This is to certify that the

thesis entitled

AUTOMATIC TESTING OF TRAFFIC RADAR
SPEED MEASURING DEVICES

presented by

Carol L. Bridge

has been accepted towards fulfillment
of the requirements for

M. S. degree in Elect. Eng.

David Fisher
Major professor

Date 2-26-81

O-7639

AUTOMATIC TESTING OF TRAFFIC RADAR

SPEED MEASURING DEVICES

By

Carol L. Bridge

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Electrical Engineering and Systems Science

1981

ABSTRACT

AUTOMATIC TESTING OF TRAFFIC RADAR
SPEED MEASURING DEVICES
By
Carol L. Bridge

This thesis details the development of an apparatus which automatically tests police traffic radar devices. The software contains two principal components--one facilitates operator interaction while the other models target and patrol vehicles moving on simulated roadways. Under program control, the operator selects between X- or K-band radar, moving or stationary operation, one or two synthetic targets, and one of four target sizes. These targets may assume any realistic speeds and initial distances from the antenna. Acceleration and deceleration of vehicles is also permitted. A signal channel is associated with each vehicle; frequencies and amplitudes are varied under program control ten times per second to update the simulation model. These signals amplitude modulate the radiation sent by the radar antenna and simulate moving objects.

The simulator meets all its design objectives and is currently recognized as a useful tool in evaluating radar devices and instructing radar operators.

ACKNOWLEDGEMENTS

There are many people who have worked with me to make this research effort a success. I am very grateful to Dr. P. David Fisher, my academic and research advisor, who has always been a source of knowledge and encouragement. In addition, I am indebted to Chuck Dorcey and Mike Schuette for their substantial help in the construction and evaluation of the simulator, and to Bill Pearson for drawing the figures and flowcharts. I would also like to extend a special thanks to Linda Strawn for the great care and patience she took in typing the manuscript.

This research was supported in part by the Michigan State Police Office of Highway Safety Planning under Grant No. MPT-81-001A.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Police traffic radar has been used to detect speeding vehicles for about the past 30 years. Over this period of time radar devices have evolved from large stationary models to the present compact units capable of monitoring traffic in both the moving and stationary modes. Although these advances have greatly improved the efficiency and effectiveness of police radar, they have also increased scrutiny by the courts and caused the public to question the accuracy, reliability, and limitations of today's police radar [1, 2].

National studies and recent court decisions have shown that there is a need to upgrade both radar equipment and the quality of operator training. To this end, the National Bureau of Standards (NBS) and the National Highway Traffic Safety Administration (NHTSA) have developed performance specifications for speed measuring devices [3]. The research effort reported here deals with the design, construction, and evaluation of a computer-controlled traffic radar simulator which is used to simulate, in a laboratory environment, traffic on a roadway. This simulator will be an important tool in both operator training and the assessment of radar units.

A simulator has an advantage over field testing for several reasons. First, it can be used to repeatedly simulate scenes that would be difficult and time consuming to set up on an actual roadway. It also has the advantage of conducting tests that would be impossible to do in the field, but are still useful in the evaluation of radar units. For instance, the simulator has a feature that allows an operator to "freeze" all the variables at any point during the test and study a condition more closely before continuing with the test. Finally, it can be used for demonstration purposes to assist in operator training.

This thesis presents the details of the design, implementation, evaluation, and usage of the traffic radar simulator. Chapter 2 details the basic design requirements of the simulator. The organization of the hardware and software is discussed in Chapters 3 and 4, respectively. Chapter 5 summarizes the evaluation tests that were done on the simulator. Finally, Chapter 6 discusses tests done on individual radar units and summarizes the development and evaluation of the simulator.

II. DESIGN REQUIREMENTS

This chapter presents the overall design requirements for the simulator. We begin by describing in general terms the types of tests that are to be performed. Next we consider the necessary simulator features. This is followed by a description of the hardware and its operator interaction requirements.

2.1 Radar Test Overview

There are various situations that develop where a radar unit could provide misleading information to the operator. One such situation arises when the unit acquires a target vehicle which is not out front. This often occurs when a larger or faster moving vehicle is further down the road. Even though this is not an error as such, it could confuse the operator if he/she expects to see the speed of the lead vehicle displayed. Two moving mode errors sometimes occur when multiple targets are present, shadowing and combining. Shadowing occurs when the patrol car speed is displayed as the difference between the patrol speed and that of a large vehicle it is overtaking. So the difference between the actual patrol speed and that which is displayed is added to the speed reading of an oncoming target, thereby increasing the displayed target speed. Sometimes the sum of the patrol speed and the speed of an approaching vehicle is displayed as the patrol car speed. This effect, known as combining, most often occurs when the patrol car accelerates from a stopped position. Other errors may occur when the patrol signal is temporarily interrupted, for example, by anti-radar detection devices that turn off the microwave oscillator.

There are other possible sources for error which NBS and NHTSA have also identified [3]. These include

* false target readings due to rapid changes in the patrol car speed
* errors due to low or high power supply voltages or low or high operating temperatures
* false readings either due to electrical interference or mechanical motion, fans, wipers, and vibration

In addition to testing for these error conditions, the simulator can also be a useful tool in checking other required radar unit features, for example, patrol and target speed ranges, lock-recall-clear, and Doppler audio characteristics.

2.2 Simulator Characteristics

In order to identify problems and evaluate new and existing radar units, there are several properties the simulator must have. First, tests should be able to be run in both the moving and stationary modes. There is a need for multiple targets in order to study effects such as target selectivity, shadowing, and combining. There is also a need for different sized targets and the ability to start them at any distance from the antenna. Moreover, these targets should be able to approach the radar unit or recede from it. The patrol vehicle and all targets should be able to accelerate and decelerate during a test. Also, there is a need for an external signal source so that the effects of adding noise or other external signals can be studied.

The operator should be able to control the length of the test since some tests might last a very long time and others just a few seconds. The operator should also be able to begin the test at his/her convenience and stop the test at any point. After the test has been stopped, the option of continuing with the old test or starting a new one should be given.

In addition, there should be the capability to set a signal of a certain frequency and amplitude without any dynamic features. Also, there should be a way to vary target signal

amplitudes to any point without considering the relationship between the amplitude and the roadway conditions.

2.3 Hardware Requirements

To simulate a moving vehicle of a certain size, speed, and distance, a signal must be generated with a frequency corresponding to the Doppler shift that would occur for that speed, and an amplitude which depends on the vehicle's size and distance away. The simulator must be such that an operator can use a terminal to specify test parameters such as speed, size, and distance so the correct signal will be generated. The operator should not need any understanding of Doppler shifts or how amplitudes depend on the target size or the distance it is from the antenna.

Three distinct signals are needed to simulate two targets and a patrol car. This requires three independent channels, each with unique frequency and amplitude components. The ability to add more channels in the future should be allowed for. The Doppler shift signals should amplitude modulate the microwave signal sent from the radar antenna and thereby, create synthetic targets. Each channel should have the capability of being sent to a separate modulator, but there should also be the option of sending the sum of all three channels to one modulator. The frequency requirements should be such that a target and the patrol car can be converging on one another at speeds from five to 100 mph each (maximum closing speed of 200 mph) with an accuracy of ±1 mph for stationary mode and ±2 mph for moving mode. In addition, the amplitude component should have a range of three orders of magnitude.

There must be a visual display in addition to that on the radar unit to display the current state of the simulator during the test. The target speeds and distances and the patrol car speed should be displayed. Also, there should be indicators of whether a test is in progress, it is moving

or stationary-mode operation, and which target has the largest signal, is out front, and is moving fastest. This will allow the operator to double check the accuracy of the unit as well as keep track of what is going on during the test.

2.4 Simulator Usage Requirements

The traffic simulator will be used to simulate actual roadway occurrences with two targets and a patrol car. After loading the simulator program into main memory, the operator must control the entire test procedure from the terminal. Before a test can be run, the operator must answer a number of questions interactively about the initial conditions. These questions must include whether moving or stationary mode is required and the number of targets that are to be in the test.

If the patrol car is going to be used, then the speed and amplitude requirements must be entered by the operator. Also, speed and amplitude requirements must be specified for each target used. The operator must be able to select between static and dynamic speed tests. With dynamic tests the vehicle's speed changes with time. If this is selected, the operator must enter the initial and final speeds and the time over which the speed is to be changed. But for static tests, the operator must only enter a fixed speed for each vehicle. The patrol car amplitude component must be specified as an integer between zero and 1000, but the target amplitudes must be computed in software from the target size and its distance from the antenna. Therefore, the operator must specify the distance in feet as well as the size of each target. The target size will be represented by a number from one to four with four corresponding to the largest and one to the smallest.

After the initial conditions have been entered, the test should begin when the proper command is typed on the terminal. At this point the simulated targets should begin moving just as they would on an actual roadway. Current values of speeds and distances must be displayed on the front panel and updated twice a second. The test continues until a pause command is entered which will cause all the variables to be held fixed until another command is entered. A sample of the initialization and command sequence is given in Figure 2.1.

In addition to traffic simulation, the system should be able to run in two other modes. The first mode should merely set up a stationary signal on one channel with a certain frequency and amplitude. Here the operator must first enter the channel that is to be used and then the frequency and amplitude components. The frequency component will be an integer that ranges from one to 700 and the amplitude component from zero to 1000. Using interactive commands, the operator must be able to change these frequencies and amplitudes. A sample terminal session is given in Figure 2.2.

The second mode should use two targets and allow the operator to specify the speed of each. This mode differs from the traffic simulation mode in that the target amplitudes are not determined from the target size and distance. Instead, one target, which must be specified by the operator, is held fixed while the other is allowed to vary. The operator must enter the initial amplitude component of both targets (an integer from zero to 1000) and then enter breakpoints. Breakpoints must be entered one at a time and it should take 10 seconds after the breakpoint is entered to move from the current amplitude to the new breakpoint. Throughout the test the speeds and current amplitude components should be displayed on the front panel of the simulator. Figure 2.3 illustrates a sample command sequence for this mode.

TRAFFIC SIMULATOR PROGRAM.

```
X BAND OR K BAND?X

MOVING OR STATIONARY MODE?S

TARGET VEHICLE 1?Y
DYNAMIC TEST?N
DESIRED SPEED (MPH)?60
TARGET DISTANCE FROM ANTENNA (FT)?5500
TARGET SIZE (1-4)?3

TARGET VEHICLE 2?N
>G
>P
>G
>P
>I
```

This test is being run on an X-band radar unit in stationary mode with one target vehicle. The target is size three and moving at a constant speed of 60 mph. It begins 5500 feet from the antenna and moves toward it.

```
X BAND OR K BAND?X

MOVING OR STATIONARY MODE?M

PATROL CAR.
DYNAMIC TEST?N
DESIRED SPEED (MPH)?45
DESIRED AMPLITUDE (1-1000)?100

TARGET VEHICLE 1?Y
DYNAMIC TEST?Y
INITIAL SPEED (MPH)?75
FINAL SPEED (MPH)?50
SPEED UP TIME (SEC)?15
TARGET DISTANCE FROM ANTENNA (FT)?4000
TARGET SIZE (1-4)?3

TARGET VEHICLE 2?Y
DYNAMIC TEST?Y
INITIAL SPEED (MPH)?-45
FINAL SPEED (MPH)?-50
SPEED UP TIME (SEC)?20
TARGET DISTANCE FROM ANTENNA (FT)?-100
TARGET SIZE (1-4)?4
>G
>P
>L
```

This is an example of a moving mode test with the patrol car moving at a constant speed of 45 mph. The first target is a size three vehicle decelerating from 75 to 50 mph in 15 seconds. It begins 4000 feet in front of the antenna and moves toward it. Target two is moving in the same direction as the patrol car and accelerating from 45 to 50 mph in 20 seconds. It is a size four vehicle and starts 100 feet behind the patrol car.

```
PATROL CAR:   +00045 +00000 +00100
TARGET ONE:   +00050 +00466 +00104
TARGET TWO:   -00050 -00001 +00000
>G
>P
>F
ILD2   (A0)     18C0-1F75 18C1
>
```

This example also illustrates the "list" feature where at any point during the test, the action may be stopped and the current values of speed, distance, and signal amplitude are listed.

Figure 2.1 Traffic Simulator Program terminal session

```
RADAR TEST PROGRAM.

DESIRED TARGET NUMBER?1
DESIRED TARGET SPEED (1-700)?650
DESIRED AMPLITUDE (1-1000)?300
>I
________________________________________

DESIRED TARGET NUMBER?2
DESIRED TARGET SPEED (1-700)?500
DESIRED AMPLITUDE (1-1000)?500
>I
________________________________________

DESIRED TARGET NUMBER?3
DESIRED TARGET SPEED (1-700)?350
DESIRED AMPLITUDE (1-1000)?20
>F
DLD2    (A0)      13C0-1F75 13C1
>
```

These tests set up a stationary signal of a prespecified frequency and amplitude. The operator enters the desired target or channel number, the desired speed or frequency component, and the amplitude component. An "I" is typed to initialize a new signal.

Figure 2.2 Radar Test Program terminal session

```
         SIGNAL STRENGTH TEST PROGRAM.

X BAND OR K BAND?X

VEHICLE 1:   DESIRED SPEED (MPH)?60
VEHICLE 2:   DESIRED SPEED (MPH)?25

INITIAL AMPLITUDE (1-1000)?100

REFERENCE VEHICLE (1 OR 2)?1
VARY TARGET 2.
>200
>300
>350
>400
>500
>100
>50
>250
>1
```

This test uses an X-band radar and two targets, one at 60 mph and the other at 25 mph. They both start at an amplitude of 100, but target two is varied to 200, 300, 350, 400, 500, 100, 50, and 250 during the test.

```
X BAND OR K BAND?X

VEHICLE 1:   DESIRED SPEED (MPH)?40
VEHICLE 2:   DESIRED SPEED (MPH)?70

INITIAL AMPLITUDE (1-1000)?200

REFERENCE VEHICLE (1 OR 2)?2
VARY TARGET 1.
>300
>500
>600
>700
>800
>150
>100
>75
>50
>10
>F
ILD2    (A0)      18C0-1F75 18C1
>
```

Here the vehicles are moving at 40 mph and 70 mph with an initial amplitude of 200. For this test the amplitude of target one is varied and target two is held constant.

Figure 2.3 Signal Strength Test Program terminal session

III. HARDWARE

Under operator control, the traffic radar simulator performs static and dynamic tests on radar units placed in an anechoic test chamber. Single and double targets of different sizes can be simulated in both the moving and stationary modes. A block diagram of the system hardware is presented in Figure 3.1. The computer, a 16-bit LSI II minicomputer manufactured by Computer Automation [4], contains 16-k of main memory, a dual floppy disk drive, and a real time clock. The TTY serves as the operator interface with the rest of the system. Using keyboard commands through an interactive operating system, the operator loads the simulator programs into main memory and selects the appropriate options. The 16-bit I/O module serves as the asynchronous interface between the computer's bus and the rest of the hardware [5]. The front panel displays the current status of the test in progress, as well as the current target and patrol vehicle speeds and distances. The main board acquires data and control messages from the computer and generates sinusoidal signals for the synthetic target generator. In this chapter the hardware implementation of the main board and front panel display is described in detail.

