A Proximity Vehicle Locator System

1974

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A PROXIMITY VEHICLE LOCATOR SYSTEM

BY

BRADLEY EVERETT THOMPSON
B.S.E., Florida Technological University, 1972

THESIS
Submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering in the Graduate Studies Program of Florida Technological University

Orlando, Florida
1974
ABSTRACT

A PROXIMITY VEHICLE LOCATOR SYSTEM

by

Bradley E. Thompson

The purpose of this paper is to discuss the design, construction and operation of the proximity vehicle locator system prototype developed for the Orlando Police Department. The objective of the project itself was to provide the O.P.D. with a simple but effective system by which constant surveillance of patrol car locations could be maintained, thus improving the department's operational efficiency. Each unit designed specifically for use in this project will be discussed in some detail, while those purchased locally for use in the project will be only briefly described, as pertaining to their functional importance to the system. In addition, some of the problems encountered in the realization of the system as a working model will also be briefly recounted.

Approved by: Ed R. McCarter
Director of Thesis
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<tr>
<td>A</td>
<td>Ampere</td>
</tr>
<tr>
<td>mA</td>
<td>Milliampere ((10^{-3} , A))</td>
</tr>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>AM</td>
<td>Amplitude Modulated</td>
</tr>
<tr>
<td>BCD</td>
<td>Binary Coded Decimal</td>
</tr>
<tr>
<td>C</td>
<td>Capacitor</td>
</tr>
<tr>
<td>D</td>
<td>Diode</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>e</td>
<td>Exponential</td>
</tr>
<tr>
<td>f</td>
<td>Farad</td>
</tr>
<tr>
<td>(\mu f)</td>
<td>Microfarad ((10^{-6} , f))</td>
</tr>
<tr>
<td>pf</td>
<td>Picofarad ((10^{-12} , f))</td>
</tr>
<tr>
<td>I</td>
<td>Current</td>
</tr>
<tr>
<td>ID</td>
<td>Identification</td>
</tr>
<tr>
<td>K</td>
<td>Relay</td>
</tr>
<tr>
<td>L</td>
<td>Coil</td>
</tr>
<tr>
<td>ln</td>
<td>Natural Logarithm</td>
</tr>
<tr>
<td>NC</td>
<td>Normally Closed</td>
</tr>
<tr>
<td>NO</td>
<td>Normally Open</td>
</tr>
<tr>
<td>P</td>
<td>Power</td>
</tr>
<tr>
<td>Q</td>
<td>Transistor</td>
</tr>
<tr>
<td>R</td>
<td>Resistor</td>
</tr>
<tr>
<td>RMS</td>
<td>Root-Mean-Square</td>
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<td>S</td>
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<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>t</td>
<td>Time (in seconds)</td>
</tr>
<tr>
<td>$t_w$</td>
<td>Time Interval</td>
</tr>
<tr>
<td>V</td>
<td>Voltage (volts)</td>
</tr>
<tr>
<td>$V_b$</td>
<td>Base Voltage</td>
</tr>
<tr>
<td>$V_{be}$</td>
<td>Base-Emitter Voltage</td>
</tr>
<tr>
<td>$V_{ce}$</td>
<td>Collector-Emitter Voltage</td>
</tr>
<tr>
<td>$V_{cc}$</td>
<td>Voltage Source</td>
</tr>
<tr>
<td>VR</td>
<td>Variable Resistor</td>
</tr>
<tr>
<td>$w$</td>
<td>Angular Frequency</td>
</tr>
<tr>
<td>Z</td>
<td>Impedance (ohms)</td>
</tr>
<tr>
<td>$\Omega$</td>
<td>Ohm (unit of resistance)</td>
</tr>
<tr>
<td>$k\Omega$</td>
<td>Kilohm ($10^3$ ohms)</td>
</tr>
<tr>
<td>$M\Omega$</td>
<td>Megohm ($10^6$ ohms)</td>
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INTRODUCTION

Through the years police work has been made increasingly easy and efficient by numerous technological advances. The modern police officer has at his disposal the best communications equipment available, for one thing, giving him access to the knowledge and filed data of other law enforcement agencies throughout the world. The tools of criminal analysis have also taken great strides forward, distinctly augmenting the natural deductive abilities required of a good police detective. This is not to say, however, that police work has reached its pinnacle of perfection.

One strong deterrent to operational efficiency occurs in the radio dispatch rooms of police stations throughout the nation. That is, it is often difficult or even impossible for a dispatcher to keep an accurate, up to date record of the locations of the units available to be sent on a call. In most cases it is only known in which district a mobile unit is operating and whether or not that unit is on call. Obviously, it would be much more advantageous to know the exact or even approximate location of each mobile unit, so that when a call occurs the nearest available unit could respond.

A number of different solutions to this problem have been proposed. One proposal, for instance, suggests that the area to be monitored should have three receiving stations located at the vertices of a large triangle. Then, if each patrol car is equipped with a continuously functioning transmitter, its location could be accurately determined through a triangulation process.
Another method requires the placement of a radio compass in each patrol car. The compass would periodically transmit the car's direction of travel back to police headquarters, along with information on the distance traveled between transmissions. This data would then be fed to a computer that would provide an accurate, continuous display of the car's location as it traveled within the city.

Still another method, and the one with which this paper is concerned, is a proximity locator system. This system, though it lacks the accuracy of some of the others, provides an approximate display of a car's location within any designated area of the city. The contents of this paper, then, will provide a description of the components of the system, along with data concerning the actual functioning of the system as a dispatching aid to the Orlando Police Department.
1. GENERAL SYSTEM DESCRIPTION

A general understanding of the operation of the system as a whole is essential before the system can be broken down into its basic building blocks for convenient analysis. Functionally, the fundamental concept of the proximity car locator system is the placement of short range radio transmitters at selected locations throughout the city, each transmitter being capable of generating its own identifying code. In that each transmitter, once placed, will remain stationary, the transmitter's identification code can be used to identify the location of the unit's placement.

Obviously, because the transmitters are short range devices, this identification code is useless unless some means of relaying it to a location where it may be put to use is provided. This is accomplished by placing radio relays in automobiles and driving them to the locations of the transmitters. Thus, when a transmitter's broadcast range is entered by one of the automobiles, its identifying code will be relayed, as desired.

This, though, is actually a transmission of useless information since the unit's location was already known. The automobiles' locations were not previously established, however, so when a location's identification code is received it becomes known to the receiver that an automobile with a radio relay unit is in the proximity of that particular intersection. If a means is also provided for each radio relay unit to generate its own individual identifying code and transmit it in conjunction with the code identifying the location, the receiver will
know not only that a car is at a specific location, but it will also be able to identify that particular car. If a continuous surveillance of the transmissions is maintained, each car's position as it travels through the city will be known. This is the foundation upon which a proximity car locator system is based, and it is indeed the basis for the system now under development for the Orlando Police Department.

In this particular system the coded transmitters are located at selected intersections throughout the northwest section of the Orlando area, and have been placed inside the traffic light control boxes at those intersections. The radio relay units have been mounted inside patrol cars and they relay their data back to the radio dispatch room at police headquarters where the information is continuously displayed on a large map of the Orlando area. This is illustrated in Fig. 1.

To aid in understanding the sequence of events that occurs when a patrol car enters the transmission range of one of the transmitters, the system can be broken down and studied as three separate and distinct sub-systems: (1) an intersection unit, (2) a mobile relay unit, and (3) the display unit at police headquarters. The block diagrams of these sub-systems are shown in Fig. 1, and will be used as an aid in describing their operation.

At the intersection level, as was previously stated, a transmitter capable of generating its own distinct identifying code is required. To accomplish this, ten combination tone generator-transmitters were purchased from a local firm. These devices, which will not be described in great detail in this paper as they were not developed specifically for use in this project, require a power supply voltage of twelve volts DC and are capable of delivering up to a half
watt of modulated output at an AM frequency of 26.975 megahertz to a long wire antenna. The coding of each individual transmitter is accomplished by the tone generator, or encoder, which is an integral part of each unit.

The encoder is actually a vibrating-reed oscillator. The reed itself is a mechanical device which, when excited, vibrates at a specific frequency determined by the physical dimensions of the reed. These mechanical vibrations are then converted to electrical oscillations which are fed into the transmitter where they are amplitude modulated and transmitted into the air as radio-frequency energy. This information, transmitted continuously from the intersection, is now available for use by any patrol car with a radio relay device that passes through that intersection.

The radio relay device consists of three discrete units: (1) a citizens' band receiver, commercially manufactured by the Pace Corporation and purchased for use in this project, (2) a police channel-four hand-transmitter, manufactured commercially by the Motorola Corporation, and (3) an interface unit, designed specifically for use in this project. Its design and construction will be dealt with in detail later in this paper.

Before the car enters the intersection the receiver section of its relay unit must be turned on, with the squelch control adjusted so that the audio amplifier section is muted. When it enters the intersection the signal is received by the RF section and demodulated, whereby the original intersection identification tone is recovered and coupled to the audio amplifier section. Simultaneously, the signal in the RF section has disabled the squelch circuit, allowing the audio
amplifier section to become active. The intersection tone, then, is amplified and fed to the speaker where it is converted to acoustic energy capable of being detected by the microphone of the police channel-four hand-transmitter. The remaining requirement is to devise a means of generating an identifying code for the radio relay unit and trigger the channel-four transmitter so that it sends the information back to the police station. The means of accomplishing this is shown in Fig. 1.

