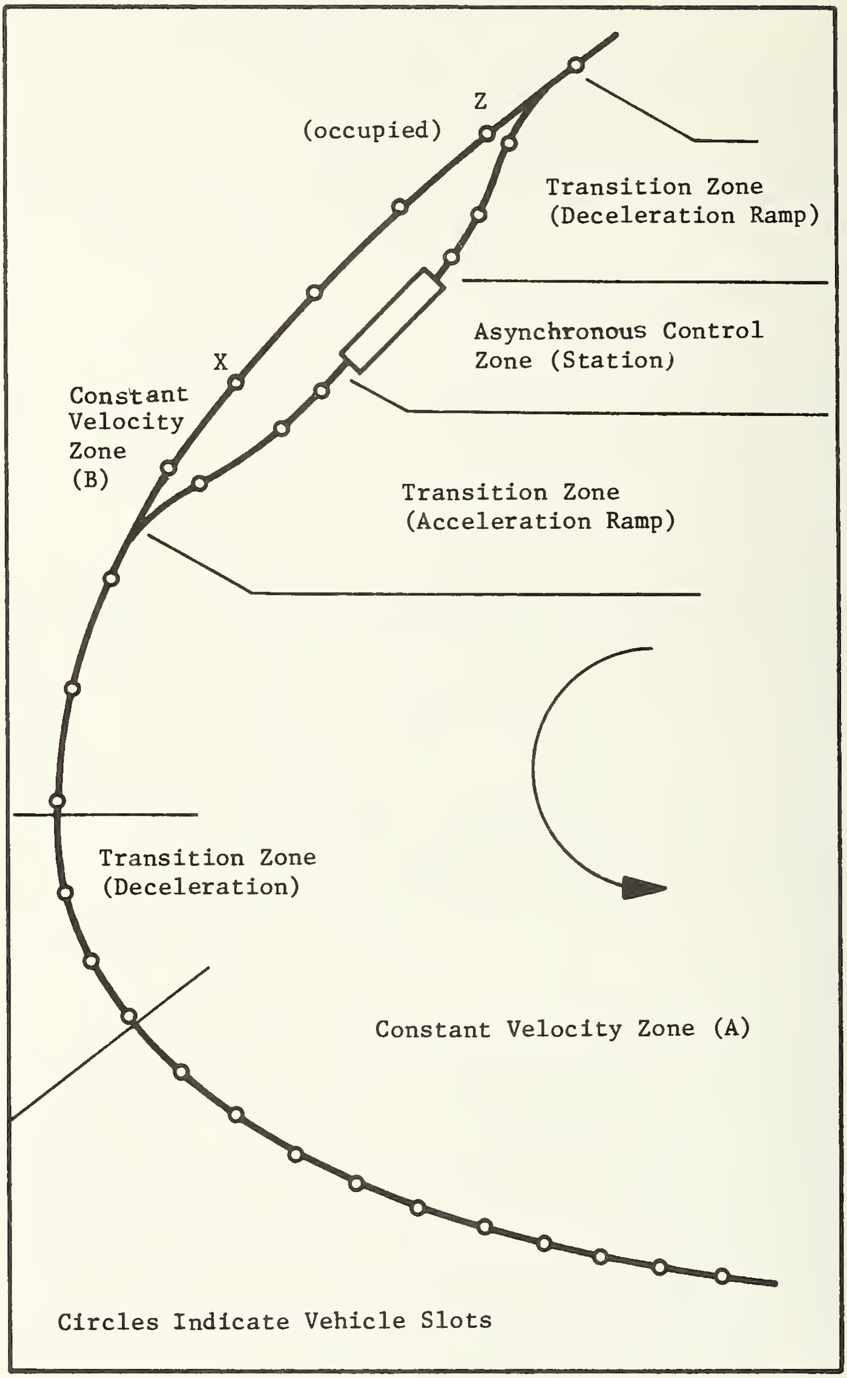


Figure 2-1. Synchronous Guideway

A schematic of the headway protection system is shown on Figure 1-1. Sequential loop antennas, which are laid along the side of the track, are illuminated by an active transmitter beacon on board the car. A signal is received on a loop whenever the transmitting antenna is within the length of the loop. Loops are arranged so that a car moves between loop centers in a fixed time.

2.1.4 Synchronous Addressing / Tracking

Control systems which require that a vehicle follow a predetermined time distance profile may be used to advantage since the number of loops which must be sampled during any time interval are reduced, thereby reducing the HSAS response time.

Since a synchronous system requires that the vehicles be positioned (conceptually) in moving slots on the guideway which travel at a fixed velocity and fixed relative separation, the local guideway units are designed so that each unit services a segment of the guideway equal in length to the separation between two slots. Thus, each unit has within its surveillance area one and only one vehicle at any instant of time (neglecting end effects). Furthermore, at any instant of time, vehicles are in the same relative position within the surveillance area of every local unit. Therefore, if a vehicle is passing over loop X at a particular instant of time in a particular local unit, then any other vehicle on the guideway should also be passing over loop X of the particular local unit monitoring its section of the guideway.

Alden's original concept involved the use of synchronous addressing in which the controller samples all loops whose relative address within each guideway segment is X and verifies that all vehicles are in their assigned slots. (This approach requires that the loop length be at least equal to the total tolerance in vehicle position and that the sampling be done at that instant when the vehicle should be passing over the center of the loop). This system is failsafe in the sense that if an onboard transmitter fails, the vehicle will not be detected in its segment when loop X in that segment is sampled and will be treated as a vehicle out of position causing a guideway shutdown or other appropriate emergency action to be initiated.

Synchronous addressing, however, has inherent limitations. It is not applicable to asynchronous systems, nor does it allow looking ahead or behind a loop for detection of a vehicle operating in a degraded mode. Therefore, the method of loop selection used in the Alden HSAS is vehicle tracking through an LGU. Prior to vehicle presence in the LGU, the LGU address counter is stepped from loop to loop by a clock provided by the headway data processor. This stepping rate is determined by the maximum time it takes the receiver to lock onto the signal from the onboard beacon. Once the receiver acquires lock, the stepping gate is closed prohibiting any further clock impulses from being sent to the address counter until the vehicle moves out of the selected loop and the received signal disappears. When loss of lock occurs a clock pulse is directed to the counter, the next loop is selected, and the receiver again locks on the beacon. Thus, as the vehicle traverses the section of the guideway being monitored by an LGU, the address counter will maintain the address of the loop in which the vehicle is located.

To minimize the initial acquisition period when a vehicle enters an LGU segment, a hand-off signal is provided. It notifies a succeeding LGU that the preceding LGU is locked onto a vehicle in the last loop of its area. This signal forces the address counter of the succeeding LGU to its last address. On leaving the preceding LGU, the succeeding LGU will move to and lock on its first loop. If the succeeding LGU happened to be already locked onto a vehicle, it would continue to track that vehicle until it left its surveillance area before forcing the address counter to the last address.

This system is also failsafe since the HLU monitors the total number of vehicles in the system. In the event of a beacon failure, a change in total vehicle count would be noted, and appropriate emergency action initiated.

2.1.5 Loop Multiplexing

To minimize the cost of the wayside signal conditioning and data acquisition equipment, all loops of a given LGU are connected through a selector switch, to a single receiver and local logic unit in that LGU. A sampling technique is then used to examine each loop for vehicle presence. An example of a typical LGU showing its local logic unit, receiver, selector switch, and the loops attached to the switch is shown in Figure 2-2.

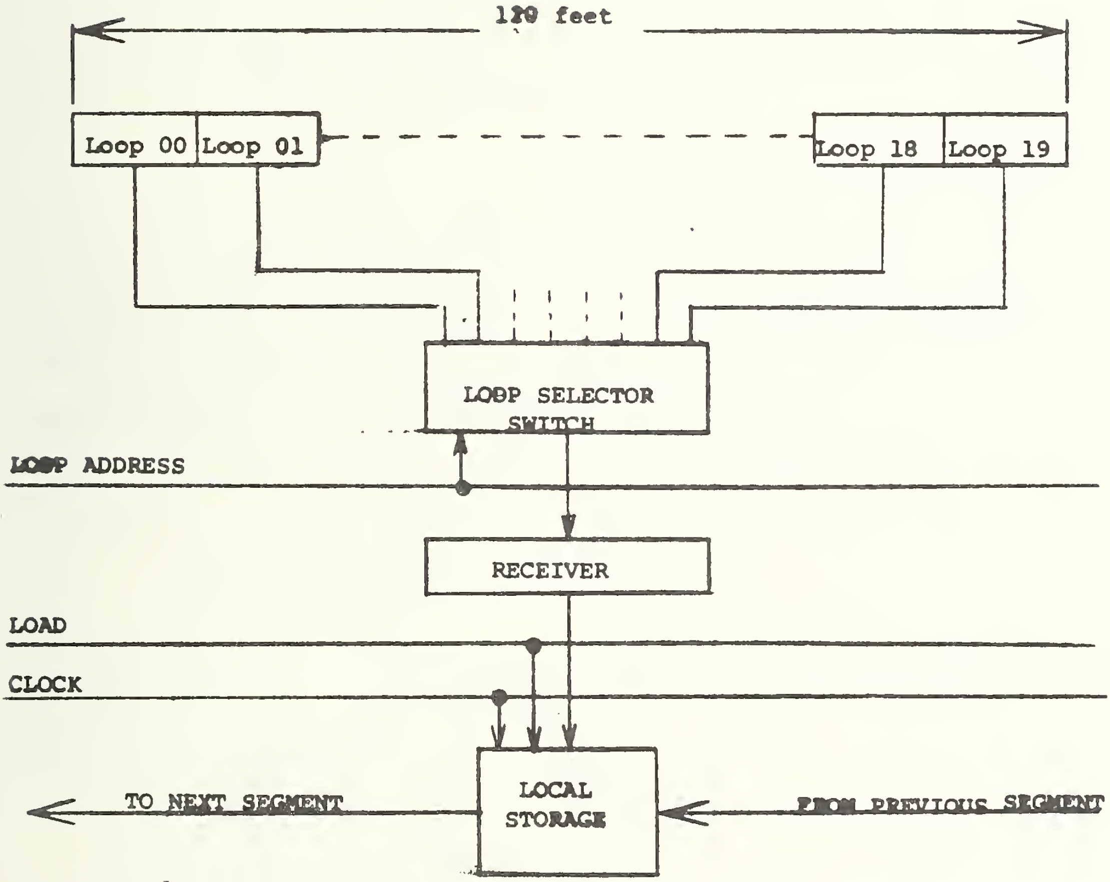


Figure 2-2. Local Guideway Unit

For illustrative purposes, the segment of guideway which is being monitored by this unit is assumed to be 120 feet long and is divided into 20 subsegments, each six feet long. An inductive pickup loop spans each subsegment and all 20 loops are brought out to a common selector switch. The switch is set by an address from the wayside controller to select one of the 20 loops, which is then connected to the receiver. If a vehicle is passing over the selected loop, its onboard transmitter activates the loop, an output is obtained from the receiver, and the address of the excited loop placed in the local storage unit. Detailed design of addressing and multiplexing circuitry is presented in the LGU Logic Design section of this report.

2.1.6 Incorporating Communications

It should be noted that the use of an onboard transmitter for the HSAS opens up the possibility that this transmitter and other elements of the HSAS can be used to establish a vehicle-to-wayside communication link. This link would then allow integration of vehicle identity, position verification and status communication tasks and the HSAS. A circuit was designed for reception of asynchronous NRZ FSK modulated data transmitted from the vehicle to the wayside; however, testing was never initiated, and there is no further discussion of the communication link in this report.

2.1.7 Extension to Asynchronous Operation

It should be noted that the operation of the headway monitoring system of the test track is predicated on the use of synchronous control law. The system hardware could, however, be adapted to asynchronous control laws by providing sufficient computational capability (software) within the HSAS to determine actual vehicle separations rather than positions relative to a moving point.

2.2 TRACKING

Successful operation of the HSAS depends on accurate tracking of a vehicle around the guideway. The following elements of tne tracking concept are discussed in this section.

1. Operation of Phase-Locked Loops
2. Edge Effects
   - Lock/Unlock
   - Beam Width
3. Scan Times
4. Handoff to Adjacent LGUs
5. Cross Guideway Tracking

2.2.1 Operation of Phase Locked Loops: The phase locked loop is a feedback system comprised of a phase comparator, a low pass filter and an error amplifier in the forward signal path and a voltage controlled oscillator (VCO) in the feedback path. The block diagram of a basic PLL system is shown in Figure 2-3. Referring to the block diagram, the basic principle of PLL operation can be explained as follows: The error votage V_d is zero if no input signal is applied to the system.

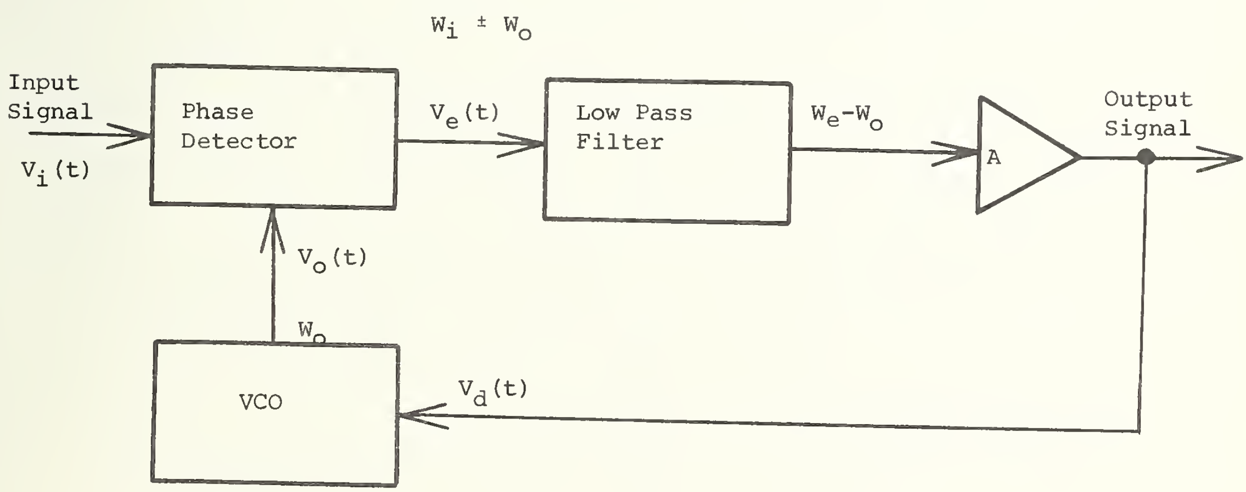


Figure 2-3. Block Diagram of a Basic PLL System

The VCO operates at a free-running frequency W_o. When an input signal is applied to the system, the phase comparator compares the phase and the frequency of the input to the frequency of the VCO. An error voltage $V_e(t)$ is generated, which is related to the phase and frequency difference between the two signals. After filtering and amplification the error voltage is applied to the VCO's control terminal. In this manner, the control voltage $V_d(t)$ forces the VCO frequency to vary in a direction that reduces the frequency difference between f_o and the input signal. When the input frequency W_i is sufficiently close to W_o, the VCO will become synchronized with the input signal. Once locked, the VCO frequency and input signals are identical except for a finite phase difference. This net phase difference Θ_0 is necessary to generate the corrective error voltage V_a to shift the VCO frequency from its free running value to the input signal frequency W_i, and thus, keep the PLL in lock. This self correcting ability of the system also allows the PLL to track the frequency changes of the input signal once it is locked. The range of frequencies over which the PLL can maintain lock with an input signal is defined as the "lock range" of the system. The band of frequencies over which the PLL can acquire lock with an incoming signal is known as the "capture range" of the system and is never greater than the lock range. Source material for the description above was taken from Reference No. 2, Section 1, where a much more detailed discussion of PLL operation is presented.

2.2.2 Edge Effects: Accurate tracking is dependent upon the lock/unlock time interval and beam width being sufficiently small. The lock/unlock interval is defined as the interval between the instant when the vehicle is leaving loop n-1 and lock is lost to the instant the vehicle acquires lock in the next loop n. Once lock is lost, the address counter will increment every 8.68 milliseconds. Assume that just as the car loses lock in loop n that a clock pulse increments the loopgate selectors to loop n+1. The receiver must acquire lock before the next clock pulse, that is, in less than 8.68 milliseconds. Actual lock/unlock intervals have been found to be 0.5 to 5.0 milliseconds, so this criteria is met.

Beam width is the distance that the beacon antenna can be placed beyond the end of a receiver loop before the loop loses lock. This distance was found experimentally to be less than 0.6 feet.

2.2.3 Scan Times: The scan time for each LGU is equal to the product of the number of loops in that LGU and the period of the LGU address counter clock, and is of the order of 100-200 milliseconds for the test track HSAS.

2.2.4 Handoff to Adjacent LGUs: Sequential loop tracking of a vehicle, from the last loop in the domain of one LGU to the first loop in the domain of the next LGU, functions without interruption, by the LGU "Loop Hand-Off" initializer. During the self-incrementation of any LGU's Address counter while in the "Search Count" mode and in the absence of any vehicle within that LGU's system, the Address Counter runs asynchronously with respect to any other system. When a vehicle is detected in the last loop of any LGU, a signal is sent to the next LGU which immediately sets the Address Counter to its highest state and holds it in that state for as long as the previous LGU has lock indication. When loss of lock from the previous LGU is sensed, the Address Counter of the LGU which is to receive the vehicle is automatically incremented from its last loop address to its first loop address where, in normal operation, it will immediately find the vehicle.

2.2.5 Cross Guideway Tracking: In the Alden system, the beacon signal is interlocked with the car's steering control circuitry, so that transmission occurs only towards the side to which the car is steering. Consequently, cross guideway tracking is nonexistent. However, in other systems not providing this interlock, simultaneous tracking of a car through two LGUs could occur (i.e., in a switch area). Software would have to be modified so that HSAS would not interpret this condition as a system malfunction and initiate shutdown.

2.3 GENERAL CONSIDERATIONS IN SYSTEM LAYOUT

Track Elements of consideration in a system layout are:

1. Basic Resolution and Loop Lengths
2. Main Guideway
3. Acceleration Ramps
4. Deceleration Ramps

Reference 1 discusses these items in detail; however, summaries are included in this chapter.

2.3.1 Basic Resolution and Loop Length

The car's control system, coupled with guideway operating conditions and the car's dynamics, determines the position error of the car. The position error places a lower limit on the size of the headway loops since there would be false shut downs if normal control errors carried the car outside the loop boundary; i.e., if position error were greater than 1/2 the loop length.

As the length of the loops is increased from this minimum, the achievable headway will increase. This increase occurs for three reasons. First, the longer the loops, the longer it takes to sense that a failure has occurred and emergency reactions are delayed. Second, since an integral number of loops must be provided between cars, there is the possibility of larger round-off errors in matching the precise headway requirement. Third, larger control errors are possible with longer loops.

2.3.2 Main Guideway

The length of the loops and the number of loops between cars are specified to guard against two basic hazards; overspeed and unexpected stop. Either may occur anywhere on the guideway, under worst combinations of load, grade, wind, brake degradation, etc. Since loops are traversed in a fixed time interval, the lengths of individual loops are directly proportional to guideway velocity. Loops on the main guideway, therefore, will be of uniform length (since main line speed is fixed), and will be larger than those of the acceleration or deceleration ramps.

On the main guideway, the prime hazard is the unexpected stop of a preceding car. Worst case is when a vehicle "just catches" the edge of a headway loop, i.e., the vehicle is considered safe at that point. The vehicle is discovered out of position one loop-interval time later, i.e., when it is due to arrive over the center of the next loop. After a delay time, the following car commences emergency braking. The safe headway must be chosen such that separation between vehicles when they come to a stop is greater than the safety margin. Further discussion is presented in the sections, "Design Studies," and "Test Track System Design (Hardware)."

2.3.3 Acceleration Ramps/Deceleration Ramps

As a vehicle decelerates into a station, loops on the deceleration ramp become shorter, proportional to speed. The opposite is true on the acceleration ramp. The deceleration ramp into the station is normally the most critical headway area, where the prime hazard is overspeed of a following vehicle. Shorter headways are allowed on acceleration ramps (following vehicles would normally be launched onto an empty acceleration ramp). Worst case overspeed on a deceleration ramp is discussed in detail in the section "Design Studies."

2.4 SAFETY

The effectiveness of the HSAS is dependent upon its ability to:

1. Recognize an Out-Of-Tolerance Vehicle
2. Verify Vehicle Position
3. Recognize Beacon Failure
4. Recognize LGU Failure
5. Be Independent of the Control Computer
6. Monitor Switch and Merge Areas

2.4.1 Out-of-Tolerance Vehicle

Position tolerance is defined by the loop length, since a vehicle must be in the loop to be considered safe. If the car is not in the proper loop, an emergency is indicated and system shut down initiated.

2.4.2 Position/Identity Verification

A vehicle being tracked by an LGU must be detected in the proper loop at each interval time or else it is out of position and constitutes a hazard. To determine this condition, the CCIU has a table, in memory, which lists the proper loop address for each basic time interval. At the center of each time interval, each LGU is commanded to load the contents of its address counter into its shift register and to set or reset the bit indicating whether or not its receiver has locked onto the signal from the onboard beacon. This information is then shifted back to the HLU, and for each LGU which indicates lock, a comparison is made between the address shifted back and the address stored in memory for that LGU for that interval. If the two addresses are equal, the system is judged to be operating safely; if not, a headway violation has occurred and the system is shut down.

2.4.3 Beacon Failure

In order to protect against beacon failure, the HLU also monitors the total number of vehicles in the system. If a beacon should fail, the absence of this vehicle in the total count would be noted and treated as a headway violation. As a backup, passive means of vehicle detection can be provided at station launch points to verify that vehicles entering the system have operable beacons.

2.4.4 LGU Failure

System shutdown in the event of LGU failure is more or less inherent since the CCIU would interpret the failure as a "phantom" vehicle present, a vehicle out of position, or a beacon failure, and consequently initiate system shut down. Failure of an LGU would predominantly occur due to malfunction of the receiver, counter, or line interface circuits. Receiver failure would result in a consistent lock or unlock indication. A constant lock output would inhibit address counter incrementation and loop sequencing would be stopped. If a vehicle was not slated to be in this LGU, the CCIU would interpret a "phantom" vehicle present and initiate shutdown. If a vehicle was to be in the LGU, the CCIU would interpret failure as an out-of-position vehicle. A consistent unlock indication would be interpreted as beacon failure once a vehicle entered the LGU.

Malfunction of counter circuitry (such as lock up) would prevent loop sequencing. Should the vehicle not be contained in the loop addressed by the failed counter (assuming the failed LGU was to contain a vehicle), lock would not occur and the CCIU would interpret this state as a beacon failure initiating shutdown.

Likewise, malfunction of LGU interface circuitry would result in transfer of information to the CCIU which would not compare to that stored in memory, resulting in shutdown initiation.

A more detailed discussion on LGU operation is presented in the section on "Detailed Hardware Design."

2.4.5 Independent HSAS

The headway system operates independently for maximum reliability of protection. The control computer's real-time clock is derived from the HSAS clock and the two timing chains are interlocked in such a way as to enforce synchronism. Should the control computer malfunction, the HSAS would still be capable of initiating system shutdown. The HSAS is discussed in detail in the section "Test Track System Design (Software)."

2.4.6 <u>Switch and Merge Areas</u>

At a switch point, a vehicle is tracked only by the LGU on the side of the guidewall towards which the vehicle is switched. The HLU is not furnished with any prior information as to which LGU will track the vehicle, but only verifies that one LGU or the other continues to track the vehicle. Thus, missed switches are not detected by the HLU; this function is performed by the control computer which has non-interfacing access to the data gathered by the HLU. This design insures the independence of the HLU.

