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PASSIVE BUS DETECTOR
AN APPLICATION OF
MICROCOMPUTER TECHNOLOGY
AND
PATTERN RECOGNITION

by

(C) Leonard Shik Wo Cheng

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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EDMONTON, ALBERTA

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Passive Bus Detector an Application of Microcomputer Technology and Pattern Recognition submitted by Leonard Shik Wo Cheng in partial fulfilment of the requirements for the degree of Master of Science in Electrical Engineering.

Supervisor

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Date April 24/79

ABSTRACT

With the advent of developments in microcomputer technology it is cost-effective to perform a wide variety of practical applications of the theories of Pattern Recognition. This project is one such application in which a low-cost Passive Bus Detection system is developed.

Vehicle signatures sensed by an Electromagnetic Loop Detector are fed into a microcomputer system. Using the Pattern Recognition technique, the system extracts characteristic features from these signatures and defines Discriminant Functions to differentiate transit busses from other vehicles.

The system has been field-tested achieving better than 99% accuracy and is now in operation as part of a busway control device in the City of Edmonton. Most of the equipment used in the system is off-the-shelf to ensure the availability of the final product. However, some necessary modifications and additional circuits were implemented.

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NOMENCLATURE

Symbol	Meaning
N	Number of Maxima within a vehicle signature
Mxi	Magnitude of the ith maximum
Mni	Magnitude of the ith minimum
Txi	Time the ith maximum detected
Tni	Time the ith minimum detected
T	Duration of a vehicle signature
ξ	Normalized time with respect to T
η	Normalized magnitude with respect to Mx2
μ	Mean value
σ	Standard deviation
n	Number of data points
ε	Tolerance value
θ_{in}	Input Threshold value
θ_{out}	Output Threshold value
$\underline{r}$	Pattern vector
p	Probability density function
p(x/y)	Conditional probability of x given y
x	Estimated value of x
$\bigcup_{i=1}^{n}$	A union of n elements
$\in$	An element of a set
∇_θ	The gradient operator

CHAPTER 1 INTRODUCTION

1.1 Background

Increasing bus ridership as means to reduce congestion and fuel consumption has been receiving a lot of attention in recent years. Reliability and efficiency are among the techniques used to attract transit patronage. In order to provide reliability and efficiency in Transit Operations, priority concessions are given to transit vehicles. These concessions include exclusive bus lanes and priority traffic signalizations. Bus lanes, both with-flow and contra-flow, are the most common ways of giving busses priority over other traffic. However, while busses almost always gain from such treatment, other traffic can suffer substantially in certain circumstances[25]; and inadequate street facilities, which are common in older neighborhoods of an urban area, will also limit or even prohibit such practice. The second concession requires the invocation of various controls that all depend on the identification of transit vehicles in the overall traffic streams. In 1967 the Federal Highway Admininstration (FHWA) of the United States initiated a research project called Urban Traffic Control System/Bus Priority System (UTCS/BPS) which substantiated the feasibility of preferential signalizations to reduce delays of transit vehicles at intersections[15] although the requirement for on-board hardware and a special detector hindered the attractiveness of the concept.

Presently two systems are used in the City of Edmonton; both using direct radio transmission to a control device. One system uses a garage door opener to transmit to the control mechanism, the other transmits a signal from a vehicle-mounted transponder to an inductive loop which indicates the presence of a bus to the local control mechanism. Both systems require all vehicles that use the route to be equipped, and this in itself creates flexibility problems for the transit operator. The other major problem is the failure rate of the various transmission devices. The use of a passive detection system will solve or minimize the above problems.

In 1976, Honeywell Inc., under a contract with the FHWA, developed an engineering model of a Passive Bus Detector[13]. However, the mathematical approach taken in the development resulted in a high-cost and large size system which impaired its practicality. It was therefore our intention to pursue the development of a low-cost and compact passive loop-based transit detection system.

1.2 The System

Previous research and recent advances in microcomputer technology indicated that a classification system based on the pattern recognition technique was within the state of the art. Conceptually the system was identified as having three major functional blocks as illustrated in Fig. 1.1. The blocks have the following functional attributes:

1. The Sensing Block provides the basic signal that the processing logic uses in the recognition algorithm.
2. The Classifier Block performs the comparative logic which determines the vehicle type.
3. The Peripheral Interface Block converts the basic signal to the digital format and provides the input/output control hardware interface such that a desired action takes place as a result of a specific

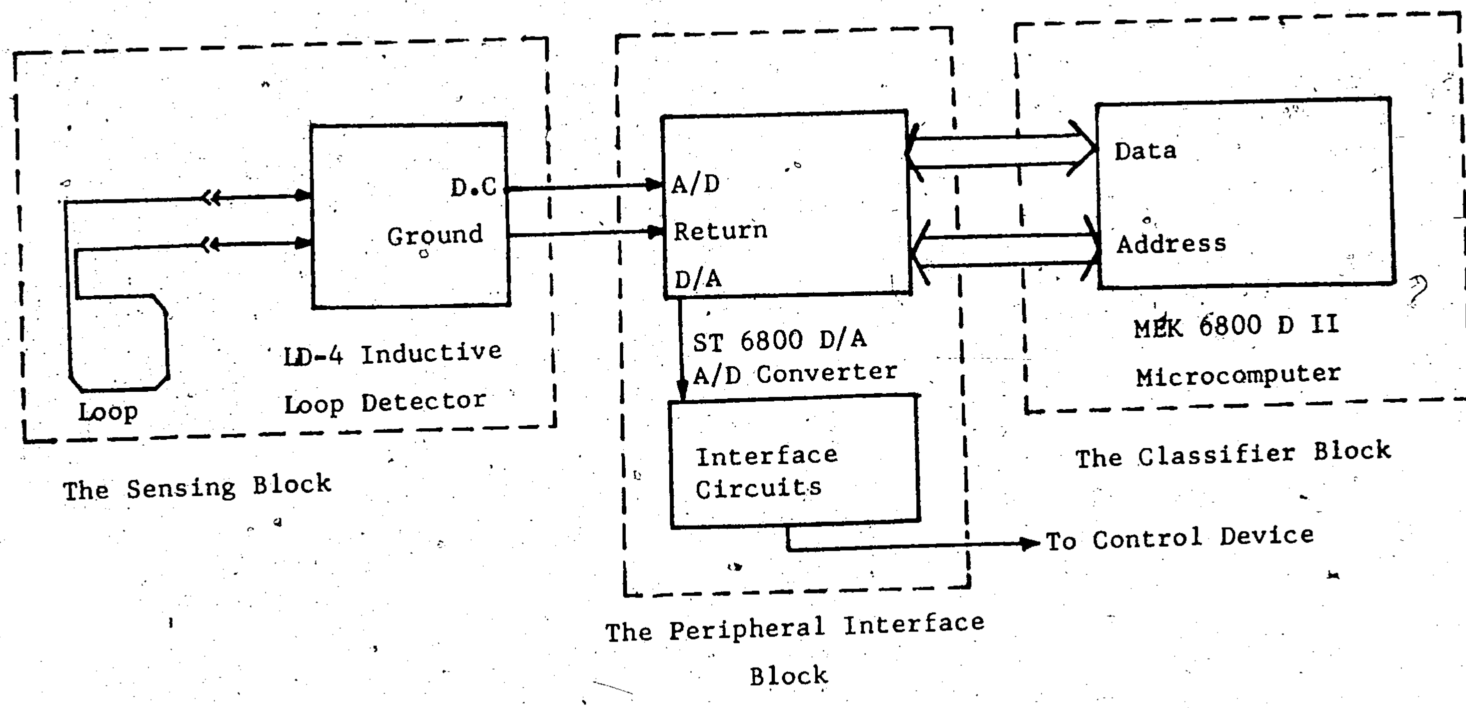


Fig. 1.1 Passive Bus Detection Functional Block Diagram

recognition.

The development of the system fell into three phases:

1. Sensing (Data Acquisition)
2. Feature Extraction (Data Analysis)
3. Development of Decision Algorithms (Software Installation)

During the course of designing the system, emphasis was placed on off-the-shelf equipment for the implementation of the final product. This will ensure availability and ease in future maintenance.

1.3 Project Objective

The objective of this project was to develop a low-cost and compact practical system which was capable of differentiating Edmonton Transit System (ETS) busses from other vehicles via a passive mode of detection scheme (i.e. neither the bus driver action nor the on-board equipment is needed) with an accuracy of 95% or better. This objective was successfully attained during the course of this project.

1.4 Scope of the Thesis

This is an interdiciplinary project involving both the Traffic Engineering and the Electrical Engineering where an operational system has been developed.

Chapter one is a desc ip ion of the background and the need indicated by the City of Edmonton for the development. It also very briefly describes the system and its development.

Chapter two is the theoretical analysis based on the collected data and the derivation of discriminant functions that are used in the final classification algorithm.

Chapter three describes the hardware development and necessary modifications to the off-the-shelf equipment to make this a fully automatic operational system.

Chapter four describes the software development in this project. A software filtering technique is discussed. Flow charts for the developed programs are also included.

Chapter five concludes this project by showing the performance of the system. It also points out the arbitrarinesses or uncertainties which may need adjustments in order to yield optimal system operations.

CHAPTER 2 THEORY

2.1 Introduction

Due to the variations of the data set (e.g. positions and magnitudes of local maxima and minima in the signatures) the pattern recognition technique seems to be suitable for solving the problem of differentiating ETS busses from other vehicles. This is one technique that can handle a large number of data and their variable nature and define a solution which is, on the average, in close agreement with the actual outcome. Therefore, it is the technique chosen in this project.