The disabling of the squelch circuit causes another circuit, the encoder trigger, to become active. When this occurs power is supplied to a tone generating encoder of the same type as those used to generate the intersection identification codes. The output of this encoder is then coupled to the audio amplifier stage of the Pace receiver, where it is mixed with the tone identifying the intersection and drives the speaker. The sound emitted by the speaker, then, is a dual tone, with one tone identifying the intersection and one tone identifying the car.

The encoder trigger also serves another useful purpose. It enables another circuit, the actuator control, to provide a pulse of approximately one second duration to a mechanical solenoid which physically actuates the press-to-talk switch on the police transmitter. The solenoid remains actuated for the duration of the pulse, resulting in a transmission time of approximately one second. It is during this one second period that the information yielding car and location is transmitted back to the police station.

The information is put to actual use in the radio dispatch room at the police station. The signal transmitted from the patrol car is
received by the channel-four receiving unit of the radio room's communications equipment. The two tones, once recovered, are sent via a 600 ohm feedline to a set of tone decoders. These decoders are, as were the encoders, vibrating-reed devices. The frequencies of these reeds are also determined by their physical dimensions, and one reed-type decoder has been provided for each frequency generated by the encoders. The decoder reeds vibrate sympathetically with the encoder reeds. That is, when a signal received contains a frequency of oscillation belonging to one of the encoder reeds, the decoder reed designated for that particular frequency will begin to vibrate. When a particular decoder reed vibrates, the output impedance of that decoder drops from a value of approximately infinity to one of approximately zero. Therefore, when the dual tone signal is received by the decoder unit the outputs of two of its decoder modules, one identifying the car and one identifying the intersection, drop to a zero impedance level.

This completes the process by which the identifying tones have been converted to a type of information compatible with the operation of the visual display unit. The input of the visual display unit (VDU) consists of twelve data lines, ten of which carry location data and two of which carry car identification data. The location data lines are connected directly to the outputs of the ten intersection tone decoders so that when location data is received the input line corresponding to that particular intersection will be brought to a zero impedance level. The car data lines, however, must be at a zero impedance level when no information is input and rise to a high level while data is present on the intersection input lines, then drop back to a low level before the intersection input lines return to their normal
high impedance levels. This requires a little logical manipulation of the outputs of the car tone decoders, and the process by which this is accomplished will be discussed later in the paper. The presence of data on both the intersection and the car lines constitutes a loading of data into the VDU. The process by which this information is converted into an actual visual display is shown by the block diagram of Fig. 2, and will be discussed briefly here and in greater detail later in the paper.

The first stage of the display unit circuitry, the BCD encoder, transforms the data on the location lines into binary form, which is more easily handled by the digital circuitry that makes up the VDU. This is done by means of a diode encoding matrix, the output of which is a four-bit positive logic binary code. This information is then transferred simultaneously to car location memories A and B, the A and B designating which car is at the received location. The information on the car identification lines determines which memory unit, A or B, will receive the information; therefore, if the level of line A rises briefly to a high level, the information will be stored in memory A and if the level of line B rises briefly to a high level, the information will be stored in memory B.

The outputs of the location memories are fed to the inputs of a multiplexing stage. This stage is a clock driven integrated circuit which, depending on whether the level of the clock signal input is high or low, will output the information from memory B or memory A respectively. The clock that drives this stage has a continuous square wave output. That is, its output waveform is a sequence of consecutive high and low levels, each of the same time duration, providing
Fig. 2. Visual Display Unit Block Diagram
a constant frequency of oscillation for the waveform of several thousand cycles per second. This means that the multiplexer will alternately output the information stored in memory A and memory B several thousand times in one second. This information, still in four-bit binary form, then enters the location decoder which converts it back to a single signal on one of ten separate output lines representing the ten different intersections. These lines are connected directly to the cathodes of the ten three-digit seven-segment light-emitting-diode readouts that visually display the identification numbers of the patrol cars on the map.

The readouts are placed at the monitored intersections on the map so that when a location memory unit indicates that a car is at a given location in the city the car's identification number will actually be displayed on the map at that location. Thus far no mention has been made of the car identification numbers' origins. This will now be dealt with.

The Orlando Police Department uses three digit numbers to identify their patrol cars. The first digit identifies the working shift; the day being divided into three shifts, the first digit will be either a one, a two, or a three. The final two digits indicate the sector the car is to patrol. In this particular case sectors thirty-five and thirty-six are to be patrolled. Therefore, the car numbers will be either 135 and 136, 235 and 236, or 335 and 336. These numbers are produced within the map circuitry by the unit identification number generator.

This section of the VDU consists of three seven-segment LED readout drivers, one for each digit of the car ID number. These devices
convert four-bit binary codes at their inputs to seven-bit codes at their outputs. When these seven-bit codes are applied to seven-segment LED readouts, arabic numerals corresponding to the input binary codes are formed. Therefore, if each digit of a patrol car's identification number is converted to a four-bit binary code and these codes are applied to the unit ID number generator's inputs, the result will be a numeric display of the car's number at a selected location on the map. It should be noted here that although the outputs of the unit ID generator are fed simultaneously to all the readouts on the map the digits will only appear at intersections that also have a signal applied by the location decoder. And the location decoder only outputs one intersection location at a time. The means of providing the binary code that identifies each car will be dealt with in detail later. At this point it is only necessary to know that codes identifying car A and car B are available to the inputs of the unit ID generator.

From Fig. 2 it can be seen that the clock signal is also fed to the unit ID generator. This provides the method of synchronizing the generation of the car numbers with their locations. That is, when the location decoder applies a signal to one of the intersection locations the ID generator must be caused to generate the correct set of digits identifying the car at that location. The clock output waveform merely synchronizes the location multiplexer and the unit ID generator so that when the multiplexer outputs the information from locations A or B the ID generator outputs the seven-segment code identifying car A or car B respectively.

Due to the fact that the three digit LED readouts contain only one set of input data lines to be shared by all three digits, it is not
possible to display all three digits of any car number simultaneously. To avoid this a three digit control device has been added to the circuitry. This device, also synchronized with the clock, has three separate output lines, of which only one at a time may provide an output pulse. That is, the first, second and third output lines will consecutively carry pulses but no pulses will occur simultaneously on more than one line. The time duration of these pulses is twice that of a clock pulse and they are used to consecutively enable the three seven-segment LED drivers. The result of this is that the first digit of car A will be displayed, followed by the first digit of car B, followed by the second digit of car A, and so on. It should be noted here that since the whole process occurs several thousand times in one second anyone viewing the map will get the impression that the six digits constituting the two car numbers are being displayed simultaneously.

The only controls external to the display unit circuitry are those controlling the flasher circuitry and shift numerals. The flasher controls are two toggle switches that provide a means of coupling a pulse train of approximately one pulse per second to the location multiplexer. This signal is used to flash the number of either car A or car B or both cars A and B to indicate when one or both units are on call. The shift control is a three position lever switch which causes the first digit of the ID generator to be either a one, a two, or a three, indicating during which shift the car is operating.

This, then, has been a general description of the sequence of events that occurs when a car enters one of the monitored intersections. It should be noted here that each time a car enters a different monitored intersection the information stored in its memory section of the
VDU circuitry will be updated and the information corresponding to its previous location will be erased. It is also of interest to note that information stored in a location memory will be displayed until it is erased. This means that during the time a car travels between two intersections the map will continue to display its ID number at the last intersection it passed through until it arrives at another intersection. By this means a fairly continuous display of the car's location as it travels within the city is achieved, and it is for this purpose that the controlling circuitry of the system was designed. The components of the system designed specifically for this project will, therefore, be discussed on the circuitry level in the next sections of this paper.
The power requirements of the encoder-transmitter units are fairly flexible. The devices will function acceptably at supply voltages ranging between nine and fifteen volts DC and only provide a current drain of approximately sixty milliamperes. In order to insure that the transmitter's output levels are relatively constant, some form of voltage regulation of the power supplies' output is required. A simple circuit to achieve this is shown in Fig. 3.

This circuit provides zener-diode regulation of the output voltage to insure its stability at a level of twelve volts DC. The voltage supplied to the regulator circuit is provided by a capacitively-filtered full-wave rectifier arrangement connected to the secondary winding of a power transformer, as shown. The analysis and design of this type of circuit is straightforward.

It has already been established that the output voltage provided by the supply will be twelve volts DC. It is also known that the encoder-transmitters require a current of sixty milliamperes. The power supply, then, will see an effective impedance across its output terminals of

\[ Z_o = \frac{V_o}{I_o} = 200 \text{ ohms.} \]  

The selection of a zener-diode for the regulator circuit is also aided by knowledge of the current drain at the output. It can be estimated that the current sink for good regulation provided by the zener-diode, assuming negligible supply or load variation, need only be a
Fig. 3.—Encoder-Transmitter Power Supply
few milliamperes. From this, the diode's power rating can be computed.

\[ P_z = V_z I_z = V_o I_z = 120 \text{ milliwatts} \quad (ii-2) \]

Knowing this, the zener-diode selected for use in the circuit was a 1N963, which is capable of dissipating four-hundred milliwatts of power and will provide a constant output of twelve volts DC when its sink current is 10.5 milliamperes. At this given sink current the forward resistance of the diode is specified as 11.5 ohms. This resistance causes a small additional voltage drop across the diode, the value of which is

\[ V_{rz} = I_z R_z = 0.121 \text{ volts.} \quad (ii-3) \]

Since this value is small compared to that of the specified zener voltage, it will be neglected in the remaining calculations.