The HLU also monitors merge points to determine if a collision is possible. This monitoring is done by crosschecking between pre-programmed pairs of LGUs along the legs of a merge point. If both members of the pair indicate lock, then a potential collision exists and shut-down of the system is initiated. As a special case of this function, the HLU also determines the cycle times during which a vehicle may be dispatched from a station to avoid collision at the merge onto the main guideway. This signal is monitored by the Local Control Computer and dispatches are initiated accordingly.

3. TEST TRACK DESIGN (HARDWARE)

The hardware elements of the headway protection system discussed in this section are:

1. Test Track Layout and Operation
2. Application of Design Studies to Alden Test Track
3. Allocation of Guideway Segments to LGUs
4. Loop Layouts

Other hardware items such as LGU Logic Design, CCIU Logic Design, and On-board Beacon Logic Design are covered in detail in Section 5 of this report.

3.1 TEST TRACK LAYOUT AND OPERATION

The headway system was installed and tested at Alden's test track in Bedford, Massachusetts. It is a 476 foot oval with two off-line stations, giving a total of 790 feet of guideway (Figure 3-1). Due to physical space limitations, track speed is limited to 10.8 mph under normal conditions. Vehicles may be "pushbutton" dispatched from one station to the other, or, after a partial orbit on the main guideway, to the station of origin. In addition, the controls permit the option of selecting a predetermined number, up to seven, of orbits before switching off into the destination station.

The test track is controlled by a PDP-8/L Computer with 4096 words of memory. The computer is interfaced to the headway protection system, two switch control transmitters, 12 velocity control transmitters (two mainline, two station creep, and two for each acceleration and deceleration ramp), a real-time clock, and miscellaneous controls and indicators.

Switch direction of the vehicles is governed by the output frequency of the switch control transmitters as the vehicle passes through the switch area.

Vehicle velocity is controlled by a 12-bit command word FSK modulated on the velocity control transmitters. Nine bits of the word govern the vehicle velocity, one bit is a master enable for the vehicle, one bit is used for vehicle synchronization, and one bit is used to pass/inhibit

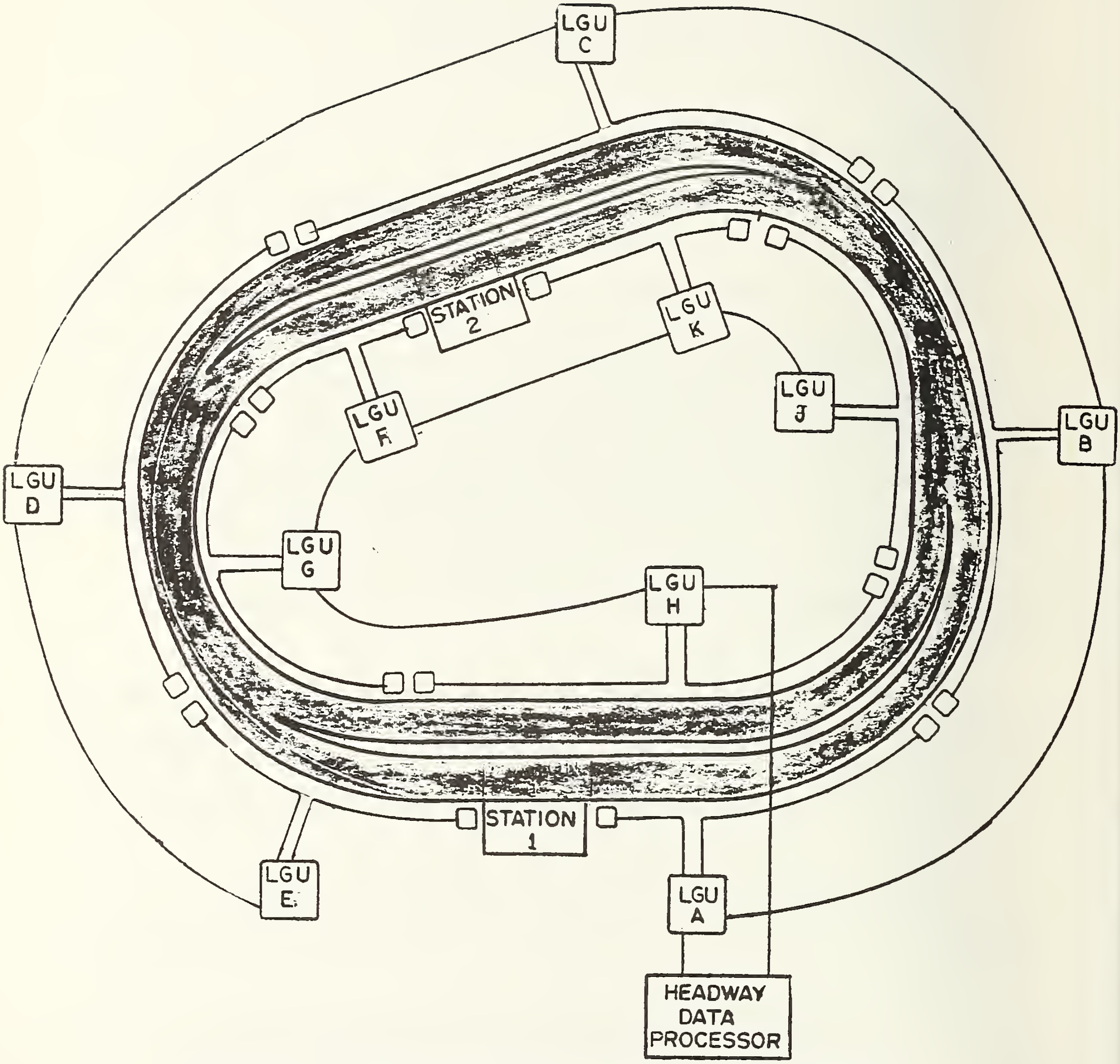


Figure 3-1. Test Track Layout and Layout of LGU Segments

beacon transmission. Noise immunity is afforded by a requirement that two identical command words be received in succession before the vehicle will recognize them as a new command. The velocity transmitters are arranged into eight groups:: mainline right, mainline left, creep 1, creep 2, station 1 accelerate, station 1 decelerate, station 2 accelerate and station 2 decelerate. The computer sees each group as a single command word output channel. In addition, on-off control is provided for each acceleration transmitter.

Test track parameters are shown on Table 3-1

3.2 APPLICATION OF DESIGN STUDIES TO ALDEN TEST TRACK

Using the computer program and the test track parameters given on Table 3-1,design calculations were made to investigate the interactions among headway, speed, and loop length for the Alden Test Track. Results are shown on Figure 3-2 Each point is the result of a computer calculation for the main guideway loop length given under the point. Thus, if main-guideway speed is 10 mph and loop lengths are three feet, cars must operate 6.9 seconds apart.

The loop lengths given correspond to the main guideway speed. They become shorter at lower speeds. For example, at the three mph station entry speed, the loops will be 0.3 times their length at 10 mph.

The safety margin, or minimum distance between cars after an emergency, is set at one foot. The speed of entry to the station platform is three mph. This speed is the lowest practical one that can be used without disproportionately compromising headways and is consistent with the speed in the platform area.

Maximum speed is set at 1.12 times the main guideway speed. This increment allows the car to adjust to the main guideway speed. Maximum possible speed can be absolutely governed on the Alden vehicle because of the characteristics of its hydrostatic transmission.

3.2.1 Critical Condition: The headways computed and shown in Figure 3-2 are all determined by overspeed on the deceleration ramp. Shorter headways are required on the main guideway, the acceleration ramp, and for unexpected stops.

TABLE 3-1. TEST TRACK PARAMETERS

1. Speed about 10 mph
2. Headway about 8.0 seconds
3. Ramp Deceleration 0.1g
4. Car Length 10.0 feet
5. Brake Tolerance $\pm$ 10% (variable grade, loading & tire coefficient)
6. Brake Delay Time 0.12 seconds (time analysis)
7. Deceleration of Failed Car 1 g (assumed, cannot be reached in demonstration)
8. Acceleration of Overspeed Car 0.3 g's (limited by hydraulic-drive relief valve)
9. Nominal Emergency Deceleration 0.3 g's (tire slip, dry pavement)
10. Correction Acceleration 0.1 g's (limited by on-board electronics)
11. Length of Main Guideway Oval 476 feet
12. Transmitting Antenna Beam Width 0.6 feet (test data)
13. Loop Lock Delay Time less than 0.01 seconds (characteristic phase-lock time)

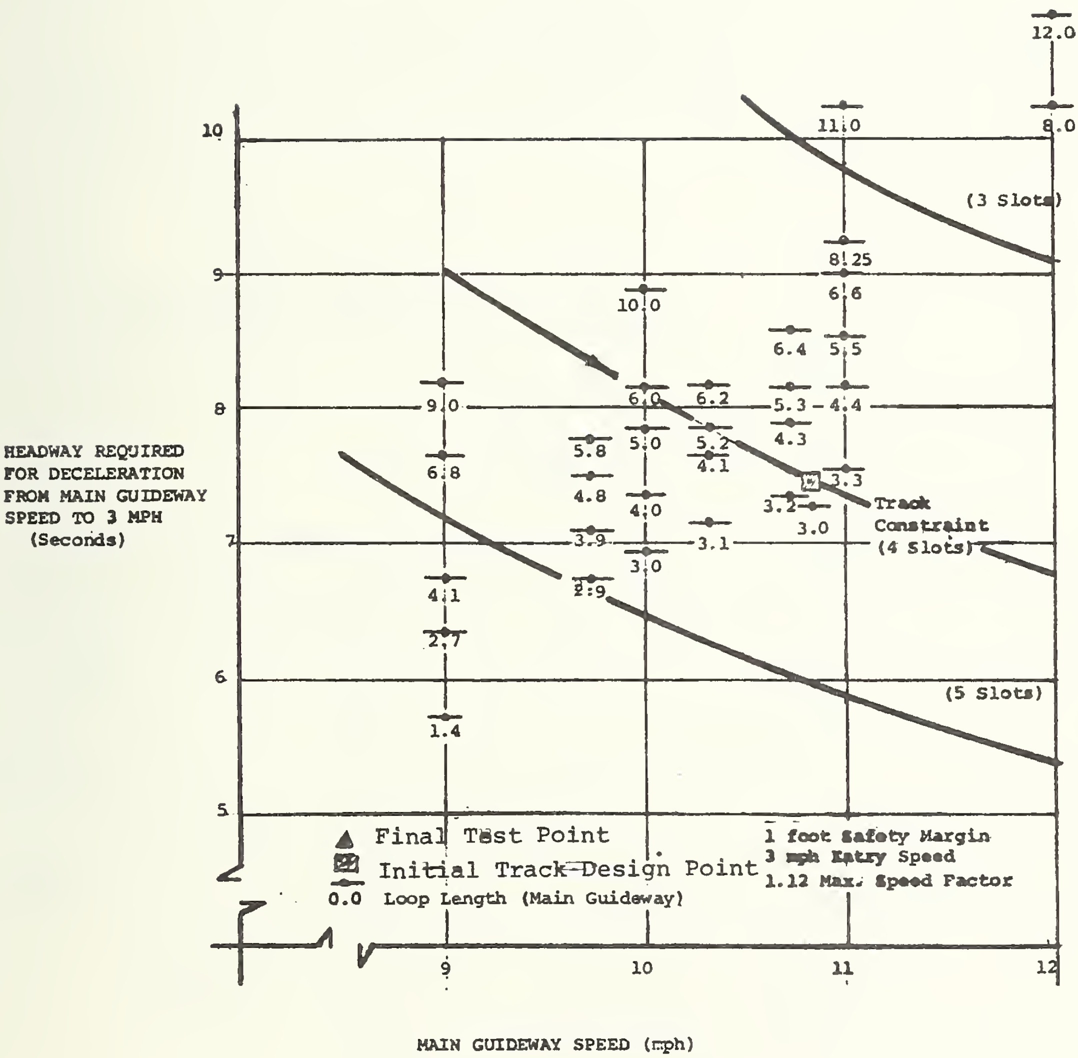


Figure 3-2. Loop Length Design Map

Constraint: The fact that there must be an integral number of slots on the main guideway oval defines the solid curves slanting down into the right on Figure 3-2. They specify the possible operating points for the test track and satisfy the equation:

$$(\text{speed}) \times (\text{headway}) \times N = (\text{circumference of track})$$

where N is an integer, equal to the number of slots.

Loop Design: It is seen from Figure 3-2 that the required headway increases with both speed and loop length. Considering all aspects of the track design and the parameters of the existing track (Table 3-1), the design point defined by the square on Figure 3-2 was chosen. The design point is summarized below.

Loop Length	- 3 feet at start of deceleration ramp
	- 6 feet on main guideway (10.82 mph)
Station Entry Speed	- 3 mph
Guideway Speed	- 10.82 mph
Headway	- 7.5 seconds
Maximum Speed	- 12.1 mph

While three-foot loop lengths, at 10.82 mph are required for the deceleration ramp, loops can be six feet long on the main guidewaw without sacrificing safety. This variation allows a cheaper installation. For the same reason, siz-foot loops at 10.82 mph are used on the acceleration ramp.

It should be noted that the guideway speed, headway, and maximum speed design points above were changed slightly in final testing. It was necessary to reduce guideway speed to 9.74 mph and maximum speed to 10.9 mph because of physical limitations of the test track. Thus, actual headway is 8.33 seconds rather than 7.5 seconds. The design point corresponding to the new parameter values used in final testing is defined by the triangle on Figure 3-2. Safe operation is maintained at this point, and in fact, loop lengths could have been increased at the lower speed.

3.3 ALLOCATION OF GUIDEWAY SEGMENTS TO LGUs

Ten LGUs are required for the test track installation. Five LGUs are used to track vehicles exciting loops mounted on the inner guiderail and five for loops on the outer guiderail. The LGUs are interconnected as shown on Figure 3-1, and the interconnecting cables brought into the building through the existing duct work.

Each LGU covers a segment of guideway equal in length to the slot separation, or headway distance required on that segment. The exceptions are the ends of the acceleration and deceleration ramps, which for geometric reasons may cover a smaller distance. The loops in a set are numbered sequentially in the direction of vehicle travel, and each set is connected to an LGU whose principal elements are discussed later in this report.

The segment of guideway spanned by the loops associated with each LGU is given in Table 3-2. These distances are measured along the center line of the guideway in the direction of travel. The zero reference point for LGU-A is at the exit end of Station 1 and for LGU-F at the exit end of Station 2.

Also indicated is the function of the principal part of the guideway covered by each LGU. Headway loops are not included in station areas -- they are restricted to the synchronous guideway. In a station, failures will not be discovered unless special provisions are made.

TABLE 3-2. SEGMENT OF GUIDEWAY SPANNED

LGU	Segment Covered (Feet)	Principal Function
(Outer) A	58.49	Station 1 Acceleration Ramp
B	118.5	Main Line
C	118.5	Main Line
D	118.5	Main Line
E	49.80	Station 1 Deceleration Ramp
	463.79	
(Inner) F	46.64	Station 2 Acceleration Ramp
G	118.5	Main Line
H	118.5	Main Line
J	118.5	Main Line
K	33.62	Station 2 Deceleration Ramp
	435.76	

3.4 LOOP LAYOUTS

Each loop is configured as a vertical figure eight with the crossover located in the center of the guiderail. The output ends are brought as twisted pairs to the appropriate LGUs. Loop fabrication is discussed in Section E of this report.

The loops along a segment of guideway spanned by a given LGU are numbered in an increasing sequence in the direction of vehicle travel. This number corresponds to the address of the loop. Normally a basic loop spans a distance that will be traveled by the vehicle in .2083 seconds. Therefore, because the headway is 8.33 seconds, a maximum of forty loops can be connected to a single LGU. These loops would be numbered from 0 to 39. However, the guideway segments covered by LGU-A, -E, -F, -K correspond to less than 8.33 seconds of travel; therefore, fewer loops are associated with these LGUs. Several basic loops may be combined (according to the resolution requirements for the guideway spanned by the combined loops) to give a loop which is traversed in some multiple of .2083 seconds.

The lengths of loops associated with each LGU are listed in Table 3-3 Lengths given are as measured at inner and outer guiderails.

TABLE 3-3. OUTER/INNER GUIDERAIL LOOP LENGTHS

TRACK LGU LOOP NO.	LOOP LENGTHS (FEET)				
	LGU-A	LGU-B	LGU-C	LGU-D	LGU-E
00	4.56	6.21	6.17	6.24	3.11
01	5.07	6.21	6.17	6.24	3.09
02	3.24	6.20	6.17	6.24	3.04
03	3.72	6.18	6.17	6.24	2.97
04	4.18	6.18	6.18	6.24	2.89
05	4.66	6.18	6.20	6.21	2.77
06	5.19	6.18	6.20	6.15	2.66
07	5.65	6.18	6.20	6.15	2.54
10	6.00	6.18	6.20	6.15	2.42
11	6.18	6.18	6.20	6.15	2.30
12	6.21	6.18	6.20	6.15	2.18
13	6.21	6.17	6.01	6.15	2.07
14		6.16	5.92	6.15	1.94
15		6.16	5.93	6.16	1.82
16		6.16	5.92	6.16	1.71
17		6.16	5.93	6.16	1.59
20		6.16	5.92	6.16	1.46
21		6.17	5.93	6.16	1.36
22		6.17	5.96	6.16	1.23
23		6.17	6.24	6.20	1.11
24					1.02
25					0.95
26					0.90
27					0.87
30					0.86
31					0.83
32					0.82
33					0.83
	60.87	123.54	121.82	123.62	51.34

TABLE 3-3. (CONT.)

TRACK LGU LOOP NO.	LOOP LENGTHS (FEET)				
	LGU-F	LGU-G	LGU-H	LGU-J	LGU-K
00	4.49	5.56	5.87	5.77	2.41
01	4.70	5.56	5.87	5.77	2.30
02	3.00	5.56	5.87	5.77	2.19
03	3.44	5.56	5.87	5.77	2.10
04	3.86	5.56	5.87	5.71	2.05
05	4.27	5.60	5.68	5.63	1.95
06	4.76	5.60	5.64	5.63	1.84
07	5.16	5.60	5.64	5.63	1.71
10	5.48	5.60	5.64	5.63	1.62
11	5.61	5.61	5.64	5.60	1.50
12		5.67	5.64	5.53	1.38
13		5.67	5.60	5.53	1.28
14		5.67	5.59	5.53	1.16
15		5.67	5.59	5.53	1.05
16		5.67	5.59	5.55	0.96
17		5.67	5.59	5.64	0.89
20		5.77	5.75	5.64	0.85
21		5.87	5.77	2.82	0.82
22		5.87	5.77	2.80	0.82
23		5.87	5.77	2.75	0.81
24				2.70	0.82
25				2.62	0.81
26				2.51	0.82
27					0.81
	44.77	113.21	114.25	112.06	33.76

4. TEST TRACK SYSTEM DESIGN (SOFTWARE)

The principal elements of the system software are:

1. Control System Software
   - A. Executive
   - B. System State Map
   - C. Timing
   - D. Application Programs

2. HSAS Software
   - A. Headway Table
   - B. HSAS Application Programs

3. HSAS Interface and Data Memory

4.1 PRESENT CONTROL SYSTEM SOFTWARE

4.1.1 <u>Executive</u> The real-time executive creates a well-defined environment for the application programs (APs) to run in, by providing supervisory, hardware interface, and housekeeping services to the APs. It is a multiprogramming monitor supporting an arbitrary number of simultaneous application programs.

The basic executive is the same for all computers in a transit system, with the set of input/output (I/O) interface modules being tailored to the specific computer and the devices it must control. A real-time executive with the features described here has been implemented on a Digital Equipment Corporation (PDP-8L) computer for purposes of controlling Alden's test track.

4.1.2 <u>System State Map</u> The System State Map (SSM) is a uniform data structure which describes the present and future status of guideway (both mainline and in station) and vehicles. The SSM weaves into a single unified whole most of the information needed to control a transit system.

4.1.3 <u>Timing</u> Vehicle headway is set at 8.33 seconds, providing a separation of 119 feet at 9.74 mph. This headway time is referred to as a cycle. Each cycle is divided into 40 phases of 208.3 milliseconds each, corresponding to the time to traverse one vehicle sensor loop. Each phase is subdivided into four time periods (TP) of 52.08 milliseconds, corresponding to the time required to transmit one uplink word. The TP is the smallest time interval visible to the track control application programs, and the cycle is the largest.

To provide a real-time clock rate suitable for task-switching, the TP is subdivided into a 20 real-time clock (RTC) periods of 2.603 milliseconds, corresponding to the uplink bit period. The uplink bit rate is therefore 381.16 Hz and the uplink word rate is 19.21 Hz.

4.1.4 Application Program Functions performed by control application programs are vehicle management, system operator interfacing, system state map management, and fault monitoring. Also included is display software, which provides a schematic outline of the test track, derived from the SSM. This outline is derived by assigning a pair of display coordinates to each node in the SSM, and displaying symbols representing the nodes at those coordinates. The nodes are connected by strings of dots, each dot representing a headway loop. The set of vehicle blocks is scanned and symbols representing the vehicles are displayed at the locations the computer thinks the vehicles are at.

Overlayed on this display is a representation of the data contained in the HSAS interface memories, consisting of symbols representing each detected vehicle at the position at which it is being detected, and a presentation of the most recent downlink data from each vehicle.

4.2 HSAS SOFTWARE

4.2.1 Headway Table A vehicle being tracked by an LGU must be detected in the proper loop at each interval time or else it is out of position and constitutes a hazard. To make this determination, the CCIU has a headway table, in memory, which lists the proper loop address for each basic time interval. At the center of each time interval, each LGU is commanded to load the contents of its address counter into its shift register and to set or reset the bit indicating whether or not its receiver has locked onto the signal from the onboard beacon. This information is then sifted back to the HLU, and for each LGU which indicates lock, a comparison is made between the address shifted back and the address stored in memory for that LGU for that interval. If the two addresses are equal, the system is judged to be operating safely; if not, a headway violation has occurred and the system is shut down.

The address for the track map look up is formed by combining the loop time count (3MSB) with the group number shown under the examined LGU. To this value a constant of 5200 is added to put this track map into the right area of memory. The column to the right of the loop column has the constant already added. Therefore, if we are examining LGU E at loop time 37, the track map address would be 5572.

4.2.2 Applications Program An Intel MCS-8 microcomputer is used for the calculations, comparisons and decisions needed to ascertain that the track operates safely. The following are those conditions which are monitored by the Headway Assurance/Safety Computer for emergency shutdown reasons.

1. Headway - Car operating over/under speed or otherwise out of position.
2. Lost Car - More/fewer vehicles in system than expected.
3. Transmitter Out - Vehicle transmitter malfunction
4. Excessive Address Parity Errors - Unreliable address data returned from LGUs.
5. Merge Violation - Collision imminent at merge point.
6. Control Computer Inoperative - Control computer not answering.

Other functions performed by the Headway/Safety Computer are:

Switch Position Verification -- not safety hazard until merge violation farther down the line.

Launch Inhibit -- Ability to prohibit launch into the system at a time in which it might be unsafe.

Appendix B contains a listing of the Headway/Safety Program and associated comments explaining what operations are being performed. This software is aimed at verifying that all enroute vehicles are in their assigned "slots." At the center of each loop time, the headway table is accessed for each LGU, in turn. The "legal" loop for that LGU at that time is calculated. Any vehicle present should be in that loop. The interface address memory location corresponding to the LGU under consideration will be read and examined for a lock indication on the proper loop address. If these check out, the vehicle is in the proper position and the next LGU is checked. If there is a discrepancy, adjacent loops may be examined in order to distinguish between overspeed, underspeed, and onboard transmitter failure.

In order to detect vehicles "lost" by the control software or stray vehicles entered into the system, a periodic scan is made and the number of vehicles detected is compared with the count of vehicles in the system.