2.2 Typical ETS Bus Signature

Before going into the analysis of the data set, it is helpful to establish the correlation between the ETS bus and its signature. Since the distortions of an electromagnetic field are caused by the size of a metallic object and its position in the field, the signature sensed by the loop electronics should correspond to the metallic structure of the vehicle's undercarriage. Measurements of the metallic lumps on the undercarriage of an ETS bus show that the heater box and gas tank are situated between 17 and 27 feet from the front bumper of a 40-foot bus (Fig. 2.1). When we normalize the mid-point of the heater box/gas tank with respect to the total length of the bus, we have

$$\frac{(17 + 27)/2}{40} = 0.55$$

which is in very close agreement with the second local maximum of the average of a 3-max. normalized ETS bus signatures (Fig.2.2). The other two local maxima are likely produced by the front-wheel axle and the

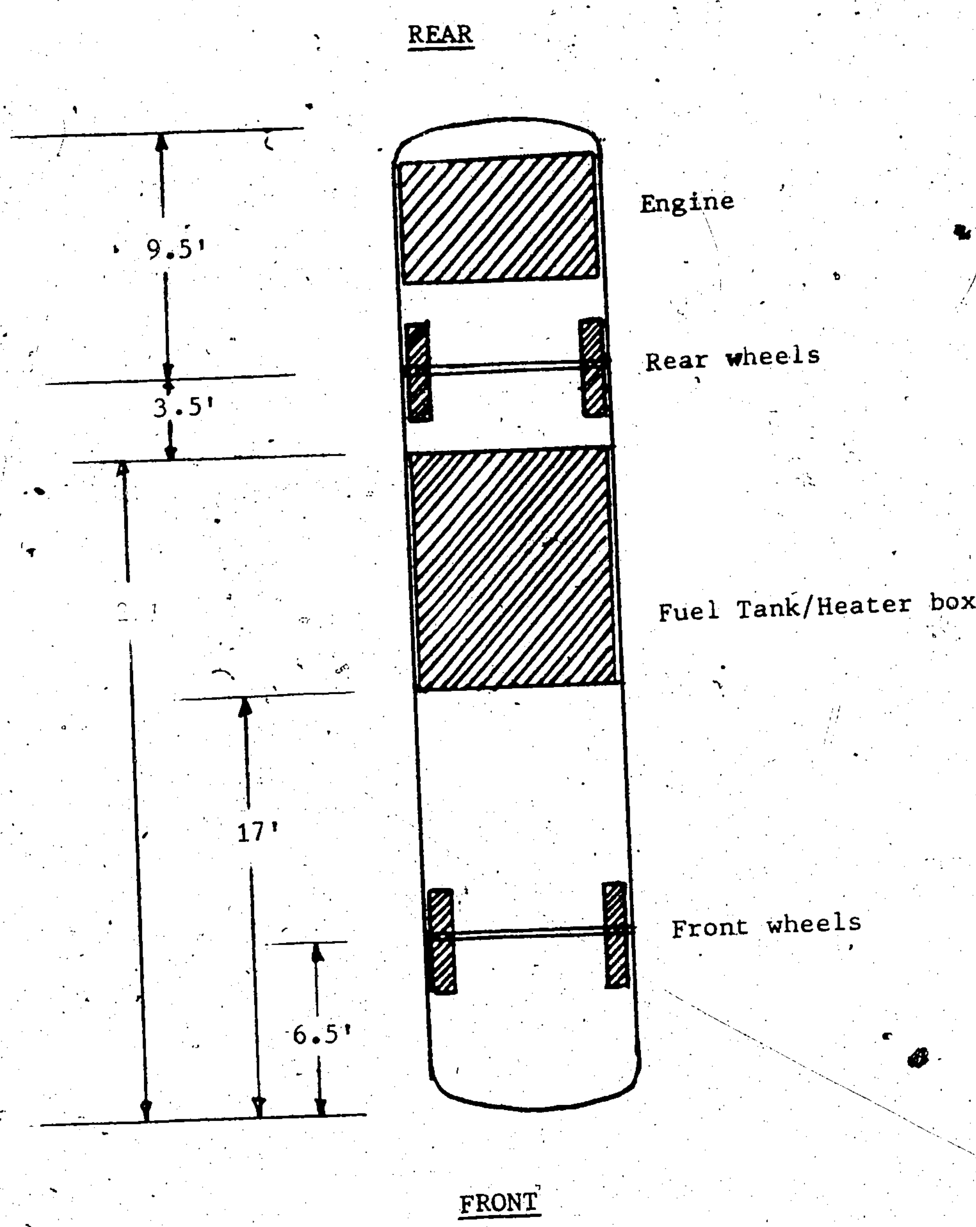


Fig. 2.1 ETS bus undercarriage diagram

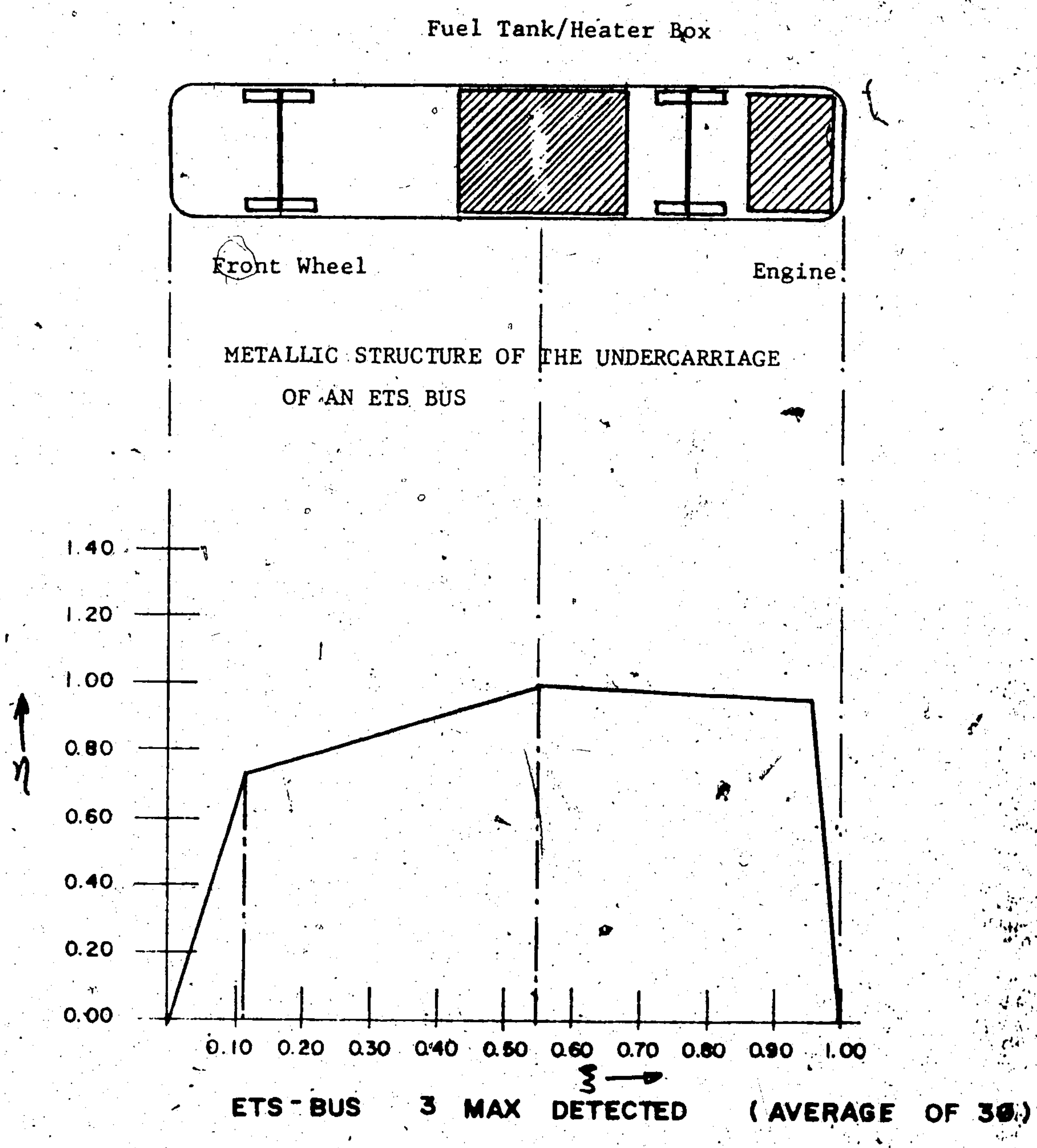


Fig. 2.2 Comparison between the Undercarriage of an ETS Bus and the Average of a 3-Max. Normalized Bus Signature

engine at the rear part of a bus. Therefore, such signature is regarded ad the typical signature of an ETS bus and will be referred to as such throughout this chapter.

A typical ETS bus signature thus consists of the following characteristics:

1. Three local maxima,
2. The second maximum has the highest value, and
3. Relative positions of these maxima, normalized with respect to the duration of the signature, are:

   1st maximum, Tx1 = 0.10 to 0.20

   2nd maximum, Tx2 = 0.425 to 0.675

   3rd maximum, Tx3 = 0.90 to 1.00.

2.3 Data Analysis

Initial analysis on the data set (Appendices 2 & 3) indicates that the feature space can be described by two dimensional pattern vectors. The components of each pattern vector ($\underline{r}$) are defined by the following two variables ξ and η , where

ξ = Normalized time position with respect to the total duration of the signature,

and

η = Normalized magnitude with respect to the detected second maximum.