3.1 Main Board

The main board consists of three separate channels which correspond to the three Doppler signals generated. These signals have two components that are determined by the computer, a frequency component and an amplitude component. The former determines the frequency of the signal sent to the synthetic target generator. This is related to the desired target speed and the frequency of the signal transmitted from the radar antenna. Similarly, the amplitude component, which is related to the target's size and distance from the antenna, determines the amplitude of the signal. The output signal from each channel goes to the output stage where it can

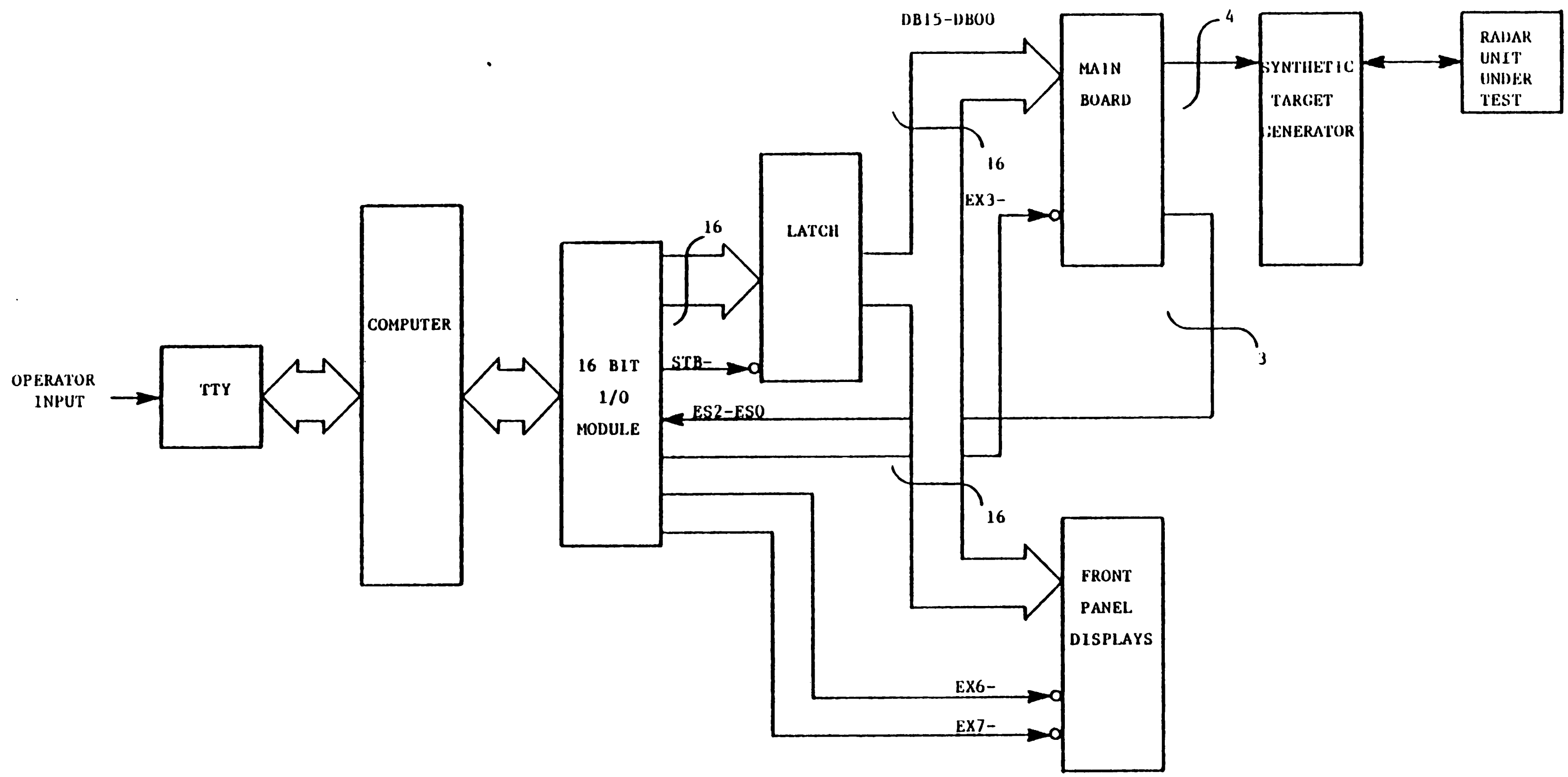


Figure 3.1 Traffic radar simulator block diagram

be fine tuned and summed with the other channels. A block diagram of the main board is shown in Figure 3.2.

3.1.1 Data Selection

The simulator software requires the frequency component to be on the range one to 700 and the amplitude component zero to 1000. Only integer values of frequency and amplitude are allowed. Therefore, the lowest 10 bits of the data bus are sufficient to output these components. Since the upper bits of the bus are not used for data, they are used to steer the lowest 10 bits of data. In particular, select line three (EX3-), which selects the main board, and the highest three bits of the bus are the inputs to a binary-to-BCD decoder. The pulse that the select line generates on the line being selected at the output of the decoder is used to strobe the data into the appropriate latches. The decoding scheme for this procedure is given in Table 3.1.

Note that a double set of latches must be used so the data will be available when the select pulse comes. The data word, which is output first, is strobed into the first latch by the output strobe line (STB-). This latch is shown on the system block diagram in Figure 3.1. The select pulse, which determines the purpose of the data, is generated during the next instruction cycle. This pulse strobes the data from the first latch into the appropriate second latch either on the main board or the front panel. Select line three (EX3-) selects the main board. Figure 3.3 illustrates the timing of these signals.

3.1.2 Frequency Channels

The frequency channels are shown in more detail in Figure 3.4. A Voltage Controlled Oscillator (VCO) is used to generate the different frequencies. The particular VCO used in this system is the XR8038 which has sine, square, and traingle wave outputs [6]. The sinusoidal output is used

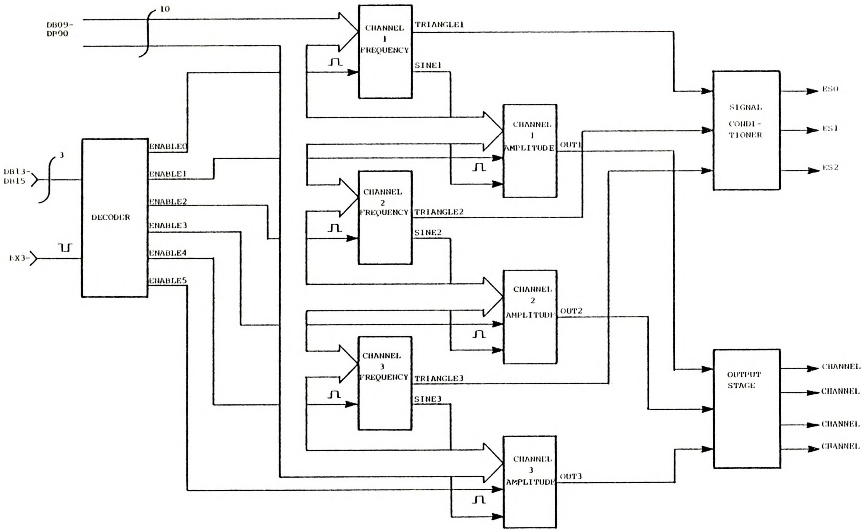


Figure 3.2 Main board block diagram

Table 3.1 Main board decoding scheme

EX3-	DB15	DB14	DB13	Data
0	0	0	0	Channel 1: Frequency component
0	0	0	1	Channel 1: Amplitude component
0	0	1	0	Channel 2: Frequency component
0	0	1	1	Channel 2: Amplitude component
0	1	0	0	Channel 3: Frequency component
0	1	0	1	Channel 3: Amplitude component

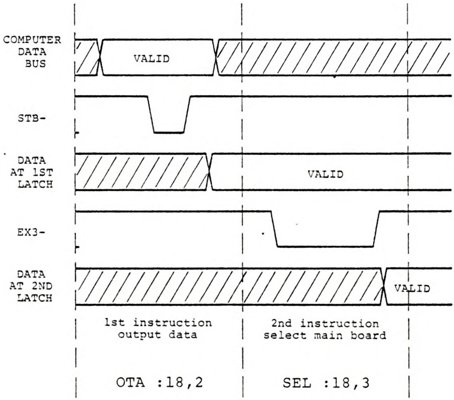


Figure 3.3 Main board timing

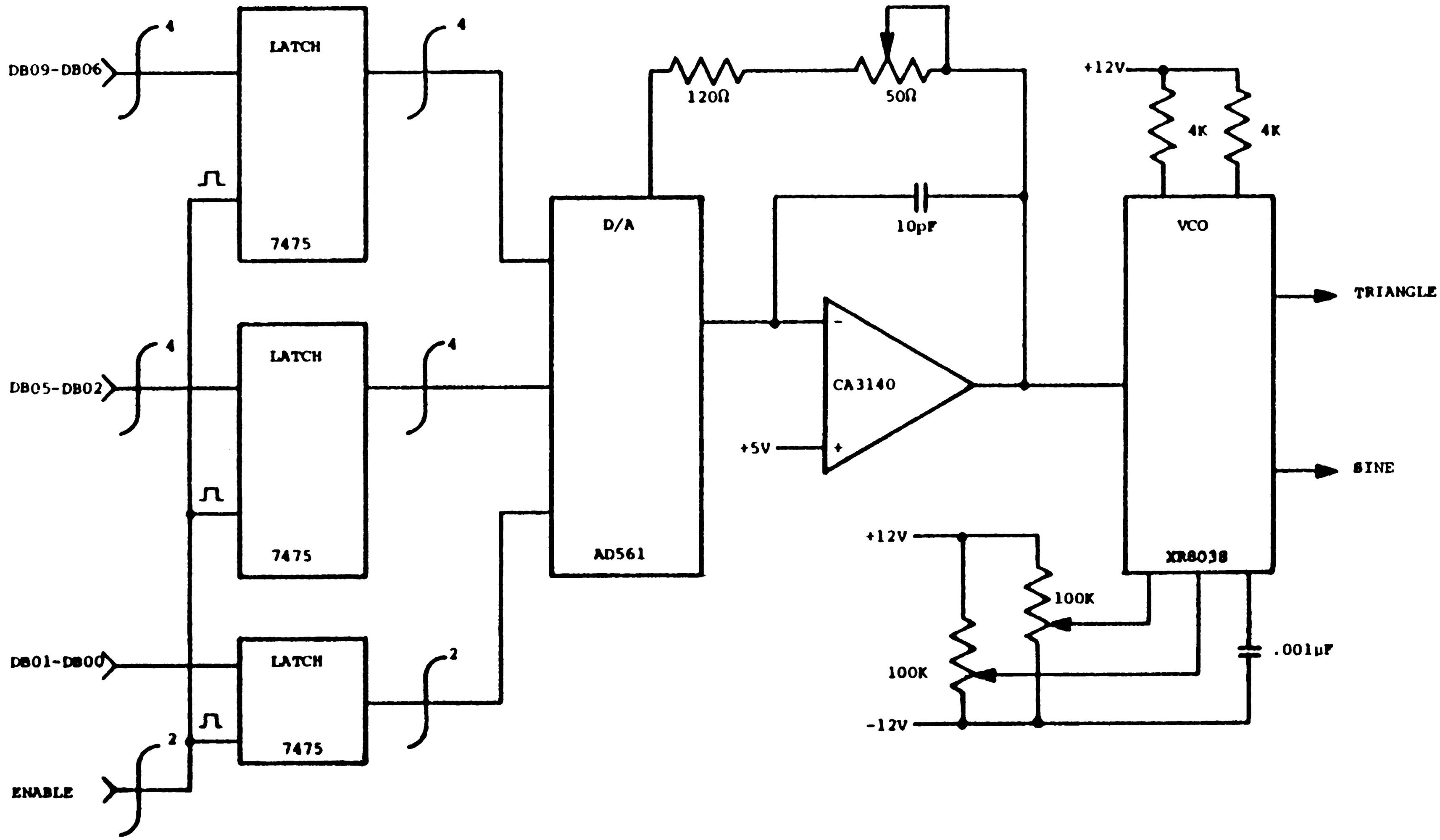


Figure 3.4 Main board frequency channels

by the target generator, and the traingular output', converted to a digital signal, is sent back to the computer for control purposes.

The digital frequency component is first transformed by the D/A converter to an analog voltage ranging from .01 to 7 Volts [7]. (Note that a change of 10 in the frequency component corresponds to a change of .1 Volt at the output of the D/A.) The range of allowable input voltages to the VCO is from 5 V to 12 V, so this voltage from the D/A is offset by 5 Volts in the operational amplifier which follows.

The two 4 kΩ resistors and the .001 μF capacitor control the frequency range of the VCO. These particular values were chosen to yield a maximum frequency of 11 kHz. The two 100 kΩ potentiometers are used to adjust the shape of the output signal.

3.1.3 Amplitude Channels

Figure 3.5 gives a detailed diagram of the amplitude channels. After the amplitude component is converted to an analog voltage, it is multiplied by the sinusoidal output from the VCO. The AD534 analog multiplier is used to perform this multiplication and thereby control the amplitude [8]. The equation for the output of the multiplier is

$$\mathrm{OUT} = \frac{(X1-X2)*(Y1-Y2)}{10} \text{ Volts.}$$

Here (X1-X2) corresponds to the analog amplitude component from the D/A and (Y1-Y2) is the signal from the VCO.

Since the analog amplitude component has an amplitude between zero and 10 Volts and the sinusoid has an amplitude of 3 Volts peak to peak, the amplitude range of the sinusoid at the output of the multiplier is from zero to 3 Volts. However, the output stage reduces the signal to the millivolt range.

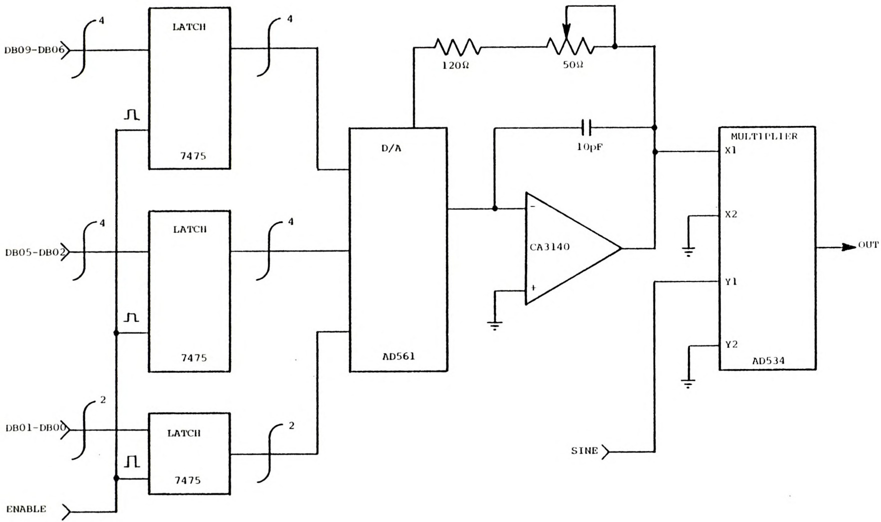


Figure 3.5 Main board amplitude channels

3.1.4 Output Stage

The output signal from each multiplier goes to the output stage. A block diagram of this stage is shown in Figure 3.6.