At a switch point, a vehicle is tracked only by the LGU on the side of the guidewall towards which the vehicle is switched. The HLU is not furnished with any prior information as to which LGU will track the vehicle, but only verifies that one LGU or the other continues to track the vehicle. Provision has been made in the HSAS software for verification of vehicle containment in a switch area. A requirement for use of this function, however, is concurrent vehicle detection by LGUs on both sides of the switch. It is therefore not applicable to vehicles incorporating interlocks which allow transmisssion only to the LGU on the side of the guideway towards which the vehicle is switched.

Merge checking software guards against a potential failure in the routing and scheduling software which allows two vehicles to conflict at a merge point. When a vehicle passes through a loop designated as a "verification loop," the appropriate HSAS memory location is examined to verify that there is no vehicle approaching the merge on the other branch.

4.3 INDEPENDENT HSAS

The HSAS interface is fairly independent of the computer controlling it. Timing signals for the interface are derived from the same clock from which the computer's real-time clock is derived and the two timing chains are interlocked in such a way as to enforce synchronism. In brief, any time at which the computer expects certain data, that data will be available.

The heart of the interface consists of four sets of memory elements for each LGU chain. There exists a fixed correspondence between individual locations within a memory and individual LGUs on a chain (set of interconnected LGUs). Data in memory is updated after each LGU scan step so that it is current at the beginning of each TP. The other three memories contain downlink data words, one memory for each of the three data words in a downlink sequence. These downlink data memories are cleared when all vehicles are nominally crossing loop boundaries (the beginning of a phase). During the phase, the LGU data receivers are continually scanned, and downlink data is entered into the memories, steered by the identifier bits in each downlink word. These memories are intended to be interrogated at the end of the phase time. Downlink data can be considered valid during any phase except the first and last of a cycle, due to the possibility of two vehicles entering and leaving the area of a single LGU at these times.

TABLE 4.1 HEADWAY

A 0	B C D 1	E 2	F 3	G H 4	J 5	K 6		Memory Loop Time
	300 0	300 0	102 2	314 12	314 12	330 24	000	520
		101 1				131 25	001	521
	101 1	102 2	303 3	115 13	115 13	132 26	002	522
		303 3				333 27	003	523
	102 2	104 4	104 4	116 14	116 14		004	524
		305 5					005	525
	303 3	306 6	305 5	317 15	117 15		006	526
		107 7					007	527
300 0	104 4	110 8	306 6	120 16	120 16		010	530
		311 9					011	531
	305 5	312 10	107 7	321 17	321 17		012	532
		113 11			322 18		013	533
	306 6	314 12	110 8	322 18	123 19		014	534
		115 13			324 20		015	535
	107 7	116 14	311 9	123 19	125 21		016	536
		317 15			126 22		017	537
101 1	110 8	120 16		300 0	300 0	300 0	020	540
		321 17				101 1	021	541
	311 9	322 18		101 1	101 1	102 2	022	542
		123 19				303 3	023	543
102 2	312 10	324 20		102 2	102 2	104 4	024	544
		125 21				305 5	025	545
303 3	113 11	126 22		303 3	303 3	306 6	026	546
		327 23				107 7	027	547
104 4	314 12	330 24		104 4	104 4	110 8	0303	550
		131 25				311 9	031	551
305 5	115 13	132 26		305 5	305 5	312 10	032	552
		333 27				113 11	033	553
306 6	116 14	134 28	300 0	306 6	306 6	314 12	034	554
						115 13	035	555
107 7	317 15			107 7	107 7	116 14	036	556
						317 15	037	557
110 8	120 16			110 8	110 8	120 16	040	560
						321 17	041	561
311 9	321 17			311 9	311 9	322 18	042	562
						123 19	043	563
312 10	322 18		101 1	312 10	312 10	324 20	044	564
						125 21	045	565
113 11	123 19			113 11	113 12	126 22	046	566
						327 23	047	567

F/D Merge Check

A/H Merge Check

Switch Verification

BJ Switch

J Switch

113 11

113 is the Octal Address returned by LGU Chain
6 LS Bits of Address
1 Lock Bit (0-Occupied; 1-Locked)
1 Even Parity Bit (MSB)
11 is the track LGU Loop Number

The ADRS for track map look up is formed by combining the loop time count (3 MSB) with the group number shown under the LGU under examination. To this value a constant of 5200 is added to put this track map into the right area of memory. The column to the right of the loop column has the constant already added. Therefore, if we are examining LGU E at loop time 37. the track map ADRS would be 5572.

5. DETAILED HARDWARE DESIGN

Elements considered in this section are:

1. Pick-Up Loops
2. Phase Lock Loop Receiver
3. Detailed LGU Design
4. Detailed CCIU Design
5. Detailed Beacon Design

5.1 PICKUP LOOPS

The magnetic field produced by the onboard ferrite rod antenna is coupled to figure-eight pick-up loops mounted end to end along the guideway guiderail. Two types of loops are presently in the system -- Type 1, in which the loops are made of copper conductive tape, and Type 2, in which the loops are formed from #22 guage wire.

The original loops were made of 0.25" wide by 0.00135" thick copper conductive tape sandwiched between two layers of 1/4" thick exterior grade plywood. A typical loop assembly is shown in Figure 5-1.

After the loop was fabricated on the plywood, the assembly was coated on both sides with a MIL-V-173B Specification varnish for environmental protection. The assembly was then mounted against another layer of 1/4" plywood which had previously been secured to the guidewall, as shown in Figure 5-2. The conductive tape was thus sandwiched, and a layer of duct tape was applied across the top edges of the plywood sheets for final weather protection.

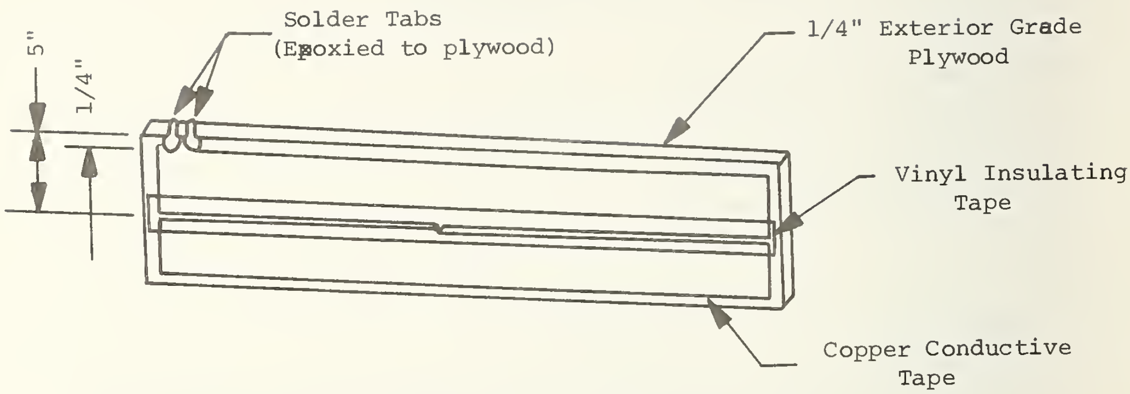


Figure 5-1 Loop Assembly

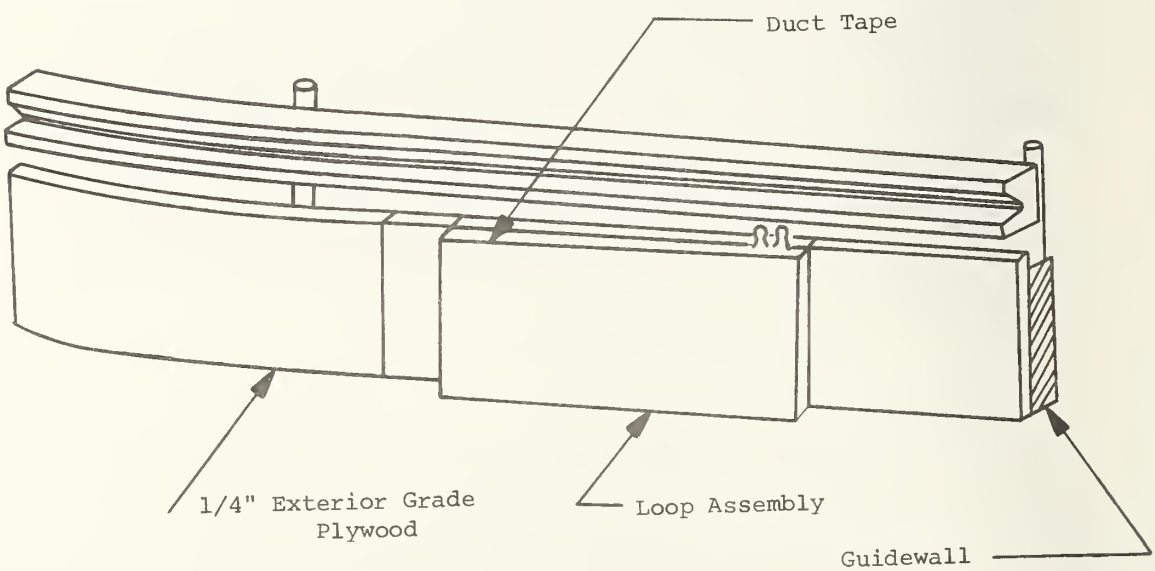


Figure 5-2 Loop Mounting

After the loops had been in service a few months they started to exhibit two failure modes. The first was breakage of the copper tape, resulting in an open loop. It was found that if the ends of the plywood backings were not mated for a plane surface, the foremost edge of the plywood backing would eventually cut through the tape since guidewheel pressure would flex the loop assembly against the edge. It was also found that weather protection was inadequate in that the protective varnish wore off resulting in loop assemblies buckling after exposure to rain and snow. This buckling was another cause of open loops since it resulted in the copper stretching until breakage occurred. The second mode of failure was shorting of the loops at the crossover. This failure mode became apparent during the winter season and investigation revealed that the vinyl insulating tape was shrinking under the extremely cold environmental conditions causing loops to short at the ends of the overlap.

Replacement loops are now the second type, formed from wire. The configuration is the same as the copper tape loops except that the loop assemblies have slots routed into them into which the wire loop is fastened. No failure has been observed for the second type of loop.

The figure-eight configuration was selected to minimize noise pickup, especially any 60 Hz induced by close proximity to the power bus. A horizontal crossover rather than vertical was selected to eliminate a dead zone at the center of the loop.

Electrical connections between the loops and the LGU's were made using unshielded twisted pairs of No. 20 guage wire. Solder connections are used at the loop terminals while screw terminal connections are used at the LGU's.

5.2 PHASE LOCKED LOOP RECEIVER

The heart of the phase locked loop receiver is an SE 567 tone and frequency decoder which is a stable phase locked loop with synchronous AM lock detection and power output circuitry. Its primary function is to drive a load whenever a sustained frequency within its detection bandwidth is present at the input. External components establish the bandwidth, center frequency, and output delay. A detailed schematic of the receiver is shown in Figure 5-3

The free running frequency of the tone decoder's current controlled oscillator (CCO), in the absence of an input signal, is defined by

$$fo \approx \frac{1.1}{R_1 C_1}$$

A 200 pf mica capacitor was selected for C_1 (because of temperature stability and availability). For a center frequency of 135 KHz, R_1 is found to be in the range of 4K Ω and thus a 5K Ω potentiometer was used. Capacitor C_2 determines the bandwidth for the receiver and its value was arrived at experimentally for a bandwidth of approximately 5KHz. Pin 8 of the tone decoder is an open collector tied to a 2.2K Ω pull up resistor. When an inband signal is present saturation of the transistor occurs, and lock is indicated by a low level voltage at pin 8 (1.0 V or less). Capacitor C_3 is required to activate the output transistor. This signal then drives the 5407 and C04009 level converters for $\overline{\text{lock}}$ and lock signals respectively; lock being approximately 15 volts and $\overline{\text{lock}}$ approximately ground potential.

The two IN914 diodes are for temperature compensation of the frequency. The 0.01 μF capacitor between pins 1 and 8 is to eliminate chatter as the output changes state, which subsequent logic would interpret as a proper signal. Frequency centering is established by the network of 580, 1.2K, and 2.8K Ω resistors; the values of which were arrived at experimentally.

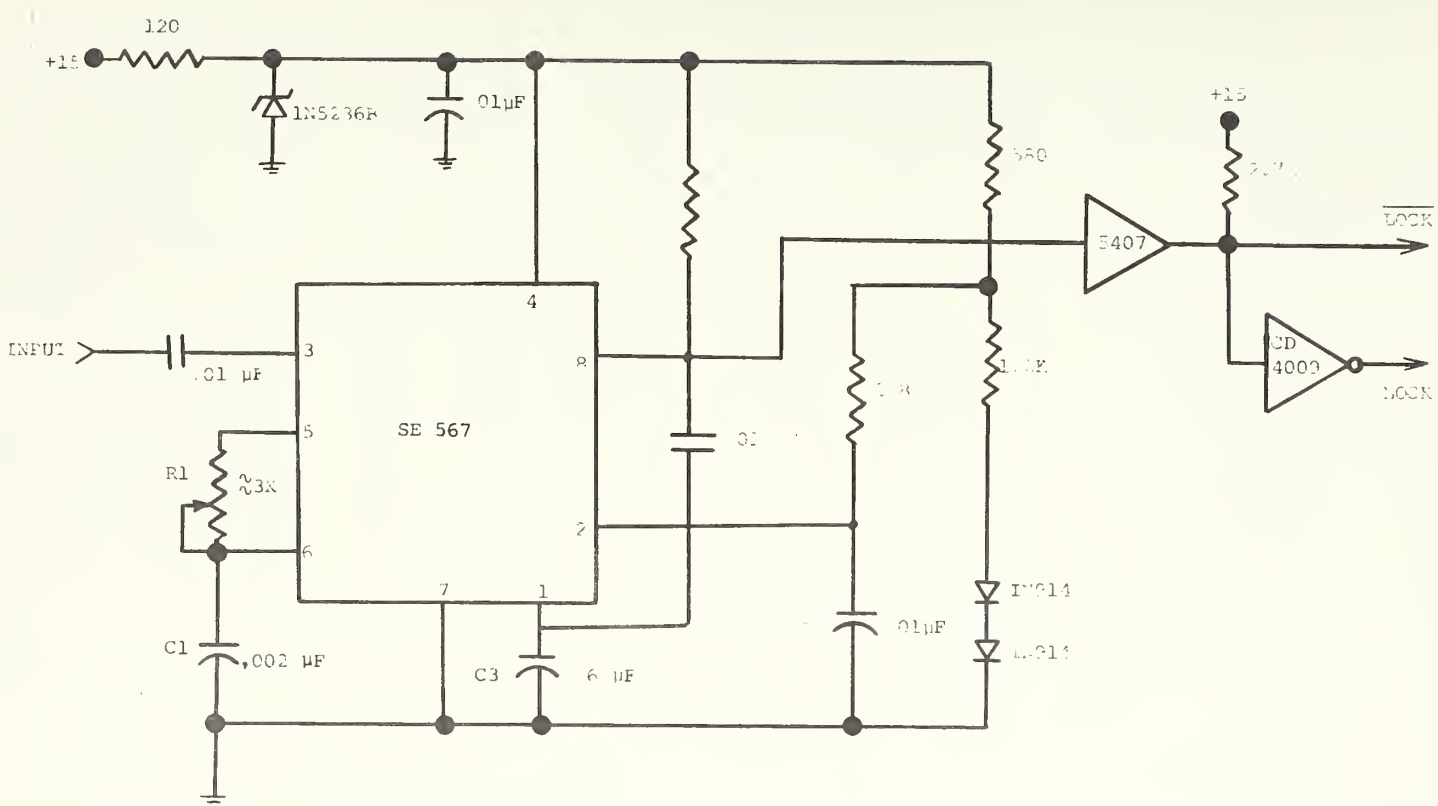


Figure 5-3. Phase Locked Loop Receiver

The circuit has a center frequency tuneable from approximately 131 to 138 KHz and a capture bandwidth of 3.5 KHz. Typical drift of center frequency over a year's operating life was in the range of 0.5 to 1.5 KHz.

For frequency stability over extended temperature ranges, R_1 and C_1 should exhibit temperature coefficients of 100 ppm/°C or less.

5.3 DETAILED LGU DESIGN

A block diagram of the LGU is presented in Figure 5-4 A vehicle is tracked by using a phase-lock receiver to lock on to the loop which is being excited by the onboard transmitter. The address of this loop is transmitted upon command back to the control computer.

The LGUs can accept the following commands from the CCIU and give the indicated response:

1. Load Address - The LGU loads the address of the loop currently being examined into the address storage register. The address is composed of six bits; an odd parity bit is computed and stored as a seventh bit.

2. Shift - The contents of the address register are shifted onto the address output line; the bits on the address input lines are shifted into the address storage register.

3. Count Up Absolute - The address counter is incremented by one regardless of whether or not the phase-locked loop receiver (PLL) is tracking a vehicle.

4. Count Down Absolute - The address counter is decremented by one regardless of whether or not the PLL is tracking a vehicle.

5. Clear Counter - The address counter is set to its maximum value.

6. Search Count - The address counter is incremented if the PLL is not locked.

Schematic segments of a typical LGU are presented in Figures 5-5 5-6 and 5-7 Figure 5-5 shows receiver/transmitter interface circuitry, Figure 5-6 details the address control decoder and counter decoding circuits, while Figure 5-7 presents address shift register, parity generator, and loop gate selector circuits. In addition, timing waveforms for a typical LGU, in this instance LGU-F, are presented in Figure 5-8