Resistor \( R_1 \) performs the function of dropping any additional voltage developed by the rectifier circuit that is above the twelve volt output level. In order to determine its value, then, the filtered output voltage of the rectifiers must be known.

The power transformer used is rated at a 25.2 volts AC center-tapped secondary voltage with a current drain of one ampere. It would be expected, then, that the anode of each rectifier would be supplied 12.6 volts AC with the transformer's center-tap grounded. This would indeed be the case if the current required by an encoder-transmitter were one ampere. Since its current drain is much less than this, however, further consideration must be given the problem.

A transformer's performance is limited by a number of internal losses that grow more prominent at higher power output levels. It can
therefore be expected that a transformer's output voltage will be slightly higher at low current drains than at high current drains. By placing a load across the secondary of this particular transformer which was similar to that provided by an encoder-transmitter unit and regulator circuit, it was found that the actual measured output of the transformer was fifteen volts AC with respect to its grounded center-tap. Using this voltage, then, the values of the rest of the components of the circuit may be computed.

If the small forward voltage drops across the rectifiers are neglected, it is seen that the voltage applied to the filter capacitor will be a full-wave rectified sine wave whose period is 1/120 second and whose RMS value is fifteen volts AC. From this the peak voltage can be computed as

\[ V_p = V_{\text{RMS}} \sqrt{2} = 21 \text{ volts.} \] (ii-4)

This voltage, applied to a capacitor with no additional load, would provide a filtered output of 21 volts DC. With a load, however, the capacitor will discharge somewhat during the time interval between the peaks of the rectified sine wave, the extent of the discharge being related to the impedance of the load and the capacitance of the capacitor by the equation

\[ V = V_p e^{-t/Z_L C} \text{ volts} \] (ii-5)

where \( V \) is the voltage after a time interval of \( t \) seconds, \( Z_L \) is the load impedance and \( C \) is the capacitance of the capacitor.

From this equation it can be seen that if the product of \( Z_L \) and \( C \) is much greater than the value of \( t \), the magnitude of \( V \) will be com-
parable to that of $V_p$, and little discharge of $C$ will occur. In the given circuit,

$$Z_L = \frac{V_o}{(I_o + I_z)} \simeq 121 \text{ ohms.} \quad (ii-6)$$

It is also known that the period of the rectified sine wave is $1/120$ second; therefore, the value of $t$ can not be greater than $1/120$ second, which is the time interval between two successive voltage peaks. Assuming that if the product of $Z_L$ and $C$ is at least ten times the value of $t$ it can be said that

$$Z_L C \gg t, \quad (ii-7)$$

and it is found that

$$Z_L C > 10(1/120) \text{ seconds.}$$

Solving for $C$ yields

$$C \simeq 10(1/120)(1/121) \text{ farads} \quad (ii-8)$$

or,

$$C \simeq 690 \text{ microfarads.}$$

The value of $C$ used in the circuit was 1000 microfarads, so it can be assumed that the average DC voltage across the capacitor will be fairly close to the peak value of 21 volts.

The value of $R_1$, then, will simply be

$$R_1 = \frac{(V_p - V_o)}{I_1} \quad (ii-9)$$

or,
$R_1 \approx 130$ ohms.

The power supplies constructed using the component values computed here performed as expected, and provided fairly well regulated DC voltages of slightly greater than twelve volts DC to the encoder-transmitters. It should be noted here that the use of the multitude of approximations in the preceding calculations was directly due to the fact that the power demands of the encoder-transmitter units are quite flexible and any power supplies that approximate these demands could be used.
iii. THE DISPLAY UNIT POWER SUPPLY

The power supply requirements of the map circuitry are much more rigid than those of the encoder-transmitter devices, and hence a more elaborate form of power supply regulation is required. In order to establish just what these requirements are, some characteristics of the map circuitry must be examined.

The control circuitry of the map is comprised of TTL integrated-circuit logic devices. The supply voltages required by some of these devices can be set between 4.50 and 5.50 volts DC, but others require a voltage closer to the five volt level, typically between 4.75 and 5.25 volts DC. It would therefore be logical to fix the power supply voltage as close to a constant 5 volts DC level as possible.

It is also necessary to remove any ripple or fluctuations in the output voltage of the supply. This is a consequence of the sensitivity of the devices used, since voltage fluctuations may be interpreted by these devices to be a presentation of data that would alter the logical sequence of their operations. For suitable operation of the map, this simply cannot be allowed.

The last thing that must be known is the total current that will be required by the map circuitry. This is not too difficult to determine since the specification sheets of the devices used state both the typical and maximum supply currents required by the devices in normal operation. A summation of these individual currents indicates that the total map current will not be greater than approximately 1.1 amperes and will most probably be closer to a typical value of 0.7 amperes.
milliamperes than to the maximum value of 1.1 amperes. Armed with this knowledge, the power supply can be designed, and its diagram is shown in Fig. 4.

The secondary winding of the power transformer selected is rated at 12.6 volts AC center-tapped with a current drain of 2.0 amperes. The actual output voltage with a load approximately equal to that presented by the map was 7 volts RMS AC, the peak value of which is close to 10 volts. If adequate filtering is provided, the output to the voltage regulator section will be close to 10 volts DC. Before a value for $C_1$ can be calculated, however, the requirements of the voltage regulator must be determined.

To simplify construction of this power supply and at the same time insure a stable, low noise output voltage, a Signetics LM109 regulator circuit was obtained. Some of the specifications are listed in the manufacturer's description of the device, as follows.

The LM109 and LM209 are complete 5V regulators fabricated on a single silicon chip. They are designed for local regulation on digital logic cards, eliminating the distribution problems associated with single-point regulation. The devices are available in two common transistor packages. In the solid-kovar TO-5 header, it can deliver output currents in excess of 200 mA, if adequate heat sinking is provided. With the TO-3 power package, the available output current is greater than 1 A.

The regulators are essentially blow-out proof. Current limiting is included to limit the peak output current to a safe value. In addition, thermal shutdown is provided to keep the IC from overheating. If internal dissipation becomes too great, the regulator will shut down to prevent excessive heating. (1)

The output voltage of this device is specified as being between 4.7 and 5.3 volts DC, these values being the limits for the worst possible operation of the device. Since it is assumed that the regulator will be used within the range of its normal operating conditions, it may be further assumed that the device's output will be very near
Fig. 4.—Visual Display Unit Power Supply
its typical value of 5.05 volts DC for inputs ranging between 7 and 25 volts DC. The quiescent current of the device will never exceed a value of 10 milliampere and the output current is limited to a value slightly greater than one ampere, which makes it more than acceptable for use in this power supply circuit. (1)

The typical level of output noise for this device is specified as 40 microvolts for frequencies ranging between 10 hertz and 100 kilohertz. This level is sufficiently small so that it will never be interpreted as data by any of the TTL chips used in the map’s logic circuitry. (1)

The value of the filter capacitor, \( C_1 \), may now be determined using the parameters of the LM109 regulator circuit. Assuming that the regulator module is a fairly efficient device, the current drain at its input should be very similar to the sum of its output current and quiescent current, or,

\[
I_1 \approx I_o + I_q. \tag{iii-1}
\]

To determine the minimum value of \( C_1 \) the maximum output current drain must be used. This results in an input current of

\[
I_1 \approx (1.1 + 0.01) \text{ amperes},
\]

or,

\[
I_1 \approx 1.11 \text{ amperes}.
\]

For ease of calculation and because it is expected that the current required by the map will never actually reach a value of 1.1 amperes, this can be rounded off so that
\[ I_L \approx 1 \text{ ampere.} \]

This represents a load across \( C_1 \) of

\[ Z_L \approx \frac{V_1}{I_L} \quad \text{(iii-2)} \]

or,

\[ Z_L \approx \frac{10}{I} \text{ ohms} \approx 10 \text{ ohms.} \]

In order to insure proper operation of the regulator, the input voltage may not be allowed to drop below 7 volts DC. To under-rate this power supply, it is assumed that the voltage input to the regulator will not be allowed to drop below 9 volts DC. The input waveform to the regulator, then, will resemble that of Fig. 5.