The 5 kΩ potentiometers at the inputs of each amplifier stage are used to adjust the voltage levels of the signals going to the synthetic target generator. Here fine tuning adjustments can be made so that the same amplitude component will correspond to the same voltage out for all three channels. Each channel may be used separately, but there is also a summing amplifier which allows the sum of the three channels to be taken off on one. The RC T-circuit at each output filters any high frequency noise from the op amp and converts the signal to be sent to the target generator to a current.

3.1.5 Signal Conditioner

The triangle wave outputs from the VCO's are taken to the signal conditioning circuit shown in Figure 3.7. This circuit consists of three comparators, one for each channel. These comparators convert the triangle wave to a TTL signal of the same frequency which in turn is sent back to the computer on the sense lines. The computer uses these lines to count the VCO frequencies generated by different frequency components. The purpose of this will be discussed further in Chapter 4.

3.2 Front Panel

The target and patrol car speeds and the distances the targets are from the antenna are continually being updated and displayed on the front panel. There is also a series of LED's indicating the presence of certain conditions. A block diagram of the front panel hardware is shown in Figure 3.8.

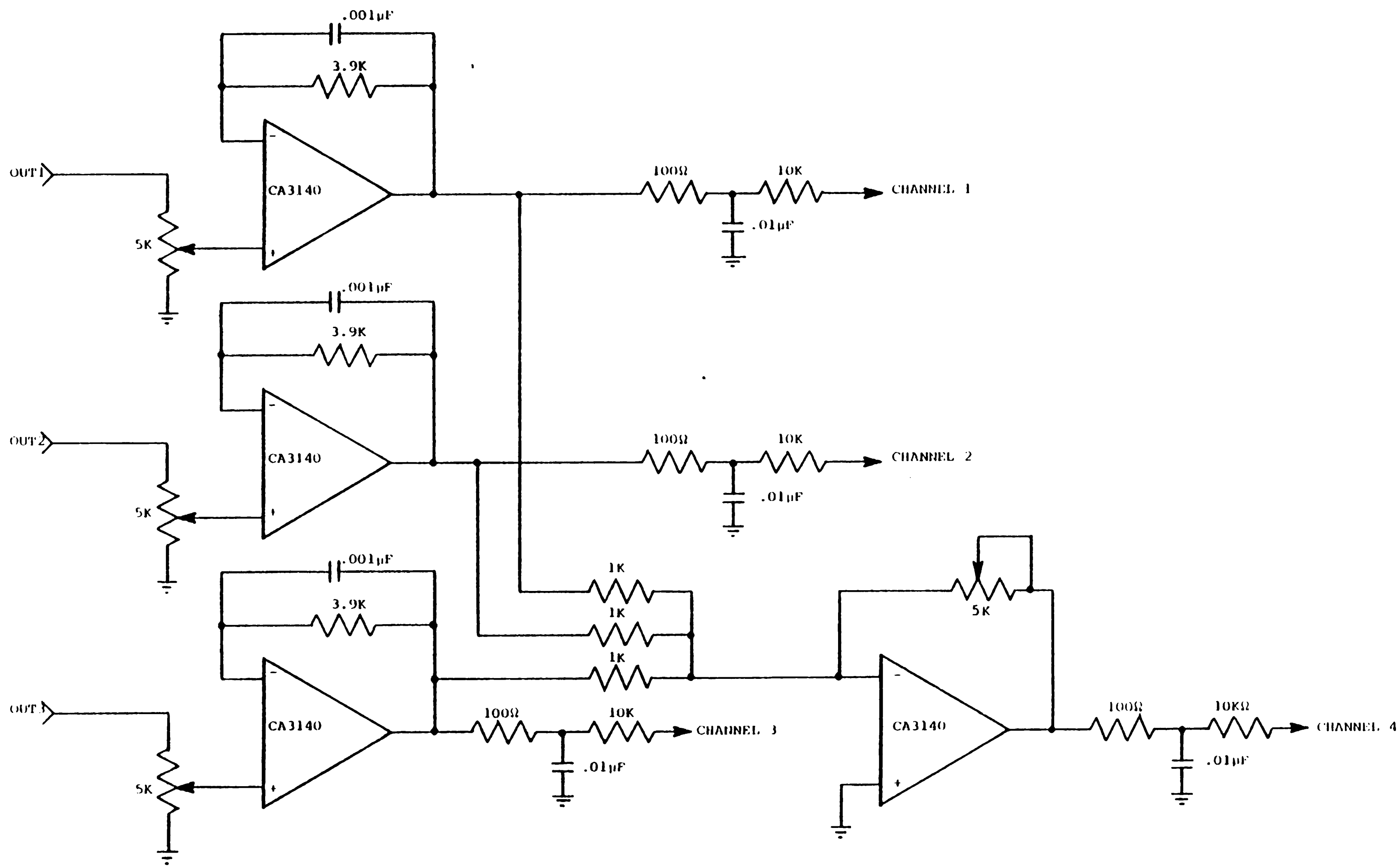


Figure 3.6 Main board output stage

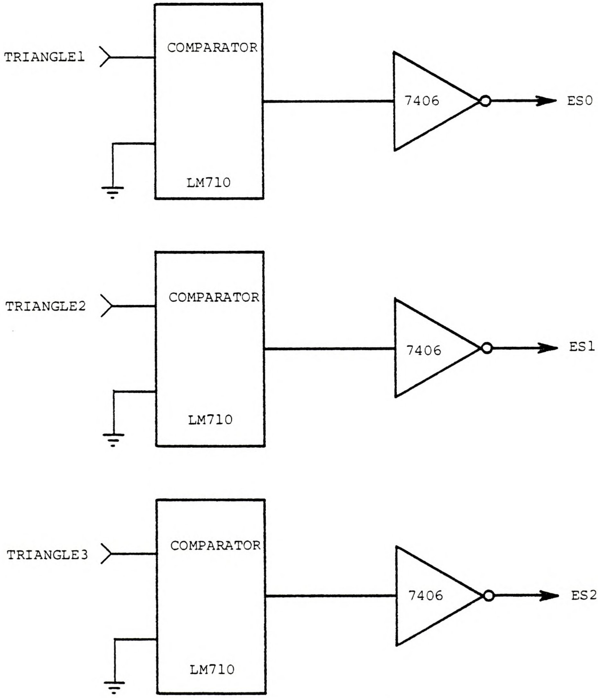


Figure 3.7 Main board signal conditioner

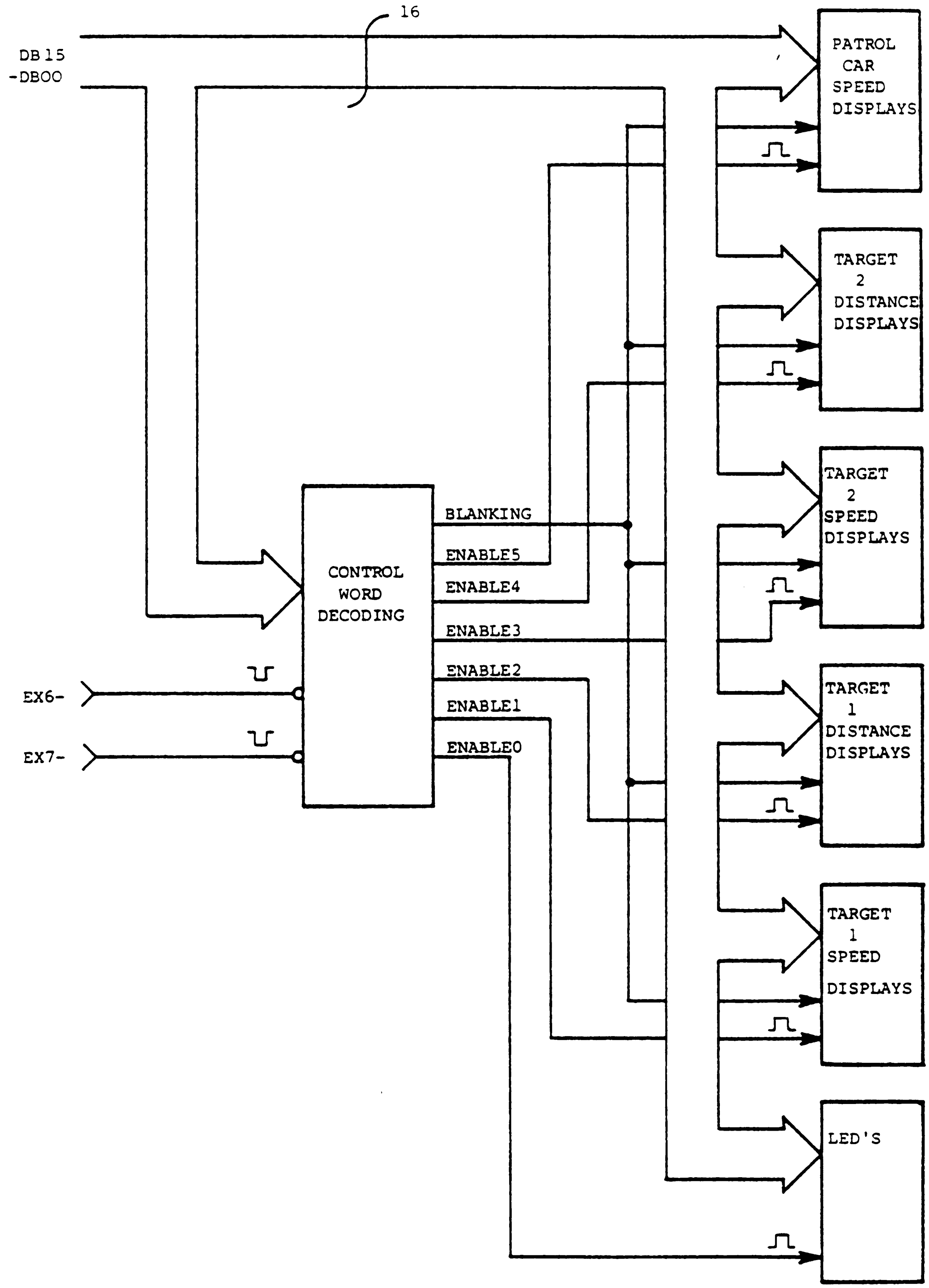


Figure 3.8 Front panel block diagram

3.2.1 Decoding Logic

The entire data bus is needed for the data to be displayed. Consequently, the decoding can no longer be done using the highest bits of the data word. Thus, two separate words are used, a control word and a data word. Moreover, two separate select lines are needed to distinguish between them. The control word, which is output first, controls where the data word is to go. The decoding for the control word is given in Table 3.2.

Once again, two levels of latches are used so that the data will be available when the select pulse is generated. Select line six (EX6-) is used to strobe the control word into the control latch and select line seven (EX7-), NOR'ed with the outputs of the control latch, strobes the data word into the data latches (See Figure 3.9). The hardware for the control word decoding is shown in Figure 3.10.

3.2.2 Speed and Distance Displays

A diagram of the speed displays is shown in Figure 3.11. ENABLE1, ENABLE3, or ENABLE5 strobes the data to be displayed into the latches for the speed of target one, two, or the patrol car, respectively. It is assumed that the vehicles will be traveling at speeds from -199 mph to +199 mph. A negative speed means that the vehicle is traveling away from the antenna rather than toward it.

Since speeds only between -199 and +199 mph will be displayed, the speed displays are made up of three digits. The most significant digit, which corresponds to the ±100 place, is a ±1 digit. Bits nine and fifteen are used to decode the data for this digit. A high level on bit fifteen turns the negative sign on and a low level on bit nine turns the "1" on. It may seem that bit eight should control the "1", but a "±1xx" is represented by a 01 in bits nine and eight while a "±0xx" is represented by a 11. Therefore, it is bit nine which determines the "1". If the value of the speed is positive, no sign bit is turned on.

Table 3.2 Front panel decoding scheme

Control Word (DB06 - DB00)	Data	
0 0 0 0 0 0 1	ENABLE0:	LED's
0 0 0 0 0 1 0	ENABLE1:	Target 1, speed
0 0 0 0 1 0 0	ENABLE2:	Target 1, distance
0 0 0 1 0 0 0	ENABLE3:	Target 2, speed
0 0 1 0 0 0 0	ENABLE4:	Target 2, distance
0 1 0 0 0 0 0	ENABLE5:	Patrol car, speed
1 0 0 0 0 0 0	ENABLE6:	Display blanking
	ENABLE7:	Display blanking