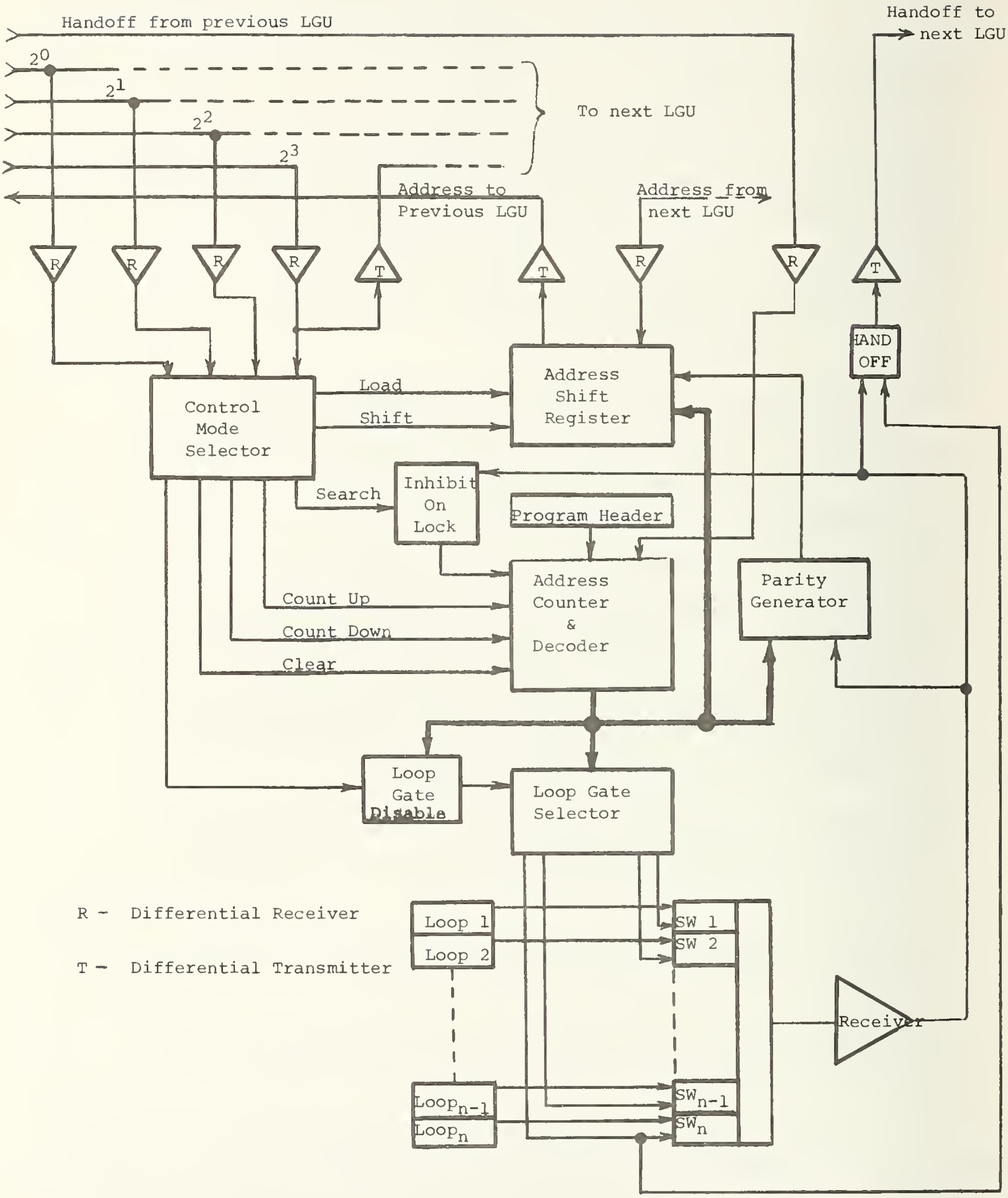


Figure 5-4. LGU Block Diagram

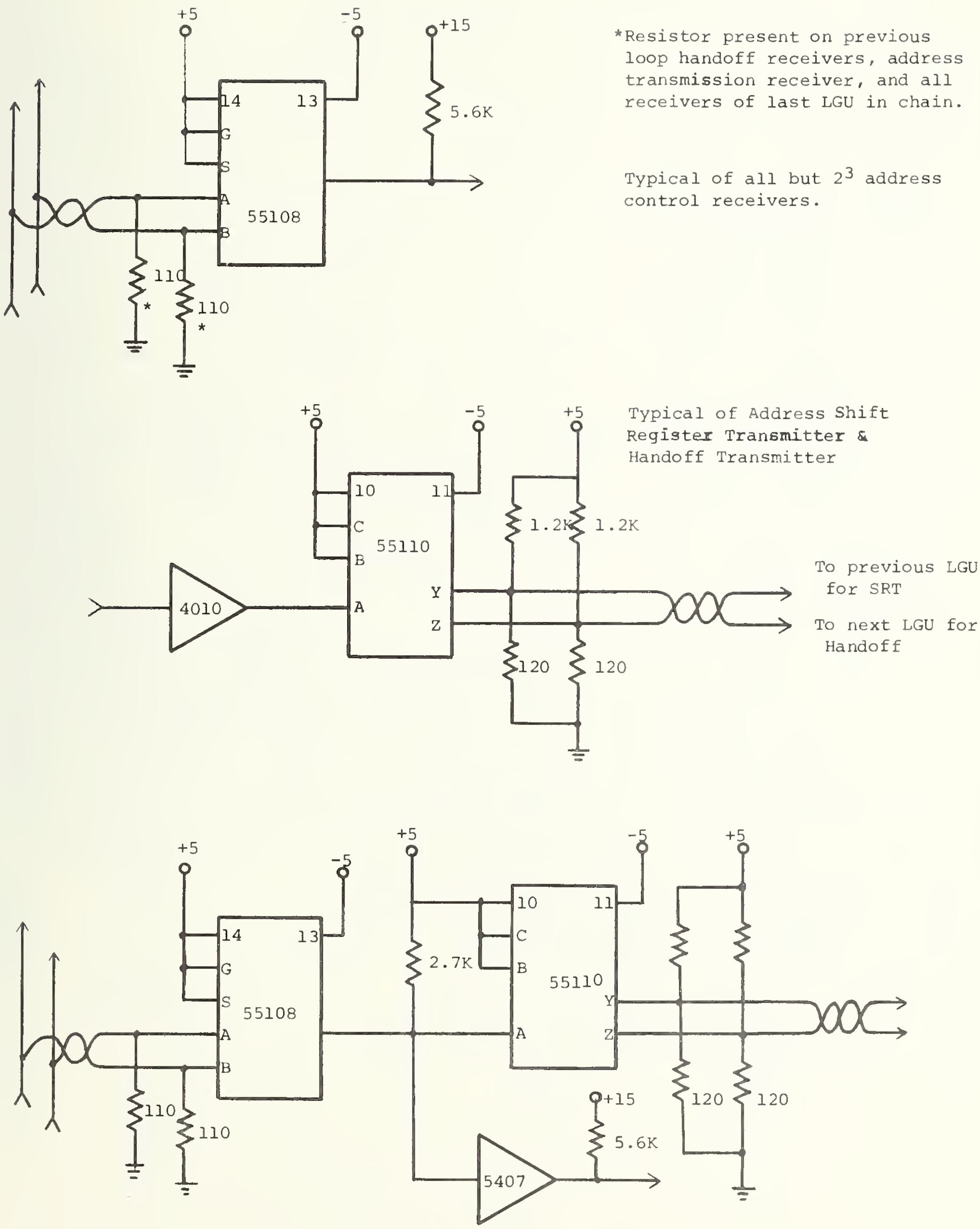


Figure 5-5. Typical 2^3 Address Control Receiver and Transmitter

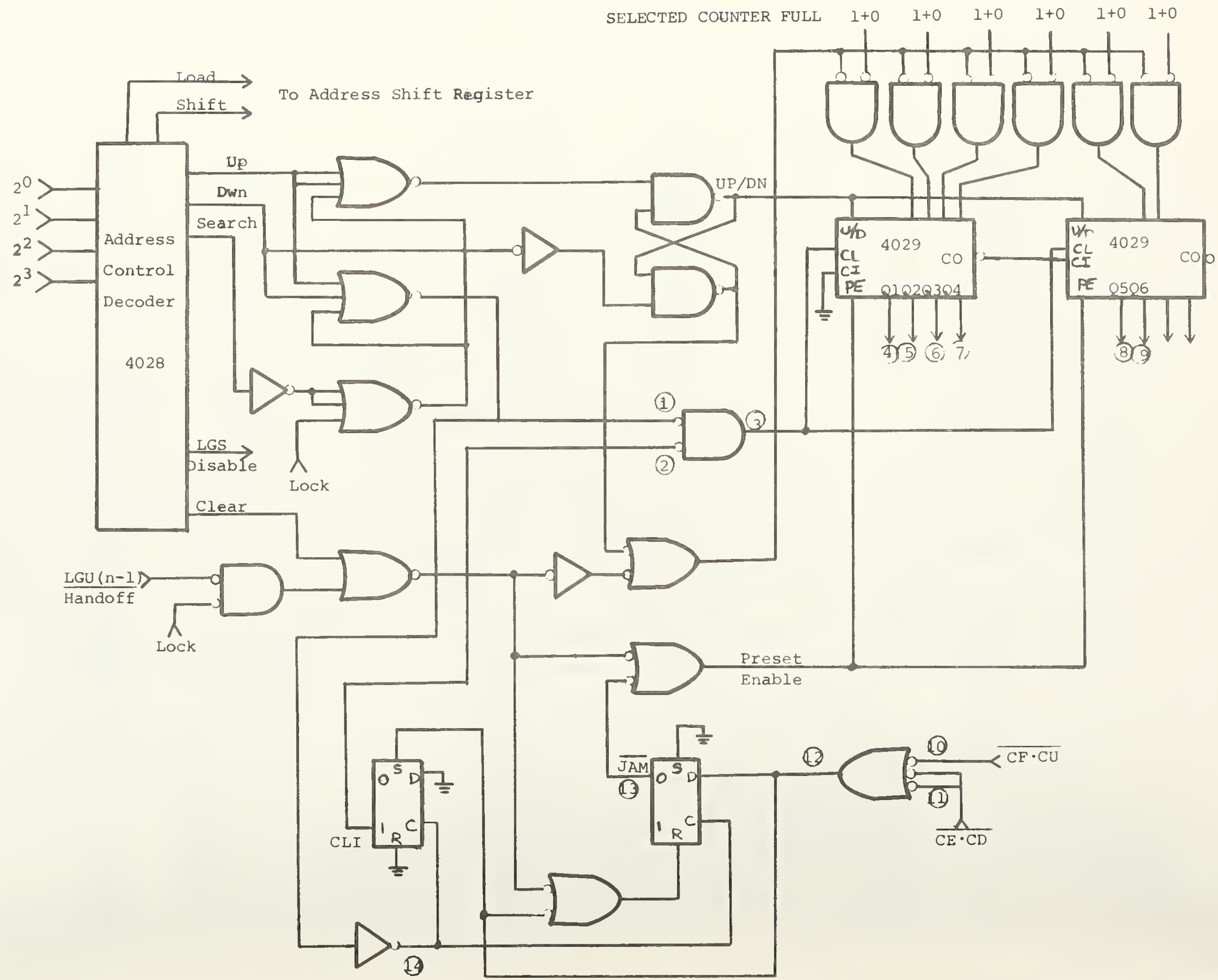


Figure 5-6. LGU Address Control Decode and Counter Decode Circuits

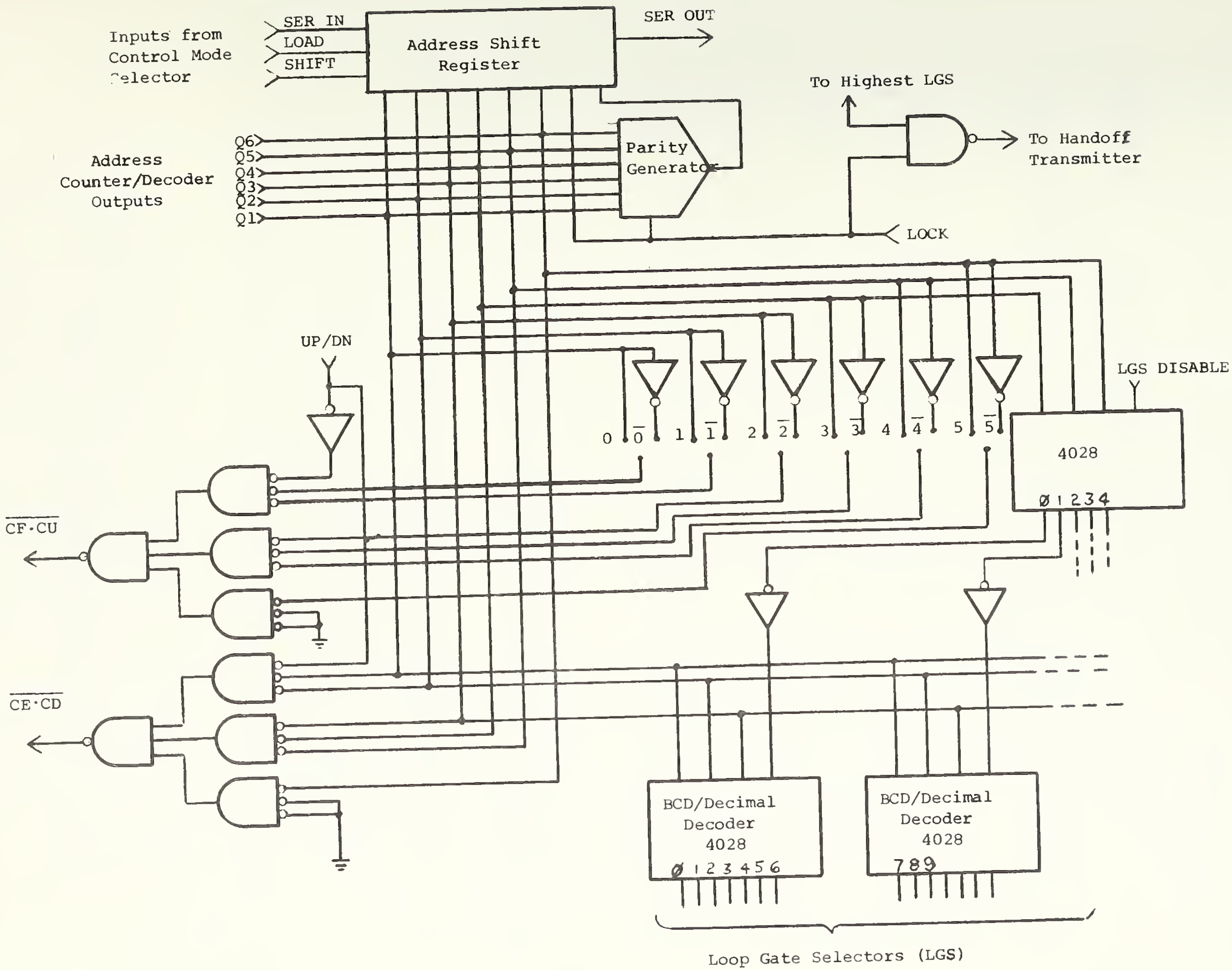


Figure 5-7. LGU Address Shift Register, Parity Generator, and Loop Gate Selector Circuits

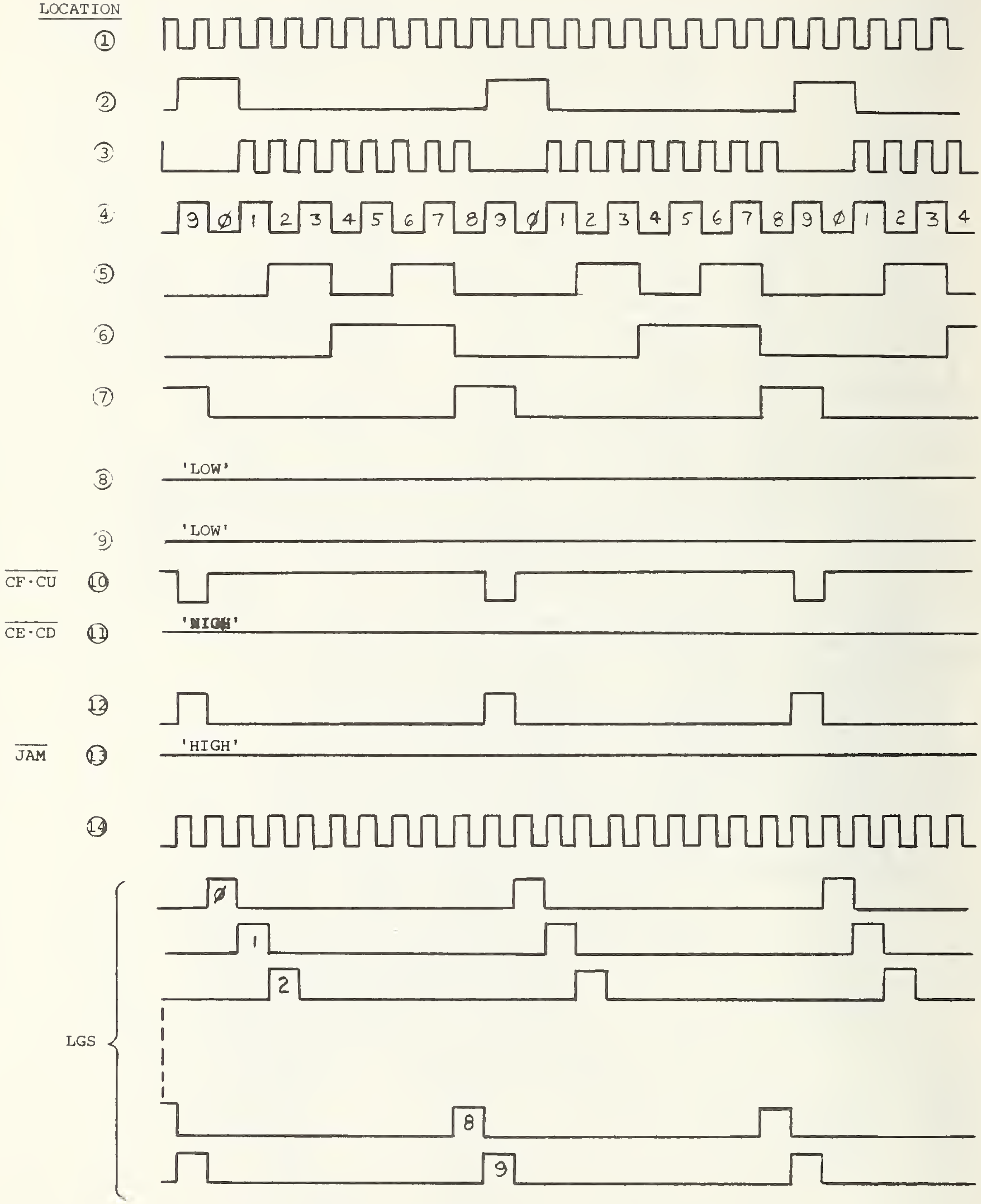


Figure 5-8. LGU F Waveforms for Search Count - $\overline{\text{LOCK}}$

The heart of the LGU circuitry of Figure 5-5 is the presettable up/down counter. The inputs consist of a single Clock, Carry-In (Clock Enable), Binary/Decade, Up/Down, Present Enable, and four individual Jam signals. The outputs are four separate buffered Q signals and a Carry Out signal.

The counter is advanced one count at the positive transition of the clock when the Carry-In and Preset Enable signals are "low," while "high" Carry-In or Preset Enable signals inhibit advancement. The clock is obtained from the Search Count output of the Address Control Decoder and is slow enough to permit obtaining a LOCK signal as the loop is excited. Since a tone burst to a frequency within the lock range is detected in something less than 5 msec, this clock frequency should be between 100-200 Hz, and is blocked from further advancing the counter when LOCK is detected.

The Carry Out signal is normally "high" and goes "low" when the counter reaches its maximum count in the "Up" mode or the minimum count in the "Down" mode provided the Carry In signal is "low." The Carry In signal in the "low" state can be considered a "Clock Enable," and must be connected to ground when not in use.

Logical 1 at the Up/Down input directs count up while Logical 0 directs count down. When the counter is in the Search Mode, it automatically counts up. The Binary/Decade input is tied to +15 volts to select binary counting mode.

A "high" Preset Enable signal allows information on the Jam inputs to preset the counter to any state asynchronously with the clock. A "low" on each Jam line, when the Preset Enable signal is "high", resets the counter to its zero count. However, a serial address is provided to the counter, thus the jam inputs will be used to preset the counter only in two instances:

1. To clear the counter to zero. This clearing is possible at any time by means of a clear signal from the computer, and
2. To provide gating that enables any arbitrary and selectable COUNTER FULL count.

This last instance requires that when the counter is in its SELECTED FULL state, and is directed to COUNT UP, the next clock pulse results in all ZEROS output. Also, when the counter is all ZERO and is directed to COUNT DOWN, the next clock pulse puts the counter in the SELECTED FULL state.

Let us now consider the Jam/Counter control. An empty counter is defined as an all zero output state, while a full counter is defined as any selectable output state other than all zeros. Selection is made through programmed headers. The jam control provides that when counting down, the counter state succeeding the selected full state is the empty state. Referring to Figure 5-5, we see that a "counter full and counting up"(CF·CU)signal is ORed with a "counter empty and counting down," (CE·CD)to signal the terminal state of the counting sequence. Upon detection of the terminal state, the "Clock Inhibit" (CLI),flip-flop is set, thereby inhibiting the subsequent clock pulse from incrementing or decrementing the counter. The "D" input of the $\overline{\text{JAM}}$ flop is also set to a "1." The trailing edge of the next clock pulse turns the PE input of the counter "high" by setting the $\overline{\text{JAM}}$ flop. If the UP/DN bus control is high, the counter is jammed to zero. If the UP/DN bus control is low the counter is jammed to its selected full. (CLI is still set by the SET input.)

As soon as the jammed count appears on the counter outputs, the (CF·CU) + (CE·CD) signal goes low. The trailing edge of the next clock pulse resets both JAM and CLI flip-flops. CLI going low provides a positive transition to the counter's CLOCK input, immediately incrementing the counter.

A CLEAR signal or an LGU HAND-OFF signal (with no lock in the domain of this LGU) immediately jams the counter "high" and resets the $\overline{\text{JAM}}$ flop. If the counter is to count up, removal of the CLOCK immediately sets the CLI flop and inhibits the counter incrementing clock pulses. The trailing edge of the next clock pulse jams the counter to zero and counting proceeds as previously described. If the counter is to count down, the JAM and CLI flops both stay reset, inhibiting any further jamming and allowing normal counter incrementation (decrementation).

When a vehicle is detected in the last loop of any LGU, a signal is sent to the next LGU which immediately sets the Address Counter to its highest state and holds it in that state for so long as the previous LGU has lock indication. Figure 5-7 shows this signal generation when LOCK is NANDed with the highest Loop Gate Selector (LGS) signal. When loss of lock from the previous LGU is sensed, the Address Counter of the LGU which is to receive the vehicle is automatically incremented from its last loop address to its first loop address where, in normal operation it will immediately find the vehicle. The Address Counter operation has been previously discussed.

5.4 DETAILED CCIU DESIGN

The "Control Computer Interface Unit" (CCIU) should perhaps be entitled "Computer Interface Unit" since it interfaces to both the Control Computer and the Headway/Safety Computer. The primary functions performed by this unit are:

1. Track Timing Generation
2. Generation of LGU Chain Control Signals
3. Interface of Control Signals and Data returns to/from LGU Chains
4. Storage of Track Data in Memory for use by both Control and Headway/Safety Computers.

A block diagram of the system is presented in Figure 5-9 System clock, timing generator interface and control schematics are shown in Figures 5-10, 5-11 and 5-12. CCIU memory and memory control circuitry are shown in Figures 5-13 through 5-19

5.4.1 Track Timing Generation

Figure 5-20 shows the derivation of the 8.33 second headway from frequency division of a master 73,728 Hz oscillator.

Necessary timing signals from the Timing Generator are made available to both the Headway and Control Computers through the Track Data Map, as follows:

Octal Mem Adrs	Timing Available
361	Loop Quarters
362	2304 Hz - 19.20 Hz
363	Loop - Headway Times

5.4.2 Generation of LGU Address Data Control Signals

1. LOAD ADRS -- Load six bit address of loop currently being examined, a bit to indicate whether a car is present in that loop; and an even bit into address shift registers.
2. SHIFT -- The contents of address shift register on Address Data Communication line at a rate of 36,864 bits/sec.
3. COUNT UP ABSOLUTE -- regardless of presence of lock/$\overline{\text{lock}}$ on vehicle, increment the address counter by one(115.2 Hz rate).
4. COUNT DOWN ABSOLUTE -- regardless of presence of lock/$\overline{\text{lock}}$ on vehicle, decrement the address counter by one (115.2 Hz).