The amount of discharge per given length of time \( t \) is

\[ V_1 = V_p e^{-t/Z_C L} \quad \text{(iii-3)} \]

or, taking the ln of each side,

\[ \ln\left(\frac{V_1}{V_p}\right) = -\frac{t}{Z_L C_1} \quad \text{(iii-4)} \]

The only undetermined quantities in this equation are \( t \) and \( C_1 \). So, in order to establish a value for \( C_1 \), \( t \) must be determined. Considering one peak of the original sine wave of Fig. 5, it is seen that

\[ V_1 = V_p \left(\sin wt_2\right) \quad \text{(iii-5)} \]

where

\[ w = 2\pi f = 120\pi \text{ rad/sec.} \quad \text{(iii-6)} \]
Substituting the desired results into this yields

$$\sin \omega t_2 = \frac{v_1}{v_p} = \frac{9}{10} = 0.9,$$

or,

$$\omega t_2 = 0.356 \pi \text{ radians},$$

and,

$$t_2 \approx 0.003 \text{ seconds}.$$

Therefore, it takes 0.003 seconds for the original sine wave to go from zero to nine volts. The discharge time of $C_1$ will be equal to the time it takes for the rectified sine wave to drop from 10 volts to ground potential and rise back to nine volts, or

$$t = t_1 + t_2,$$  \hspace{1cm} (iii-7)

where $t_1$ is simply equal to the time required for the original sine wave to complete one-fourth of a cycle, or

$$t_1 = \frac{1}{4} \left( \frac{1}{f} \right) = \frac{1}{4} \left( \frac{1}{60} \right) = \frac{1}{240} \approx 0.004 \text{ seconds}.$$

Therefore,

$$t \approx 0.007 \text{ seconds}.$$

Substituting this value into equation (iii-4) yields

$$\ln \left( \frac{9}{10} \right) \approx -0.007/103_1,$$

or,

$$C_1 \approx 6,670 \text{ microfarads}.$$
In the actual circuit a value of 10,000 microfarads was used and the output of the voltage regulator held constant at a level very close to 5 volts DC with the map circuitry in full operation. As a safety feature, the input to the power transformer was fused. The maximum current in the primary of the transformer may be determined to be

\[ I_p = \frac{V_s I_s}{V_p} \]  

(iii-8)

where \( V_s \) is the secondary voltage, \( I_s \) is the maximum current in the secondary, and \( V_p \) is the primary voltage. Thus,

\[ I_p = \frac{(7.0)(1)}{117} \text{ amperes} \approx 60 \text{ milliamperes}, \]

and the fuse used had a current rating of 0.1 amperes.
iv. THE VISUAL DISPLAY UNIT

The most complex of the devices used in this project is the visual display unit (VDU), which performs a number of simultaneous functions in the process of converting data presented to it into a humanly-comprehensible visual-information display. Thanks to modern solid-state technology and the advent of integrated circuits, however, the design and construction of such a device is not as formidable as it might first appear. A basic working knowledge of the operation of TTL integrated-circuits and an examination of the configuration of the circuits used is needed to understand the operation of the VDU. The circuitry involved is shown in Figs. 6-9, and will be discussed here in some detail.

The data input to the VDU, as has been previously mentioned, consists of high or low impedance levels on ten separate intersection lines and two separate car lines. The normal levels of the intersection lines are high, while the normal levels of the car lines are low, and it is desired to convert the information they carry when not in these states into a form compatible with the operation of the VDU's circuitry.

To facilitate the design of this system, it would be helpful to reduce the number of data lines. And, since there are only two car lines as opposed to ten intersection lines, the logical procedure would be to leave the car lines as they are and find some way to reduce the number of intersection lines. An easy way to accomplish this is to encode the data on the intersection lines into a binary code, as shown
As can be seen from Table 1, each intersection has been given a number that can now be used to identify that particular intersection. The intersection numbers range from one to ten and, from Boolean Algebra, it is known that any one of these numbers can be represented by a four-bit binary code. In this case, since the line levels are normally characterized by a high impedance, the non-active lines will be represented by 1's, while lines carrying information will be represented by 0's. Thus, if a 0 appears on intersection line 5 the output code (with the least-significant-digit at the right) will be 1010, while a 0 on line 7 will provide the output code 1000, and so on. A physical means of converting the ten inputs to four outputs in the coded form indicated is required. This is accomplished through the use of the diode encoding matrix of Fig. 6.

This matrix can be designed directly from the information presented in Table 1 if the 0's are interpreted as shorts to ground and

<table>
<thead>
<tr>
<th>Input Lines Active</th>
<th>Intersection Levels</th>
<th>Output Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td>a b c d</td>
</tr>
<tr>
<td>......</td>
<td>1 1 1 1 1 1 1 1 1 1</td>
<td>1 1 1 1</td>
</tr>
<tr>
<td>1</td>
<td>1 0 1 1 1 1 1 1 1 1</td>
<td>1 1 1 0</td>
</tr>
<tr>
<td>2</td>
<td>1 1 0 1 1 1 1 1 1 1</td>
<td>1 1 0 1</td>
</tr>
<tr>
<td>3</td>
<td>1 1 1 0 1 1 1 1 1 1</td>
<td>1 0 1 1</td>
</tr>
<tr>
<td>4</td>
<td>1 1 1 1 0 1 1 1 1 1</td>
<td>1 0 1 0</td>
</tr>
<tr>
<td>5</td>
<td>1 1 1 1 0 1 1 1 1 1</td>
<td>1 0 0 1</td>
</tr>
<tr>
<td>6</td>
<td>1 1 1 1 1 0 1 1 1 1</td>
<td>1 0 0 0</td>
</tr>
<tr>
<td>7</td>
<td>1 1 1 1 1 1 0 1 1 1</td>
<td>0 1 1 1</td>
</tr>
<tr>
<td>8</td>
<td>1 1 1 1 1 1 1 0 1 1</td>
<td>0 1 1 0</td>
</tr>
<tr>
<td>9</td>
<td>1 1 1 1 1 1 1 1 0 1</td>
<td>0 1 0 1</td>
</tr>
<tr>
<td>10</td>
<td>1 1 1 1 1 1 1 1 1 0</td>
<td>0 1 0 1</td>
</tr>
</tbody>
</table>
Fig. 8.—Number Generating Circuitry
Fig. 9.—Pulse Train Generator
the 1's are interpreted as open lines. Then Table 1 indicates that if an input line is shorted to ground, its corresponding output lines must also be shorted to ground. This can be accomplished by placing diodes between the input lines and their corresponding output lines, as shown. Thus, if a 0 appears under a certain input line in the table, the output lines in that same row represented by 0's must be connected to the input lines through the diodes. If this is done systematically, the diode matrix of Fig. 6 will be obtained.

It should be noted here that thus far a zero level on a data line has represented significant information. Unfortunately, the logic circuitry used in the bulk of the VDU requires that high levels be used to represent significant data. This means that the information on the output lines of the diode matrix must be inverted. This is accomplished simply by feeding each line into both inputs of four separate nand-gates. Since the output of each gate is the inverse of its inputs when both inputs are the same, their outputs represent data which is compatible with the rest of the VDU circuitry.

The inverted output lines of the diode matrix are connected directly to the paralleled inputs of the two quadruple bistable latches that serve as the system's memory unit. The operation of these latches is outlined in the manufacturer's description of the devices.

The N7475 is a monolithic, quadruple bistable latch with complementary Q and Q outputs. Information present at a data (D) input is transferred to the Q output when the clock is high, and the Q output will follow the data input as long as the clock remains high. When the clock goes low, the information (that was present at the data input at the time the transition occurred) is retained at the Q output until the clock is permitted to go high. (2)

Thus, if one car data line is connected to each latch package's
clock input, a pulse on a particular car line will enable that package to store the four bits of information present at its inputs. This information will then be present at the Q outputs of the package until the next clock pulse occurs.

The next section of the VDU's circuitry performs the function of multiplexing the information at the outputs of the two memory packages so that it can be alternately displayed on the map. This is done through the use of two dual four-line-to-one-line data selector/multiplexer packages. Each multiplexer is a device that has four inputs and one output plus two additional lines, the data on which determines which input will be made available at the output. The internal configuration of a multiplexer package is shown in Fig. 10 along with a truth table describing its operation. (5)

To achieve the desired results, the output lines from the car A memory were fed into the devices' CO inputs while the output lines from the car B memory were fed into the Cl inputs. From the truth table it can be seen that if the devices' B select lines are tied to ground, a pulse train of alternating high and low levels at the A select lines will cause the CO and Cl inputs to alternately appear at the devices' outputs. This is the desired result, and all that is necessary to achieve it is to provide a pulse train as specified to the A select lines. The pulse generator will be discussed later; right now, however, it might be interesting to notice how the flashing function, also a part of the multiplexing section, is performed.

From the truth table of the multiplexers it can be seen that the strobe inputs must be at a low, or ground, level or the outputs will all be low rather than identical to the selected data inputs. Suppose
**Fig. 10.**—Multiplexer Configuration And Truth Table

**Truth Table**

<table>
<thead>
<tr>
<th>ADDRESS INPUTS</th>
<th>DATA INPUTS</th>
<th>STROBE</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>A</td>
<td>C0</td>
<td>C1</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>L</td>
<td>L</td>
<td>L</td>
<td>X</td>
</tr>
<tr>
<td>L</td>
<td>L</td>
<td>H</td>
<td>X</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

L = LOW LEVEL, H = HIGH LEVEL, X = IRRELEVANT
that the strobe inputs are connected to the data output of another multiplexer whose CO and Cl inputs can either be switched to ground level or to a pulse train of alternating high and low levels. This multiplexer must also have its A select line connected to the clock that drives the other devices’ A select lines, so that its output will be synchronized with theirs. Then, if both its CO and Cl lines are switched to ground, the devices output will be a continuous low-level, enabling the information multiplexers to function continuously. If, however, one or both inputs are switched to a line carrying a pulse train, the device’s output will alternate between high and low levels, which will, in turn, cause the outputs of the information multiplexers to drop from their normal data levels to a low level, which represents a zero output for that device. Thus, if the CO line were tied to the pulse train line, the multiplexers would output their CO data while the pulse is at zero level, but when it goes to a high level, the devices’ outputs would be zero. It can be seen, then, that if the driving pulse train is very slow, say in the neighborhood of one pulse per second, the outputs will flash at a rate that will be noticeable when the information is displayed on the map.