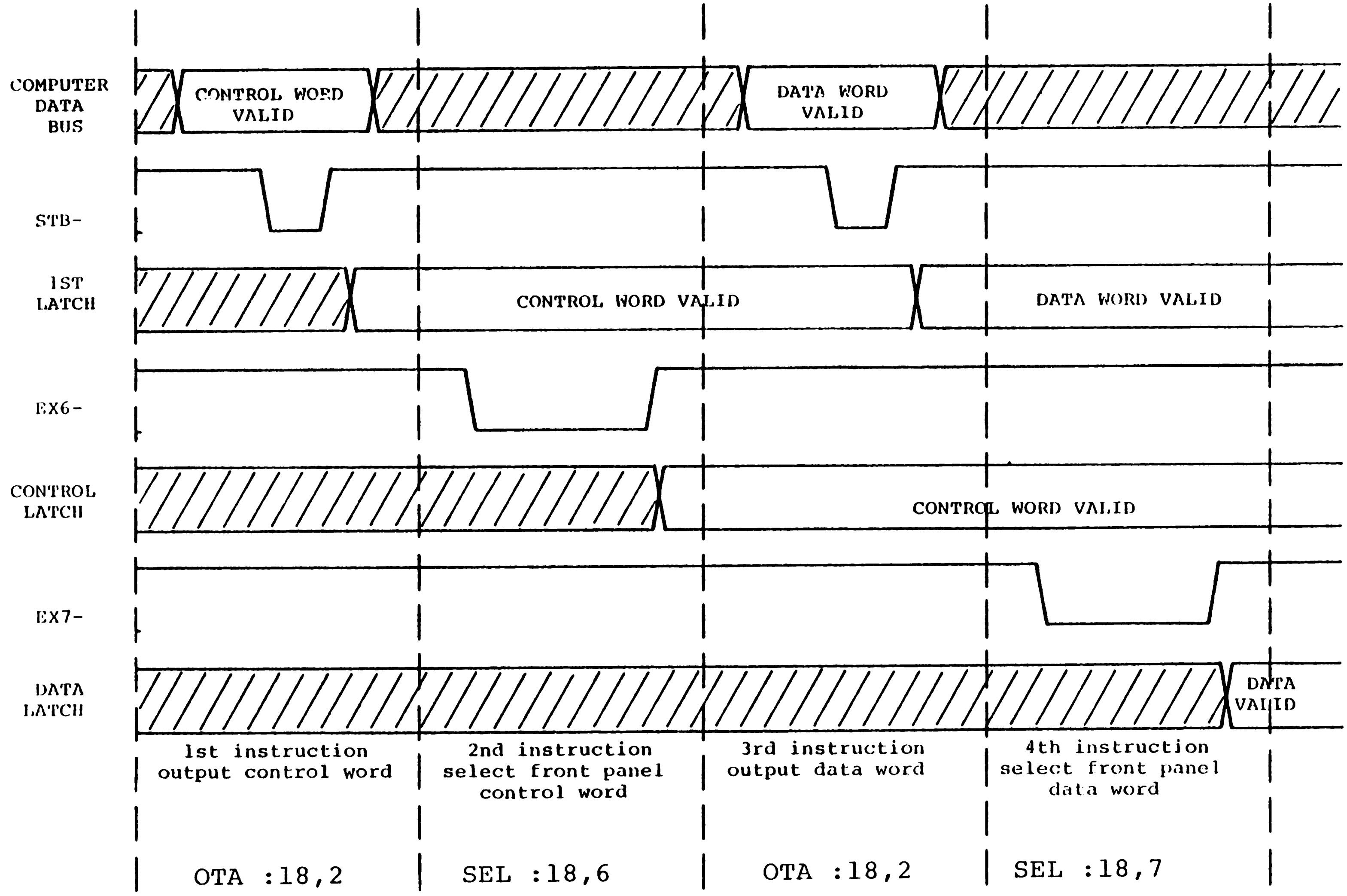


Figure 3.9 Front panel timing

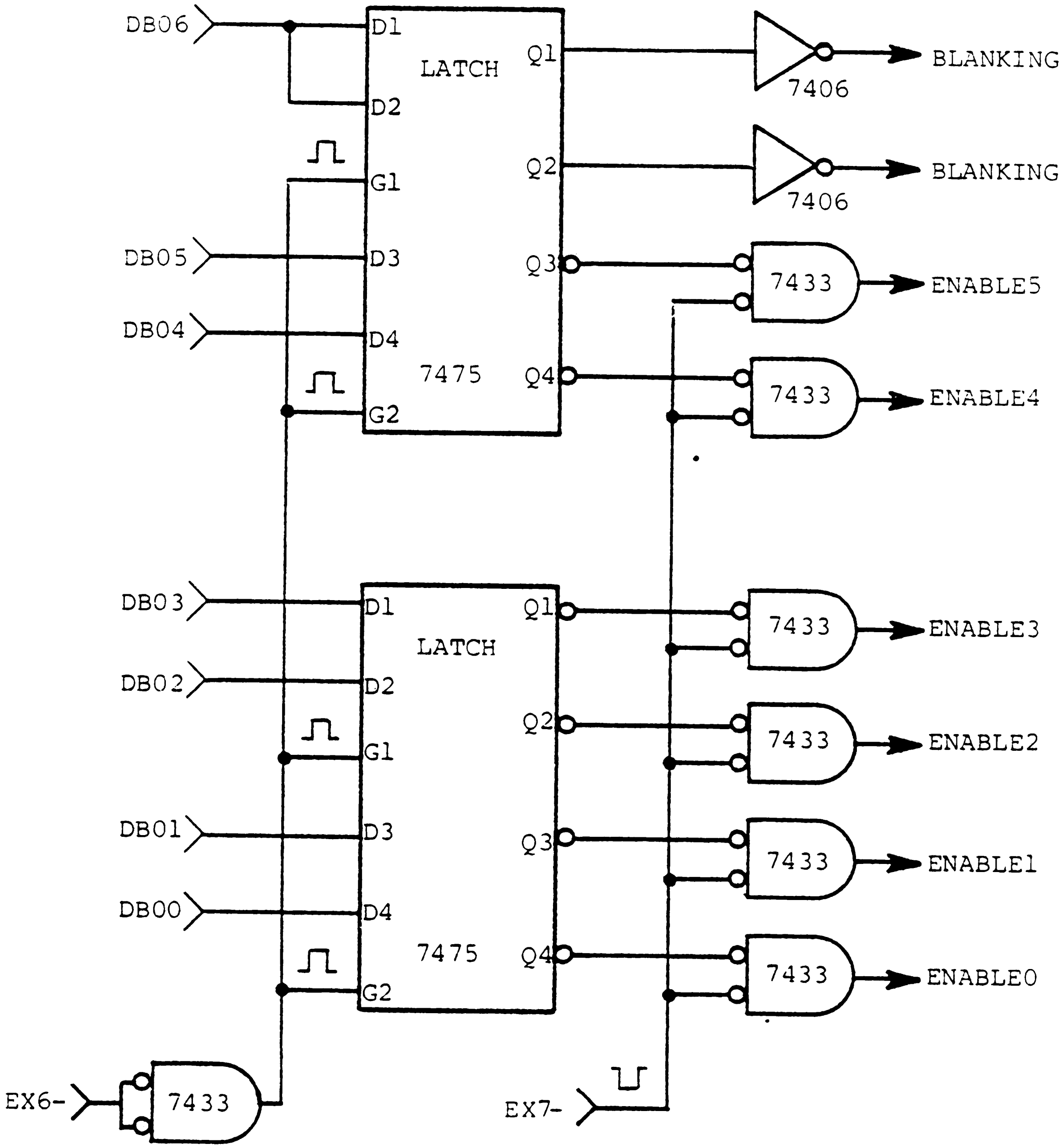


Figure 3.10 Control word decoding

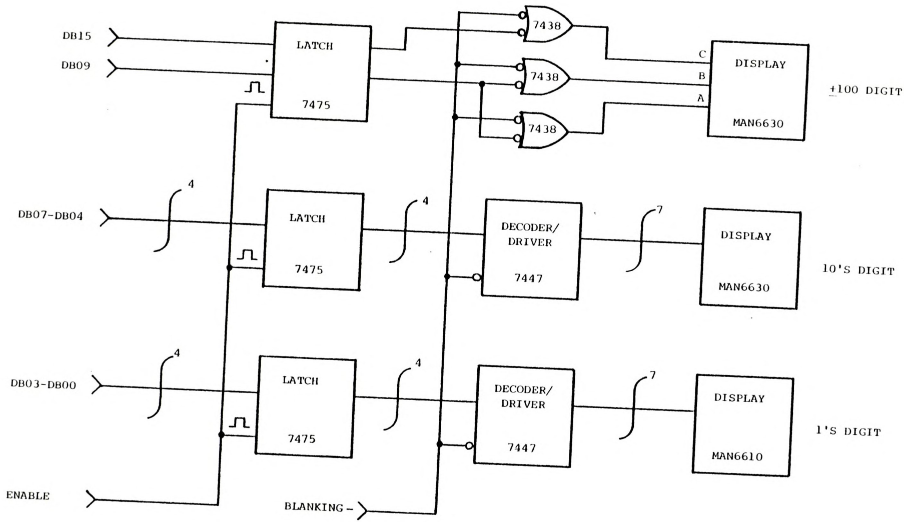


Figure 3.11 Speed displays

The two least significant digits are standard 7-segment displays [9]. Bits four through seven contain the value of the ten's digit in BCD code and bits zero through three contain the value of the one's digit. The decoder/driver chip is a BCD to 7-segment decoder. From the BCD inputs to the decoder, each of the seven outputs determine whether each of the seven segments of the display should be on or off.

The distance displays, as shown in Figure 3.12, are more straight forward than the speed displays. They are controlled by ENABLE2 and ENABLE4 for target one and two, respectively. It is·assumed that the antenna is in the patrol car, so the distance from the antenna to the patrol car is always zero.

Distances of one to 9999 feet from the antenna are displayed. Although the software allows distances greater than 9999 feet and less than one foot, they are not displayed. The four distance digits in BCD code are stored in the data bus as follows: bits twelve through fifteen correspond to the thousand's digit, bits eight through eleven to the hundred's digit, bits four through seven to the ten's digit, and bits zero through three to the one's digit.

All of the displays may be blanked by ENABLE6 and ENABLE7 when a control word of 1000000 is output. It is desirable to blank the displays in this way when there is no valid data to be displayed. In addition, each display may be blanked separately by sending four ones to the 7447 decoder. Leading zeros of both the speed and distance displays are blanked in this manner.

3.2.3 LED Display Circuit

The diagram for the LED display circuit is shown in Figure 3.13. There are four LED's which correspond to the

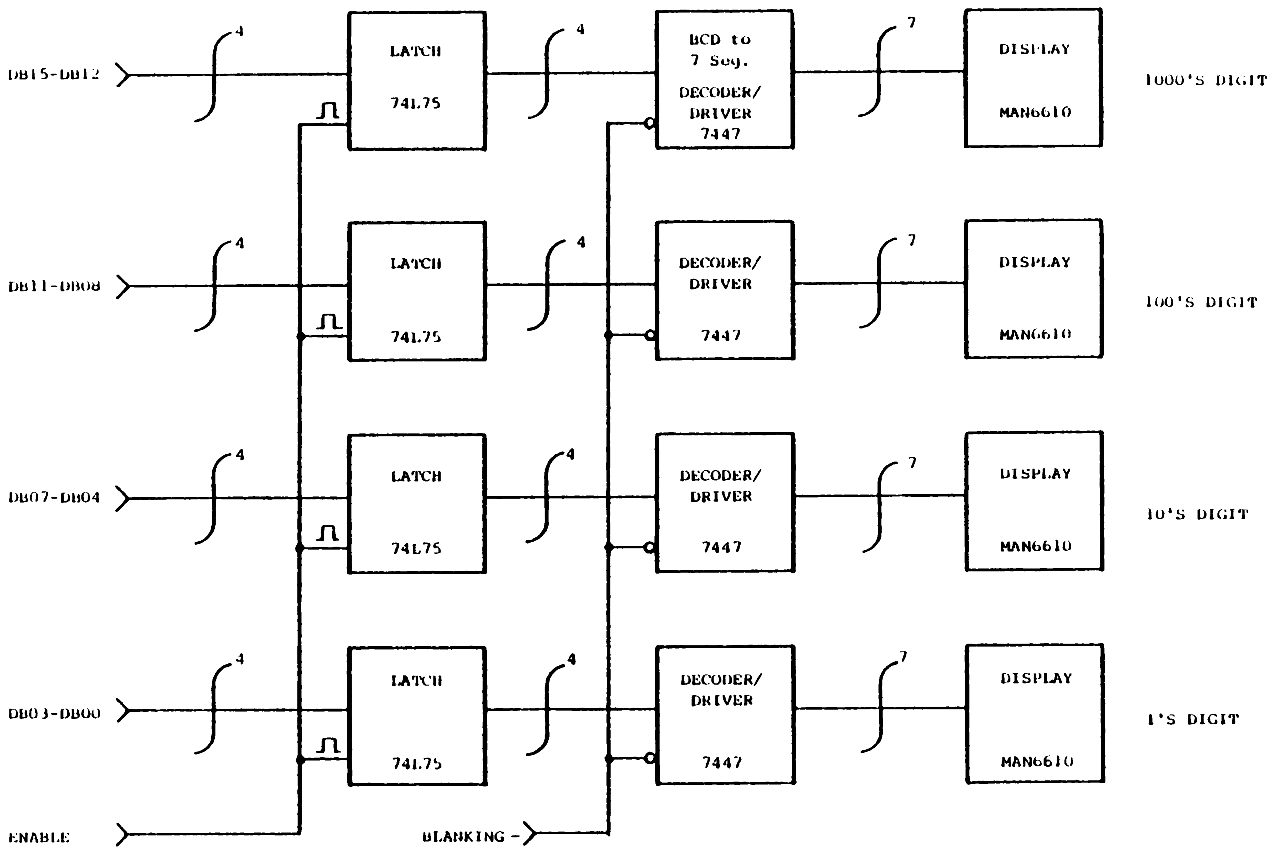
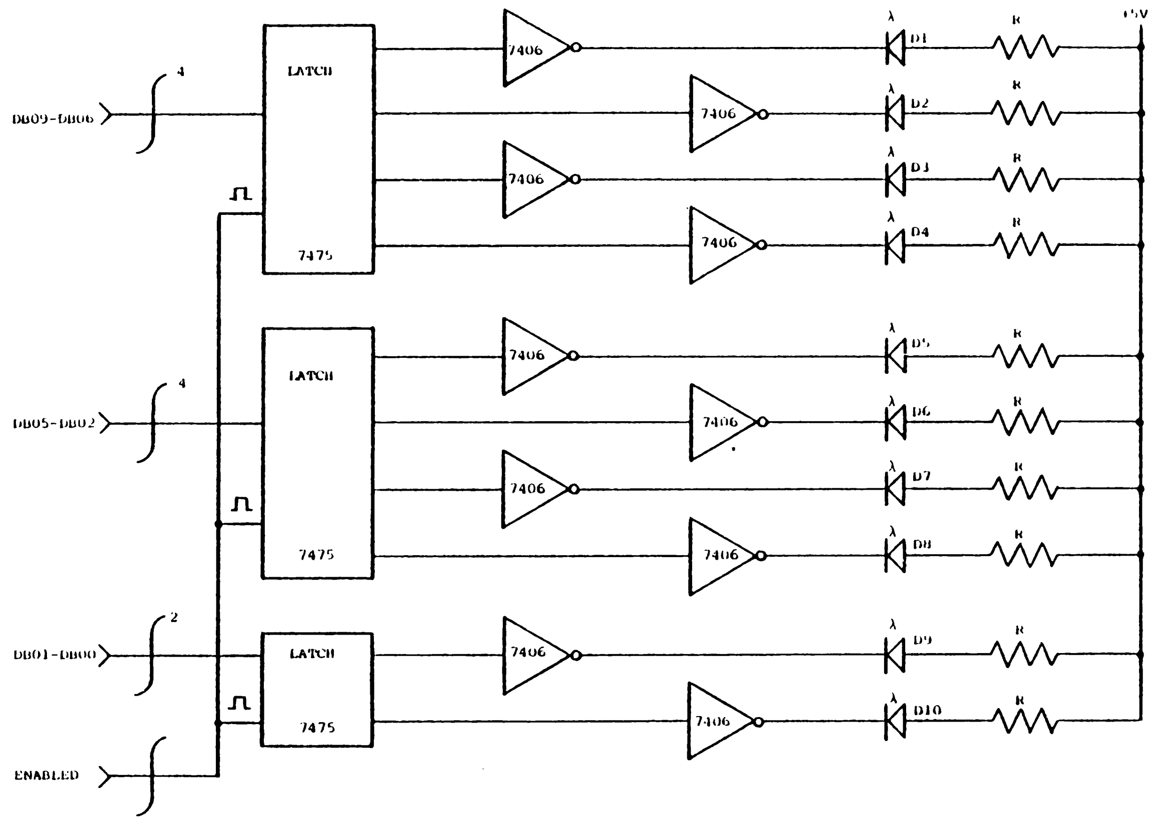


Figure 3.12 Distance displays



*ALL RESISTORS ARE 150Ω

Figure 3.13 LED display circuit

following conditions: "test in progress," "pause," "moving mode," and "stationary mode." Six additional LED's are used to indicate whether it is target one or two that is moving fastest, is closest to the antenna, or has the largest signal. A summary of the functions of these ten LED's is given in Table 3.3.

A 10-bit data word contains the state of these LED's. The format of the word is shown in Figure 3.14. The hardware for the LED powering consists of a 10-bit latch into which the LED data word is strobed by the ENABLE0 pulse. The drivers provide enough current to power each LED.

3.3 External Signal Source

There is potential for an additional input to the system which has not been discussed previously. This input is an external signal source and may be data recorded in the field, a random noise generator, or an oscillator. It is not affected at all by the computer, and may be used alone or with the rest of the system. So this external signal source becomes a fourth channel and gives the operator the opportunity to add some other source of data.

3.4 Synthetic Target Generator

The sum of the sinusoidal signals from the main board with frequencies and amplitudes determined by the test conditions is sent to the synthetic target generator. The synthetic target generator amplitude modulates the microwave signal sent from the radar antenna by this signal from the main board. This modulated signal is sent back to the antenna and is detected as the Doppler shift caused by one or more moving objects.