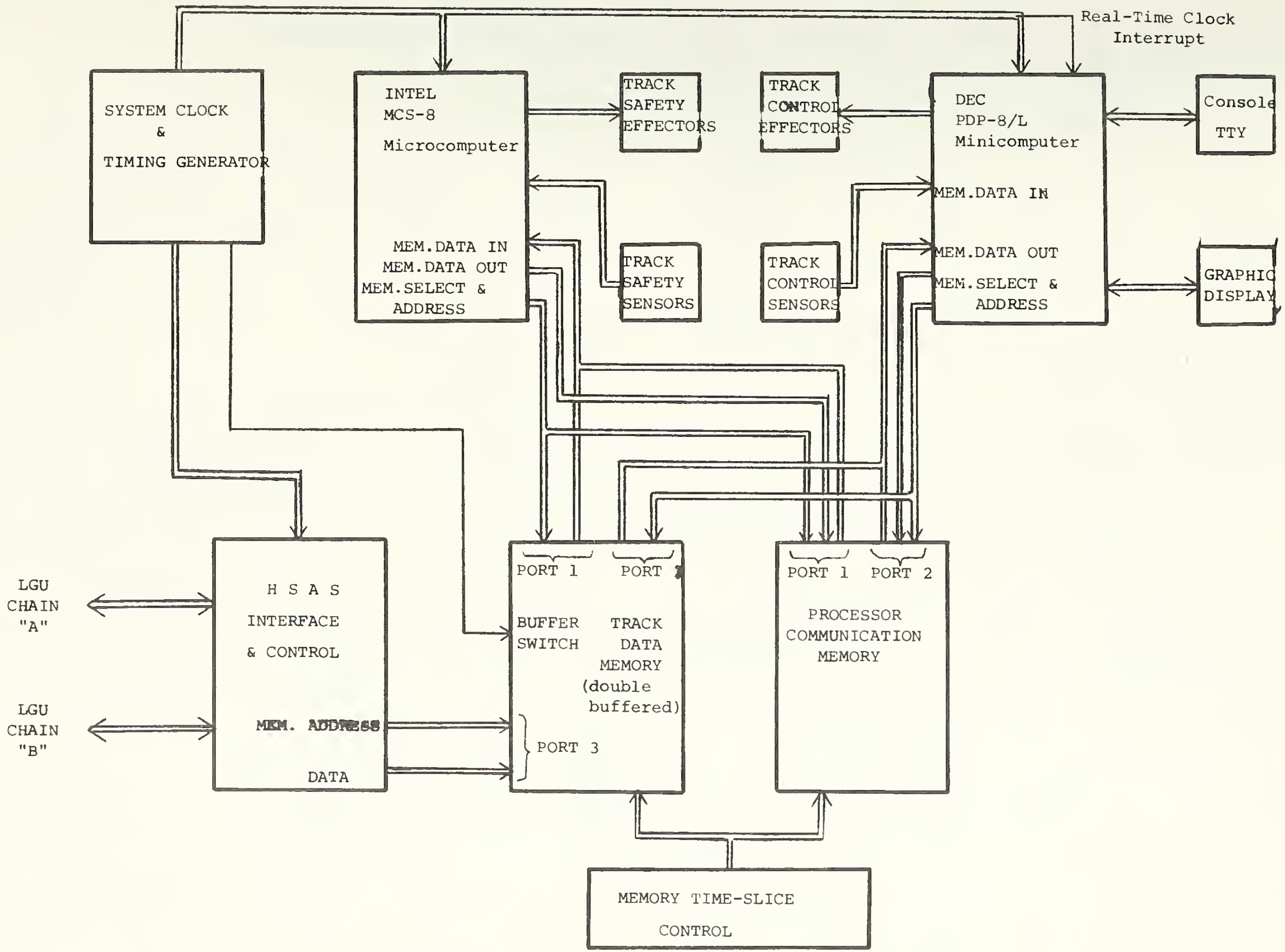


Figure 5-9. System Block Diagram

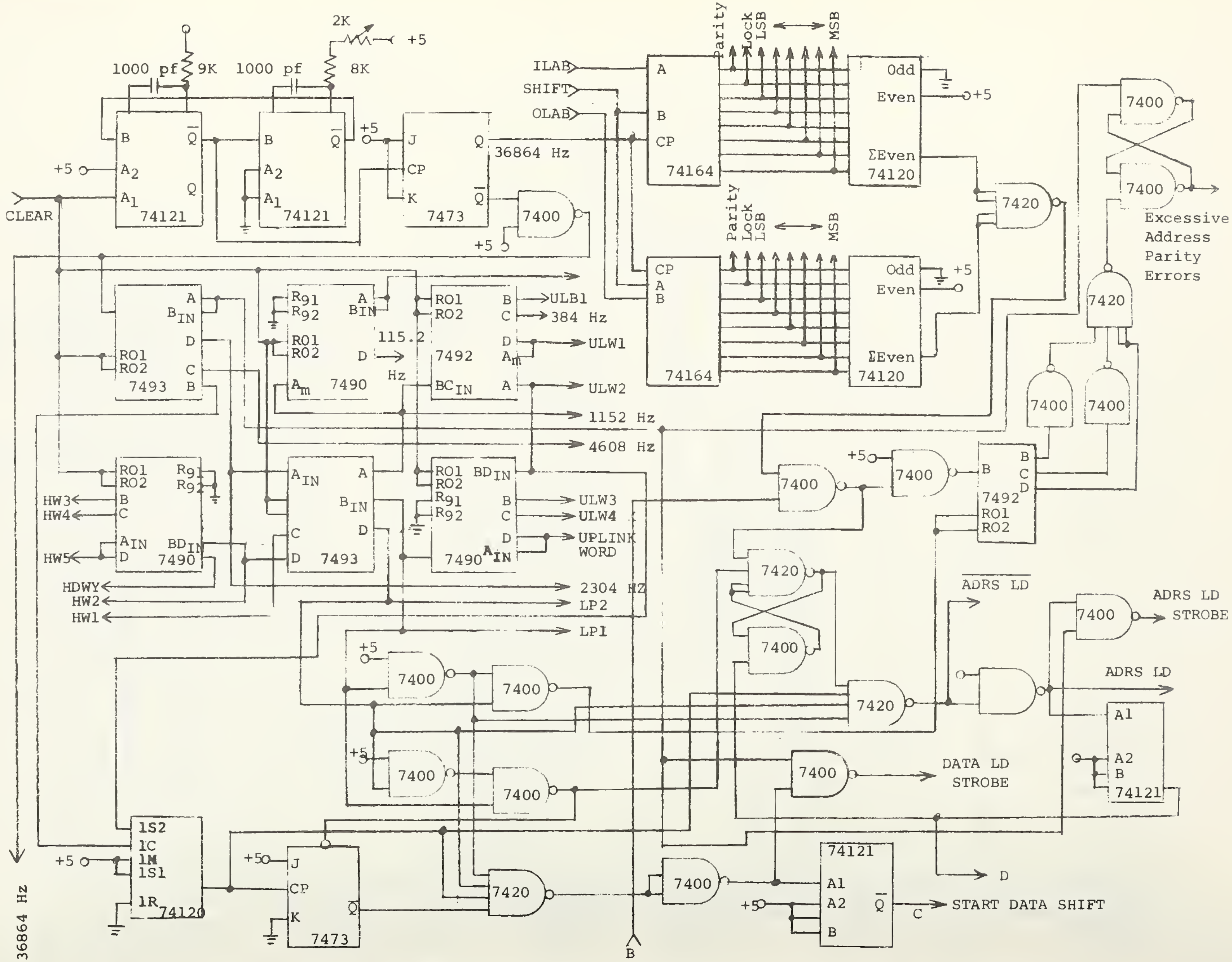


Figure 5-10. System Clock, Timing Generator Interface & Control Schematics

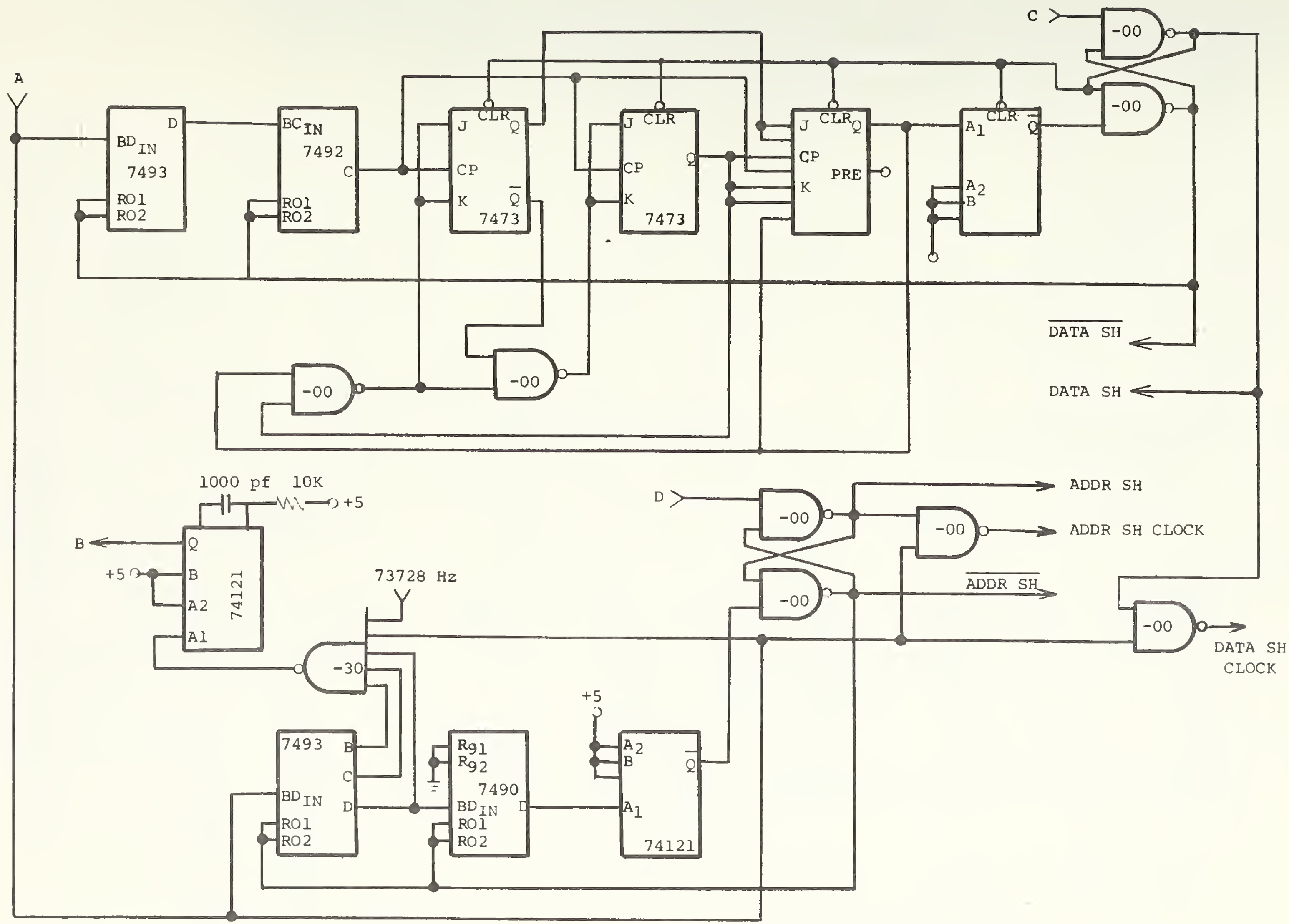


Figure 5-11. System Clock, Timing Generator Interface & Control Schematics

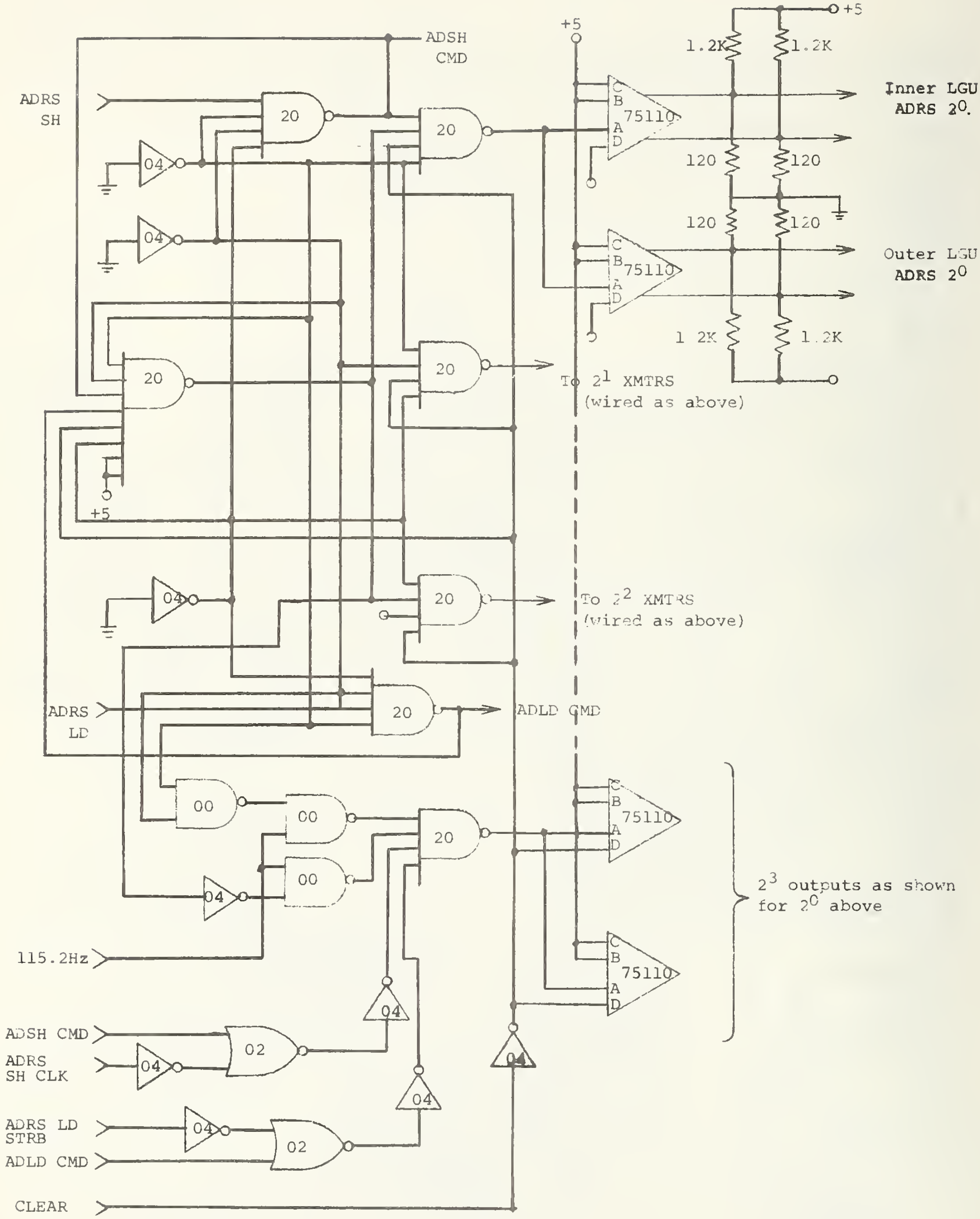


Figure 5-12. System Clock Timing Generator Interface and Control Schematics

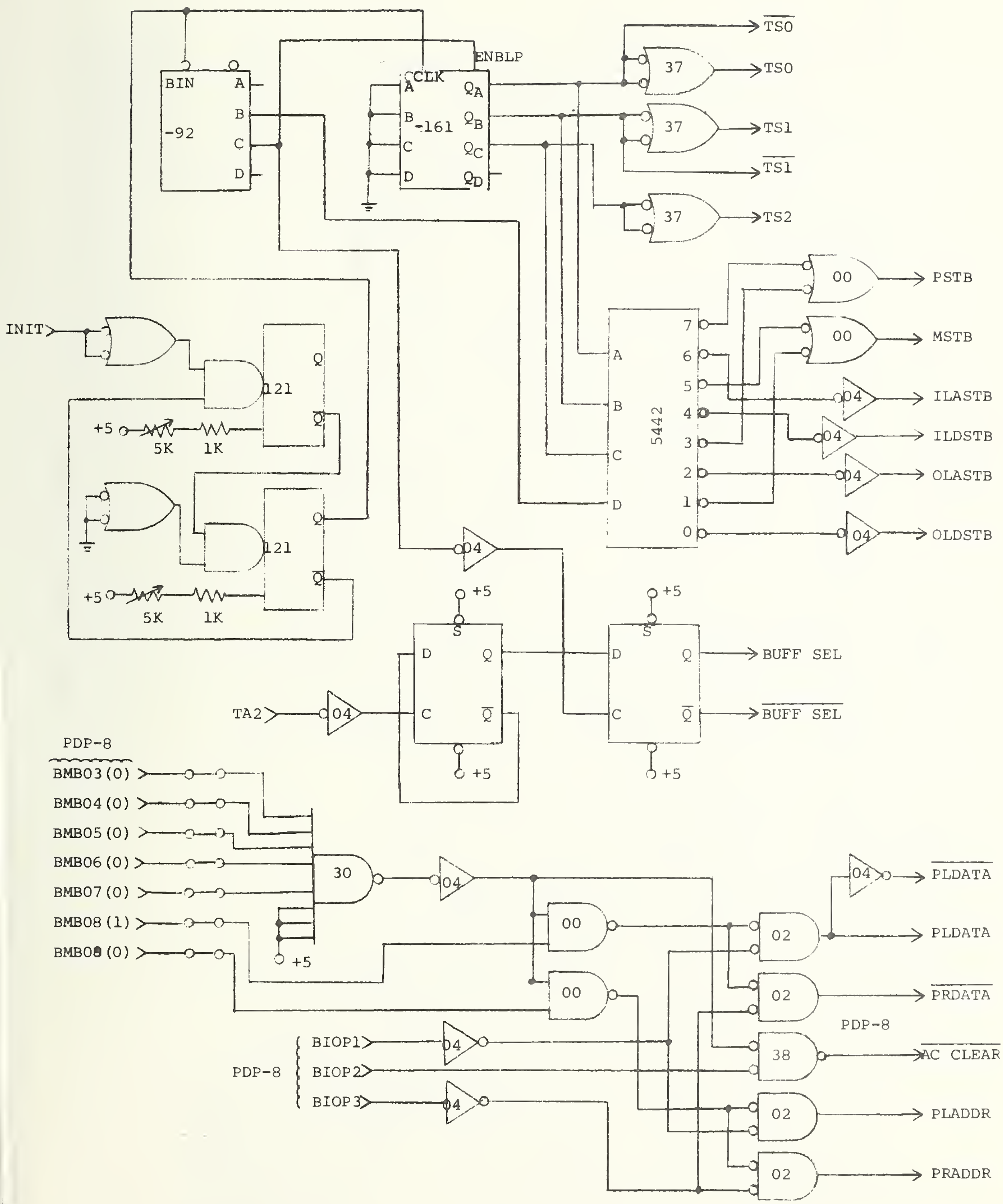


Figure 5-13. System Memory and Memory Control Circuits

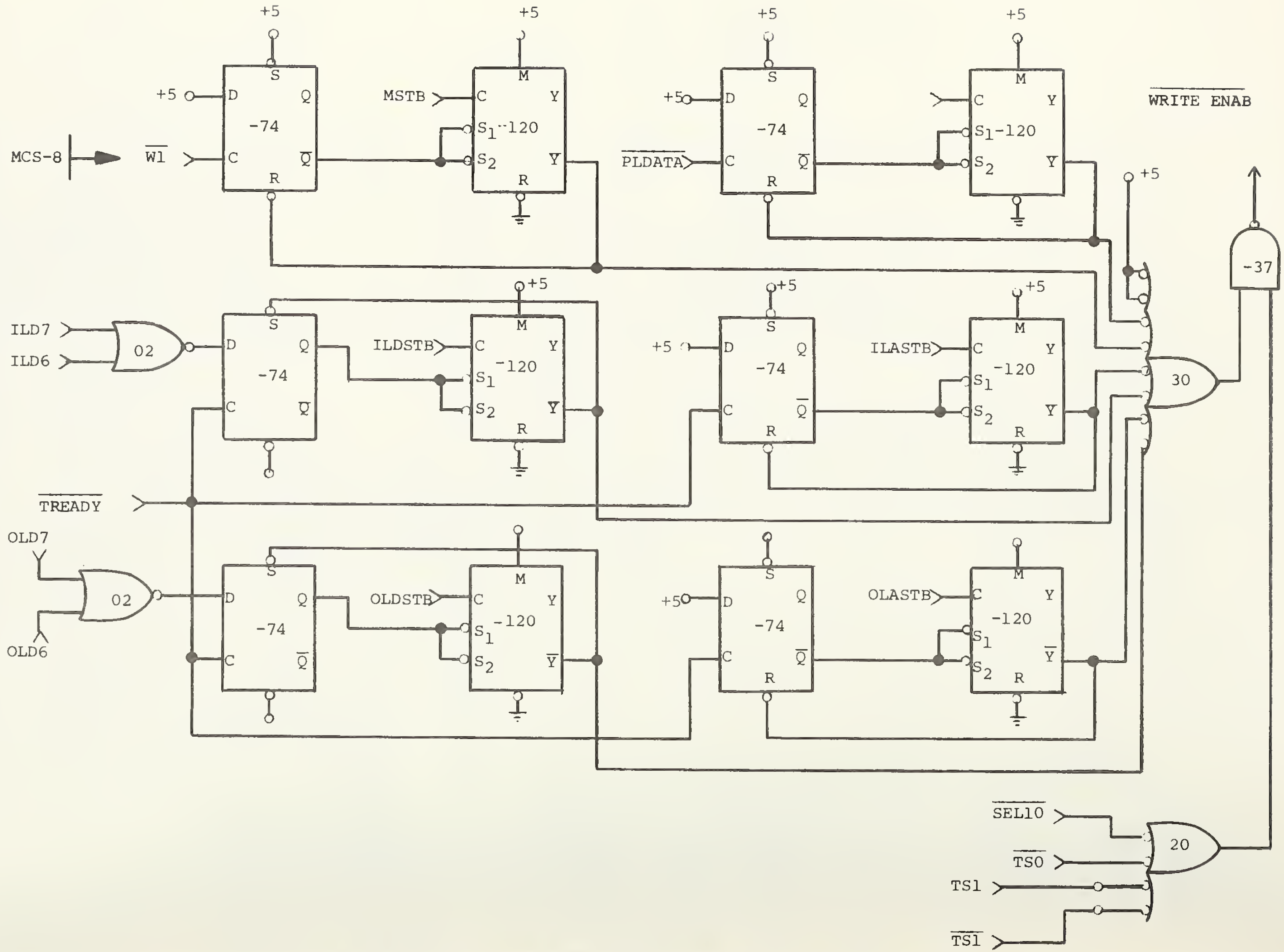


Figure 5-14. System Memory and Memory Control Circuits

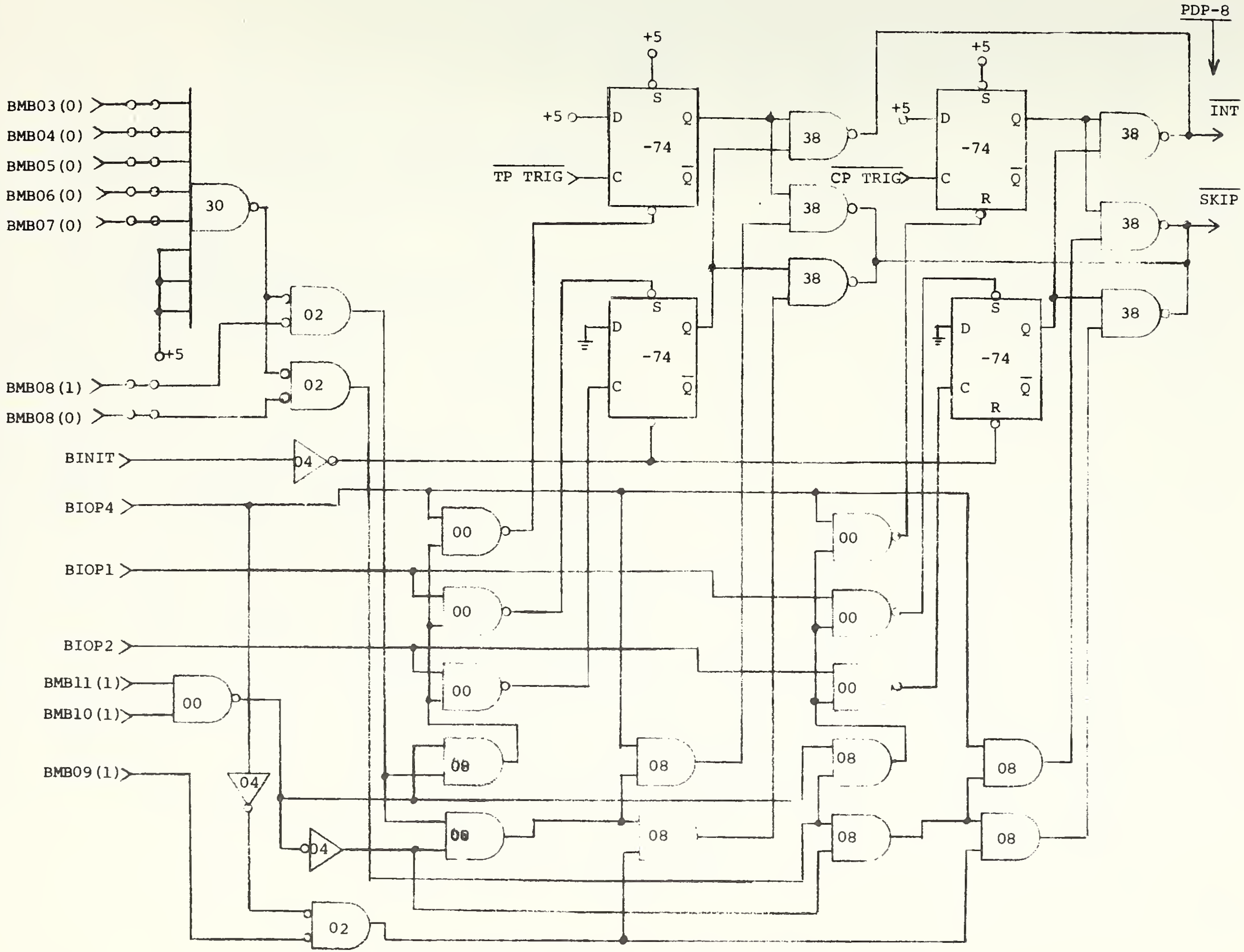


Figure 5-15. System Memory and Memory Control Circuits

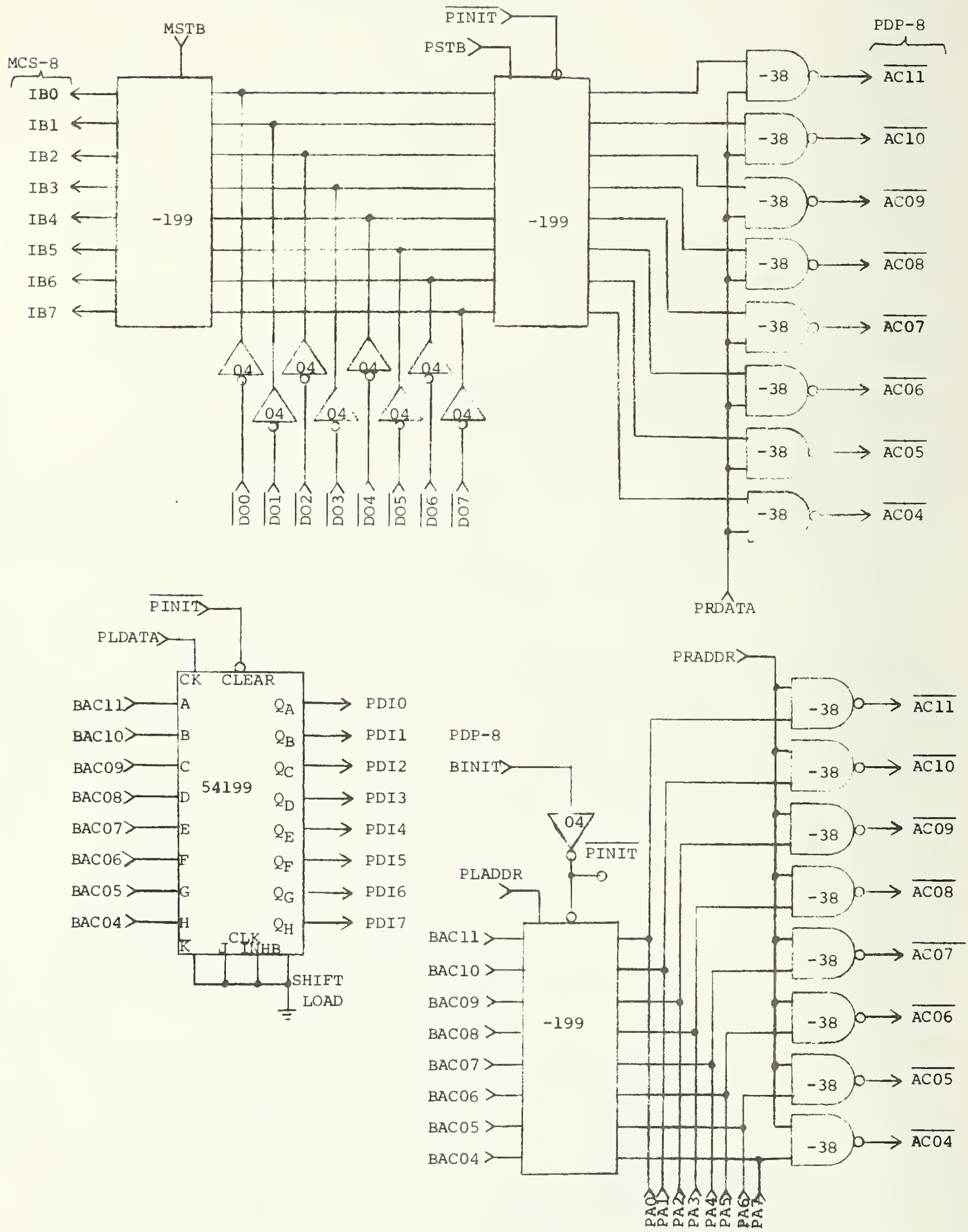


Figure 5-16. System Memory and Memory Control Circuits

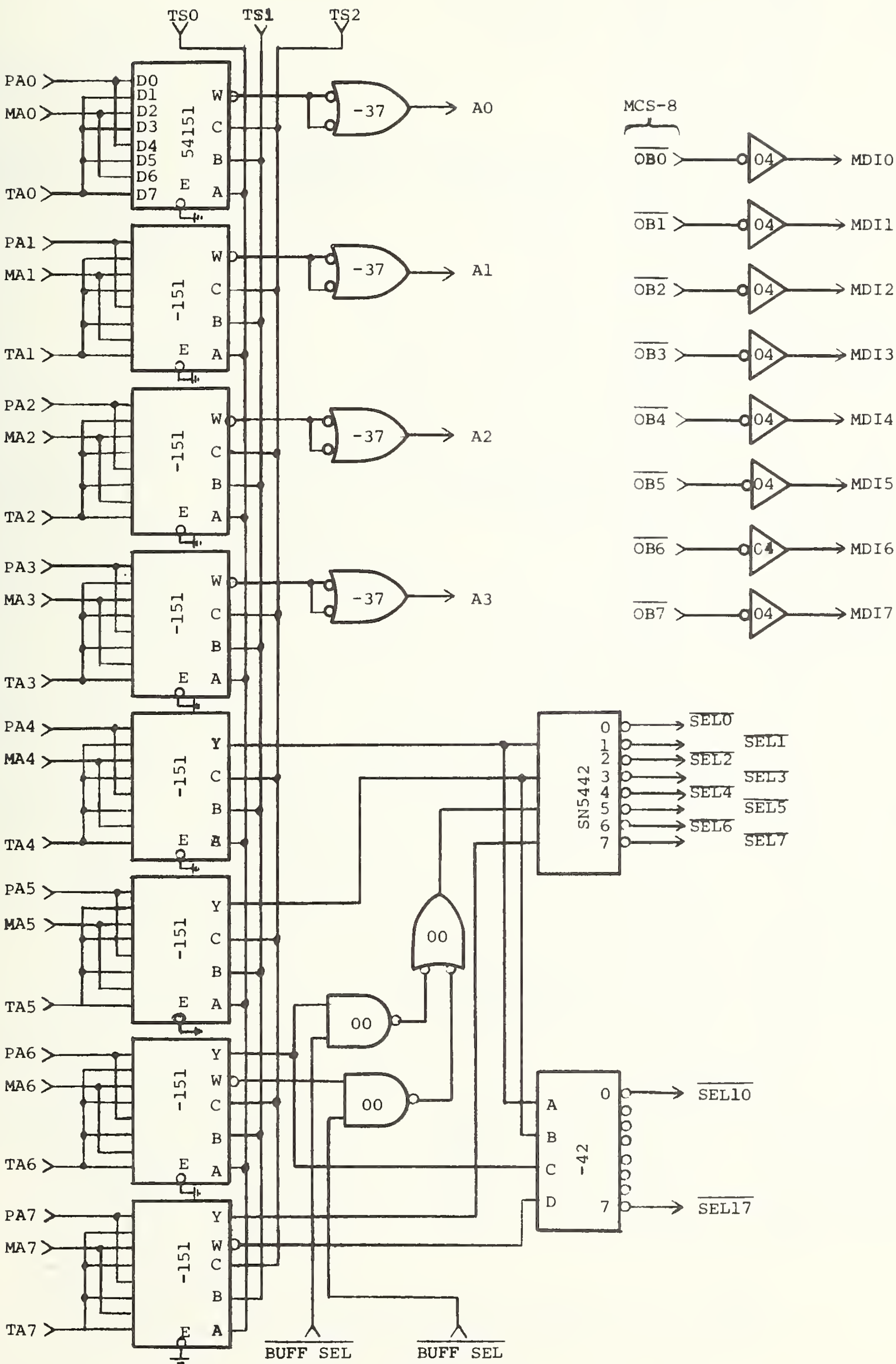


Figure 5-17. System Memory and Memory Control Circuits

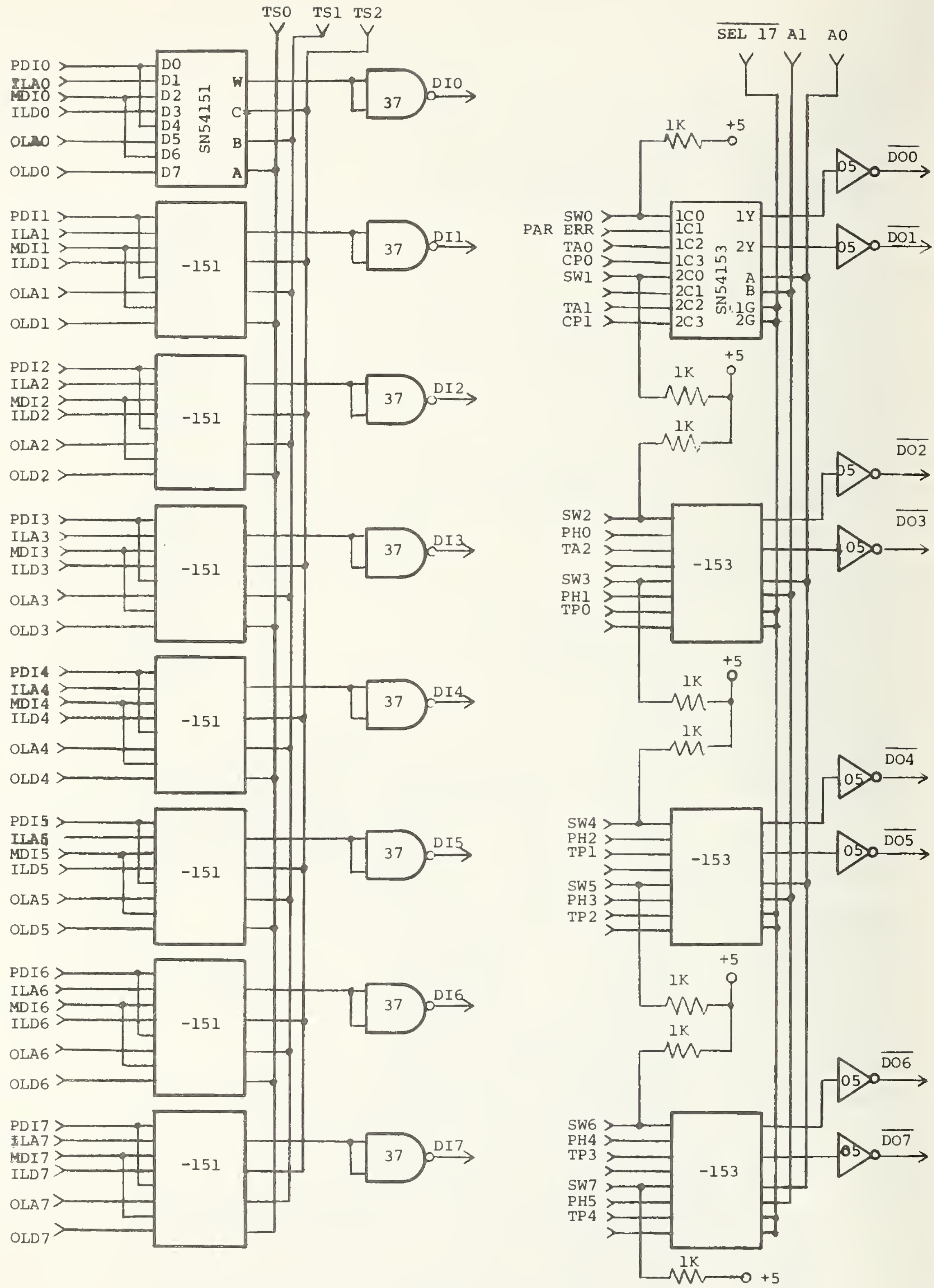


Figure 5-18. System Memory and Memory Control Circuits

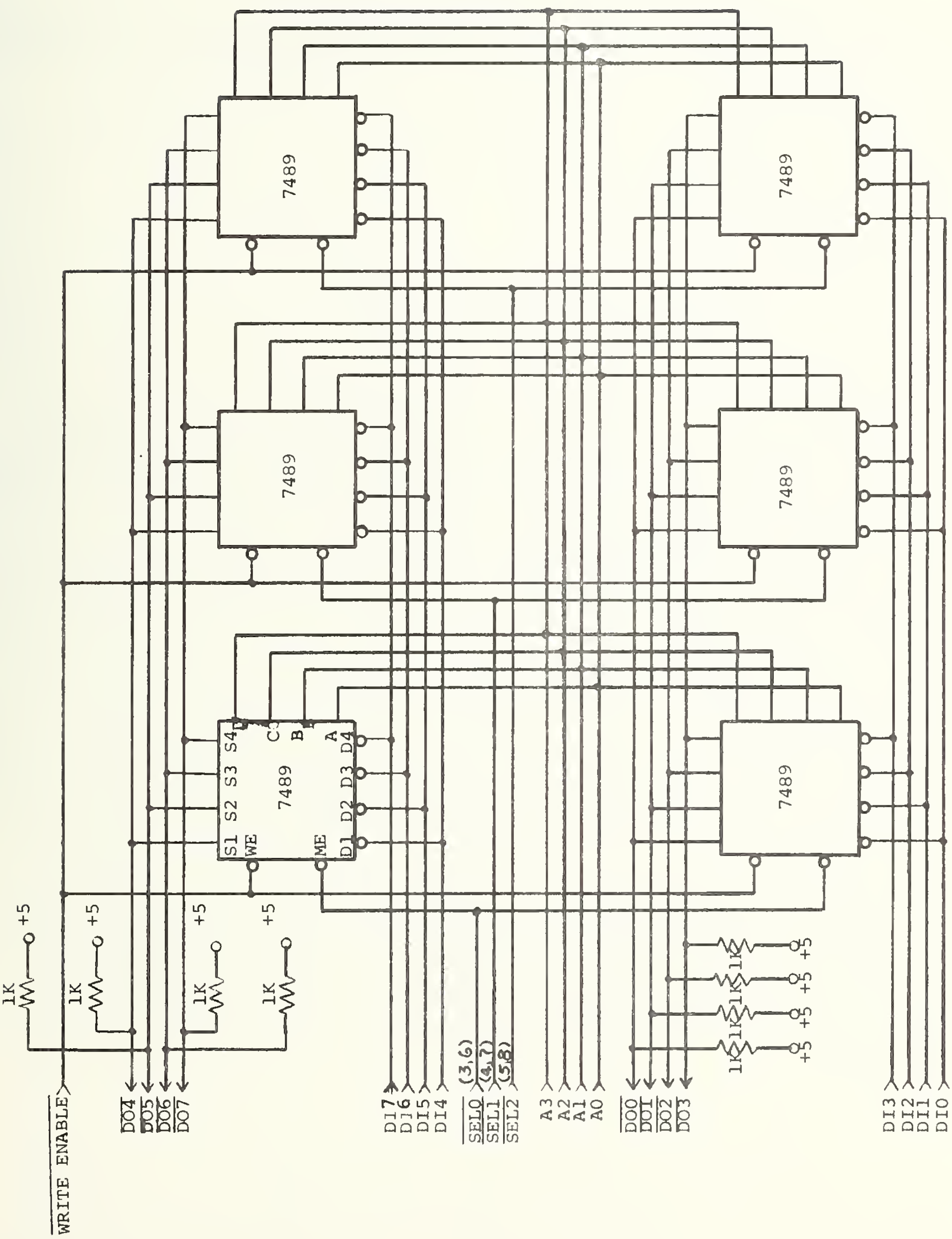


Figure 5-19. System Memory and Memory Control Circuits

5. CLEAR -- the address counter in each LGU is set to the highest value for that particular LGU (number of last loop in that LGU) so that the next loop address is loop number 0.

6. SEARCH CLOCK -- The 115.2 Hz timing clock that allows the address counter to search each loop in a particular LGU until a car is located and "locked" with the phase lock loop receiver. The search clock then allows tracking of a vehicle within any LGU.

During normal track operation the Load, Shift and Search Commands are sent in the following manner. In the middle of each loop time when each vehicle should be in the center of the loop it occupies, a "Load" command and strobe are sent to the inner and outer LGUs. Following this operation, a "Shift" command and 40 (8 bits per address word X 5 LGUs per chain) shift strobes are outputted on the LGU command lines. As the address data is received by the CCIU, even parity is verified. If non-valid parity is detected, a second Load/Shift sequence is sent out (118.6 msec after the first). Parity is checked a total of three times. If, after these three attempts (237 msec - 3.38 ft) valid parity data is not received, an "Excessive Parity Error" flag is set for the Headway/Safety Computer. When the Headway/Safety Computer senses this flag's presence, car location data is not valid and a Safety hazard is declared.

The "Count Up/Down Absolute" and "Clear" signals are used for test purposes to verify correct operation of the LGUs. A "Clear" signal given on the LGU Command lines will set all address counters so that the next count command (search or count up/down absolute) will force all zeros in the counter. The operation of all address counter logic is checked by clearing, sending a predetermined number of "Count Up Absolute" strobes and a non-identical number of "Count Down Absolute" strobes, and then comparing the address words returned after a load/shift pair with a predicted value.

5.4.3 Interface of Control Signals and Data Returns to/from LGU Chains

Matched receivers/drivers are used with balanced, terminated twisted pairs. The receivers detect low level differential signals in the presence of common mode noise and temperature and supply voltage variations.

5.4.4 Track Data Memory

As the Address Data is serially shifted along the Address Transmission line, it is converted to the eight bit "Par, Lock, Adrs" word associated with the proper LGU identifier and read into the Track Data Memory. The Octal Memory addresses for each LGU's address word are:

Octal Memory Adrs	LGU	
000	A)	
001	B)	
002	C)	-- Outer Loop
003	D)	
004	E)	
010	H)	
011	J)	
012	K)	-- Inner Loop
013	F)	
014	G)	