The pattern vector is therefore denoted by:

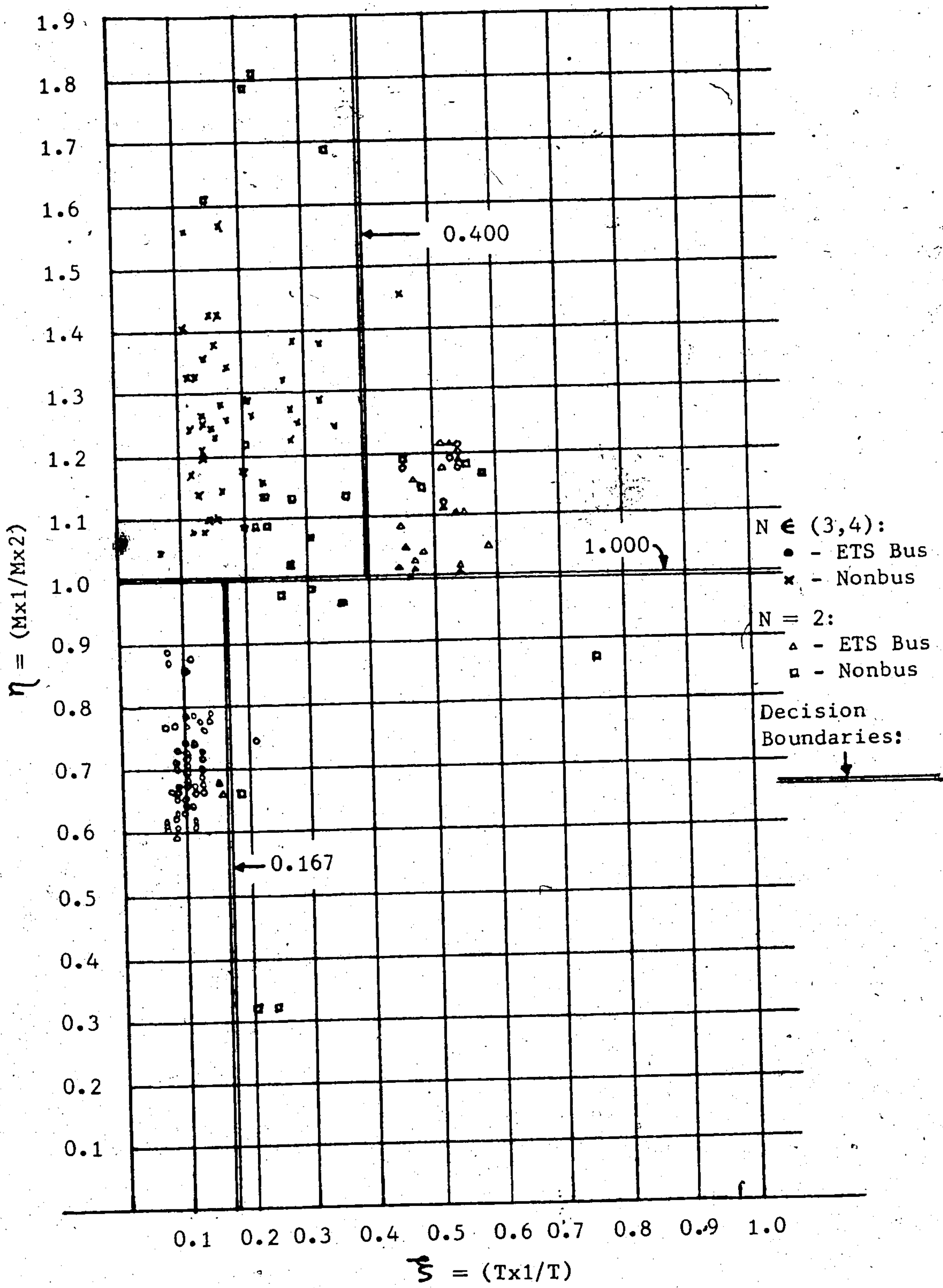
$$\underline{r} = (\xi , \eta).$$

Distributions of data from the two classes (i.e., ETS busses and other vehicles) show three nearly disjoint clusters (Fig 2.3), thus indicating that decision lines of high accuracy may be defined. Also, the formation of these clusters suggests the possibility of using only one-dimensional decision algorithms if the data are partitioned by means of some value of the η component. Based on the analysis in the preceding section, the value of $\eta = 1.0$ is chosen.

Now, if we consider only the ξ component the data distribution of ETS busses closely resembles the Normal type (Fig. 2.4). On the other hand data distribution of other vehicles does not quite behave in the Normal manner. This is expected since the class of other vehicles consists of a variety of vehicles and thus it may be considered as the sum of a number of Normal distributions. However, when estimating mean values, μ, and standard deviations, σ, of ξ for these two classes using the Maximum Likelihood Method (Appendix 1), the distributions of data of both classes are treated as the Normal type and adjustments are made when decision lines are defined.

2.3.1 Hierarchical Decision Tree

From the collected data, it is obvious that the number of maxima and their positions and magnitudes in a signature characterize the vehicle it belongs to (Fig. 2.5, 2.6, 2.7). However it was later noted that, after the feature extraction procedure, the number of maxima in a signature of a particular vehicle type is not as unique as we like it to be. For example, signatures of ETS busses are found to have two, three or even four local maxima as depicted by table 2.1. One possible explanation for this would be the measurement error due to noise and/or



Total Number of Signatures = 156
Misclassified vehicles: ETS Bus - None
Other Vehicles - 8