The synthetic target generator is comprised of the following: a Narda Model 640 standard gain horn, which receives the CW microwave signal from the radar under test and then re-transmits the signal as an amplitude modulated wave; a Hewlett Packard Model X375A variable attenuator,

Table 3.3 LED functions

D10	"Test in Progress"
D9	"Pause"
D8	"Moving Mode"
D7	"Stationary Mode"
D6	"Target 1 fastest"
D5	"Target 2 fastest"
D4	"Target 1 out front"
D3	"Target 2 out front"
D2	"Target 1 largest signal"
D1	"Target 2 largest signal"

	Largest #2	Largest #1	Out front #2	Out front #1	Fastest #2	Fastest #1	Stationary mode	Moving mode	Pause	Test in progress
bit	9	8	7	6	5	4	3	2	1	0

Figure 3.14 LED status word

which allows the operator to control the level of the received/ transmitted signal; and a Hewlett Packard Model X485B detector mount with a 1N23B diode, which serves as the modulator.

IV. SOFTWARE

The last chapter defined the hardware for the traffic radar simulator. Throughout the discussion, the existence of the correct amplitude and frequency components and the correct data for the display panel was assumed. This chapter will examine the simulator's software and how these components are determined.

The software for the simulator consists of three main programs. The largest is the Traffic Simulator Program and will be discussed in detail in the following sections. The Signal Strength Test Program and the Radar Test Program apply many of the same concepts as the Traffic Simulator Program and will be discussed in some detail later in this chapter.

4.1 Input from the Operator

The Traffic Simulator Program simulates actual roadway occurrences with two target vehicles and a patrol car. A flowchart for this program is given in Figures 4.1 and 4.2. Before the test begins, there are a number of decisions about the test that must be made by the operator. These decisions will be discussed in the following paragraphs.

There are two types of radar devices that are presently being used: X-band and K-band. The X-band device is designed to operate in the frequency range of 10,500 to 10,550 MHz and has a Doppler shift of 31.384 Hz/mph while the K-band device operates in the frequency range of 24,050 to 24,250 MHz and has a Doppler shift of 72.012 Hz/mph. The program can run tests on either the X- or K-band device and the operator must specify which device is being tested.

The program may also be used for both moving and stationary mode tests. The operator must specify whether moving or stationary mode is desired. If moving mode is specified, the operator must enter the patrol car speed

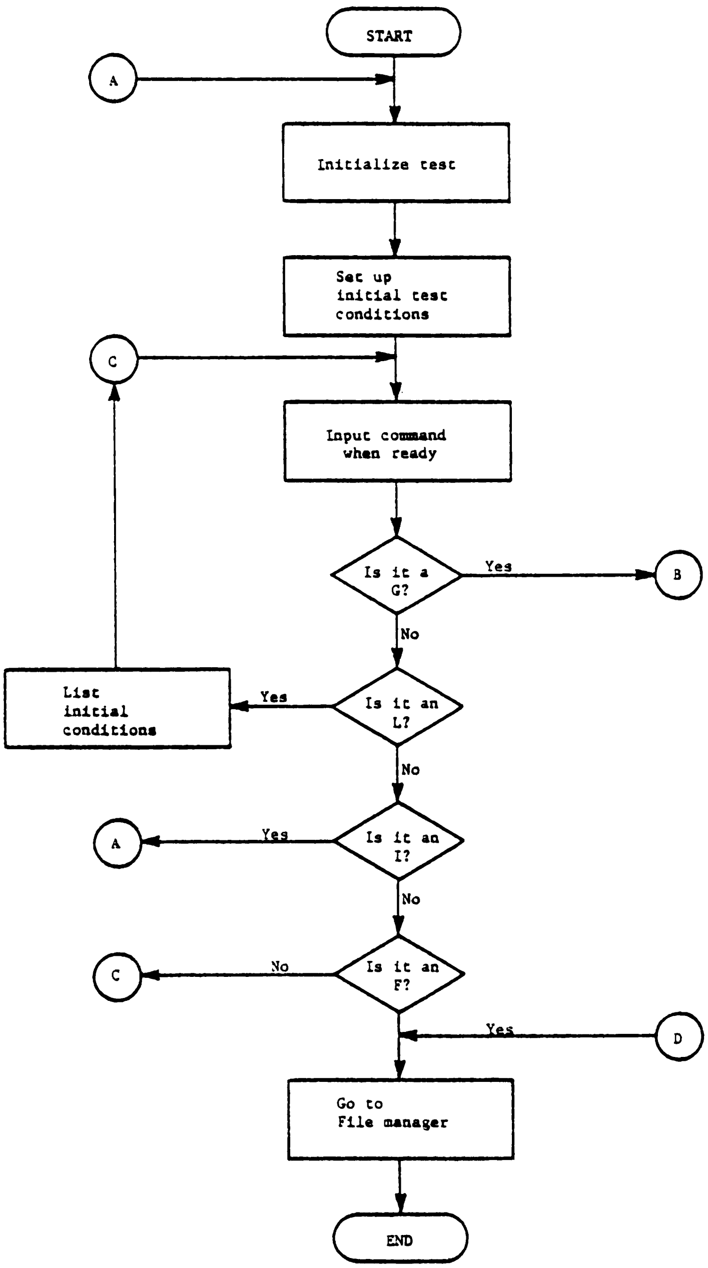


Figure 4.1 Traffic Simulator Program flowchart I

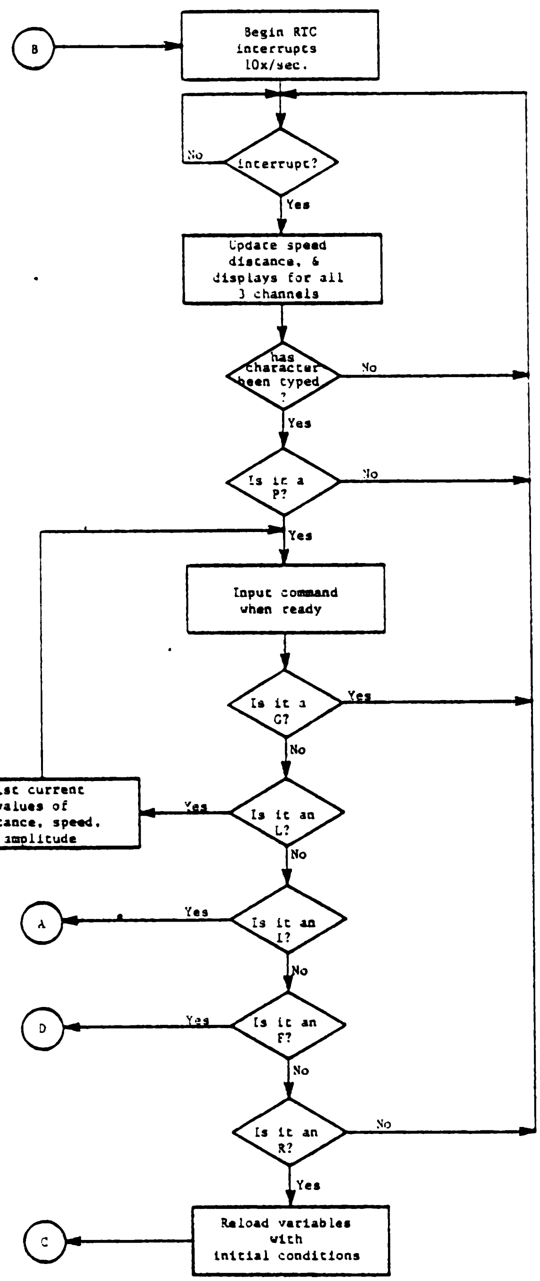


Figure 4.2 Traffic Simulator Program flowchart II

requirements and the patrol car amplitude. On the other hand, if stationary mode is specified, the patrol car speed and amplitude components are zeroed for the duration of the test.

The test may be run on either target one, target two, or both targets. The operator must enter a "Y" after each target number that is to be used in the test and an "N" otherwise. If a target is used in the test, the operator must specify the speed requirements, the initial distance from the antenna, and the size of the target. Otherwise, the target speed and amplitude components are set to zero.

After the initial conditions have been entered, there are a number of commands which can be used throughout the testing process. A summary of the commands is given in Table 4.1.

The "G" command begins the test after all the test conditions have been determined. At this time, the synthetic targets start moving either toward or away from the antenna if their speeds are positive or negative, respectively. The display panel, which is updated twice a second, displays the current state of the variables.

At any time during the test, a "P" may be typed to enter the pause mode. At this point, the variables stop changing and are held at their current values until another command is entered. This allows the operator to stop and examine certain conditions at any point during the test.

When the program is in the pause mode, any of the other commands listed in Table 4.1 may be entered. A "G" will continue the test from the point it had stopped, or an "I" allows the operator to enter a new set of initial conditions. If an "R" is entered, the initial conditions from the previous test will be reloaded into the variables and a "G" will start the previous test over. The list command, "L" will list the present speeds, distances from the antenna, and signal amplitudes of the two targets and

Table 4.1 Traffic Simulator Program Commands

"G"	Go
"P"	Pause
"I"	Initialize
"R"	Repeat
"L"	List
"F"	File manager

the patrol car. Finally, the "F" command takes control out of the current program to the file manager, where a different file can be loaded if it is desired to do so.

4.2 Program and Subroutines

The flowchart of the entire Traffic Simulator Program, which is shown in Figures 4.1 and 4.2, can be broken down into several smaller problems. These smaller problems will be examined in the following subsections.

4.2.1 Initialization

After the program has been loaded and each time an "I" command is used, the program goes through an initialization routine. The flowchart for the initialization procedure is shown in Figure 4.3. This procedure consists of three events: writing the program heading, calibrating the VCO's, and resetting all the variables from the previous test. The program heading, "Traffic Simulator Program", is only written out at the loading of the program. After the first test has been run, the initialization procedure begins with calibrating the VCO's. This consists of determining an equation from which to calculate the frequency component. If the frequency component is assumed to have a linear relation with the actual frequency of the signal produced by the VCO, the equation would be of the form

$$V = M*F+B.$$

Here V is the frequency component, F is the actual frequency produced by the VCO, and M and B are constants to be determined. This linear equation gives results within the allowed accuracy, however the values for M and B tend to drift over a period of time. For this reason, M and B are recalculated each time a new set of initial conditions is entered.

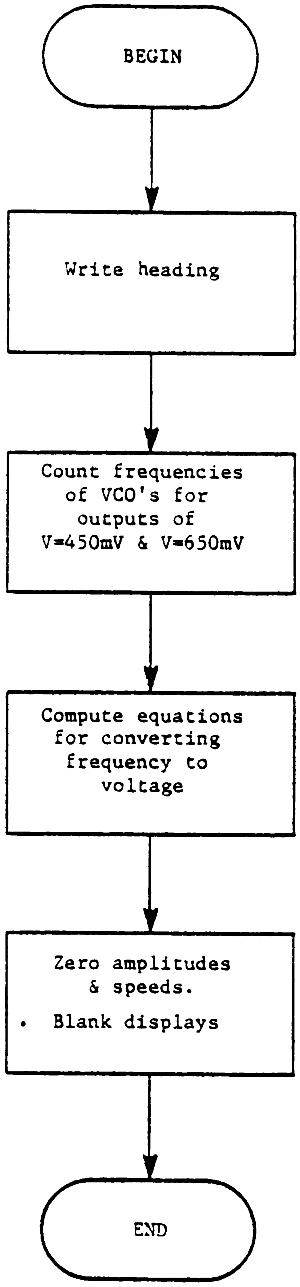


Figure 4.3 Initialization procedure flowchart

To calculate M and B, two points on the line must be obtained. The points used are those corresponding to frequency components of 450 and 650. Each component is output to all three channels and the frequency produced by each VCO is counted. Since each VCO may have somewhat different characteristics than the others, a unique M and B are determined for each channel expanding the values to be determined to M1, M2, M3, B1, B2, and B3. When the frequencies corresponding to the two components have been counted for each channel, the values for M and B may be obtained from the following formulas.

$$M = \frac{200}{F(650) - F(450)}$$

$$B = 450 - M*F(450)$$

where F(V) corresponds to the frequency produced by a frequency component of V.

The counting of the frequencies is done using sense lines zero through two (ES0 - ES2). As discussed in Section 3.1.5, each sense line has a TTL signal on it with the same frequency as the frequency of its corresponding VCO. To count the frequency of this signal, the real time clock interrupts are set up to send a SYNC interrupt after one second. Each rising edge of the signal is counted between the time the interrupts are enabled and the time the SYNC interrupt occurs. The count at the time that the SYNC occurs corresponds to the frequency of the signal within an accuracy of ±1 Hz. A flowchart for the count subroutine is shown in Figure 4.4.

The detection of each rising edge is outlined in the flowchart. When a zero is sensed, the flag corresponding to that sense line is reset. Then when a one is sensed, the flag is set and, if it has not been previously set, the count is incremented. But it is only incremented for the first one in a series because any ones that occur after the flag is set are not counted. Therefore, the count is only incremented on a rising edge.

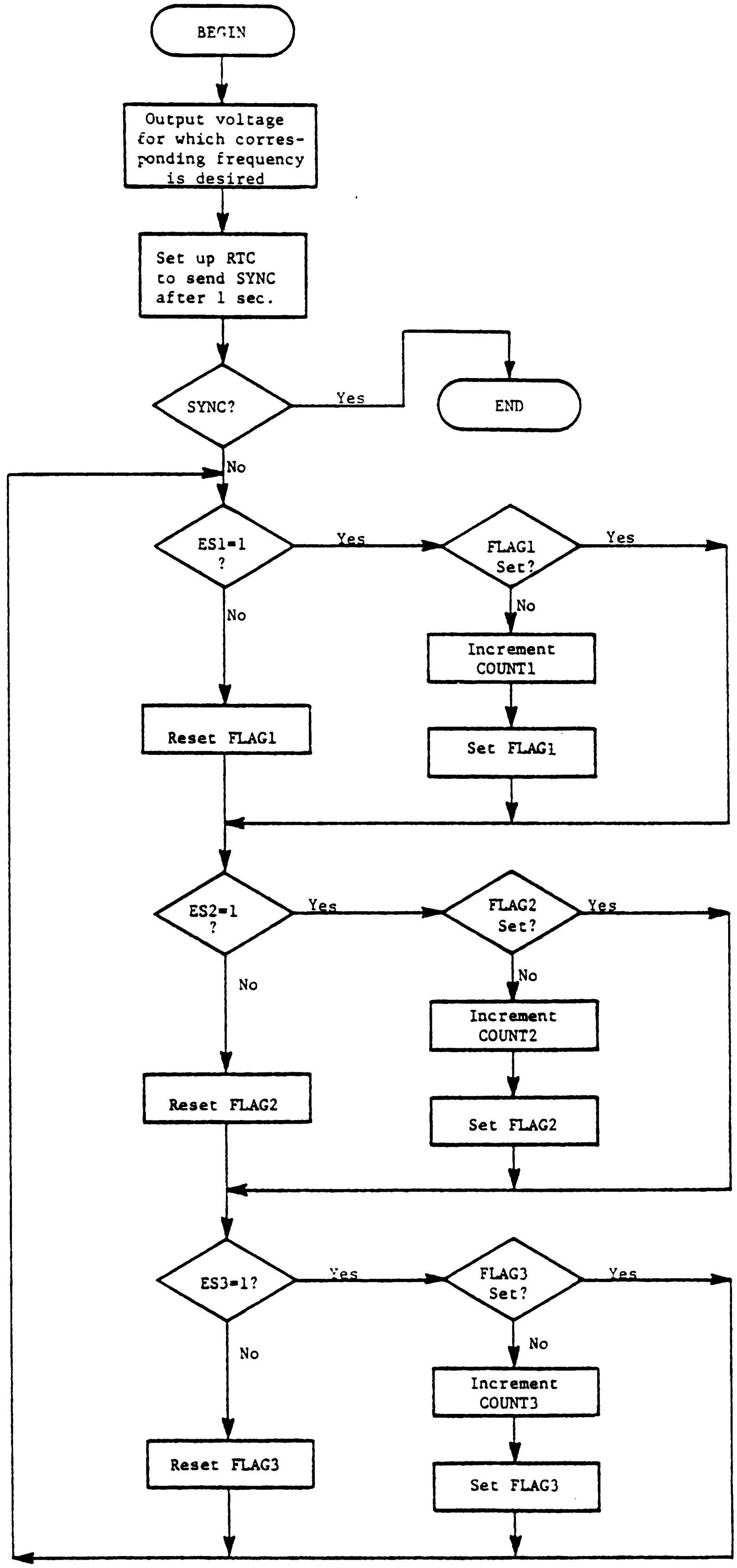


Figure 4.4 VCO frequency counter flowchart

4.2.2 Initial Conditions

Figure 4.5 shows the determination of the initial test conditions that were discussed in Section 4.1. It is first determined whether an X- or K-band device is being used, then whether moving or stationary mode operation is desired. If moving mode is desired, the speed requirements and amplitude of the patrol car are determined. For each target that is desired in the test, the speed and amplitude requirements of the target are then determined.