The next important section of the VDU’s circuitry is that which decodes the information on the four multiplexer output lines and transforms it back to a single low level on one of ten separate output lines. The devices that perform this function are called four-line-to-sixteen-line decoder/demultiplexers, and it is necessary to have three of these, one for each digit of the cars’ identification numbers, in the circuit.

The operation of these devices is very simple. Each package has
four inputs, so the four lines from the multiplexer section are paralleled into each of the three packages. The output of each package, then, will be a low level on one of ten lines corresponding to the coded information presented to the device's inputs. Since all packages have the same input information, they will have low levels on the same output lines. Corresponding output lines from each package go to each of the three digits at each intersection on the map. Thus, the original intersection location information has been routed to the proper location on the Orlando area map.

At the intersection locations the three leads from the decoders are connected to the three cathodes of the three-digit seven-segment LED readouts. These readouts are manufactured by Hewlett-Packard and are specified as the 5082-7402 series, which are 0.11 inch high, seven-segment Gallium-Arsenide-Phosphorous readout devices. (3)

These devices have three cathode connections, one for each digit, and seven data lines that are common to each digit. Therefore, if it is desired to display three different digits on the devices, they must be multiplexed in such a way that the cathodes are sequentially dropped to ground level so that only one cathode may be grounded at a time. Also, the information present on the seven data lines must be changed each time a cathode is grounded. If this is done rapidly enough, the visual effect will be that three different digits are being displayed simultaneously.

The accomplishment of this process is fairly simple. Each of the three decoder/demultiplexer devices has a pair of inputs which, when presented with a high level, will cause all its outputs to go to a high state. Therefore, if these inputs of only one decoder at a time
are grounded, only that decoder will function and output a low level on one of its data lines. By sequentially causing this condition for each decoder, the result will be that the three LED cathodes at a particular intersection will be consecutively grounded, allowing the input data to be displayed separately for each digit. This is accomplished by applying three synchronous pulse trains to the three decoders, the time sequences of which are shown in Fig. 11. The means of generating these pulses will be discussed later, along with the clock circuitry.

It is now necessary to examine the circuitry that presents data to the seven input lines of the LED readouts. The basic unit involved consists of three 7447 seven-segment decoder/driver integrated-circuits. These devices have four data inputs which receive binary coded information in high level significant form and convert it to a code on their seven output lines that causes a seven segment LED readout to display the arabic numerals 0 through 9. Also of importance to the operation of these units are their blanking inputs which, when a low level is applied, allow all the outputs to rise to a high state. It should also be noted here that these units have open-collector outputs, which means that the output lines must be connected to the positive voltage source through some value of limiting resistor before any data can be output. This restriction will be shown to be quite useful very shortly. (5)

The 7447 presents output data in low level significant form. Since, however, the LED readouts can only accept high level significant data, its outputs must be inverted. This is accomplished as shown in Fig. 8.
Fig. 11.--Pulse Trains: A) N74123 output, B) clock waveform, C) decoder/demultiplexer enabling waveforms, D) decoder/driver blanking waveforms.
The resistors shown are used to limit the current through each of the LED segments. If not for these resistors, the readouts would burn out quickly, since they have a very low forward resistance. The values of the resistors are determined by the maximum amount of current that the LED's will be allowed to conduct for the applied logic voltage of five volts DC. The resistances, then, were found to be

\[ R = \frac{V}{I_{\text{max}}} = \frac{5}{(5 \times 10^{-3})} \text{ ohms} = 1 \text{ kilohm}. \]  

(iv-1)

The method used to provide three different sets of data to the inputs of the LED's is a direct consequence of the fact that the decoder/drivers are open-collector devices. Realizing this, it is possible to parallel the outputs of the three units, if sufficient current limiting is provided by the collector resistors, as shown in Fig. 8. The values of these resistors is determined by considering the current drain of each output of the decoder/drivers and the supply voltage. Or,

\[ R = \frac{V}{I_d} = \frac{5}{(15 \times 10^{-3})} \text{ ohms} = 333 \text{ ohms}. \]  

(iv-2)

Now, if each of the three decoder/drivers has information at its input representing a different number, and two out of three of the devices are blanked at any given time, each of the three digits may be separately displayed. Since the devices require low level blanking signals, a set of three pulse trains like those shown if Fig. 11 will produce the desired results. It should be noted that the pulse that brings each digit out of blanking occurs at the same time as the pulse that causes the intersection selection line for that same digit to drop to a ground state, but that the pulses are the inverse of each
other. Therefore, these pulses can be provided by inverting the outputs of the pulse generator that provides the pulses for the intersection decoder/demultiplexers. This will be discussed more fully later.

Assuming, for the moment, that a black box is available to provide the necessary pulses for proper operation of the system, a method of differentiating between the numbers that identify car A and car B remains to be determined. This allows them to be alternately displayed. It is obvious that since only three decoder/drivers are being used, and are shared by both cars A and B, the information present at their inputs must be altered depending upon whether car A or car B is being displayed. In this particular case this is easy to achieve since each car number only differs in the third digit. The first digit, as previously mentioned, is the shift digit, either a 1, a 2, or a 3. A simple switching arrangement, as shown in Fig. 8 can be used to change these numbers. The second digit in each car number will be a 3, which is represented in four-bit binary-code as 0011, with the 1's representing high levels and the 0's representing low levels, the least-significant-digit again being at the right. By connecting the correct inputs to either ground or $V_{cc}$, this number can be permanently supplied to the decoder/driver.

In the case of the third digit, either a 5, represented by 0101, or a 6, represented by 0110, must be displayed. It is seen that the last two data bits are the same for each number, so they can be connected to $V_{cc}$ and ground permanently. The first two digits must be changed, however, depending on which car number is being displayed. Therefore, when car A is being displayed, the first data bit must be
high level and when car B is being displayed it must be a low level. This can be accomplished by tying this input line directly to that which carries the clock pulses, since the clock line is high when car A is displayed and low when car B is displayed. The second data input bit must be low when car A is displayed and high when car B is displayed. This is the inverse of the clock pulse train, and is also available from the black box pulse generator. Thus, the numbers for car A and car B can be alternately displayed, as desired.

This completes the description of the logic circuitry that operates on the data presented to the inputs of the VDU. It should be noted that many of the important parameters of the individual devices used, such as fan in, fan out, rise time, and so on, have been neglected. This can be done by assuming that the devices will always be operated within the limits of their restricting conditions, since the most important information needed here was that concerning the actual operations of the devices. It is necessary now to examine the unit that provides the sequences of pulse trains required by the map circuitry, and the discussion of the VDU will be complete.

The basic sequence of operations that enables the pulse generator to create the necessary pulse trains is composed of three different but related steps. First, an impulse generator provides a series of equally spaced pulses, as shown in Fig. 11. Next, these pulses are input to a JK flip-flop that converts them to a square wave whose period is equal to two of the individual pulse periods. This square wave is, as has been previously mentioned, the clock signal that differentiates between cars A and B, and will be coupled to a
synchronous divide-by-three network which provides the pulse trains required by the decoder/drivers and decoder/demultiplexers.

The impulse generator was constructed from an N74123 retriggerable monostable multivibrator, as shown by Fig. 9. When this device is connected as shown, the values selected for \( R_1 \) and \( C_1 \) determine the time interval between the spikes in its output waveform. The equation for this time interval is given by the manufacturer as

\[
t_w = 0.32R_1C_1(1+0.7/R_1)
\]

where 0.32 and 0.7 are constants evaluated specifically for the N74123 integrated-circuit. (5)

It can be seen that for any large value of \( R_1 \), this will be approximately

\[
t_w = 0.32 R_1 C_1
\]

so that if the period of the clock waveform is to be one millisecond,

\[
t_w = (1\times10^{-3})/2 = 0.5 \text{ millisecond}
\]

and, selecting \( C_1 \) as one microfarad,

\[
R_1 = t_w/0.32C_1 = 1.56 \text{ kilohms.}
\]

The functioning of the multivibrator itself can be seen by examining its configuration, also shown in Fig. 9. Essentially, it is no more than a flip-flop driven by an AND-gate such that when the AND-gate receives two high signals the flip-flop will have a logical 1 at its Q output. It will remain in this state for the length of time \( t_w \), and will then change state so that the logical 1 appears at
the \( \overline{Q} \) output. The \( \overline{Q} \) line, however, is coupled back to one of the AND-gate's inputs, the other input being tied to ground through an inverter so that it always maintains a high level. Therefore, when the 1 appears at \( \overline{Q} \), the AND-gate causes the flip-flop to return to its original state, for which the 1 appears at \( Q \), with the result that the \( \overline{Q} \) line stays in the logical 1 state for a very short period of time. Thus the impulse spike has been produced, and the continuation of the process will result in the impulse train shown in Fig. 11.