Memory Locations 200 through 217 are available for communications between the Headway and Control Computers. Either computer may read or write into these locations. For example, the word in location 203 is the switch verification word written by the Headway Computer and read by the Control Computer. The 100_8 bit when high signifies that a car is in the switch area. The 001 bit signifies switch at the BJ switch area, whereas the 002 bit signifies switch at the DG switch area. The switch bit is low for a switch right and high for a switch left. Therefore, if a vehicle arrived at the switch verification location after the BJ handoff area and was on the inner loop (LGU J) the word in location 203 would be 101_8 (assuming no vehicle in DG switch area).

The timing of the Track Data Memory is such that both the Headway and Control Computers have free access to track data without interfacing with data availability of the other computer.

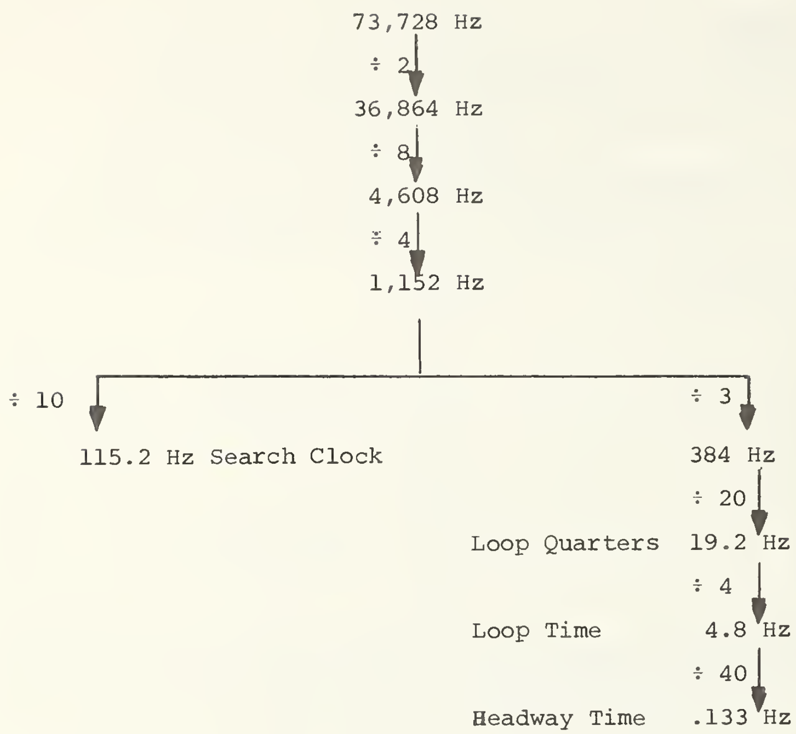


Figure 5-20. Derivation of 8.33 Second Headway

5.5 DETAILED BEACON DESIGN

The on-board transmitter provides a beacon signal of 135 KHz by which the vehicle may be tracked through the system. The transmitter consists of a voltage controlled oscillator (SE 566 Function Generator) whose output is switched to drive a power amplifier stage exciting an antenna on the right side of the car or a secondary power amplifier to excite an antenna on the left side of the car. The antennas are mounted on or immediately behind the guidewheels, and are excited by a minimum current of 2.0 amperes pk-pk.

A block diagram of the system is presented in Figure 5-21

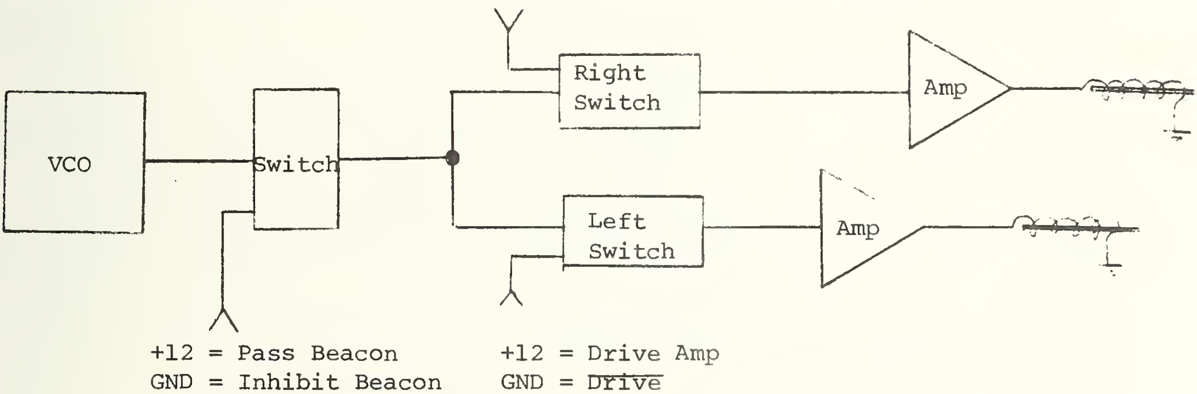


Figure 5-21. Block Diagram of System

Note that the block diagram also includes a beacon inhibit switch. This switch is used to simulate a transmitter failure by shutting off drive to both antennas upon receipt of a computer command to do so. The right and left switches are actuated by on-board electronics allowing transmission only to the wall towards which the car is switched.

A detailed schematic of the VCO, beacon inhibit switch, and right and left drive switch circuitry is shown in Figure E-22. Power amplifier circuitry is presented in Figure E-23 and antenna construction in Figure E-24.

The SE 566 Function Generator was selected as the basic frequency source because of its extreme stability of frequency (100 ppm/°C typical) and for its ease of frequency adjustment (frequency adjustable over 10 to 1 range with same capacitor). For oscillation, the control terminal (pin 5) must be biased externally with a voltage (V_C) in the range

$$3/4\ V^{+} \leq V_C \leq V^{+}$$

where V_{CC} is the total supply voltage (refer to Figure 5-22 Control voltage V_C is set by the voltage divider formed with resistors R2 and R3, and the temperature compensation diodes D1, D2, and D3. With the supply voltage (V^+) of 10.94 volts and values of R2 and R3 being 1.8K Ω and 10.0K Ω respectively, V_C is established at 9.57 volts and the above condition satisfied. The frequency is given approximately by

$$fo \approx \frac{2(V^+ - V_C)}{R_1 C_1 V^+}$$

where R_1 is in the range $2K < R_1 < 20K$ Ω.
A value of 220 pf was chosen for C_1 (primarily because temperature stable mica capacitors of this value range were readily available), resulting in a nominal value of 8.4K Ω for R_1 for an oscillation frequency of 135 KHz. As may be seen from the schematic R_1 is comprised of a 2K Ω potentiometer in series with 7.5 K Ω for frequency adjustment. The oscillator was tested over a temperature range of -40°C to 85°C and found to deviate 0.5% or less from reference frequency at 25°C. For frequency stability over extended temperature ranges, R_1 and C_1 should exhibit temperature coefficients of 100 ppm/°C or less. The transistor stage prior to the beacon pass/inhibit switch is used to prevent loading effects on the oscillator when the right and left amplifier loads are switched in or out.