The speed requirements are shown in greater detail in Figure 4.6a. The program allows for a dynamic test for which the vehicle may speed up or slow down over a period of time. If a dynamic test is desired, the initial speed, final speed, and speedup time must be entered. Otherwise, one speed is entered and the final and initial speeds are set equal to that speed for the entire test. The speedup increment is then computed from the formula

$$\Delta\text{speed} = \frac{(\text{final speed}) - (\text{initial speed})}{(\text{speedup time})}$$

This determines the amount per second that the speed is changed while going from the initial speed to the final speed in the speedup time specified. Note that for a stationary test, the final speed equals the initial speed and the speedup increment is therefore zero.

If a dynamic test is being run, the frequency component corresponding to the initial speed of each vehicle will be output to the frequency channels initially. As soon as the "G" command is entered to begin the test, the speeds will start increasing or decreasing according to their speedup increments. This is a linear change with time. As soon as each vehicle reaches its final speed, it stops changing and remains at that speed throughout the remainder of the test.

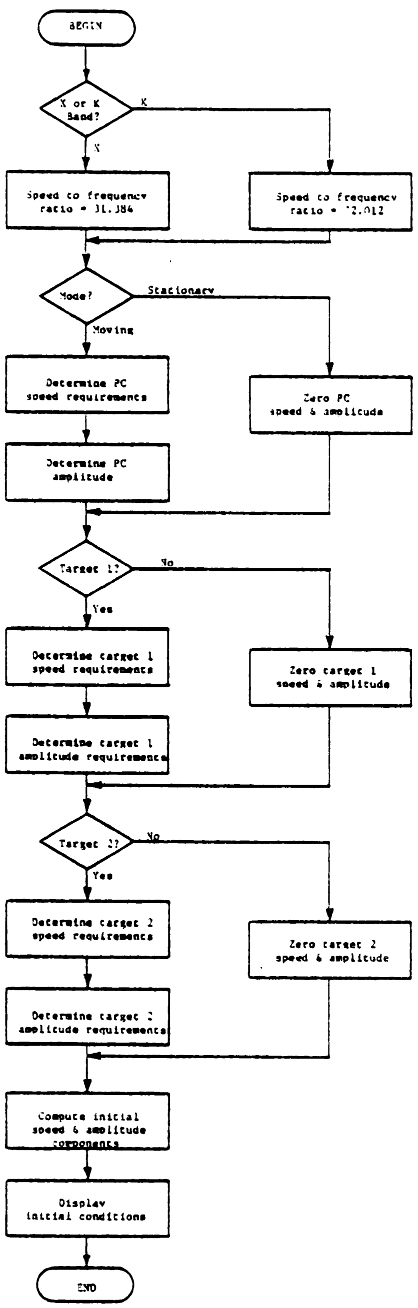
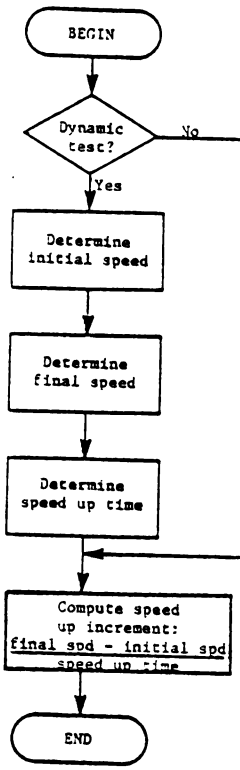
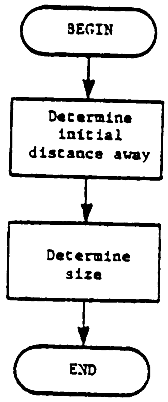


Figure 4.5 Initial conditions flowchart



a.



b.

Figure 4.6 a. Speed requirements flowchart

b. Amplitude requirements flowchart

There are two factors that determine the amplitude of the target signals, target distance from the antenna and target size. As shown in Figure 4.6b, the amplitude requirements consist of entering the initial distance the target is from the antenna and its size. The initial distance is to be entered in feet and can be any signed five place decimal number. A number one through four is to be entered to specify the size of the target, with four corresponding to the largest vehicle and one corresponding to the smallest.

A few special considerations must be made for the patrol car if moving-mode operation is desired. First of all, in order to avoid errors, the patrol car speed must be established before any targets appear. For this reason, as soon as the initial patrol speed is determined, its frequency component is output while the target frequency components are not output until after all the initial test conditions have been determined. There is also a short delay in the repeat routine so that the patrol speed may be established before any target speeds. Another consideration that must be made is that the amplitude of the patrol signal does not depend on its distance and size, but on factors such as the roadway surface and surroundings. For this reason, instead of entering distance away (the patrol distance is zero anyway) and size, the desired amplitude component is entered. An amplitude component of 100 has been found satisfactory for many of the tests that have been run.

4.2.3 Computation of the Frequency Component

Throughout each test, the value of the frequency component is continually being updated and computed from the values for the desired speeds of the vehicles under test. The current speed of each vehicle is stored in the variables CSPD1, CSPD2, and CSPD3 for targets one, two, and the patrol car, respectively. It is the closing speed that the radar device actually picks up, so if the patrol car speed is something other than zero, it must be added to the target speeds before the computation of the frequency component. Therefore, two new variables are defined:

CLSPD1 = CSPD1 + CSPD3

CLSPD2 = CSPD2 + CSPD3

for the closing speeds of targets one and two, respectively. From these variables, the frequencies the three channels are computed from the equations

F1 = K*|CLSPD1|

F2 = K*|CLSPD2|

F3 = K*|CSPD3|

where F1, F2, and F3 are the desired Doppler frequency shifts of targets one, two, and the patrol car, respectively, and K is the speed to frequency conversion factor. K is 31.384 and 72.012 for X-band and K-band, respectively. Since negative speeds are allowed, the absolute value of the speeds must be used to compute the frequencies.

Now that the desired frequency shifts have been obtained, the formulas derived in the VCO calibration procedure can be used to determine the frequency component.

VSPD1 = M1*F1+B1

VSPD2 = M2*F2+B2

VSPD3 = M3*F3+B3.

These equations yield the frequency components (VSPD1, VSPD2, and VSPD3) for the three channels from the desired frequencies and the M's and B's that were derived in Section 4.2.1.

4.2.4 Computation of the Amplitude Component

The amplitude of the patrol car signal does not change during a test, so it requries no computation or updating.

However, the amplitude of the two target signals must be computed at each time step based on target size, which doesn't change during the test, and target distance, which does change. The equations used to compute the amplitude components are given below.

$$VAMP1 = \left[\frac{Kx}{R1 + 1811}\right]^3$$

$$VAMP2 = \left[\frac{Kx}{R2 + 1811}\right]^3$$

VAMP1 and VAMP2 are the amplitude components for targets one and two, respectively and R1 and R2 are the distances each target is from the antenna. If R1 or R2 is less than zero, the amplitude component is set to zero. The constant Kx corresponds to K1 through K4 for sizes one through four, respectively and the values for K1 through K4 are 6177, 8542, 10,727, 15,277, respectively. The values for the K's and the pole at 1811 were chosen so that a size four vehicle would have an amplitude component of 20 at 5280 feet and a component of 600 at zero. In addition, an amplitude component of 20 should be obtained for size three at 3168 feet, size two at 2112 feet, and size one at 1056 feet.

4.2.5 Output Routine

After the frequency and amplitude components have been computed, they are output to the main board. As discussed in Section 3.1, a decode word must be added in the most significant bits of each component to steer the data to the appropriate channel. The code for the output of the component is given below.

```
LDA  Component    Load accumulator with component
ADD  Decode Word  Add decode word to component
OTA  :18,2        Output component + decode word to
                    main board
SEL  :18,3        Generate select pulse to strobe latches
```

The decode word for the components are given in Table 4.2.

Table 4.2 Amplitude and frequency components decode word

:0000	Target one frequency
:2000	Target one amplitude
:4000	Target two frequency
:6000	Target two amplitude
:8000	Patrol car frequency
:A000	Patrol car amplitude

4.2.6 Updating Frequency and Amplitude

When a test is in progress, the real time clock interrupts are set so that a SYNC interrupt will be generated ten times a second. Every time a SYNC interrupt occurs, the current speeds and distances are updated. Figure 4.7 illustrates the procedure required to update the speeds and distances.

To update the speed, the final vehicle speed is compared with the current speed. If they are the same, the current speed is not changed. However, if they are different, one-tenth of the speedup increment is added to the current speed. One-tenth of the increment is used because there are ten increments added in a second. The next step is to compute the frequency component as described in Section 4.2.3 and output the updated frequency component to the main board.

To update the amplitude, the distance the vehicle traveled during the time interval must be computed. The following equations can be used to compute the distance traveled from the closing speeds of the vehicles.

INDIST1 = .1466667*CLSPD1

INDIST2 = .1466667*CLSPD2

The new distances can be computed by subtracting the above distance increments from the current distances. If the speed is positive, the vehicle will move closer to the antenna and if the speed is negative, it will move farther away. The new amplitude component may be computed as described in Section 4.2.4 and output to the interface. Note that the patrol car amplitude does not change during the test.

4.2.7 Display Panel

After every five SYNC interrupts (twice a second), the display panel is updated. This requires converting the current speeds of the three vehicles and the two target distances to BCD and outputing each speed and distance to

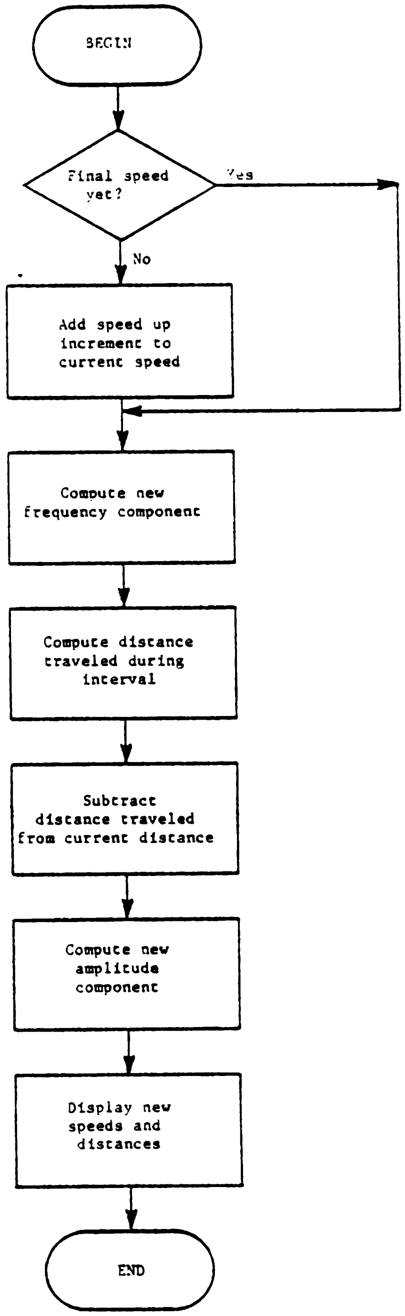


Figure 4.7 Speed and distance update flowchart

the appropriate display latches. It also requires updating the LED status word and outputing that to the appropriate latch. The code for outputing data to the front panel is given below.

```
LDA  Control Word   Load accumulator with control word
OTA  :18,2          Output control word
SEL  :18,6          Select front panel control word
LDA  Data Word      Load accumulator with data word
OTA  :18,2          Output data word
SEL  :18,7          Select front panel data word
```

The control word determines where the data is to be routed as discussed in Section 3.2 and Table 3.2 lists the control words for each display.

The LED status word was also discussed in Section 3.2. It is updated by comparing the amplitudes, distances from the antenna, and speeds of the two targets. If target two has a larger signal, bit nine is set, otherwise bit eight is set. Similarly, if target two is closer to the antenna and moving faster, bits seven and five are set. Otherwise, bits six and four are set. For stationary-mode operation, bit three is set and for moving-mode, bit two is set. Finally, if a test is in progress, bit zero is set, otherwise the pause bit, bit one, is set.

4.3 Other Programs

Two additional software packages were developed. The Radar Test Program performs simple tests on one channel at a time to ensure that the VCO and multiplier circuitry works properly. And the Signal Strength Test Program tests the response of a radar unit when the signal strength is varied. These two routines are described in the remainder of this chapter.

4.3.1 Radar Test Program

A flowchart for the Radar Test Program is given in Figure 4.8. It tests one channel which is prespecified by the operator. During the test, the other two channels have their frequency and amplitude components set to zero. For the channel under test, the operator must specify the frequency component and the amplitude component desired. As for the traffic simulator program, the frequency component may range from one to 700 (.01 V to 7 V) and the amplitude component may range from zero to 1000 (0 V to 10 V).

A signal will be set up on the desired channel corresponding to the values for the amplitude and frequency components that are specified. The higher the amplitude component, the higher the actual signal amplitude will be, while the higher the frequency component, the lower the actual signal frequency will be. By adjusting the amplitude and frequency components, any signal in the range of zero to 200 millivolts and 25 to 11,000 hertz may be obtained. No computation needs to be done since the components are output in the same form as they are input. The output routine is the same as that discussed in Section 4.2.5 for the Traffic Simulator Program and the display panel is left blank throughout this program.

When the test is completed, the operator may type an "I" to initialize the variables for a new test, or an "F" to go to the file manager and call a new program.

The simplicity of this program makes it useful when simple tests or minor adjustments are being done on the hardware. It also provides a quick check that the hardware is working properly.