The conversion of this impulse train to the clock pulse train is quite simple and only requires the use of one JK flip-flop. The operation of the JK flip-flop is such that when its \( J \) and \( K \) inputs are tied to a high level its output state will change each time the clock signal input to the device goes from a high level to a low level. Thus, if the \( Q \) output is high when one impulse appears it will go to a low level and remain there until the next impulse occurs, at which time it will return to a high level. This causes the clock pulse train, also shown in Fig. 11.

The remaining circuitry of Fig. 9, composed of two flip-flops and two NAND-gates, performs the function of producing the three synchronous pulse trains required by the decoder/drivers. The inverse of these signals, required by the decoder/demultiplexers, is also produced by this circuitry.

The design of this network can be derived from a knowledge of the demands that will be placed on it. First, it must have three separate and distinct sequential outputs. Realizing this, it can be seen that only two flip-flops will be required since each flip-flop has two such outputs and some combination of these outputs can
be used to produce the desired three outputs. In this particular case it is assumed that one output will occur when both \( \bar{Q} \) states are high, another when \( Q_1 \) is high and \( Q_2 \) is low, and the third when \( Q_1 \) is low and \( Q_2 \) is high. This is shown in Table 2 in relation to the clock pulses that will cause the state changes.

### TABLE 2

<table>
<thead>
<tr>
<th>Clock Pulses</th>
<th>( Q_1 )</th>
<th>( Q_2 )</th>
<th>( \bar{Q}_1 )</th>
<th>( \bar{Q}_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before First Pulse</td>
<td>0 0</td>
<td></td>
<td>1 1</td>
<td></td>
</tr>
<tr>
<td>After First Pulse</td>
<td>1 0</td>
<td></td>
<td>0 1</td>
<td></td>
</tr>
<tr>
<td>After Second Pulse</td>
<td>0 1</td>
<td></td>
<td>1 0</td>
<td></td>
</tr>
<tr>
<td>After Third Pulse</td>
<td>0 0</td>
<td></td>
<td>1 1</td>
<td></td>
</tr>
</tbody>
</table>

Since the required sequence of outputs is now known, they can be made to occur by causing the J and K inputs of the two flip-flops to be in the correct states at the time each clock pulse occurs. These states are determined from the flip-flop's truth table, designated as Table 3.

### TABLE 3

<table>
<thead>
<tr>
<th>( t_n )</th>
<th>( t_{n+1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>K</td>
</tr>
<tr>
<td>0 0</td>
<td>0</td>
</tr>
<tr>
<td>0 1</td>
<td>0</td>
</tr>
<tr>
<td>1 0</td>
<td>1</td>
</tr>
<tr>
<td>1 1</td>
<td>1</td>
</tr>
</tbody>
</table>

Examination of this table allows the construction of another table, Table 4, which shows the J and K input conditions at the time of each clock pulse necessary to obtain the proper outputs after the clock pulses. From this table it can be seen that the K inputs must
always maintain a zero level; therefore, they will be connected directly to ground. The J inputs, however, must be changed sequentially with each clock pulse.

**TABLE 4**

**REQUIRED JK INPUTS**

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Inputs At t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse At Time t</td>
<td>J₁ J₂ K₁ K₂</td>
</tr>
<tr>
<td>First pulse</td>
<td>0 1 0 0</td>
</tr>
<tr>
<td>Second pulse</td>
<td>1 0 0 0</td>
</tr>
<tr>
<td>Third pulse</td>
<td>0 0 0 0</td>
</tr>
</tbody>
</table>

At the time of the first clock pulse it will be assumed that Q₁ and Q₂ are both at zero level. After the pulse, the required output conditions of Q₁ and Q₂ are 1 and 0 respectively. To accomplish this, J₁ must be at a zero level and J₂ at a high level. Since the levels of Q₂ and Q₁ meet these requirements at the time of the pulse, J₁ and J₂ will be tied to them as shown. A continuation of this process shows that these two connections are all that is necessary to meet the requirements placed on the circuit. Thus, the Q output of the first flip-flop will provide one output line, that of the second flip-flop will provide another, and an AND operation on Q₁ and Q₂ provides the third. Since the Q outputs are the inverse of the Q outputs, the pulse trains required by the decoder/demultiplexers can be obtained directly from this circuit, as shown.
v. THE CAR UNIT

The radio relay unit mounted in the patrol car is the connecting link between the intersections and the radio dispatch room at police headquarters. As has been previously mentioned, it serves a double purpose. First, it receives the tones transmitted from the intersections and re-transmits them back to the police station. Secondly, it generates and transmits a tone that identifies the mobile unit in which the device is mounted.

Before actually designing the circuitry to accomplish these objectives, it is necessary to take a close look at the restrictions that will govern its operation. First of all, the control circuitry constructed must be compatible with that of the commercially made devices already obtained for use in the project. These devices, listed again here for convenience, are the Pace receiver, the tone encoder, and the police channel-four hand-transmitter. It is desired, then, that the circuitry designed will in no way alter the normal operation of these devices.

In order to avoid unnecessarily long interruptions of the traffic on channel four, it is also required that the radio relay unit's transmission time be kept within a time interval of one to two seconds. This length of time will enable the transmitted data to be available at the decoders in the radio dispatch room long enough to ensure their proper operation but will not seriously hamper communications on police channel four.

It is also desired that the radio relay unit only transmit data
once while the car is in the proximity of a particular intersection. This is primarily an extension of the restriction concerning the interruption of channel-four transmissions, but is also warranted by the fact that the map circuitry only needs one signal from an intersection in order to establish a car's location and will store that location in memory until another signal is received. Therefore, another signal from the same intersection may be considered useless information and need not be transmitted.

Keeping all these restrictions in mind, it can be seen that a possible means of providing the desired functions would be to cause the presence of an intersection signal in the Pace receiver to trigger the tone generator and timing circuitry simultaneously. By this means both the intersection and car identification signals will be available to the hand transmitter at the same time, and will both be transmitted when the timing circuitry triggers the solenoid that actuates the press-to-talk switch. The necessary circuitry can now be designed.

The tone encoder, shown in Fig. 12, has an internal relay that may be used to cause the device to begin oscillation; thus, if some means is provided to actuate this relay when an intersection signal is received, the encoder will begin to function and continue until the signal is removed. An examination of the Pace receiver's squelch circuitry, shown along with its pre-amplifier section in Fig. 13, suggests a possible solution to the problem. (4)

The squelch section consists of Q₆ and Q₇ and receives a signal from the receiver's IF amplifier when a transmission is received. This signal, applied to the base of Q₆ by squelch control VR₂, causes Q₇ to cease conduction, which causes the voltage at the emitter of Q₆
Fig. 12—Encoder Trigger Circuitry

- AUDIO OUTPUT
- 1700pF
- 50kΩ
- R₆
- 2.2 MΩ
- 2N3804
- Q₄
- 10kΩ
- R₄
- 22kΩ
- R₃
- 270 Ω
- 2N3804
- Q₂
- 1.5kΩ
- R₅
- Vₑ = 12 VDC
- 402
- TONE ENCODER
to drop from a squelched value of 6 volts DC to a non-squelched value of approximately 0 volts DC. Thus, the circuitry that triggers the encoder must provide an output to actuate the encoder's relay when its input is 0 volts DC. A simple circuit to accomplish this is shown in Fig. 12.

Terminal B is the circuit's input and it is connected to the emitter of Q₈ of the receiver's audio pre-amplifier section. When the input voltage is 6 volts DC Q₁ conducts heavily since it is biased in its saturation region, and thus, the base of Q₂ is at approximately ground potential, a condition which prevents its conduction. This means no voltage will appear across the encoder's actuation relay and the encoder will not function. When the input at B drops to 0 volts DC, however, Q₁ ceases conduction and voltage appears at the base of Q₂. This causes Q₂ to saturate and creates a path by which current may flow to ground through the coil of the encoder relay, triggering the relay and causing the encoder to begin oscillation.

Both transistors used in the circuit are 2N3904's, and the values of the necessary resistors may be determined by examination of the transistors' saturation curves. These curves may be found in any good transistor reference book, and will not be shown in this paper.

From the transistors' saturation characteristics it is found that they may successfully perform their switching functions for collector currents ranging between one and one-hundred milliamperes. Thus, the value of R₁ was chosen as 1.5 kilohms. Knowing this, the collector current of Q₁ can be determined to be

\[ I_{c1} \approx \frac{V_{cc}}{R_c} \]
if $V_{ce}$ is negligible. Therefore,

$$I_{cl} \approx \frac{12V}{1.5 \text{ kilohms}} \approx 8 \text{ milliamperes}.$$ 

Knowing this, the saturation curves show that $Q_1$ will be saturated for base currents greater than approximately 0.2 milliamperes. Therefore, neglecting the transistor's base-emitter resistance,

$$R_2 < \frac{V_{in}}{I_b} < \frac{6V}{2 \times 10^{-4}} < 30 \text{ kilohms.} \quad (v-2)$$

The value selected for the circuit was 22 kilohms.