Overall Accuracy = 94.87%

Fig. 2.3 Data Distribution and Decision Boundaries

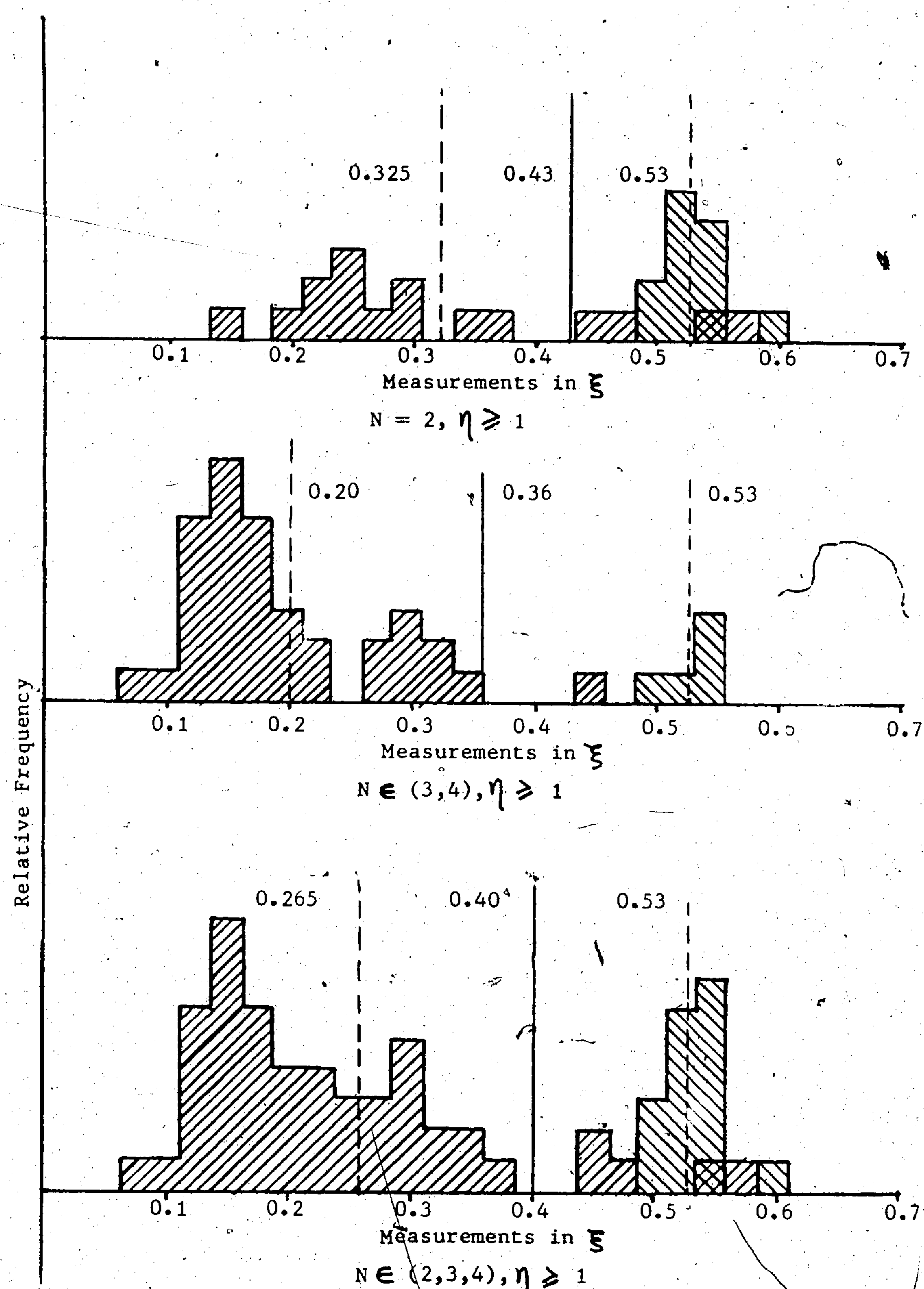


Fig. 2.4 Distributions of Stored Data

——— Decision Boundary

- - - - Mean Value

Other Vehicles

ETS Busses

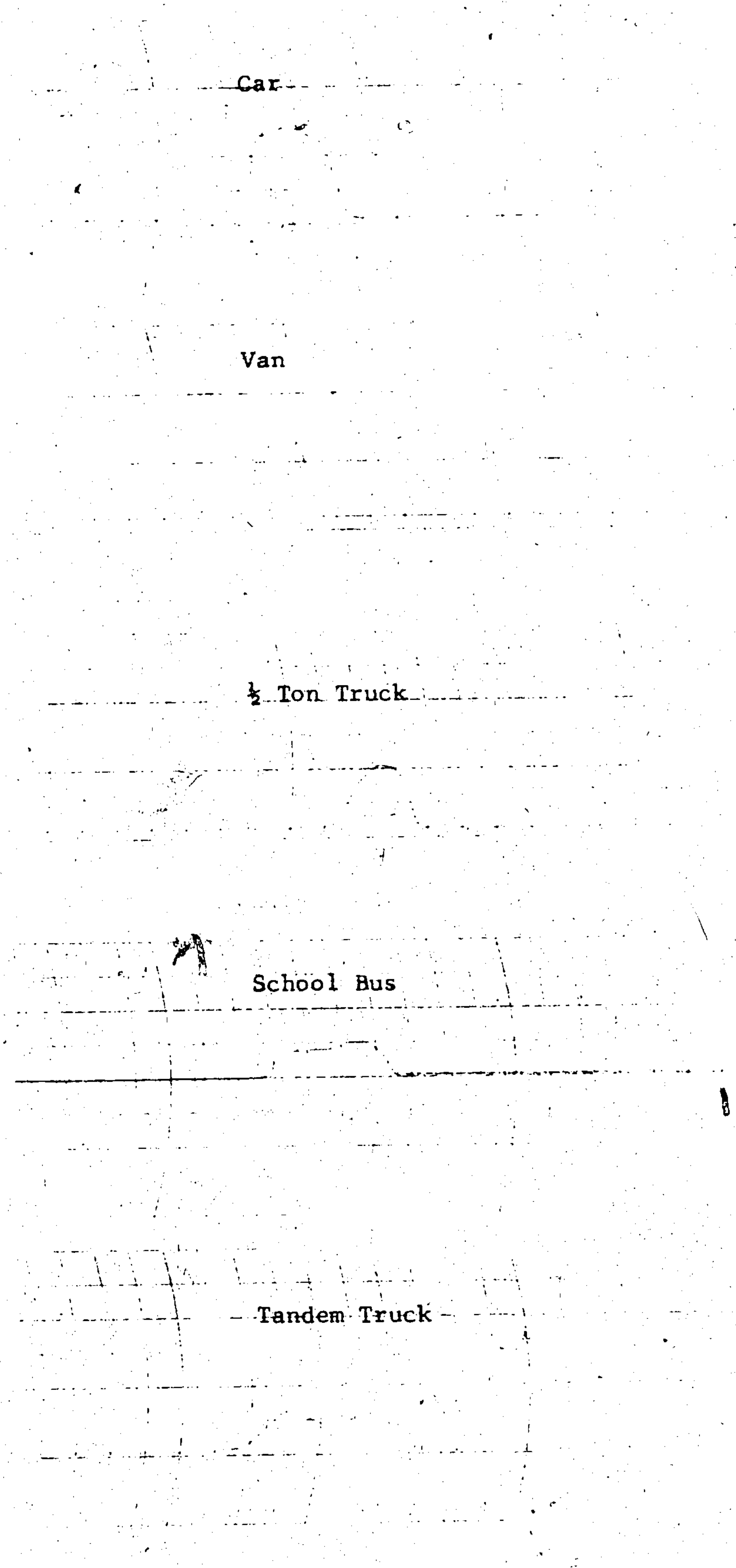


Fig. 2.5 Typical Vehicle Signatures

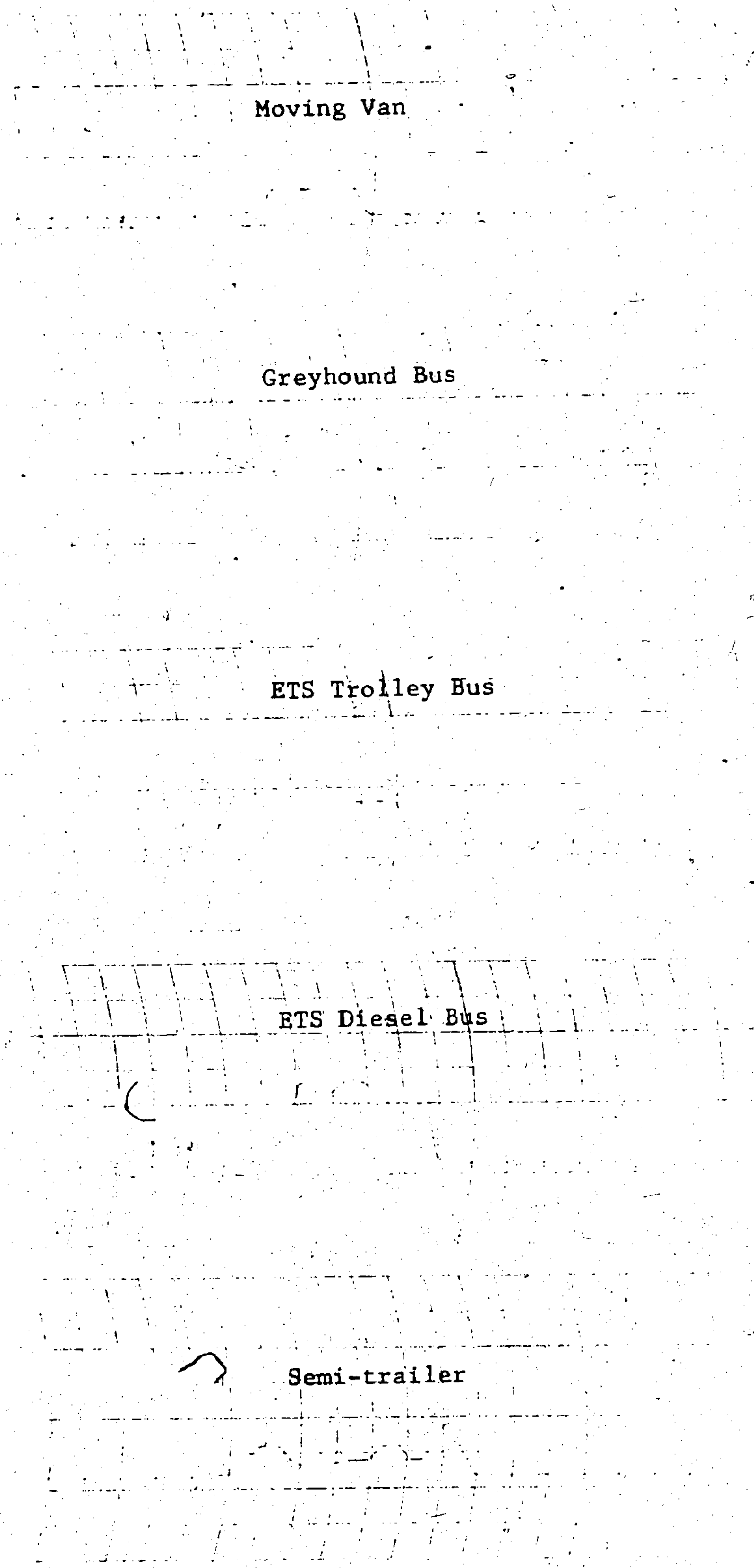


Fig. 2.6 Typical Vehicle Signatures (Cont'd)

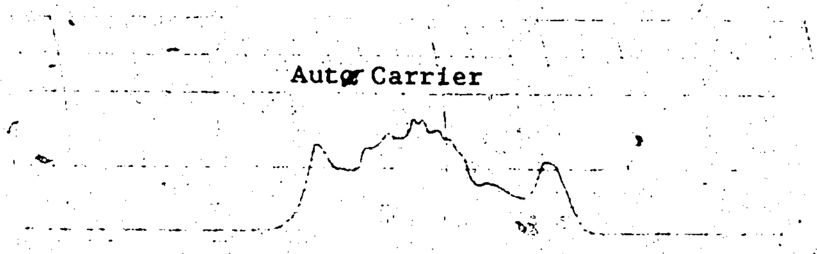


Fig. 2.7 Typical vehicle Signatures (Cont'd)

Auto Carrier			X	X	X	X	X	
Semi-trailer			X	X				
ETS Diesel Bus		X	X	X				
ETS Trolley BUS		X	X	X				
Greyhound Bus	X	X						
Moving Van		X	X					
Tandem Truck		X						
School Bus	X	X						
½ Ton Truck	X	X						
Van	X	X						
Car	X	X						
	1	2	3	4	5	6	7	8

Number of Maxima

Table 2.1 Number of Maxima vs Vehicle Types the lateral displacement of the vehicle relative to the detection zone of the inductive loop. A more careful analysis indicates that, in the case of ETS busses, when only two maxima are detected, either the first or the third maximum is missing and the second maximum, which is the global maximum in the signature, is always present. In other words, when only two maxima are detected the first detected maximum is actually either the "real" first or the "real" second maximum in a typical ETS bus signature. It is, however, possible to determine whether or not it is the "real" first maximum by comparing the relative time position this maximum is detected with the duration of the whole signature. Based on the charted signatures, the typical signatures of ETS busses exhibit three distinct local maxima (Figure 2.6), thus only the first three local maxima will be considered in the software logic. For a signature which consists of more than four local maxima, the signature will be considered as that of an auto-carrier rather than an ETS bus.