Antenna mounting and position relative to wayside receiver loops is shown in Figure 5-25

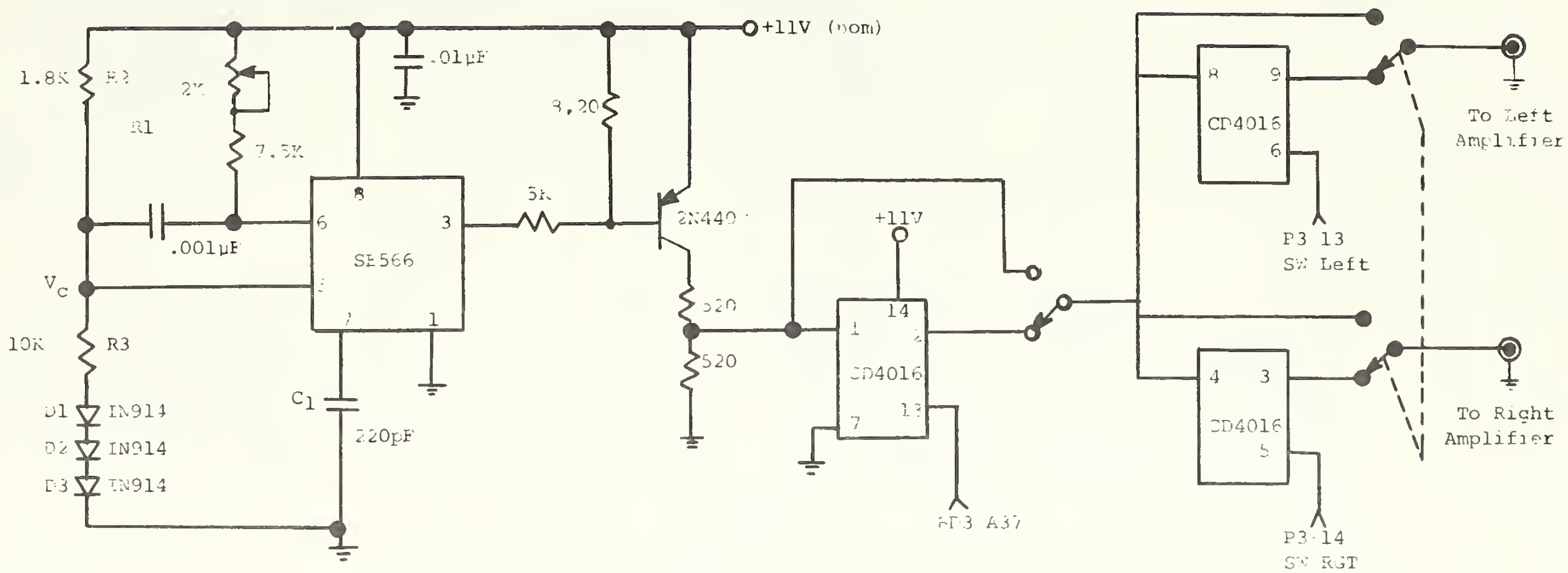
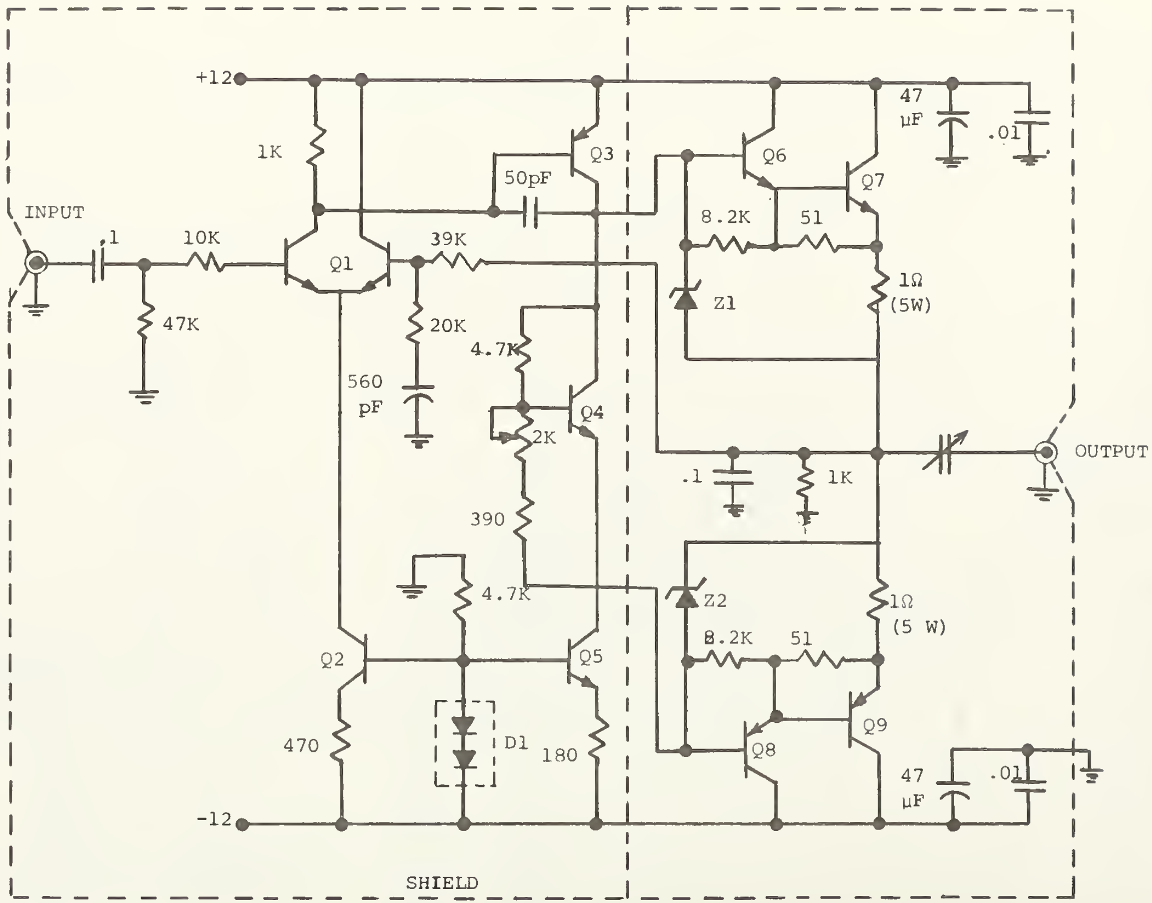


Figure 5-22. HSAS 135 KHz Beacon Transmitter Frequency Source & Switching Circuits

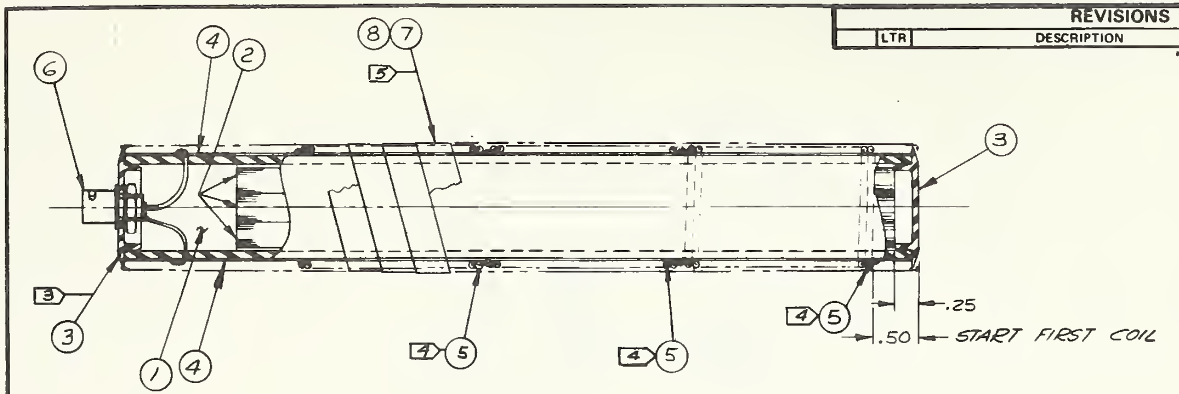


Q1 - 2N2920
Q2,Q4,Q5 - 2N4401
Q3 - 2N4403
Q6 - 2N4237
Q7 - 2N5067
Q8 - 2N4234
Q9 - 2N4901

D1 - Mz2361
Z1, Z2 - IN5231B

Figure 5-23. HSAS 135 kH Beacon Transmitter Power Amplifier (RGT and Left Amplifiers are Identical)

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



1. MAT'L: .33±.02 DIA x 7.52 LG. Q1 ANTENNA ROD OR EQUIV. INDIANA GENERAL VALPARISO, IND. 46383
2. CUPLUGS DIV. PROTECTIVE CLOSURES Co. INC. BUFFALO, N.Y. 14207
3. DRLL THRU CUPLUG (3) INSTALL CONNECTOR (6)
4. SOLDER ONE END OF WIRE (5) TO TAPE (4) TURN 67 FULL TURNS & SOLDER TO OPP. TAPE. TYP 3-PLACES
5. MASK WIRES (5) FULL LENGTH WITH MASKING TAPE (7) & WETHER PROVE WITH 2-COATS OF VARNISH (8)

QTY	PART NO.	FIND NO.	DESCRIPTION	NOTE
A/R		8	VARNISH	
A/R	.50 WIDE	7	DUCTING TAPE	
1	UG-1094/U	6	CONNECTOR, ANTENNA	
A/R	3 COND # 26	5	WIRE ELECTRICAL, INSULATED	
A/R	.25 WIDE X1194	4	COPPER, CONDUCTIVE TAPE	
2	BPF-1	3	CAPLUG - BUTTON PLUG	2
7	F214-1	2	ANTENNA ROD	1
1	1.00 ID x 9.00 LG.	1	TUBE (PVC FLEX. TUBING)	
-/-	-1	-/-	ANTENNA ASSY	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLES ±2°
DECIMALS XXX ±.010
DECIMALS XX ±.030
FRACTIONS ±1/16"

DWN	LWatten	2-2-73
CHK	K. Cowey	2-2-73
ENGR	K. Cowey	2-2-73
ORG		
PROGRAM APPROVAL		
NEXT ASSY		

ALDEN SELF-TRANSIT SYSTEMS CORPORATION
MILFORD INDUSTRIAL PARK
MILFORD, MASS. 01757

SIZE B | SCALE FULL | SH 1 of 1 | REV.

Figure 5-24. Antenna Assembly

1 POWER COLLECTOR

2 BUS BAR HOUSING

3 TRANSMITTER ANTENNA

4 LATERAL GUIDEWHEEL

5 RECEIVER LOOPS

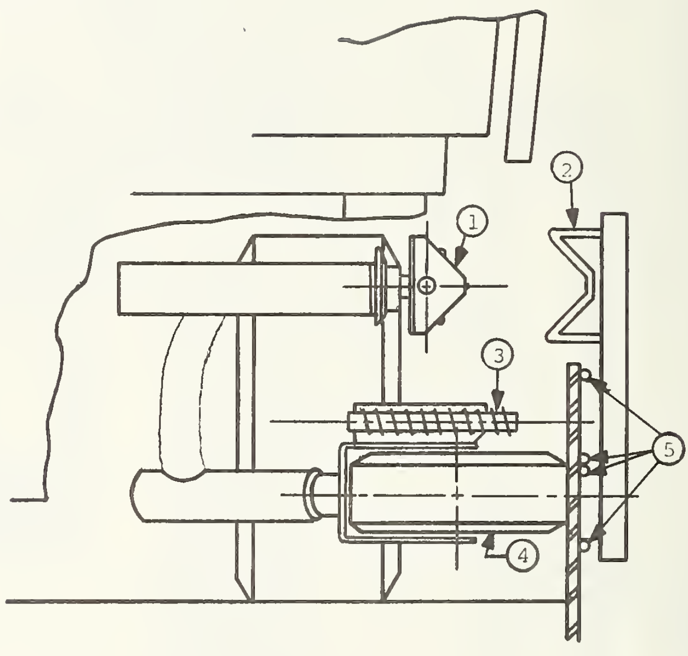


Figure 5-25. Beacon Transmitter Antenna Mounting

6. TEST PROGRAM

The test program was designed to evaluate, under controlled test conditions, the performance of the HSAS designed under this contract and installed at the Alden test track facility at Bedford, Massachusetts. The design was based on the following concepts:

1. An onboard transmitter drives a current-fed antenna at a nominal frequency of 135 KHz which is used as a beacon to locate the vehicle.
2. This antenna is magnetically coupled to short receiving loops mounted end-to-end along the guideway.
3. The outputs from these loops are fed in groups, each group through a selector switch, to a single phase-lock receiver arranged to "track" a vehicle proceeding loop to loop. A single group of loops and its associated receiver is referred to as a Local Guideway Unit (LGU).
4. The location of all vehicles (i.e., the loop which is receiving the signal from the onboard transmitter) is communicated to a wayside computer which determines if the system is operating safely, and if not, initiates system shutdown.

6.1 TEST PLAN OBJECTIVES

The test plan specified four types of tests:

1. Static Tests -- To determine that the components of the system performed as designed prior to installation at the test track.
2. Installation Tests -- To verify the operation of system components under the ambient conditions present at the test track.
3. Parameter Tests -- To verify that the parameter values used in the HSAS design were correct.
4. System Tests -- To demonstrate the HSAS, as designed and installed, was adequate to protect the system safely in case of either overspeed or underspeed on the acceleration/deceleration ramps as well as the main line.

Prior to discussion of test results, the following items are noted:

1. Trip Definitions -- The Alden test track facility consists of two off-line stations situated approximately opposite each other on an oval guideway. The control system can schedule trips from one station to the other or from either station back to itself. Up to seven orbits may be scheduled; an orbit consists of passing the launch station on the main guideway. Thus, a trip from Station 1 to Station 2 with two orbits would consist of launching the vehicle from Station 1, allowing it to circulate on the main-line guideway passing Station 1 twice, and then switching it into Station 2.

2. Data Displays -- A CRT display has been developed which shows the complete test track or portions thereof. The display shows status of the test track, vehicle positions as seen by the HSAS, etc. The display was intended primarily for use in system check-out, but was also used to the extent feasible in system testing.

6.2 RESULTS OF HSAS TESTING

Test descriptions and results are discussed in this section. Raw data for tests is found in Appendix A.

A. Bench Tests: All LGUs and onboard transmitters were bench tested prior to installation at the track. These tests were as follows:

1. For each LGU it was verified that each loop address selected the proper loop, and that each loop address selected only one loop.

2. Each LGU was tested for correct reception, decoding, and response to the following commands from the computer:

   A. Load Address
   B. Shift
   C. Count Up Absolute
   D. Count Down Absolute
   E. Clear Counter
   F. Search Count

The beacon transmitter oscillator was tested over a temperature range of -40° C. to 100° C. and found to vary less than .5% frequency change from -40° C. to 80° C. A curve of this test is presented on Page I-1 of Appendix A.

B. Installation Tests: These tests consist of:

1. Noise Susceptibility
2. Tracking

6.2.1 Test Plan Objectives In this test, both vehicles were used under manual control. The first vehicle was launched from Station 1 and was controlled to attain a velocity of approximately ten miles per hour. The second vehicle was launched from Station 1 approximately eight seconds later and followed the same trip as the first vehicle. This trip consisted of remaining switched right at Switch No. 1, switching left at Switch No.2, remaining left at No.1, (this caused the vehicle to enter Station 2) and switching right at No. 2 to re-enter Station 1. The test run consisted of repeating this trip ten times. During the run, the HSAS transmitters were shut off, but all command transmitters remained on. (This included the transmitters on the acceleration/deceleration ramps.)

As the vehicles were circulating around the track, the computer controlled the LGUs with the command sequence shown on Page II-1 of Appendix A. This sequence caused the LGUs to first inspect all loop 0's for vehicle occupancy and then at approximately ten millisecond intervals loop 1's, 2's, etc. until the guideway was completely inspected.

In this test run of ten trips, no LGU indicated loop occupancy and the system is therefore considered to have passed the test.

6.2.2 Tracking It was originally planned that for this test, a single vehicle, under manual control, would make two orbits from Station 1 to Station 2, and two orbits from Station 2 to Station 1, at an approximate main line velocity of 10 mph. The computer would then control the LGUs with the command sequence used in the Noise Susceptibility Test. After the vehicle was launched, it would be tracked by successive LGUs for the entire test run, with no more than one LGU indicating vehicle presence at any one time.

This test was never formally performed for the specified number of orbits; however, in debugging the LGUs after installation, similar testing was performed. The computer printouts of data for the Controllability Test (pages III-4 to III-31, Appendix A) show tracking through individual LGUs. Confirmation that only one LGU at a time would indicate vehicle presence, was made by observation of the CRT data display. Although this data shows the car did not lock on all loops and thus technically failed the test requirements, it should be noted that this failure was not due to HSAS logic but to loop and test track hardware problems. These problems will be covered later on in this report.

6.3 PARAMETER VALUE TESTS

These tests consisted of

1. Lock/Unlock
2. Beam Width
3. Vehicle Controllability

6.3.1 Lock/Unlock

The lock/unlock interval may be defined as the time between the instant that the vehicle, in leaving loop n-1, causes the phase lock loop to become unlocked to the instant that the vehicle is positioned in the next loop n, causing the phase lock loop to again lock up.

Test values for this parameter were obtained by monitoring typical LGU lock signals by use of the test set up shown on Page III-1 of Appendix A. The car was manually driven around the track at approximately system speed, and the test was performed on two randomly chosen loop boundaries in each LGU. Three runs were performed for each boundary. Typical measured intervals were 0.3 to 2.0 msec, with an occasional interval of 3.5 to 4.5 msec. Full test data is listed on Page III-2 of Appendix A.

6.3.2 Beam Width

Beam Width is the distance that a vehicle mounted antenna can be placed beyond the end of a receiver loop before the receiver locks onto the loop. See Figure 6-1

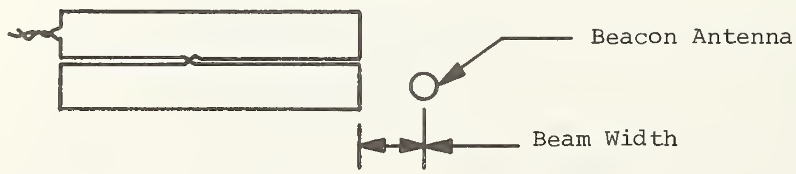


Figure 6-1. Beam Width

Measurements were made by disconnecting loop n-1 and moving the beacon transmitter antenna towards loop n until lock was obtained. The parameter was measured at two loop boundaries at each LGU. Results are shown below.

LGU NO.	Loop Boundary	Beam Width
A	2-3	2.5"
A	8-9	2.5"
B	1-2	2.5"
B	7-8	3.5"
C	2-3	2.0"
C	10-11	2.75"
D	2-3	3.0"
D	6-7	3.5"
E	3-4	2.5"
E	12-13	2.5"
F	1-2	3.0"
F	5-6	2.75"
G	4-5	3.5"
G	7-8	6.25"
H	6-7	3.5"
H	10-11	3.5"
J	2-3	2.5"
J	7-8	2.5"
K	3-4	2.5"
K	9-10	1.0"

Design criteria was for a maximum beam width of 0.6 feet, thus the test is considered passed.

6.3.3 Vehicle Controllability The purpose of this test was to determine if vehicle controllability was equal to or better than the controllability assumed in the headway calculations. Controllability determines loop size and is most important on the deceleration ramps. Prior to conducting this test, the vehicle onboard control electronics were adjusted to give optimum performance.

For this test, a single vehicle was used under computer control, with various trip profiles. The onboard transmitter was on and the HSAS was set to the tracking mode. As the slots passed over the center of each loop, the computer commanded the LGUs to transmit their status back to the computer. During the test runs, only one LGU indicated vehicle presence at any one time. Comparison of the loop address containing the vehicle with the loop address of the slots determines the controllability. If the two are not equal, the controllability is worse than the assumed value.

```
LGU C

4567/ØØØ4 3?
4567/ØØØ4 3
4570 /ØØØ3 2
4563/ØØØØ Ø

W
5353 /Ø223
5354 /Ø3ØØ
5355 /Ø3ØØ
5356 /Ø3ØØ
5357 /Ø3ØØ
5360 /Ø3ØØ
5361 /Ø3ØØ
5362 /Ø3ØØ
5363 /Ø3ØØ
5364 /Ø1Ø1
5365 /Ø1Ø1
5366 /Ø1Ø1
5367 /Ø1Ø1
5370 /Ø1Ø1
5371 /Ø1Ø1
5372 /Ø1Ø1
5373 /Ø1Ø1
5374 /Ø1Ø2
5375 /Ø1Ø2
5376 /Ø1Ø2
5377 /Ø1Ø2
5400 /Ø1Ø2
5401 /Ø1Ø2
5402 /Ø1Ø2
5403 /Ø1Ø2
5404 /Ø3Ø3
5405 /Ø3Ø3
5406 /Ø3Ø3
5407 /Ø3Ø3
5410 /Ø3Ø3
5411 /Ø3Ø3
5412 /Ø3Ø3
5413 /Ø3Ø3
5414 /Ø1Ø4
5415 /Ø1Ø4
5416 /Ø1Ø4
5417 /Ø1Ø4
5420 /Ø1Ø4
5421 /Ø1Ø4
5422 /Ø1Ø4
5423 /Ø1Ø4
5424 /Ø3Ø5
5425 /Ø3Ø5
5426 /Ø3Ø5
5427 /Ø3Ø5
5430 /Ø3Ø5
5431 /Ø3Ø5
5432 /Ø3Ø5
5433 /Ø3Ø5
5434 /Ø3Ø6
5435 /Ø3Ø6
5436 /Ø3Ø6
5437 /Ø3Ø6
5440 /Ø3Ø6
5441 /Ø3Ø6
```

Figure 6-2. Sample Computer Printout of LGU-C Status

Computer printouts of LGU status for all LGUs are given on Pages I-26 thru I-53 of Appendix A. A sample of this data is presented in Fig. 6-2. Here we are looking at the status of the first six loops in LGU C. At time intervals corresponding to printout addresses 5357, 5367, 5377, 5407, 5417, and 5427, the car should be at the centers of the loops 0, 1, 2, 3, 4, and 5 respectively in LGU C. The data at these time intervals indicate by the first two bits whether lock has occurred (01 or 03 indicates lock, 00, or 02 indicate no lock), and by the third and fourth bit, the loop the vehicle is in. Thus at time interval corresponding to address 5357, 0300 shows the car locked on loop 00, at 5367 the vehicle is locked on loop 01, etc.

Printout addresses corresponding to the times the slots pass loop centers are given in Table 6-1.

Table 6-2 presents a summary of LGU status as reduced from computer printout data. A Ø (zero) indicates the vehicle was in the correct loop. An A"n" indicates the vehicle was ahead n loops and a Bn indicates the vehicle was behind n loops. An X indicates the loop in question did not lock onto the vehicle.

The data shows the vehicle to be ahead one loop for the first nine loops of acceleration LGUs A and F. The explanation for this discrepancy is as follows: Figure 6-3 shows the vehicle track position prior to launch.

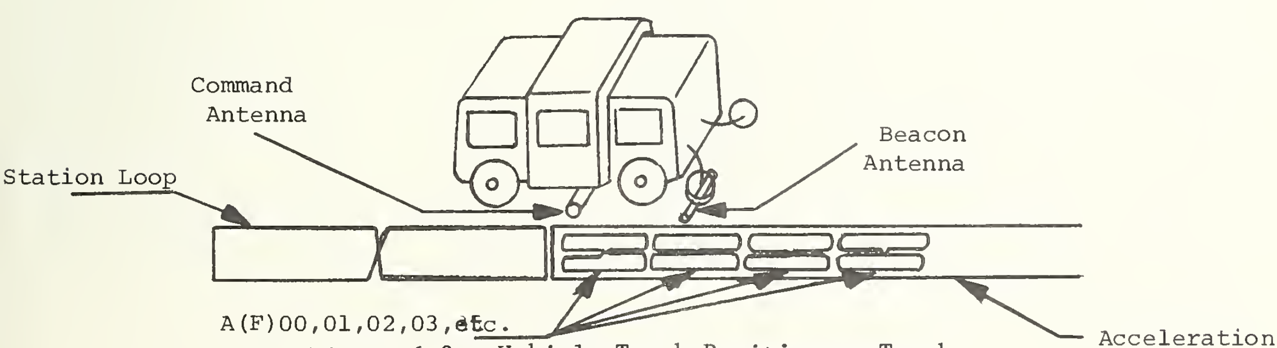


Figure 6-3. Vehicle Track Position on Track Prior to Launch

The car creeps forward until loss of station carrier occurs as detected by command receiver antennas. Because of inductive coupling between the station and acceleration loop, loss of carrier does not occur until the vehicles command antenna is 1-2 feet past the beginning of the acceleration loop.