It should be noted that, since this value is much greater than that of the emitter resistor of $Q_8$ in the Pace circuitry, the input of this circuit will not cause an appreciable change in the bias levels of the receiver circuitry, and will, therefore, not alter its normal operation.

To determine the value of $R_3$, the resistance of the encoder relay's coil must be known. It was measured to be 500 ohms and it was also found that a minimum current of 10 milliamperes is required to trigger the relay. The saturated collector current of $Q_2$ to trigger the relay, then, must be greater than 10 milliamperes, and $R_3$ can be found to be

$$R_3 + 500 < \frac{V_{cc}}{I_{c2}} \quad (v-3)$$

or,

$$R_3 < \frac{12}{10 \times 10^{-3}} - 500$$

so that

$$R_3 < 700 \text{ ohms}.$$
Thus, $R_3$ was chosen as 270 ohms.

The actual collector current, then, will be

$$I_{c2} \approx \frac{V_{cc}}{(R_3 + 500)} \approx 12/0.770 \text{ milliamperes} \quad (v-4)$$

or,

$$I_{c2} \approx 15.6 \text{ milliamperes.}$$

From $Q_2$'s saturation characteristics, this requires a base current of

$$I_{b2} > 0.5 \text{ milliamperes} \quad (v-5)$$

or,

$$R_4 + R_1 + 500 < \frac{V_{cc}}{I_{b2}}. \quad (v-6)$$

Thus,

$$R_4 < (12/5)x10^4 - 0.2x10^4 \text{ ohms.}$$

and,

$$R_4 < 22 \text{ kilohms.}$$

The actual value of $R_4$ used, as shown in Fig. 12, is 10 kilohms.

The remaining circuitry of Fig. 12, consisting of $R_5$, $R_6$, and $C_1$, is used to adjust the level of the audio output of the encoder and provides coupling between the encoder's output and the base of the second audio pre-amplifier transistor ($Q_9$) of the Pace receiver. The values of these components were determined experimentally as those which provided the best tone, in both level and purity, at the output.
of the receiver. A detailed derivation of their values is therefore unnecessary and will be omitted.

It can also be seen from Fig. 12 that a connection has been made to the contacts of the encoder relay. This connection, leading to terminal A, provides 12 volts DC to the timing circuitry when the relay is activated. The timing circuitry is shown in Fig. 14.

The operation of this circuit can be understood without elaborating on the mathematical intricacies that describe its exact performance. The basic functional sequence is that when 12 volts DC, supplied by the contacts of the encoder relay, appears at input A, power transistor Q3 saturates and supplies approximately 12 volts DC to the rest of the circuitry. The major portion of the network is composed of two separate timing circuits that supply power to two relays, one with normally-open and the other with normally-closed contacts. These contacts are connected in series with the coil of the mechanical solenoid that actuates the channel-four transmitter so that when no signal is applied at A there is no current path from Vcc to ground through the solenoid's coil. When A receives a 12 volt DC signal, however, the timing circuits begin to function. After the 12 volts has been applied for approximately one and one-half seconds the normally-open contacts close and the solenoid is actuated. A short time later, the normally closed contacts open and the solenoid is released. The two relays will maintain this condition until the encoder relay deactivates (i.e., the car is no longer in the intersection), at which time they will return to their normal conditions.

Brief consideration can now be given to the conditions that cause the delay times in the two relays. Since both time delay sections are
Fig. 14.—Solenoïd Control Timing Circuitry
essentially the same, it will only be necessary to examine one of the two, that consisting of $Q_4$, $Q_5$, and Relay 1 (the coil of which is designated as $I_1$). It should be noted, however, that the differences in the component values of the two sections arise from the fact that the current requirements to actuate the relays differ; hence, the biasing networks of the transistors will not be identical. The only other difference in the two circuits is that the second contains a variable resistor network composed of $R_{10}$ and $R_{11}$. The combination of $R_{11}$ and $C_2$ sets the minimum time delay for the normally closed relay. $R_{10}$, when added to $R_{11}$, allows adjustment of the time interval between the actuations of Relay 1 and Relay 2, thus regulating the on-time of solenoid $S_1$.

The operation of the timing circuit containing $Q_4$, $Q_5$, and $L_1$ may now be examined. From Fig. 14 it can be seen that when $Q_3$ begins to conduct due to a signal at A, $C_2$ will start to charge through $R_8$ from its initial value of 0 volts DC towards the applied voltage of 12 volts DC. As it charges, the base voltage of $Q_4$ will rise and cause an increase in $Q_4$'s collector current. This current, coupled to the base of $Q_5$ through $R_9$, will cause an increase in $Q_5$'s collector current. When $Q_5$'s collector current reaches the level required to trigger Relay 1, the contacts of the relay will close and the time delay process will have reached completion.

There are a number of difficulties that arise in attempting to compute the actual time delay of this type of circuit, most of which stem from the nonlinearities inherent in the circuit. First of all, it should be noted that, since the base voltage of $Q_4$ is initially at a zero level, the transistor will not be operated within its linear
region over the entire charging interval of \( C_2 \) and, hence, the relationship between base voltage and collector current will not be linear. Secondly, this also implies that the input resistance will vary as the base voltage of \( Q_4 \) increases, which means that the timing circuit will be based on an RC form with a non-linearly varying value of R. At this point it would seem that the difficulties in calculating the required time delay might be insurmountable; however, if a number of assumptions are made, an approximate time delay value may easily be computed.

Consider first the part of the delay circuitry composed of \( Q_5 \) and \( L_1 \). If it is assumed that the only important conditions on \( Q_5 \) occur at the time the relay is activated, \( Q_5 \) can be eliminated from the circuit. It is known that the relay will actuate when the voltage across its coil reaches a value of 7 volts DC. This, then represents a collector current for \( Q_5 \) of

\[
I_{c5} = 45 \text{ milliamperes.}
\]

It is also known (by curve-tracer measurement) that \( Q_5 \) will have a current gain factor (Beta) of 100. Therefore,

\[
I_{b5} \approx I_{c5}/( \text{Beta} ) \approx 45 \text{ mA/100} \approx 0.45 \times 10^{-3} \text{ amperes. (v-7)}
\]

Also, since \( I_{c4} \) is identical to \( I_{b5} \), it follows that \( I_{c4} \) must be 0.45 milliamperes.

Knowing the collector current of \( Q_4 \) at relay actuation allows the part of the network composed of \( R_2 \), \( Q_5 \) and \( L_1 \) to be replaced by a constant load in the emitter circuit of \( Q_4 \). The total voltage drop across this load may be calculated as
\[ V_{\text{load}} = I_{\text{ch}} R_2 + V_{\text{be}5} + V_{\text{L1}} \]  \hspace{1cm} (v-8)

or,

\[ V_{\text{load}} \approx (0.45 \times 10^{-3})(3.9 \times 10^{3}) + 0.7 + 7 + 9.45 \text{ volts.} \]

For actuation of Relay 1, then, the base voltage of \( Q_4 \) must rise to a level of

\[ V_b \approx V_{\text{be}4} + V_{\text{load}} \]  \hspace{1cm} (v-9)

or,

\[ V_b \approx 0.7 + 9.45 \approx 10.15 \text{ volts.} \]

If it is now tacitly assumed that the input resistance at the base of \( Q_4 \) is much greater than that of \( R_8 \), the approximate time delay can be computed using the basic equation

\[ V_b = V_{\text{cc}} (1 - e^{-t/RC}) \]  \hspace{1cm} (v-10)

which may be rearranged for a direct solution of time as

\[ t \approx -R_8 C_2 \ln(1 - V_b/V_{\text{cc}}) \].  \hspace{1cm} (v-11)

Using the circuit values shown in Fig. 14, the computed value for \( t \) may be found to be 2.34 seconds, which is relatively close to the actual value of the time delay which, by approximate measurement, was found to be one and one-half seconds.

The circuit described above could be greatly improved by making a minor change in its configuration. That is, the relay and its bypass diode could be removed from the emitter circuit of \( Q_5 \) and placed
instead in its collector circuit, allowing $Q_5$'s emitter to be connected directly to ground. This configuration would alleviate some of the computational problems mentioned in the previous model. For one thing, the input impedance at the base of $Q_5$ would be extremely high, being approximately equal to

$$R_{in5} \approx (\beta)R_2$$  \hspace{1cm} (v-12)

or,

$$R_{in5} \approx 100(3.9) \text{ kilohms} \approx 390 \text{ kilohms}.$$  

This value is sufficiently high that it may be justifiably neglected in any calculation of the circuit's RC time delay.

Using this configuration would also reduce the voltage level at the base of $Q_4$ required to actuate the relay. In that the seven volts required for actuation would no longer be in $Q_5$'s emitter circuit, the total base voltage on $Q_4$ at that time would be

$$V_b \approx 0.7 + 1.75 + 0.7 \text{ volts} \approx 2.14 \text{ volts}.$$  

This means that the base voltage required to trigger the relay would be reached during a fairly linear portion of $C_2$'s logarithmic charging curve. This fact, when added to the previously mentioned increased input resistance, creates a considerably more accurate basis for calculation of the circuit's time delay.
vi. CAR TONE DECORDER DATA CONVERSION

It has been previously established that the data input to the VDU on the car identification lines must be presented in a specific form. That is, while the intersection identification line is at a high impedance level, the car line must rise from its normal low level to a high level and return to its low level before the intersection line returns to its normal high level. The means of accomplishing this is shown in Fig. 15.