A Hierarchical Decision Tree is thus formulated (Fig. 2.8). Given a vehicle signature, the system first makes a decision as to whether or not the vehicle is a prospective candidate to be classified as an ETS bus by counting the number of detected local maxima; for $2 \leq N \leq 4$ (N = number of local maxima detected), data will be further processed to yield a classification decision. In the case where $N < 2$ and $N > 4$, the system will reject the signature and consider it to be that of a non-(ETS)-bus. A detailed analysis for the cases where $2 \leq N \leq 4$ is given in the following sections; and the prospective signatures are divided into the following four cases as shown in the heirarchical decision tree:

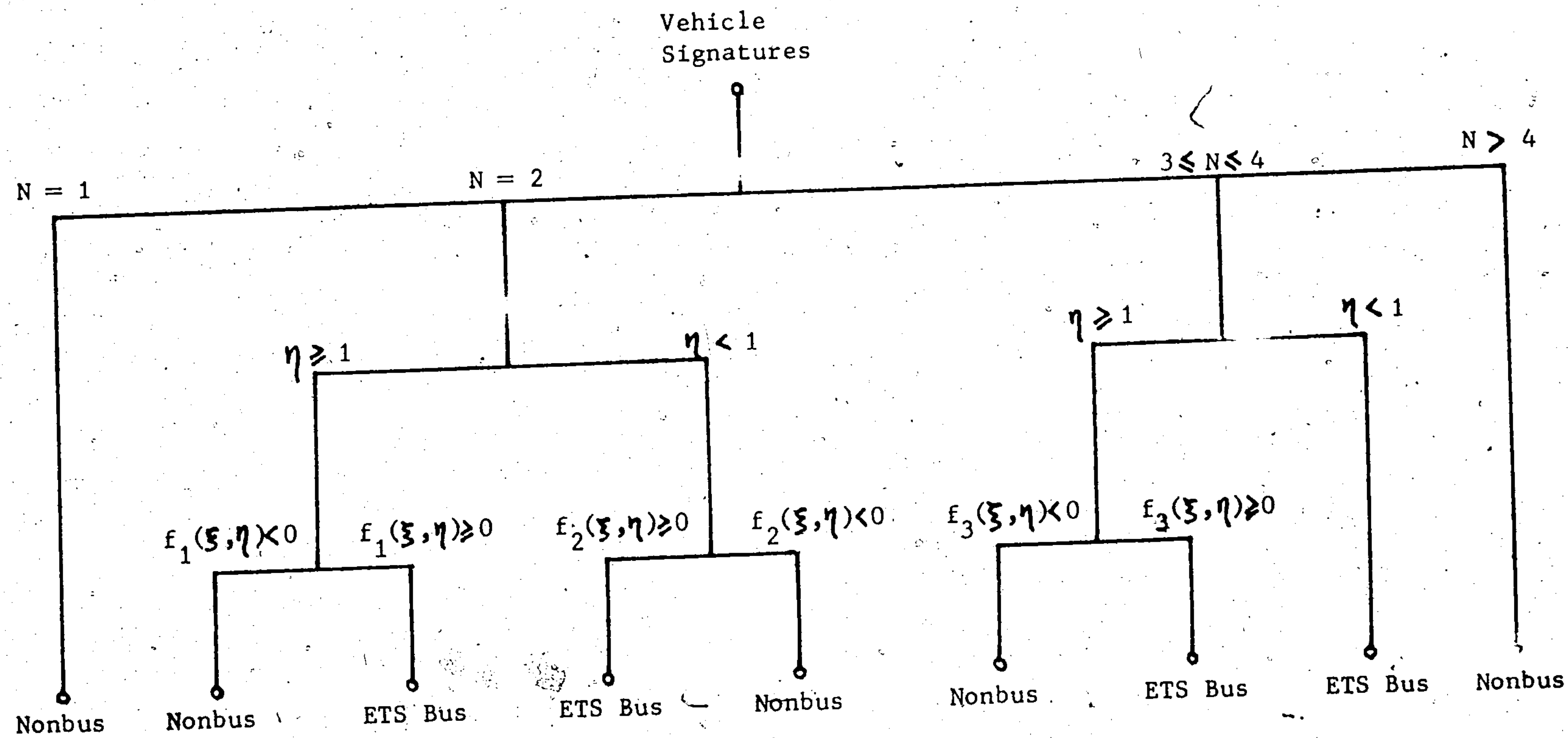


Fig. 2.8 Hierarchical Decision Tree

N = Number of Maxima
ξ = (Tx1/T), Normalized Time Position of 1st detected maximum
η = (Mx1/Mx2), Ratio of 1st detected max. to 2nd deted maximum

1. $N = 2, \eta \geq 1$
2. $N = 2, \eta < 1$
3. $N \in (3,4), \eta \geq 1$
4. $N \in (3,4), \eta < 1$

2.3.2 Signatures with 2 local Maxima

The majority of vehicle classes have this characteristic, namely, cars, vans, half ton trucks, school busses, moving vans, greyhound busses and ETS busses (Table 2.1). To distinguish the ETS busses from the rest of the list above, we first investigate the magnitude ratio of the maxima in the signature. As mentioned before, when only two maxima are detected, either the first or the third maximum in the typical signature is undetected. Therefore, if $\eta \geq 1$ the first detected maximum is actually the "real" second maximum in the signature; and if $\eta < 1$ the "real" first maximum is detected. These two cases will be considered separately.

2.3.2.1 In the case $N = 2, \eta \geq 1$ (Fig. 2.9)

In this case, mean values (μ) and standard deviations (σ) of ξ are estimated from the collected data to be:

For ETS busses, $\mu_b = 0.532$

$\sigma_b = 0.023$

For other vehicles, $\mu_o = 0.33$

$\sigma_o = 0.124$

where subscripts b and o denote ETS busses and other vehicles respectively.

The centroid (mean value) of ETS busses clearly indicates that when N =

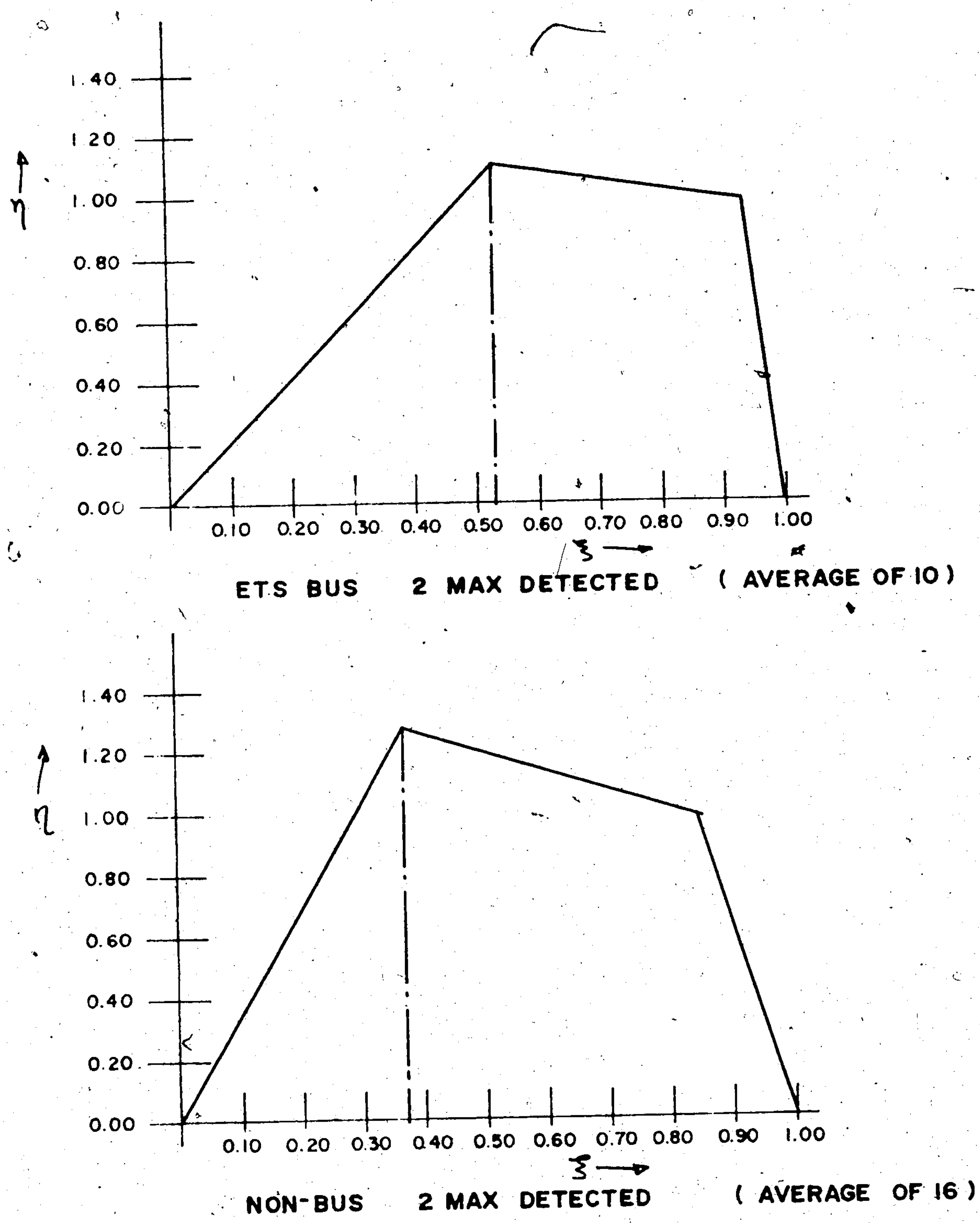


Fig. 2.9 Averages of Normalized Signatures

$N = 2,\ \eta \geq 1$

2 and $\eta \geqslant 1$ the detected first maximum is actually the "real" second maximum in a typical ETS bus signature since it is situated very close to the mid-point of the signature (ξ = 0.532) just like the second maximum in a typical ETS bus signature. A linear discriminant function, $f_1(\xi, \eta) = f_1(\xi)$, is then defined as,

$$f_1(\xi, \eta) = f_1(\xi) = \xi - \frac{0.532 + 0.33}{2}$$

i.e., $\quad f_1(\xi) = \xi - 0.431$

and $\quad f_1(\xi) \geqslant 0$ implies ETS busses, and

$f_1(\xi) < 0$ implies other vehicles.