TABLE 6-1. PRINTOUT ADDRESSES

Loop	LGU-A	LGU-B,C,D,G,H	LGU-E	LGU-F	LGU-G	LGU-H
00	5433	5357	5355	5373	5357	5355
01	5463	5367	5361	5423	5367	5361
02	5477	5377	5365	5437	5377	5365
03	5507	5407	5371	5447	5407	5371
04	5517	5417	5375	5457	5417	5375
05	5527	5427	5401	5467	5427	5401
06	5537	5437	5405	5477	5437	5405
07	5547	5447	5411	5507	5447	5411
10	5557	5457	5415	5517	5457	5415
11	5567	5467	5421	5527	5467	5421
12	5577	5477	5425		5477	5425
13	5607	5507	5431		5507	5431
14		5517	5435		5517	5435
15		5527	5441		5527	5441
16		5537	5445		5537	5445
17		5547	5451		5547	5451
20		5557	5455		5557	5455
21		5567	5461		5565	5461
22		5577	5465		5571	5465
23		5607	5471		5575	5471
24			5475		5601	5475
25			5501		5605	5501
26			5505		5611	5505
27			5511			5811
30			5515			
31			5521			
32			5525			
33			5531			

TABLE 6-2. SAMPLE TIME: LOOP CENTER

0 = Vehicle in correct loop

An = Vehicle ahead n loops

Bn = Vehicle behind n loops

X = No lock condition

SAMPLE TIME: LOOP CENTER

	L	G	U							
LOOP NO.	A	B	C	D	E	F	G	H	J	K
00	A1	0	0	0	0	A1	X	0	0	0
01	A1	0	0	0	0	A1	0	X	0	0
02	A1	0	0	0	0	A1	0	0	0	0
03	A1	0	0	0	0	A1	0	0	0	X
04	A1	0	0	0	0	A1	X	0	0	0
05	A1	0	0	0	0	A1	0	0	0	0
06	A1	0	0	0	0	A1	0	0	0	0
07	A1	0	0	0	0	A1	0	0	0	A1
10	A1	0	0	0	0	A1	0	0	0	A1
11	0	0	0	0	0	0	0	X	0	A1
12	0	0	0	0	0		0	0	0	A1
13	0	0	0	0	0		X	0	0	A2
14		0	0	0	0		0	X	0	X
15		0	0	0	A1		X	X	X	X
16		0	0	0	A1		X	X	0	A3
17		0	0	0	A1		0	0	0	A3
20		0	0	0	A1		0	0	0	A3
21		0	0	0	A1		0	0	0	A4
22		0	0	0	A1		X	0	X	A4
23		0	0	0	A1		0	0	B1	A4
24					A1				0	A4
25					A2				0	A4
26					A2				0	A4
27					A3					A4
30					A3					
31					A3					
32					X					
33					X					

Since the command receiver antenna is mounted at the middle of the vehicle, and the beacon tranmitter antenna is mounted at the front of the vehicle, the beacon antenna winds up in Loop 01 of LGU-A or F when the car is at rest (prior to launch). This discrepancy could be corrected by modification of antenna locations and/or change of station and acceleration loop placement. It should be noted, however, that even with this initial error, the vehicle is in sync with the slot by the time it reaches main line (LGU-B and/or G).

The vehicle remained in sync in main line LGUs B, C, and D. Disregarding for the moment, the loss of lock indicated in Main line LGUs G, H, and J, the vehicle is seen to have remained in sync except for Loop 23 of LGU-J. The last six loops of LGU-J lie at the beginning of the deceleration ramp, and investigation of the data shows that error starts to build up at this location on the track. Change of deceleration ramp timing and more precise LGU loop placement in this area should correct controllability problems here.

It should again be noted that loss of lock was primarily due to loop and track hardware problems and not HSAS logic problems. Hardware problems are discussed in the section, "Problems and Recommendations."

In both deceleration zones (LGUs E, K), the vehicle is seen to initially be in synchronization but to eventually pull ahead of its theoretical slot. From the consistent direction and rate of error, it may be concluded that controllability here would be improved by changing the deceleration ramp.

After a review of the test data and causes of observed errors, it is felt that the controllability is equal to that used in the headway calculations.

6.4 SYSTEM OPERATION TESTS

System operation is investigated for conditions of

1. Vehicle Underspeed
2. Vehicle Overspeed
3. Beacon Transmitter Failure

6.4.1 Vehicle Underspeed

The purpose of this test was to determine the number of loops that a vehicle would travel past a loop in which an underspeed mode of failure was initiated (i.e., number of loops of travel before HSAS recognizes vehicle is not in its slot). For this test, a single vehicle, under computer control, was launched and on its first orbit was made to fail. Failure was initiated by changing the velocity command word when the car was detected in a predetermined loop. A computer printout of results for a failure initiated in a main line LGU are shown in Figure 6-4. As may be seen from this printout, when the vehicle was detected in Loop 02, an Underspeed Task was initiated in the computer. The computer then transmitted a new velocity command word for a 26 percent underspeed condition. This word was sent out twice, corresponding to printout address intervals 5375 and 5376, since onboard electronics requires two identical commands prior to its acceptance as being valid. At the time corresponding to address location 5377 the vehicle starts to decelerate to 7.2 mph. The HSAS would detect the failure at time corresponding to address 5457 since the vehicle should at this time be in the center of Loop 10 but is detected as being in Loop 07. Each time interval corresponds to approximately 52 milliseconds, so the failure is detected about 2.54 seconds after underspeed starts, corresponding to approximately 26.9 feet (4-1/2 loops) of travel. Results show the HSAS response time to be well within that required to initiate a system shutdown. Had there been a vehicle traveling at main line speed in its correct slot behind the failed vehicle, the distance between them would have narrowed only by 8.8 feet before failure was detected, and shutdown initiated.

6.4.2 Vehicle Overspeed The purpose of this test was to determine the number of loops that a vehicle would travel past a loop in which an overspeed mode of failure was initiated (i.e., number of loops of travel before HSAS recognizes the vehicle is not in its slot). For this test a single vehicle, under computer control, was launched and made to fail on its first orbit. As in the case of underspeed, failure was initiated by changing the velocity command word when the car was detected in a predetermined main line loop. Computer printouts for results of 26% and 13% overspeed conditions are shown in Figures 6-5 and 6-6. In these cases, the Overspeed Task was initiated in the computer when the vehicle was initially detected in Loop 12 of LGU-B. The vehicle started its overspeed condition approximately 156 milliseconds later, corresponding to address 5477. Again, results show the HSAS response time to be well within that required to initiate a system shutdown. Let us assume that a second vehicle had been traveling in its correct slot in front of the vehicle which started a 26% overspeed. At time corresponding to address 5557 on the printout, the HSAS would detect the failure as the vehicle should have been in Loop 20. The failure was detected about 2.54 seconds after overspeed started, corresponding to approximately 40.5 feet of travel. Had the leading car been traveling at main line speed, it would have traveled 36.3 feet, so the

5361	/Ø3Ø0
5362	/Ø3ØØ
5363	/Ø3ØØ
5364	/Ø1Ø1
5365	/Ø1Ø1
5366	/Ø1Ø1
5367	/Ø1Ø1
537Ø	/Ø1Ø1
5371	/Ø1Ø1
5372	/Ø1Ø1
5373	/Ø1Ø1
5374	/Ø1Ø2
5375	/Ø1Ø2
5376	/Ø1Ø2
5377	/Ø1Ø2
537Ø	/Ø1Ø2
54Ø1	/Ø1Ø2
54Ø2	/Ø1Ø2
54Ø3	/Ø1Ø2
54Ø4	/Ø1Ø2
54Ø5	/Ø1Ø3
54Ø6	/Ø1Ø3
54Ø7	/Ø1Ø3
541Ø	/Ø3Ø3
5411	/Ø3Ø3
5412	/Ø3Ø3
5413	/Ø3Ø3
5414	/Ø1Ø4
5415	/Ø1Ø4
5416	/Ø1Ø4
5417	/Ø1Ø4
542Ø	/Ø1Ø4
5421	/Ø1Ø4
5422	/Ø1Ø4
5423	/Ø1Ø4
5424	/Ø3Ø5
5425	/Ø3Ø5
5426	/Ø3Ø5
5427	/Ø3Ø5
543Ø	/Ø3Ø5
5431	/Ø3Ø5
5432	/Ø3Ø5
5433	/Ø3Ø5
5434	/Ø3Ø5
5435	/Ø3Ø6
5436	/Ø3Ø6
5437	/Ø3Ø6
544Ø	/Ø3Ø6
5441	/Ø3Ø6
5442	/Ø3Ø6
5443	/Ø3Ø6
5444	/Ø3Ø6
5445	/Ø3Ø6
5446	/Ø1Ø7
5447	/Ø1Ø7
545Ø	/Ø1Ø7
5451	/Ø1Ø7
5452	/Ø1Ø7
5453	/Ø1Ø7
5454	/Ø1Ø7
5455	/Ø1Ø7
5456	/Ø1Ø7
5457	/Ø1Ø7
546Ø	/Ø11Ø
5461	/Ø11Ø

B1 (2.54 sec. after underspeed starts, corresponding to approx. 26.9 ft.)

Initiate Underspeed Task

Transmit New Velocity

Underspeed Starts

Figure 6-4. 26% Underspeed Test Data Printout

5471	/Ø311
5472	/Ø311
5473	/ØØ12
5474	/Ø312
5475	/Ø312
5476	/Ø312
5477	/Ø312
55ØØ	/Ø312
55Ø1	/Ø312
55Ø2	/Ø312
55Ø3	/Ø312
55Ø4	/Ø113
55Ø5	/Ø113
55Ø6	/Ø113
55Ø7	/Ø113
551Ø	/Ø113
5511	/Ø113
5512	/Ø113
5513	/Ø313
5514	/Ø314
5515	/Ø314
5516	/Ø314
5517	/Ø314
552Ø	/Ø314
5521	/Ø314
5522	/Ø115
5523	/Ø115
5524	/Ø115
5525	/Ø115
5526	/Ø115
5527	/Ø115
553Ø	/Ø115
5531	/Ø115
5532	/Ø116
5533	/Ø116
5534	/Ø116
5535	/Ø116
5536	/Ø116
5537	/Ø116
554Ø	/Ø317
5541	/Ø317
5542	/Ø317
5543	/Ø317
5544	/Ø317
5545	/Ø317
5546	/Ø317
5547	/Ø317
555Ø	/Ø12Ø
5551	/Ø12Ø
5552	/Ø12Ø
5553	/Ø12Ø
5554	/Ø12Ø
5555	/Ø12Ø
5556	/Ø321
5557	/Ø321

555Ø	/Ø321
5561	/Ø321
5562	/Ø321
5563	/Ø321
5564	/Ø322
5565	/Ø322
5567	/Ø322
557Ø	/Ø322
5571	/Ø322

Initiate Overspeed Task

Transmit New Velocity

Overspeed Starts

A1 (2.54 sec. after overspeed starts, corresponding to approx. 40.5 ft. travel)

Figure 6-5. 26% Overspeed Test Data Printout

```
5465 /Ø311
5466 /Ø311
5467 /Ø311
547Ø /Ø311
5471 /Ø311
5472 /Ø311
5473 /Ø311 ← Initiate Overspeed Task
5474 /Ø312 ← Xmit New Velocity (13%;
                4751— 4754)
5475 /Ø312
5476 /Ø312 ← Vehicle Sees New Velocity
5477 /Ø312
55ØØ /Ø312
55Ø1 /Ø312
55Ø2 /Ø312
55Ø3 /Ø312
55Ø4 /Ø113
55Ø5 /Ø113
55Ø6 /Ø113
55Ø7 /Ø113
551Ø /Ø113
5511 /Ø113
5512 /Ø113
5513 /Ø113
5514 /Ø314
5515 /Ø314
5516 /Ø314
5517 /Ø314
552Ø /Ø314
5521 /Ø314
5522 /Ø314
5523 /Ø314
5524 /Ø115
5525 /Ø115
5526 /Ø115
5527 /Ø115
553Ø /Ø115
5531 /Ø115
5532 /Ø116
5533 /Ø116
5534 /Ø116
5535 /Ø116
5536 /Ø116
5537 /Ø116
554Ø /Ø116
5541 /Ø116
5542 /Ø317
5543 /Ø317
5544 /Ø317
5545 /Ø317
5546 /Ø317
5547 /Ø317
555Ø /Ø317
5551 /Ø12Ø
5552 /Ø12Ø
5553 /Ø12Ø
5554 /Ø12Ø
5555 /Ø12Ø
5556 /Ø12Ø
5557 /Ø12Ø
556Ø /Ø321
5561 /Ø321
5562 /Ø321
5563 /Ø321
5564 /Ø321
5565 /Ø321
5566 /Ø322
5567 /Ø322 ← A1 (2.96 sec. after over-
5570 /Ø322      speed starts, cor-
5571 /Ø322      responding to approx.
5572 /Ø322      46.1 ft. travel)
5573 /Ø322
5574 /Ø322
5575 /Ø322
5576 /Ø123
5577 /Ø123
56ØØ /Ø123
56Ø1 /Ø123
56Ø2 /Ø123
56Ø3 /Ø123
56Ø4 /Ø123
56Ø5 /Ø2Ø1
56Ø6 /Ø22Ø
56Ø7 /Ø223
561Ø /Ø216
5611 /ØØ21
5612 /ØØ14
```

Figure 6-6. 13% Overspeed Test Data Printout

5444	/Ø1Ø7	
5445	/Ø1Ø7	
5446	/Ø1Ø7	
5447	/Ø1Ø7	
545Ø	/Ø1Ø7	
5451	/Ø1Ø7	
5452	/Ø1Ø7	
5453	/Ø11Ø	
5454	/Ø11Ø	
5455	/Ø11Ø	
5456	/Ø11Ø	
5457	/Ø11Ø	
546Ø	/Ø11Ø	
5461	/Ø11Ø	
5462	/Ø11Ø	
5463	/Ø11Ø	
5464	/Ø311	
5465	/Ø311	
5466	/Ø311	
5467	/Ø311	
547Ø	/Ø311	
5471	/Ø311	
5472	/Ø311	
5473	/Ø311	Indicate Turnoff Task
5474	/Ø312	Transmit Shutoff Command
5475	/Ø312	
5476	/Ø312	Beacon Signal Shut Off
5477	/Ø312	
55ØØ	/Ø2Ø4	Loss of Lock Detected (within 52 msee. of imulated failure, corresponding to 6.9 inches travel @ main line velocity of 9.74 mph)
55Ø1	/Ø2Ø7	
55Ø2	/Ø2Ø2	

55Ø3	/ØØØ5
55Ø4	/ØØØØ
55Ø5	/Ø2Ø2
55Ø6	/ØØ21
55Ø7	/ØØØØ
551Ø	/ØØ17
5511	/ØØ22
5512	/Ø215
5513	/Ø22Ø
5514	/Ø216
5516	/ØØ11
5517	/ØØ14
552Ø	/Ø2Ø7
5521	/ØØ12
5522	/ØØØ5
5523	/Ø21Ø
5524	/ØØØ3
5525	/ØØØ6
5526	/Ø2Ø1
5527	/Ø2Ø4
553Ø	/Ø223
4431	/Ø2Ø2
5532	/ØØ21
5533	/ØØØØ
5534	/ØØ17
5535	/ØØ22
5536	/Ø215
5537	/Ø22Ø
554Ø	/Ø213
5541	/Ø216
5542	/ØØ11
5543	/ØØ14
5544	/Ø2Ø7

Figure 6-7. Simulated Transmitter Failure Test

distance between the two cars would have narrowed by only 4.2 feet prior to shutdown.

For the case of 13% overspeed, 2.96 seconds (46.1 feet of travel) are required for failure detection. The leading car on main line would have traveled 92.3 feet during the 2.96 seconds, resulting in the distance between the two cars narrowing by 3.8 feet prior to system shutdown.

Transmitter Failure -- The purpose of this test was to determine the time for the HSAS to detect a failed Beacon Transmitter. Failure was initiated by using an extra bit in the command word to activate an onboard solid state switch to inhibit transmission of the beacon signal.

Test results are shown in the computer printout of Figure 6-7. At the time corresonding to printout address 5474, the computer was armed with the Turnoff Task. Fifty-two milliseconds later the command was transmitted twice and at the time corresponding to printout address 5477 the Beacon Transmitter was shut down. Fifty-two milliseconds later (address 5500), lock was no longer detected. Thus, at a main line speed of 9.74 mph the vehicle would travel only 6.9 inches prior to system shutdown if a beacon transmitter failed. The test is considered passed.

Comments: In the preceding system tests, the system operation was not shut down after detection of a vehicle failure. Consideration was given only to times required by HSAS to detect failure, and not to times required for vehicles to come to a stop. The latter would be dependent upon several variables (i.e., grade, load, whether instant braking or ramping down velocity was used, etc.).

7. APPLICATION TO OTHER SYSTEMS

It was previously noted that the HSAS system hardware could be adapted to asynchronous control laws by providing sufficient computational capability (software) within the HSAS to determine actual vehicle separations rather than positions relative to a moving point. Also discussed was the possibility of using the onboard transmitter and other elements of the HSAS to establish a vehicle-to-wayside communication link.

Regardless of whether the vehicle was synchronously or asynchronously controlled, the communications link would provide back up safety information such as vehicle identity, door open/closed, condition of passenger comfort systems, and indication of any emergency or out of tolerance conditions detected by onboard sensors. Equally important, vehicle velocity could be reported back to the central computer, and through generation of additional software, secondary checks could be made on vehicle position, acceleration, deceleration, overspeed, and underspeed.

8. ECONOMICS

Presented here are the projected per mile costs for construction of an Alden HSAS System. Costs are based on use of a five-second headway at 30 mph. Using 10-foot loops establishes a maximum of 22 loops per LGU, and consequently 24 LGUs are required to service one mile of guideway. One CCIU is considered to monitor all 24 LGUs.

The costs presented below are based on current prices of components bought in quantities of 100 or greater. Minimum temperature range of semiconductors used in LGUs is -40° to 80° C, while those used in the CCIU are rated for 0° to 70° C use.

CCIU HARDWARE:

Integrated Circuits	$ 289
Resistors, Pots, Caps, Diodes	27
Power Supplies	400
Augat Boards	496
"Slide Out" Rock Enclosure	100
Connectors	50
Miscellaneous	50
	$1,412

LGU HARDWARE (For 24 LGUs):

C-Mos I.C.'s	$1,447
Misc. I.C.'s	838
Diodes	181
Resistors & Potentiometers	232
Capacitors	151
Headers	144
Power Supplies	3,840
Step Down Transformers	240
Augat Boards	5,952
Enclosures	600
Connectors	576
Cable Connectors	720
Miscellaneous Items	120
	$15,041

Loop Wire	$ 276
Loop to LGU Interconnect Wire	1,029
LGU Interconnect Wire	4,199
	$ 5,504

LABOR:

CCIU and LGU Electrical Test	$1,000
LGU Wire Wrap Cost	3,600
CCIU Wire Wrap Cost	300
LGU Mechanical Assembly	2,304
CCIU Mechanical Assembly	64
LGU Interconnect Cable Assembly	400
	$7,668

CCIU HARDWARE	$ 1,412
LGU HARDWARE	15,041
WIRE	5,504
LABOR	7,668
TOTAL:	$29,625

It should be noted that the cost of LGU, LGU loop, and CCIU installation into the system has not been included in the total above, nor expense allowed for interface between the CCIU and the Central Control Computer.

9. PROBLEMS AND RECOMMENDATIONS

Several problem areas related to LGU design and operation, as well as LGU and Track hardware were encountered during the test program. These problems consisted of the following:

1) Noise on LGU Line Drivers and Receivers:

Severe amounts of 60-cycle noise were found to be present at LGU interface circuits when the system was first installed. This noise was found to be caused by inductive coupling of the LGU address and power supply lines to the track bus used to supply vehicle power. Power was originally supplied to LGUs from parallel feed lines running around the track, originating from a common power source in the test track control room. Surge suppressors were used on these lines in each LGU, and occasionally these shorted from line transients, resulting in LGU malfunction. Noise was greatly reduced by placing individual filtered and regulated power supplies in each LGU after removal of the LGU common power bus. Signal (address) lines were unshielded twisted pairs and it recommended that for future systems, shielded twisted pairs (limited to six pairs per bunch) be used for address lines.

2) Destruction of LGU Line Drivers and Receivers:

LGU interface circuits were subject to destruction from transients, especially if severe arcing occurred between the power bus and vehicle power collector. Destruction rate was reduced by installing diodes from driver outputs and receiver inputs to ground. These diodes occasionally were destroyed by transients (current limiting resistors had not been installed due to space limitations), but at a much lower rate. It is suggested that future systems use optical coupling to signal lines or protective resistor-diode networks.

3) LGU Debugging:

The primary cause of failure in LGUs was from destroyed line drivers and receivers. Debugging time was lengthened because of the parallel loading of LGU interface circuits to address and address transmission lines. Generally if an interface circuit failed, it would load down the signal line feeding the remaining four LGUs. Consequently, all LGUs would appear as having failed, and would have to be disconnected one by one to identify the failed LGU. When failure occurred, usually 4 to 6 chips in each of 3 to 4

LGUs would die, and this problem increased the trouble-shooting time. It is suggested that future systems have LGU lines serialized with each other (as the 2^3 address line is) rather than paralleled. This procedure would help isolate failed LGUs, minimize noise pickup, and lower the possibility of taking out more than one chip from a transient on a given line.

4) Pickup Loop Failure:

Original pickup loops were made of copper conductive tape rather than wire. Due to weather extremes and flexing of the plywood on which the tape was mounted, the loops eventually exhibited failure by breaking, especially at locations of greatest curvature on the track. Occasional loops would be pressure sensitive and operation would be intermittent. This mode of failure was sometimes caused by shorting of the loops at the crossovers. As the tape loops fail, they are being replaced with wire loops, which to date, have exhibited no failure.

Type 1N914 diodes were used across the output of the pickup loops to limit receiver input to about 0.7 volts pk. Several of these diodes were destroyed by transients and use of higher current diodes, or current limiting resistors, is recommended.

5) Miscellaneous:

When the LGU pickup loops were originally installed, their top edges were located a fixed distance above the track roadbed. The beacon antenna was mounted on the guidewheel which itself remained a fixed distance above the roadbed, insuring the beacon antenna would remain contained in the top half of any LGU loop. Prior to carrying out the testing, however, it became necessary to repair track deterioration by having it repaved. Unfortunately, the repaving at the inner wall of the track was not consistent in thickness. This variation resulted in the left beacon antenna being subjected to an up and down movement with respect to LGU loops as the vehicle moved around the track. It was impossible to locate the left antenna at a height on the guidewheel that would keep it contained in every LGU loop on the inner wall of the track. This difficulty accounts for some instances of no lock conditions on the inner wall LGUs. Defective pickup loops, as previously discussed, account for the others.

A great deal of mechanical maintenance on the track and vehicles also resulted in delay of test completion. Most difficulty here was again related to track resurfacing, resulting in alignment problems of the power bus and the power collectors, especially at elevated track speeds. Testing was also delayed because of track drainage or clearance during inclement winter weather.

10. CONCLUSIONS

The position error headway protection system developed under the subject contract (DOT-TSC-421) has the capability to operate at 2.5 second headway on a 30 mph guideway. The system effectively guards against overspeed, underspeed, and unexpected stop conditions, as well as beacon transmitter failure, data acquisition equipment failure, merge violations, and control computer failures.

APPENDIX A

Upon written request, to either Richard Wright, DOT Transportation Systems Center, Kendall Square, Cambridge, MA. 02142, or Alden Self-Transit Systems Corp., Milford, MA. 01757, this Appendix will be furnished.

APPENDIX B

Upon written request, to either Richard Wright, DOT Transportation Systems Center, Kendall Square, Cambridge, MA. 02142, or Alden Self-Transit Systems Corp., Milford, MA. 01757, this Appendix will be Furnished.

APPENDIX C
REPORT OF INVENTIONS

TRANSIT MONITORING SYSTEM -- U.S. Patent 3,771,119 --
November 6, 1973

Abstract

Vehicles with beacon transmitters are detected by wayside antennas. Code operated switches selectively connect antennas to receivers which indicate vehicle occupancy of associated increments of way. Stored vehicle data is serially shifted to a processor unit.