In the case of an intersection tone decoder, one contact of the output relay is tied to ground while the other is connected directly to a VDU input line. Thus, when the decoder is not active, its normal output impedance is extremely high due to the relay’s normally open contacts. A signal at the decoder's input will activate the relay, closing its contacts and presenting a zero level on its output line.

For a car decoder, however, one contact of the output relay is connected to the twelve volts DC voltage source while the other is connected to the additional circuitry shown. Thus, the correct tone at the decoder’s input will cause the circuitry to begin to function by supplying it twelve volts DC. When this occurs, capacitor C₁ will begin to charge through resistor R₁, causing the voltage at the base of Q₁ to rise above ground potential. When this increasing base voltage reaches a level that creates sufficient collector current to actuate the collector circuit relay (K₂), the base of Q₂ will be supplied enough current to cause the transistor to saturate. It should be noted that, due to the time delay between the actuations of K₁
and $K_2$, $Q_2$ saturates a short time after the car tone has actually reached the decoder. This means that by the time $Q_2$ saturates, the output of an intersection line should already be in its low impedance state.

The saturation of $Q_2$, then, supplies twelve volts DC to the network composed of $R_3$, $C_2$, $D_1$ and $K_3$. At the instant this occurs $C_2$ experiences a heavy chargrin current, which supplies approximately twelve volts to the coil of $K_3$, causing its actuation. This opens its normally closed contacts and provides the desired high impedance level at the VDU's input. As $C_2$ continues to charge, however, the voltage across the coil of $K_3$ will decrease until it drops below the level required to maintain actuation, at which point its contacts will return to their normally closed state. When the decoder relay's contacts open again $C_2$ will discharge through $R_3$ and $D_1$, assuring that the coil of $K_3$ will not be re-energized by the discharge current and will maintain its de-energized state until another signal appears at the decoder's input.

The mathematics involved in determining the component values of this circuit are quite similar to those used in the derivation of the component values of the car unit's timing circuitry, and will not be repeated here. Instead, it need only be re-emphasized that timing component values chosen must allow the contacts of $K_3$ to close again before the intersection decoder de-activates, else the information on the intersection line will be lost.
vii. SYSTEM ADJUSTMENTS AND ALTERATIONS

It would be unrealistic to assume that even the most brilliantly conceived and carefully designed system would prove operational on the occasion of its initial trial. And thus it was that, in keeping with the laws of nature that seemingly govern such events, the Proximity Vehicle Locator System stubbornly resisted all early efforts to collect data substantial to prove the merit of the conception which ultimately gave it birth. An examination of the system's problems revealed that none seemed insurmountable; in fact, no major design alterations were indicated, and the solution of each problem led the system closer to the level of performance expected of it. The following material, then, deals with a number of the problems that have been, or should be, eliminated from the system.

Problems at the Intersections

The mounting of the transmitters in the traffic control boxes gave rise to no unusual difficulties other than in one instance, when the traffic engineer assigned the task chose the wrong power source, with the result that the transmitter at that intersection ceased transmission when the amber caution light was on. This condition, however, was easily remedied.

The most prevalent problems at the intersections resulted from the insufficient output levels of a number of the transmitters. In the more extreme cases a car passing through the intersection on the side where the control box was located could pick up the transmitter's signal only if his receiver was lightly squelched, and passing through
from the opposite direction the signal was completely undetectable.

Another undesirable offshoot of this problem was that, since the receiver had to be operated with minimum squelch, an approach to an intersection whose transmitter was stronger than usual would result in a fringing effect. That is, as the car entered the outer fringes of the transmitter's blanket of coverage, the car would pass through areas where the signal would be strong enough to bring the receiver out of squelch and activate the radio relay unit. Then the signal would die out briefly, allowing the radio relay to de-activate, only to be re-activated when another area of reception was entered. This resulted in numerous transmissions of varying signal levels from some of the intersections, a situation detrimental to communications on channel four.

The solution to this problem was quite simple. Originally, the transmitters installed at the intersections were equipped with one-quarter wavelength (approximately nine feet) of antenna wire. These antennas were fed through small holes in the traffic control boxes and strung along the outer surfaces of the boxes, which are made of iron and are well grounded. The problem, then, was one of loss of signal. The antennas were not long enough to be strung away from the metal boxes, and a great deal of a transmitter's output was lost to ground absorption. To solve the problem, another one-quarter wavelength of antenna was added to each transmitter, and was hung away from the control box to reduce absorption.

The result of this procedure was that a car could now pass through the intersections from any direction with its receiver heavily squelched and still pick up the intersection identification signals.
Also, the use of more squelch requires a stronger signal to bring the receiver into operation. Thus, the weak fringe area signals were eliminated, ending the problem of premature triggering of the radio relay unit.

With the transmitters functioning as desired, one can only guess at problems that may crop up in the future. For one thing, it is not yet known how well the transmitters will endure the frequent lightning strikes that knock out traffic control units throughout the summer months. The transmitters are all well grounded, but so is the traffic control equipment, and it doesn't seem to do much good. Only time and several thunderstorms can provide data regarding this problem.

The Car Unit

The radio relay unit mounted in the patrol car performed its mechanical duties exactly as desired. That is, the timing circuits and actuator controls did indeed trigger the channel four transmitter to relay signals back to the police station. And once the ignition noise was filtered out of the receiver and the intersection transmitter's signal outputs were boosted, the signal to noise ratio of the received signals was adequate to provide relatively noise free tones at the decoders at the police station.

The major problem with the car unit was that since the receiver and transmitter must function simultaneously, some means had to be provided to keep the transmitters signal from entering the receiver. It would seem that the two units should not normally interfere with each other since the receiver operates at 27 megahertz and the transmitter at 450 megahertz, but with the transmitter mounted directly beneath the receiver, the signal from the transmitter easily leaked
back into the receiver to create a feedback loop. The loop occurred when the intersection and car ID tones were coupled from the output of the receiver to the input of the transmitter, which then transmitted them right back into the receiver. The problem was solved by merely moving the receiver away from the transmitter. This required, however, that the receiver's speaker be mounted above the transmitter and that wires be run from the receiver to its now disjoint speaker.

The only remaining problem with the car unit is that the audible tones tend to wear on the nerves of the officers who have to listen to them each time a monitored intersection is passed. A possible solution to this would be to acquire a channel four transmitter that could be permanently incorporated into the unit. Then the receiver's output and transmitter's input could be electrically, rather than acoustically, coupled and the tones would no longer be audible to the officers in the patrol car.

The Decoders

The biggest problem with the decoders was one of adjustment of input levels. This became rather critical, because when the decoders are driven too hard, more than one at a time (usually those closest to the frequency of the incoming signal) may provide an output which causes inaccurate data to be supplied to the VDU. To remedy this situation, a network was placed at the input of the decoder unit that allowed adjustment of the incoming signal levels. Such a simple network need not be discussed here.

Once the input level was adjusted, it was found that some of the decoders were more sensitive than others, and would actuate when a strong signal close to their frequencies appeared at their inputs.
This, too, caused erroneous data to be fed to the VDU. Minor alterations to each decoder's circuitry made the decoders' sensitivities adjustable, and they were finally set at a level that allowed the input to vary between one-half to twenty volts with only the correct decoder being actuated.

Another problem that can be dealt with at the decoder unit is that which occurs when a car ID tone arrives without an intersection ID tone. This can occur when a car passes through an area of radio noise strong enough to bring the receiver out of squelch, which causes generation and transmission of the car tone even though the car was nowhere near a monitored intersection. When this occurs, the car ID line to the VDU enters data without data on one of the intersection lines, which erases the map. To correct this situation, which rarely occurs anyway, a logic network could be installed on the decoder unit's output lines that would not allow the car data to reach the VDU if no data appeared on an intersection line.

The Map

The map circuitry functioned perfectly throughout all the tests. The only complaint that can be made about the map is that the LED's used for the numeric displays are a little too small to be read comfortably at distances of more than a few feet. Using larger readouts would solve the problem, but they would also require more space for mounting, which could cause problems when the intersections to be monitored are only about one inch apart on the map. This problem, one of human engineering, could be solved in a number of different ways, all of which are tacitly ignored in this paper.
CONCLUSIONS

The system described in this paper, admittedly, has a number of serious drawbacks. In order to obtain the best possible monitoring of a car's location in a large city, a great number of intersection transmitters would be required. Although the cost of each transmitter is relatively low, the man-hours required for installation and maintenance might prove prohibitive. For a smaller community, however, it might prove to be a worthwhile system. Not as many transmitters would be needed, and probably the knowledge of a car's approximate location would be sufficient for the police dispatch operator. In such a situation, the cost of such a small scale system would probably not be out of reach of the community's budget, as would some of the more sophisticated systems now available.

There are available at this time systems, ideal for large metropolitan areas, that promise a great degree of accuracy through computer data manipulation. These systems, already reduced in price through their acceptance and use, tend to make the system described here obsolete for large scale applications.
REFERENCES CITED