During the process of defining the decision boundary, the mid-point is used instead of a point proportional to their respective standard deviations because it was decided that a much heavier penalty would be imposed on the misclassification of ETS busses than that of other vehicles.

2.3.2.2 <u>In the case N = 2 and $\eta < 1$</u> (Fig. 2.10)

Only a few data points were gathered in this catagory (a total of 7, 2 ETS busses and 5 other vehicles). The centroids of these two classes were estimated to be:

For ETS busses, $\mu_b = 0.155$

For other vehicles, $\mu_o = 0.26$

It is obvious that, since $\eta < 1$ and the second maximum is the global maximum in a typical ETS bus signature, the detected first maximum is in fact the "real" first maximum and the "real" third maximum is missing. From the size of the data set, it appears to be a rare case although these

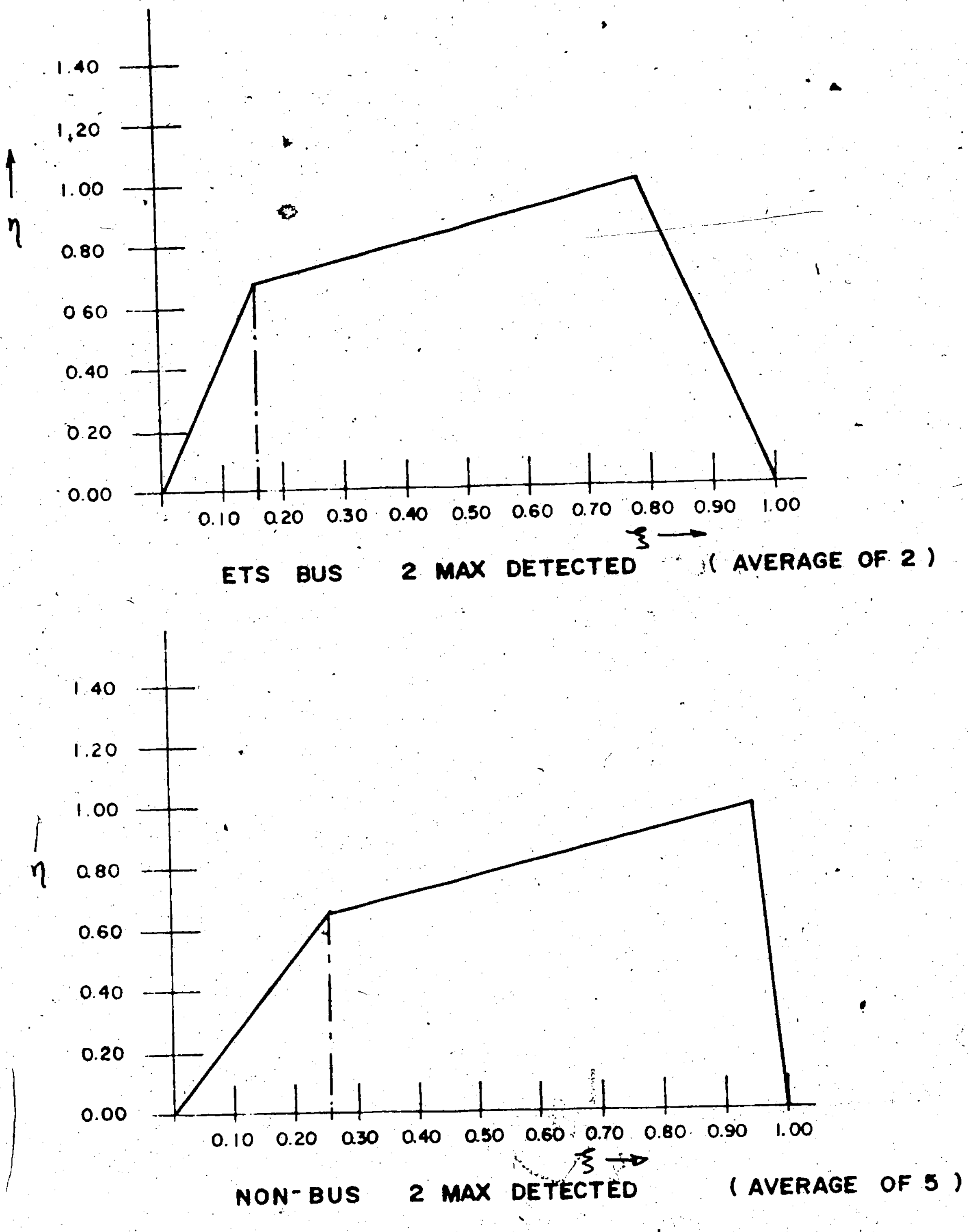


Fig. 2.10 Averages of Normalized Signatures

$N = 2, \ \eta < 1$

signatures do exist. Using the same argument as in section 2.3.2.1, we arrive with a discriminant function as follows:

$$f_2(\xi, \eta) = f_2(\xi) = \frac{0.155 + 0.26}{2} - \xi$$

i.e., $f_2(\xi) = 0.208 - \xi$

and $f_2(\xi) \geqslant 0$ implies ETS busses, and

$f_2(\xi) < 0$ implies other vehicles.

2.3.3 Signatures with 3 or 4 Local Maxima

Referring to table 2.1, the vehicle classes that exhibit this characteristic are moving vans, ETS busses (trolley and diesel), semi-trailers and auto-carriers. Following the same argument as in section 2.3.2, we first proceed with the case where $\eta \geqslant 1$ and then $\eta < 1$.

2.3.3.1 In the case $N \in (3,4)$ and $\eta \geqslant 1$ (Fig. 2.11).

Mean values of the ETS busses and the other vehicles were estimated as follows:

For ETS busses, $\mu_b = 0.532$

For other vehicles, $\mu_o = 0.20$

Again, in this case, the detected first maximum is actually the "real" second maximum in a typical ETS bus signature and the discriminant function, $f_3(\xi, \eta)$, is defined as:

$$f_3(\xi, \eta) = f_3(\xi) = \xi - \frac{0.532 + 0.20}{2}$$

i.e., $f_3(\xi) = \xi - 0.366$

and $f_3(\xi) \geqslant 0$ implies ETS busses, and

$f_3(\xi) < 0$ implies other vehicles.

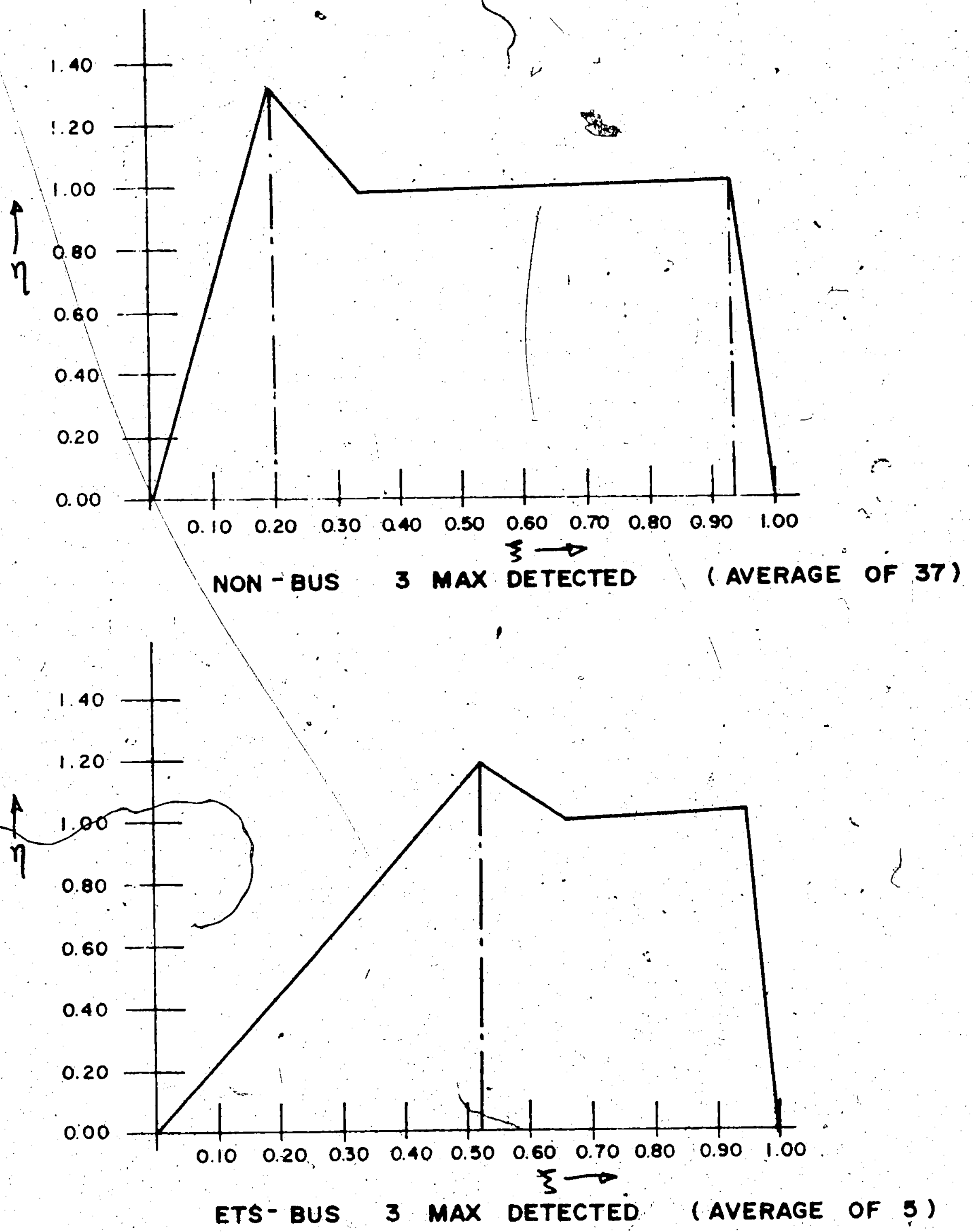


Fig. 2.11 Averages of Normalized Signatures

$N \in (3,4), \ \eta \geq 1$

2.3.3.2 In the case $N \in (3,4)$ and $\eta < 1$ (Fig. 2.12)

This is the case where the majority of the ETS busses falls into. It includes basically all the characteristics of a typical ETS bus signature. Since no other vehicle signatures exhibit these characteristics from the collected data set, any signature which possesses such characteristics will be considered as that of an ETS bus.