4.3.2 Signal Strength Test Program

The Signal Strength Test Program only uses channels one and two. A flowchart of the program is given in Figure 4.9. In this program, the operator selects a desired speed for each

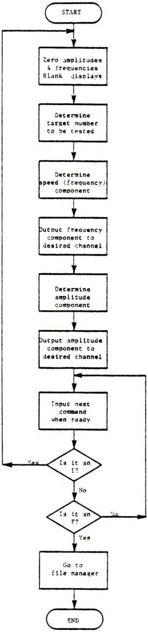


Figure 4.8 Radar Test Program flowchart

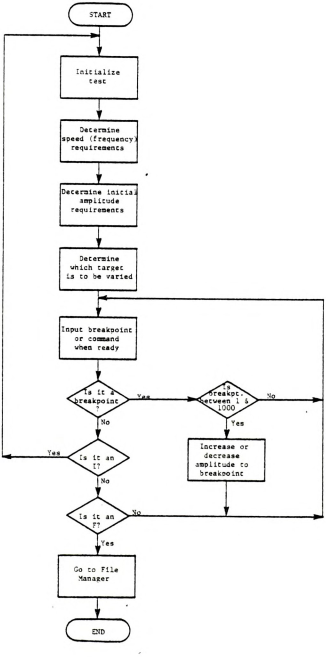


Figure 4.9 Signal Strength Test Program flowchart

target which remains constant throughout the test. The operator also selects the initial amplitude component of the two signals. Again, the amplitude component is a number between zero and 1000.

After the initial amplitude and speeds are determined, the amplitude of one of the channels is allowed to vary. The operator selects which channel is to be varied and may then begin entering breakpoints. If the breakpoint is followed by a space or a carriage return, the amplitude of the desired channel will change linearly from its current amplitude to the amplitude specified by the breakpoint while the amplitude of the other channel is held constant. After the amplitude of the breakpoint has been reached, the operator may enter another breakpoint or a command. An "I" will initialize the amplitude and speeds or an "F" will transfer control to the file manager.

The frequency components are computed in the same manner as described in the discussion of the Traffic Simulator Program with calibration of the VCO's at the initialization of every new test. The output of the frequency and amplitude components to the interface is also done in the same way as the previous two programs. The speeds of the two vehicles are displayed on the display panel, and in the place where the distances were displayed for the Traffic Simulator Program, the amplitude components of the two channels are displayed. In other words, at any point during the test, the current amplitude component is displayed on the front panel.

Figure 4.10 shows the flowchart of the subroutine that changes the amplitude from one breakpoint to the next. The amplitude increment is computed by

$$\Delta \text{Amp} = \frac{\text{(New breakpoint)} - \text{(Current amplitude)}}{100}$$

which is added to the current amplitude at every SYNC interrupt. Again, the SYNC interrupts occur ten times a second, so after ten seconds, the final amplitude will be reached.

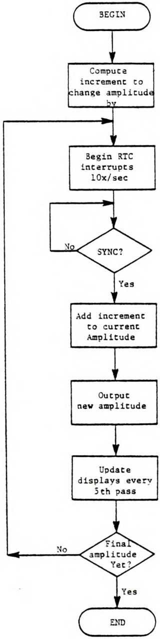


Figure 4.10 Amplitude variation flowchart

This program is especially useful in testing the hysterisis effects of radar units. Two different speeds may be entered and this program may be used to determine the amplitudes when one speed is detected over another. Results of hysterisis tests will be presented and discussed further in a later chapter.

V. SIMULATOR EVALUATION

The previous two chapters presented the details of the hardware and software for the simulator. Figures 5.1 through 5.3 show different aspects of the simulator. The entire setup is shown in Figure 5.1. The operator, through use of the teletype, provides the necessary test data to the computer and the anechoic test chamber is shown in the lower right hand corner. A close up of the computer and the simulator front panel is shown in Figure 5.2. The computer is on the bottom of the cabinet; the floppy-disk drive is above it; the main board and front panel are housed in the top compartment. The top section of the cabinet slides out as shown in Figure 5.3. The main board is mounted horizontally in the drawer and the display board stands vertically against the front. The power supplies necessary for this hardware are mounted on the bottom of the drawer below the main board.

Several experiments have been conducted to evaluate the simulator. The results of these experiments are presented in the following sections.

5.1 Amplitude Component versus Output Signal Level

The simulator transforms integer amplitude components to a corresponding voltage. This voltage is applied to the T-filter network (Figure 3.6) and the modulator diode to produce a change in conductance. Ultimately, then the amplitude component represents a target signal strength.

The first test measures the voltage level out of the simulator for different amplitude components. Voltage levels for amplitude components between zero and 1000 were recorded for several different frequency components and for each of the three channels. Since the data were consistent for all the channels at all different target speeds, the results for just one channel at 55 mph are plotted in Figure 5.4.

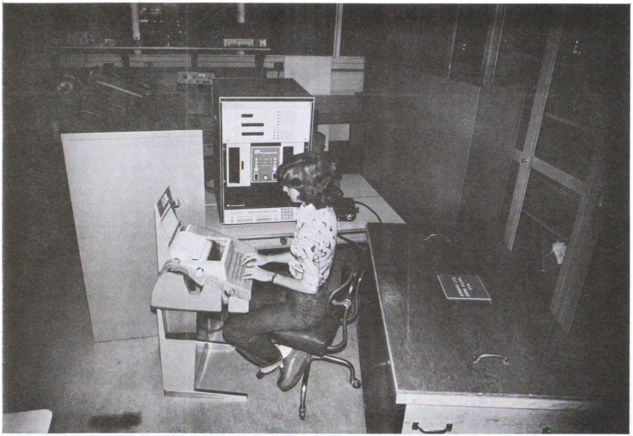


Figure 5.1 Entire simulator setup

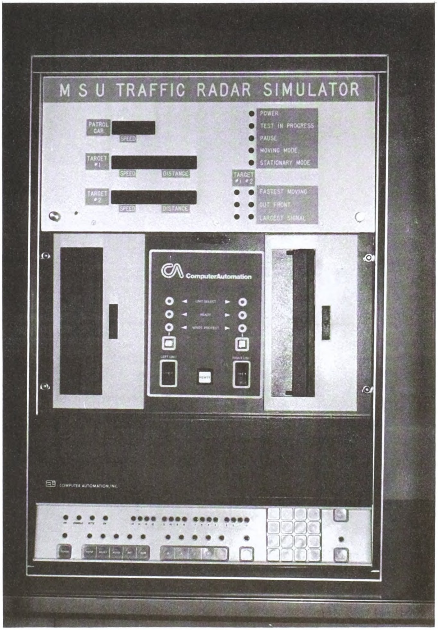


Figure 5.2 Computer and simulator front panel

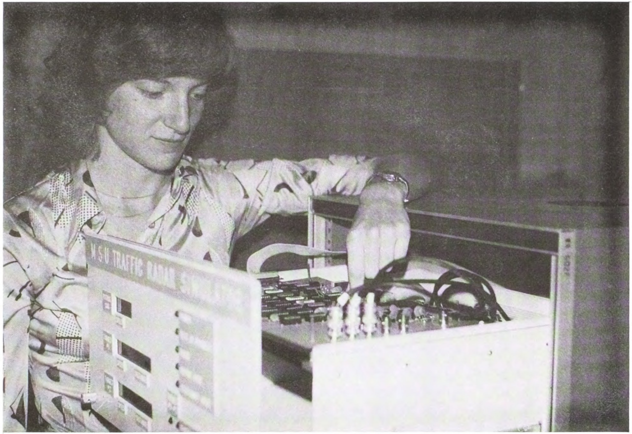


Figure 5.3 Storage for main board and front panel

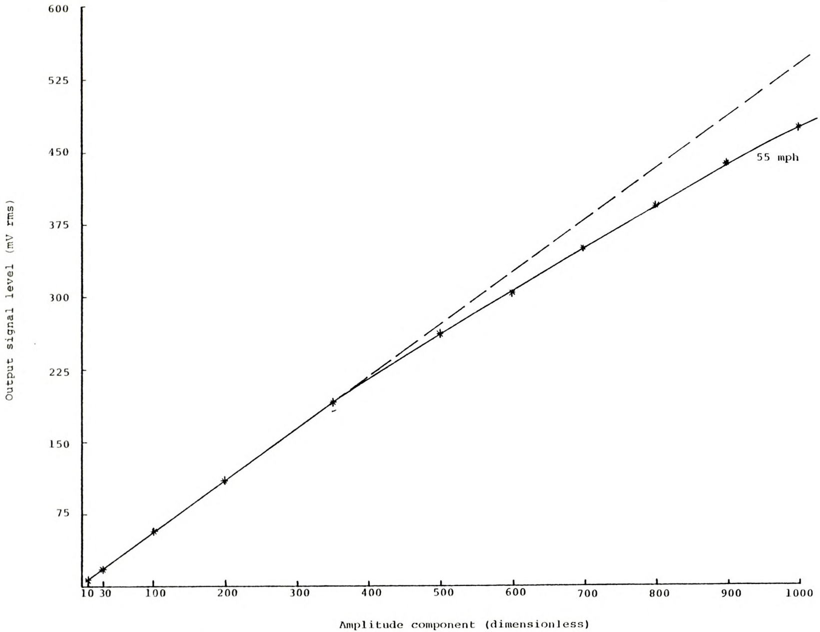


Figure 5.4 Amplitude component versus output signal level

It was assumed in the software design of the simulator that the relationship between the amplitude component and the output signal level was linear for the entire amplitude range. However, as seen in Figure 5.4, this relationship only holds for amplitude components up to about 400. For reasons stated later in this chapter, the actual amplitudes are restricted to be less than 600. At this amplitude, the maximum deviation between the assumed and the actual returned target signal strength corresponds to an uncertainty in distance of about the length of the target vehicle. This is quite small compared with other approximations. Moreover, size four target vehicles are the only ones which reach this maximum amplitude (see Figure 5.6). If this nonlinear effect does prove to lead to significant errors, it can easily be accounted for in software.

5.2 Distance versus Output Signal Level

This test examines the output signal level versus the distance the target is from the radar antenna. The equation for determining the amplitude component from the distance and size was obtained empirically after analyzing data that was collected in field tests on actual highways. It was found that the amplitude of an approaching vehicle varies as

$$\text{Amp.} = \left[\frac{K}{\text{Dist.} + 1811}\right]^3.$$

The size coefficients (K) and the pole at 1811 were chosen such that targets may be "just acquired" at one mile, six-tenths, four-tenths, and two-tenths of a mile. Several runs were made with targets of different sizes at different speeds, and the significant results are plotted in Figures 5.5 and 5.6.

Figure 5.2 is a plot of distance versus signal level for target one, size three, moving at 55 mph. The theoretical

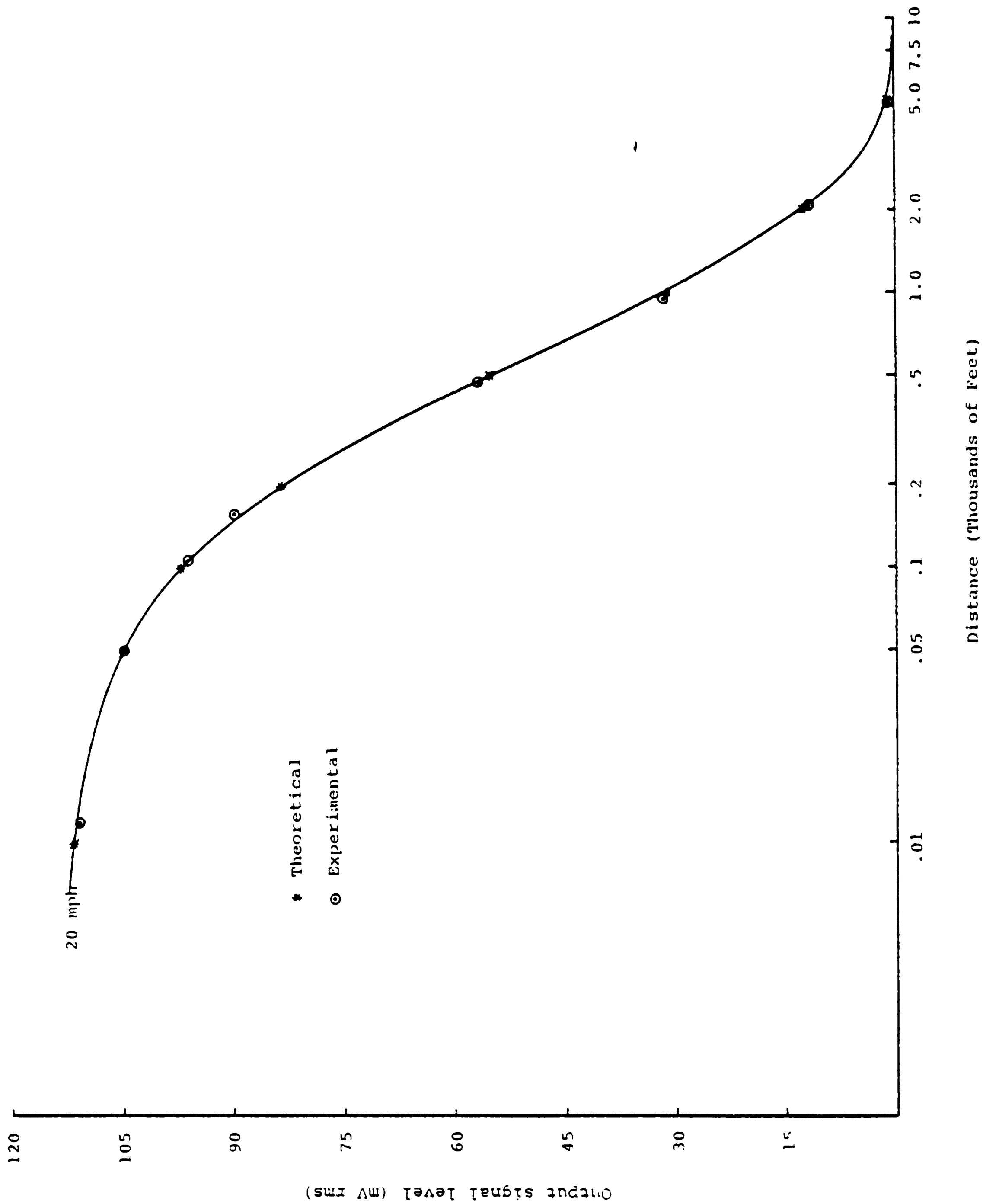


Figure 5.5 Distance versus signal level

curve on this figure is a plot of

$$\text{Amp} = \left[\frac{10{,}727}{\text{Dist.} + 1811}\right]^3$$

that has been normalized to the same scale as the experimental data. Of course, this is the equation that is used in the software to calculate the amplitude component from the distance. The shape of the theoretical curve agrees well with the actual signal levels. In fact, the error is less than one target vehicle length for distances up to one-half mile and less than two vehicle lengths for targets up to a mile away from the antenna.

Figure 5.3 illustrates how the target size affects the amplitude of the signal. This is a plot of all four sizes of target one at 55 mph. It shows the difference between the amplitude of a very large vehicle, such as a truck, and a small vehicle, such as a motorcycle, when all other conditions are the same. Although the data shown are for target one at 55 mph, the results are virtually identical for both targets at all reasonable speeds.