2.4 Summary and Conclusion

2.4.1 Summary - Final Decision Algorithms

For ease in software implementation, the final discriminant functions are modified and summarized as follows:

1. For $N = 2$, $\eta \geq 1$

   $f_1(\xi) = \xi - 0.4$

   $f_1(\xi) \geq 0$ implies ETS busses, and

   $f_1(\xi) < 0$ implies other vehicles.

2. For $N = 2$, $\eta < 1$

   $f_2(\xi) = 0.167 - \xi$

   $f_2(\xi) \geq 0$ implies ETS busses, and

   $f_2(\xi) < 0$ implies other vehicles.

3. For $N \in (3,4)$, $\eta \geq 1$

   $f_3(\xi) = \xi - 0.4$ (same as case 1)

   $f_3(\xi) \geq 0$ implies ETS busses, and

   $f_3(\xi) < 0$ implies other vehicles.

4. For $N \in (3,4)$, $\eta < 1$

   The vehicle is classified as an ETS bus.

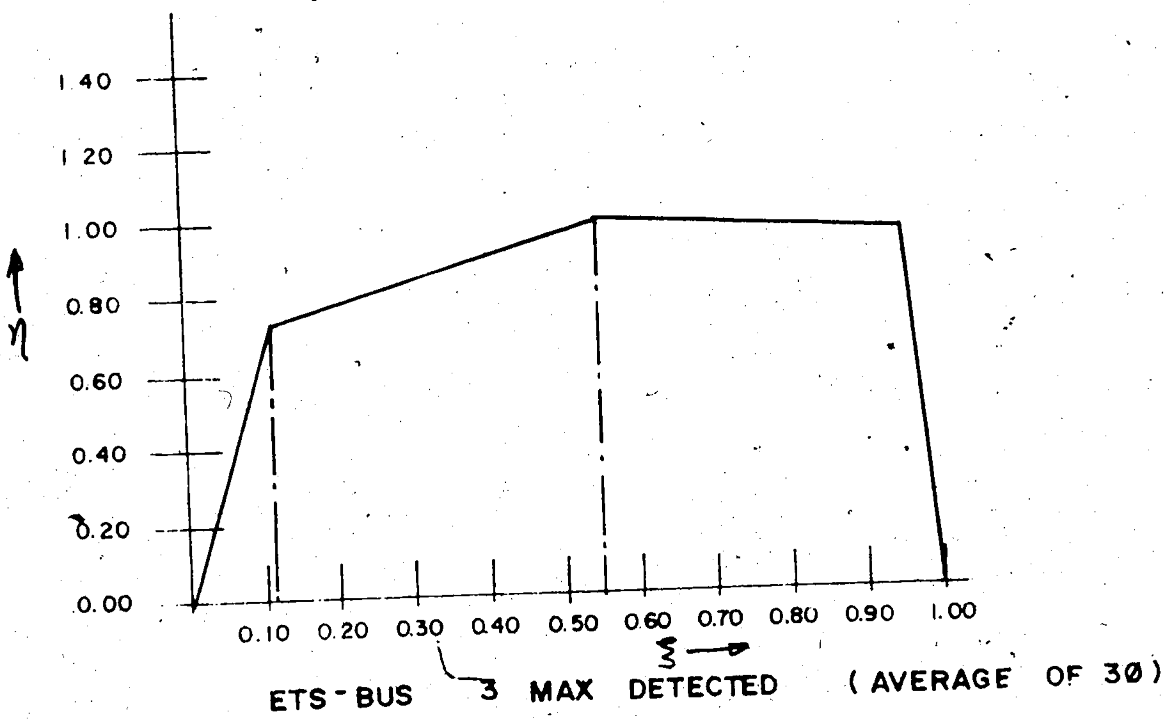


Fig. 2.12 Average of Normalized Signatures

$N \in (3,4), \; \eta < 1$

2.4.2 Conclusion

After the final decision algorithms were implemented in the software in the microcomputer memory, the system was field tested to have an accuracy very closed to 100%.

CHAPTER 3 HARDWARE DEVELOPMENT

3.1 Introduction

The hardware implementation of the system consists essentially of three major units. They are:

1. The sensing unit,
2. The peripheral unit, and
3. The processing unit.

The following sections will describe these units and their operations.

3.2 The Sensing Unit

Out of the list of presently used equipment by Edmonton Power, the LD-4 loop vehicle detector of the LFE Corporation was chosen after some extensive testing to be the suitable candidate for the sensing unit. It is a solid-state self-tuning phase-shift vehicle detector. The basic principle of operation of this unit is described in the following section.

3.2.1 Basic Principle of Operation of a Phase-shift Vehicle Detector

The sensing electronics of a phase-shift vehicle detector is essentially a RLC resonant circuit depicted in fig. 3.1.

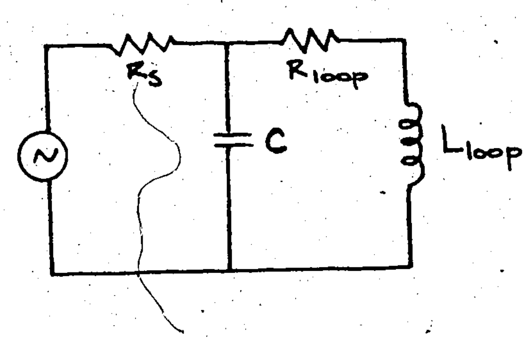


Fig. 3.1 A RLC Resonant Circuit

When the loop is excited with a high-frequency (about 100KHz) AC current, the presence of a vehicle (or a metallic object) in the electromagnetic field of the loop will cause a net decrease in its self-inductance due to the metallic frame of the vehicle. As a result, since the resonant frequency is defined by

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

it will shift to a higher frequency inversely proportional to the square root of the self-inductance. (Fig. 3.2)

$$\frac{f_{r1}}{f_{r2}} = \sqrt{\frac{L_2}{L_1}}$$

where f_{r1} = resonant frequency of the tank circuit in the absence of metallic object,

f_{r2} = resonant frequency of the tank circuit when a metallic object is in the electromagnetic field of the loop,

L_1 = self-inductance of the loop in the absence of a metallic object, and

L_2 = self-inductance of the loop when a metallic object is in its electromagnetic field.

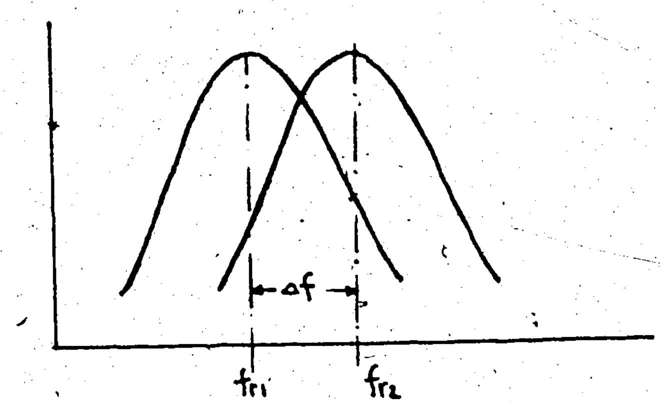


Fig. 3.2 Change of frequency by a metallic object

where Δf = the shift in resonant frequency .

This change in frequency is then detected in the form of a phase-shift by a phase-shift detector within the detector electronics as shown in fig 3.3.