5.3 Turn on Drift

When the simulator is first turned on, the frequencies of the signals from the VCO's drift. This drift is due to changes in component temperature. Table 5.1 presents the results of the tests that were run to measure the turn on drift. The system was left off overnight and the frequencies were measured periodically after it was turned back on. It appears that 30 minutes to an hour is sufficient time to allow the simulator to reach equilibrium. All the other tests in this section were performed after this warm-up period. There is no noticeable amplitude drift.

5.4 Harmonic Distortion

By the very nature of the microwave modulator, we expect not only to obtain modulated microwave signals at the

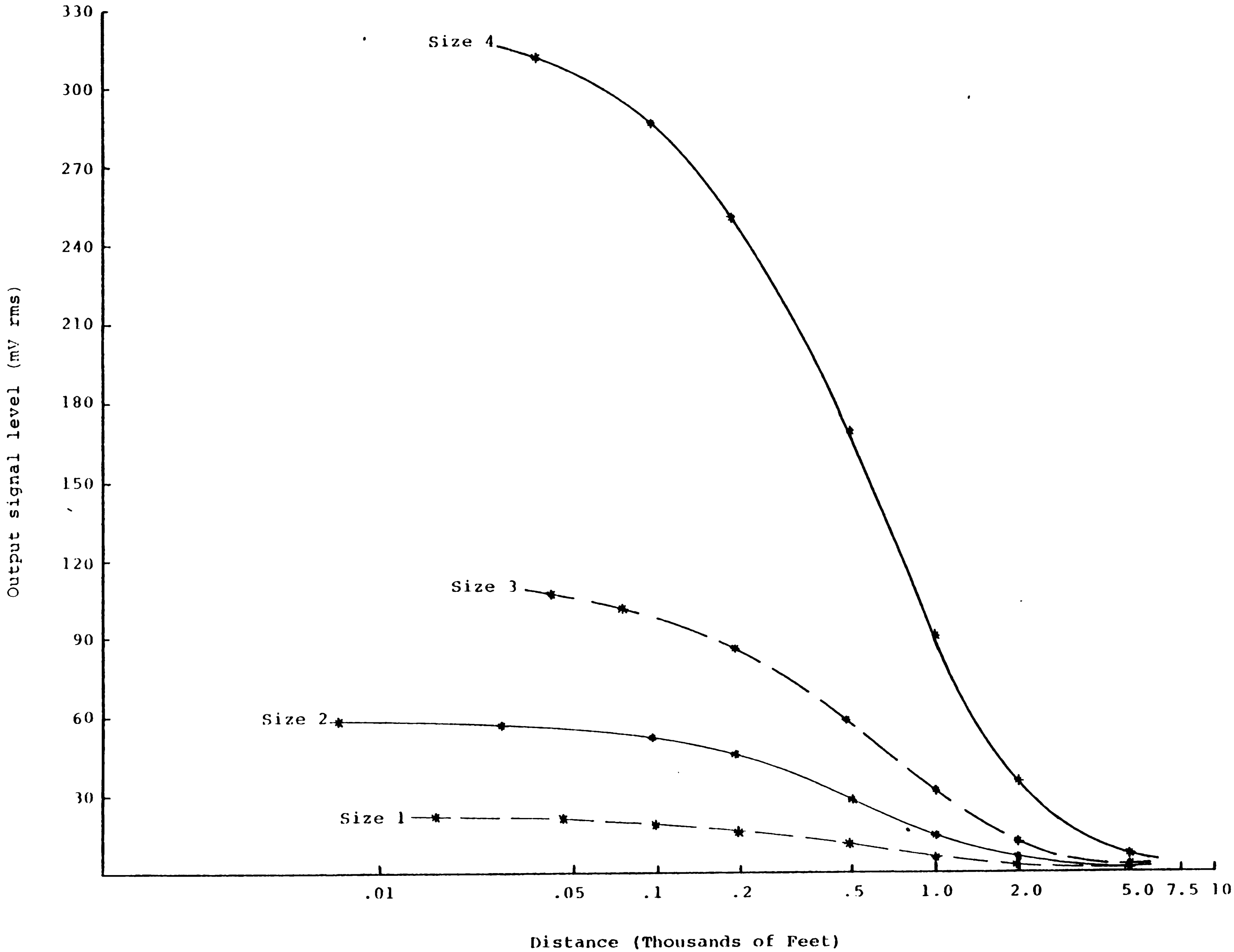


Figure 5.6 Distance versus signal level for different target sizes

Table 5.1 Simulator warm-up frequency drift

Time (min.)	Speed = 55 mph amp. comp. = 500	Speed = 55 mph amp. comp. = 200	Speed = 20 mph amp. comp. = 200
1	93.1	92.0	92.0
2	93.8	92.6	92.4
4	94.7	93.5	93.7
10	96.0	95.3	95.7
15	96.8	96.3	96.8
20	97.5	97.0	97.5
30	98.3	98.0	98.5
45	99.3	99.0	99.2
60	99.8	99.7	99.7

Tabulated figures represent frequency as a percent of the final value in a 70 minute test.

frequencies of the VCO's but also harmonics of these frequencies and the mixing of signal frequencies from different channels. While these harmonics and mixed frequency signals are unwanted, they are tolerable as long as they do not produce false radar readings. Based upon radar manufacturer's specifications for speed/signal strength selectivity, we chose to maintain these unwanted signals to less than -16dB of the desired signal. Table 5.2 summarizes the distortion measurement results for 55 mph targets. From these results we conclude that the allowed range for the amplitude component is zero to 600.

5.5 Accuracy of Frequency

This test compares the actual simulated target speed (Doppler shift) with the desired speed (Doppler shift). Actual simulated Doppler shift frequencies were measured and the actual speeds computed as follows:

$$\text{speed} = \frac{f}{31.384} \text{ for X-band, and}$$

$$\text{speed} = \frac{f}{72.012} \text{ for K-band.}$$

The test results are presented in Table 5.3.

There are many sources of error in the actual frequency versus the desired frequency: nonlinearity in the VCO's and rounding in the computation of the frequency component are two primary ones. However, the results of this test are still very acceptable. Speeds to an accuracy of ±1 mph can be achieved in the stationary mode and ±2 mph in the moving mode (an error of ±1 mph for the patrol car adds an additional ±1 mph error to the target vehicle). If desired, software could be written to further improve the accuracy.

Table 5.2 Simulator output harmonic distortion

Harmonic	amp. = 500 no modulator	amp. = 50 modulator	amp. = 500 modulator	amp. = 600 modulator	amp. = 1000 modulator
1	0	0	0	0	0
2	-33.0	-37.3	-18.0	-16.1	-14.2
3	-25.1	-23.8	-23.5	-22.9	-22.2
4	-50.9	-57.2	-31.6	-29.4	-27.7
5	-65.9	-63.5	-50.4	-44.3	-39.4
6	-	-	-	-43.3	-38.3
7	-	-	-	-50.7	-53.8

All tests made on channel 1, speed 55 mph.

Figures tabulated represent power (dB) of harmonics 2-7 relative to the 1st.

Table 5.3 Simulator speed synthesis accuracy

Desired speed (mph)	X-band Frequency (Hz)	X-band Actual speed (mph)	K-band Frequency (Hz)	K-band Actual speed (mph)
10	339	10.80	738	10.24
20	639	20.35	1434	19.81
30	955	30.41	2135	29.72
40	1256	40.00	2883	40.01
50	1558	49.60	3618	50.26
60	1876	59.75	4345	60.49
70	2179	69.39	5065	70.36
80	2492	79.36	5797	80.24
90	2813	89.59	6513	90.08
100	3147	100.22	7228	99.96

Both channels are essentially identical.

VI. SUMMARY

The goal of the research effort described herein was to design, implement, and evaluate an automatic test apparatus for police radar speed measuring devices. The primary purpose of this apparatus is to instruct radar devices under controlled conditions and to educate operators in their proper use. This chapter summarizes the development and implementation of the traffic radar simulator which realizes this goal.

6.1 The Traffic Simulator

The computer-controlled simulator tests X- and K-band radar units in both the moving and stationary modes of operation. One or two target vehicles of four different sizes may be used in the simulation. They may start at any realistic speed and position on the roadway, move in either direction, and accelerate or decelerate according to the initial preprogrammed specifications. The patrol vehicle, which can also be programmed to accelerate and decelerate, may be set to any realistic speed and amplitude. The starting time and duration of the test is completely controlled by the operator. Moreover, at any point during the test, the action may be frozen to examine a condition more closely. Throughout the test, current values of speeds and distances are continually updated and displayed on the front panel. Three pairs of LED's also identify which target is out front, which is moving fastest, and which has the strongest signal.

Two additional modes of operation may be used with the simulator. One mode establishes a stationary signal of a desired amplitude and frequency on a single channel. The other allows the operator to specify speeds for two channels and vary the amplitude of one while holding the other amplitude fixed. This second mode is a particularly useful tool in determining speed/signal strength sensitivity and selectivity.

This project commenced in January, 1980. The first two months were spent in the definition phase. Here we specified the types of radar devices that would be tested; the nature and scope of these tests; operator interaction requirements; and hardware precision, accuracy, and range requirements. The next three months were spent designing and building the main board and defining software requirements. After the main board was built, software was written to control the frequencies and amplitudes of the three signal channels. While the software was expanding to include more features, additional work was done to design and build the front panel, including the compartment where the main board and front panel are mounted. Construction of the hardware and software was completed in November, 1980. Since that time the simulator has been evaluated, used to test radar devices, and used for demonstrations. Documentation has been prepared to aid in the calibration and repair of the simulator, as well as materials necessary to instruct operators in its use. Table 6.1 presents an assessment of the approximate total cost of the traffic simulator.

Important characteristics of the completed simulator include the following:

* minimum warm-up time is 30 minutes;
* harmonic distortion is less than -16dB of the fundamental;
* maximum target distance uncertainty is less than two target vehicle lengths;
* maximum target speed uncertainty is less than 1 mph for stationary-mode operation and less than 2 mph for moving-mode operation;
* allowed speed range for targets or the patrol vehicle is ±199 mph for X-band radars or a

Table 6.1 Approximate simulator costs

Item	Approximate cost
Main board including XR8038 VCO's, AD534 multipliers, AD561 D/A converters, and other components	$ 250
Display board including MAN6610 displays and other components	150
Computer including Computer Automation LSI II minicomputer, Teletype terminal, 16-bit I/O module, dual floppy-disk drive	10,000
Hardware including front panel construction, cabinet, power supplies, cables and connectors	1,000
Test chamber including materials for chamber, labor, modulators, attenuators, and horns	3,500
Labor including graduate assistantship (1100 hours) and part-time undergraduate assistantship (500 hours)	12,500
TOTAL COST	$27,400

maximum closing speed of 150 mph for K-band radars;

* target vehicles and the patrol vehicle may be programmed to move at constant speeds or accelerate/ decelerate.

6.2 Tests on Individual Radar Units

Throughout the development of the simulator, demonstrations of its capabilities have been given to several groups, including radar operators, manufacturers, the Michigan Radar Task Force formed by the Michigan State Police's Office of Highway Safety Planning, and the public. In addition to being used as an educational tool, the evaluation of individual radar units has also begun. Many of the tests outlined in the proposed radar standards [3] have been performed using the simulator. These include

* Display Speed Lock Test: verify that the correct vehicle speed is locked onto the display when a target is present and the lock switch is activated;
* Display Clear Tests: verify that the display reading is cleared when a switch other than the lock switch is activated;
* Signal Processing Channel Sensitivity Tests: determine the minimum signal amplitude necessary to acquire a target.
* Low and High Speed Tests: verify that the specified low and high speeds can be acquired for the targets and the patrol car;
* Patrol Speed Change Tests: determine that the radar unit is capable of displaying the correct patrol speed when the patrol speed is being increased or decreased at a rate of three mph per second.

These tests are actually rather simple for the simulator to perform since most only require one signal at a constant frequency. Much more sophisticated tests are possible with the simulator. For instance, the ability to

* simulate conditions for shadowing and combining;
* simulate roadway and patrol vehicle interference with programmed noise sources;
* perform multiple target tests where the target vehicle(s) and/or patrol vehicle dynamically change speed;
* determine target selectivity and signal sensitivities as a function of speeds and return signal strengths.

A decided advantage of the simulator over manual test procedures is that simple or complex tests can be performed in a repeatable manner.

6.3 Future Improvements

Using the existing hardware, additions could be made to the software to make the tests more realistic. For instance, stationary and moving-mode cosine effects could be taken into account. More sophisticated speed profiles could be incorporated with the vehicles changing speeds quadratically or exponentially as well as linearly, or adding a feature which allows the operator to specify a delay time before a vehicle speed begins to change. Also, additional channels could be added to simulate more than two targets without changing the original design concepts, but a new cabinet would have to be built to have space for the additional hardware.

The traffic simulator in its present state was built at minimum hardware expense. The computer and terminal used were already available at the university. An alternative approach would be to use a small desk-top computer with built-in CRT display, bulk storage, keyboard, and printer, such as a Hewlett Packard 9845. In addition, synthesizers could be used for more accurate control of the frequencies and amplitudes of the output signals. If this latter approach is taken, the overwhelming majority of the simulator could be constructed around off-the-shelf items.

6.4 Conclusions

The simulator meets or exceeds all of the design requirements stated in Chapter 2. When the idea for the simulator was conceived, federal performance and test standards for radar speed measuring devices did not exist. In part because of this, the simulator has much greater testing capability than the standards call for, especially in the area of dynamic testing.

This simulator clearly demonstrates that it is feasible to build a realistic automatic test apparatus to exercise radar speed measuring devices under conditions similar to those actually encountered on the nation's roads and highways. To minimize cost and speed of development, we elected to build the simulator around a 16-bit minicomputer (a Computer Automation LSI II) and a Teletype terminal. Current advances in computer technology point the way toward the next generation traffic radar simulator. The computer could be a small, self-contained desk-top variety with built-in color graphics. The CRT display could visually illustrate the simulated target vehicles and patrol vehicle moving along the roadway. Simultaneously, test conditions could be displayed and hard-copy test documentation generated.

Even in its present form, this traffic simulator will be a useful apparatus for several important user groups. It can be used to evaluate the performance of newly introduced or purchased radar devices and newly repaired equipment. In addition, the simulator will be a useful tool in training radar operators, as well as in the education of the legal profession and the public at large regarding both the merits and shortcomings of police radar speed measuring devices.

REFERENCES

1. Fisher, P.D., "Shortcomings of Radar Speed Measurement," IEEE Spectrum, Vol. 17, No. 12, December, 1980, pp. 28-31.

2. Police Radar: Is it Reliable?, National Highway Traffic Safety Administration, U.S. Department of Transportation, No. DOT/HS805254, February, 1980.

3. "Performance Standards for Speed Measuring Radar Devices," Federal Register, Vol. 46, No. 5, January 8, 1981, pp. 2097-2119.

4. Naked Mini LS1 Series Computer Handbook, Computer Automation, Inc., October, 1974.

5. 16-Bit Input/Output Module, Product Number 13213-00, Computer Automation, Inc., August, 1972.

6. "XR8038 Precision Waveform Generator," Exar Function Generator Data Book, Exar Integrated Systems, Inc., April, 1979, pp. 30-33.

7. AD561: Low Cost 10-Bit Monolithic D/A Converter, Analog Devices, September, 1976.

8. AD534: Internally Timed Precision lC Multiplier, Analog Devices.

9. "FND6710, FND6740 Dual Digit Numeric LED Displays," Optoelectronics Data Book, Fairchild, 1979, p. 4-48.