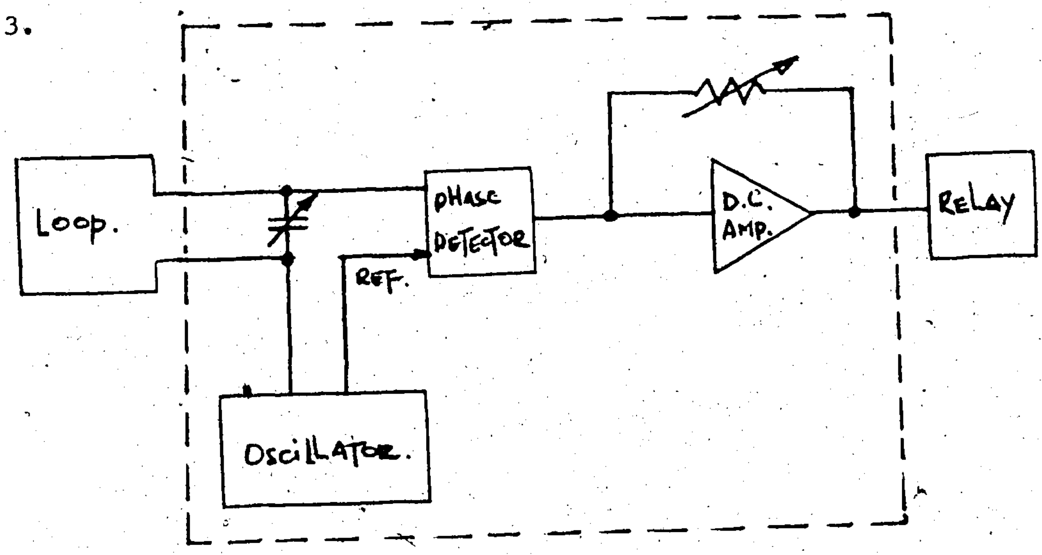


Fig. 3.3 A phase-shift loop vehicle detector (Block diagram)

The output from the phase detector, in the form of a DC voltage, is then amplified to trigger the relay to close or open thus rendering a detection. In this project, however, a more sophisticated approach is taken at the signal output from the DC amplifier. Since the change (decrease) in self-inductance of the loop, hence the resonant frequency of the tank circuit, is dependent on the structure of the undercarriage of the vehicle and on the distance between the loop and these metallic lumps, the output of the DC amplifier thus takes the form of a continuous signal somewhat proportional to the metallic structure of the undercarriage of the vehicle. This continuous signal is defined as the signature of the vehicle type.(The signature is the essence of the whole project as it is rather unique for each type of vehicles and carries all characteristics needed for the vehicle classification.)The analog signal is then amplified and filtered before it goes to the peripheral unit.

3.2.2 Amplifier and Filter

The signal amplification was designed by using an integrated circuiy (IC) difference amplifier (fig. 3.4). The signal from the LD-4 detector was fed to the positive input of the μA741 while a reference signal was fed to the negative input. The voltage gain is controlled by four resistors as shown:

$$V_{out} = \left(\frac{R_1 + R_2}{R_3 + R_4}\right)\left(\frac{R_4}{R_1}\right)V_2 - \left(\frac{R_2}{R_1}\right)V_1$$

Choosing $R_1 = R_3$ and $R_2 = R_4$ to minimize the offset error due to biased current, we have

$$V_{out} = \left(\frac{R_2}{R_1}\right)(V_2 - V_1)$$

and the gain is therefore,

$$\frac{V_{out}}{(V_2 - V_1)} = \frac{R_2}{R_1} = \frac{R_3}{R_4}$$

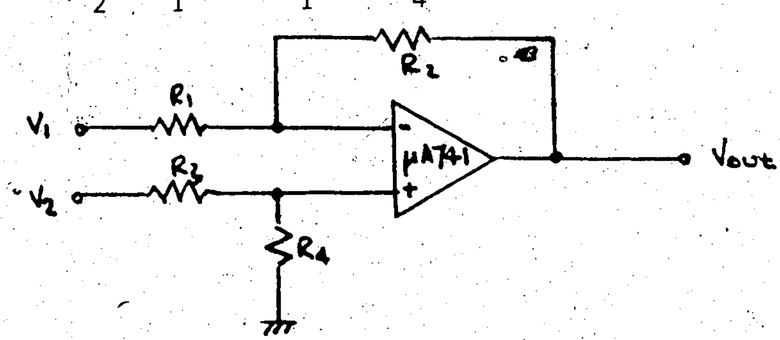


Fig. 3.4 Difference Amplifier

The output, V_{out}, is then fed to the input of a unity gain Voltage-Control-Voltage-Source (VCVS) Butterworth Low Pass Filter (LPF) to enhance the signal to noise ratio (S/N) of the signature. The LPF is designed to cut off noise frequencies higher than the signal itself and a cut-off frequency of approximately 10 Hz was chosen.

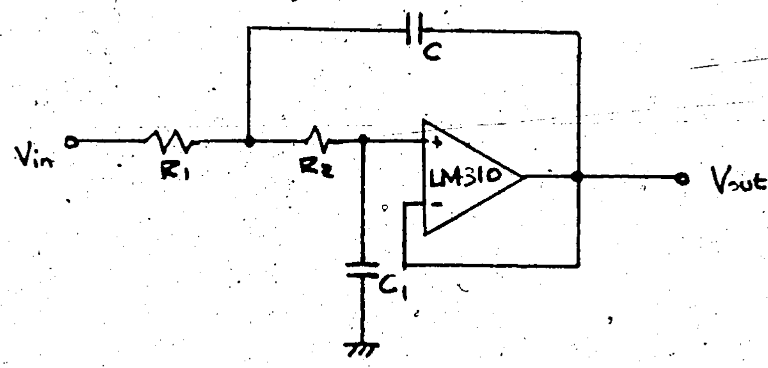


Fig. 3.5 VCVS Butterworth LPF

Values of the components in the above circuit were derived using the following formula:

$$C = \left(\frac{100}{Kf_c}\right) \mu f$$

where the parameter K is chosen to be 1, and f_c is the cut off frequency which is equal to 10 Hz. Hence,

$$C = \frac{100}{10} = 10 \mu f$$

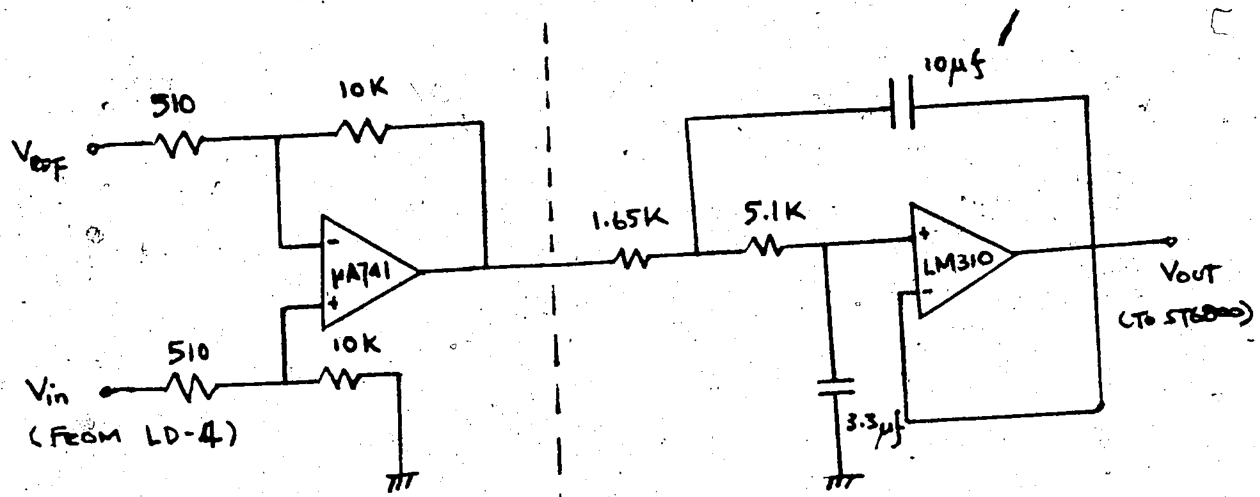
and the values of the other components are, from a design table,

$R_1 = 1.65$ K

$R_2 = 5.1$ K

$C_1 = 3.3 \mu f$

The overall interface circuit is depicted by fig. 3.6



Signal (Difference) Amplifier

$$\text{Gain} = \frac{100K}{510} \sim 20$$

Unity gain VCVS Butterworth LPF

Cut off frequency

$f_c \sim 10$ Hz

Fig. 3.6 Overall interface circuit

3.3 The Peripheral Unit

3.3.1 Description

The ST-6800B1A is an analog peripheral unit manufactured by the DATEL Systems, Inc. It is compatible to Motorola's M6800 microcomputer systems. This is a real time programmable unit and is capable of interfacing both the analog input and output signals to this microcomputer system.

This A/D-D/A peripheral device accepts 16 analog input channels and outputs 2 analog channels. Under program control from the microcomputer, particular input channels are selected and digitized. The digitized data is then stored in user-selected memory locations so that it may be further processed.

The ST6800B1A A/D-D/A system provides a 12-bit binary resolution and is organized as a memory-mapped input/output (I/O) device. It appears to the M6800 microcomputer unit (MPU) as a block of 512 consecutive memory locations. Analog input channels may be either randomly or sequentially converted and stored in memory at rates of up to 28,000 samples per second.

3.3.2 Operation

As shown in figure 3.7, addresses A1 through A7 from the M6800 MPU address bus are loaded into the A/D address latch by a $\overline{\text{STROBE}}$ command while the MPU is in a $\overline{\text{HALT}}$ state. The output from this latch then selects and enables one of the 16 input channels.

The trailing edge of the $\overline{\text{STROBE}}$ command then triggers the Sample and Hold One-Shot (S/H OS.) which in turn triggers a CONVERT comand. The leading edge of this CONVERT pulse places the S/H amplifier in the HOLD state and the trailing edge initiates the A/D conversion. After the conversion is completed the A/D converter will issue an output to reset the GO/$\overline{\text{HALT}}$ Flip Flop (FF) so that the MPU can resume its operation. (see figure 3.8)

3.3.3 Base Address

The 512 consecutive memory locations required by the ST6800B1A board are alocated at $4000 through $41FF in the M6800 memory system by jumper connections. ($ sign represented hexadecimal number)

3.4 The Processing Unit

3.4.1 Descriptions

The MEK6800DII is a completely self-contained microcomputer module. It includes the following devices:

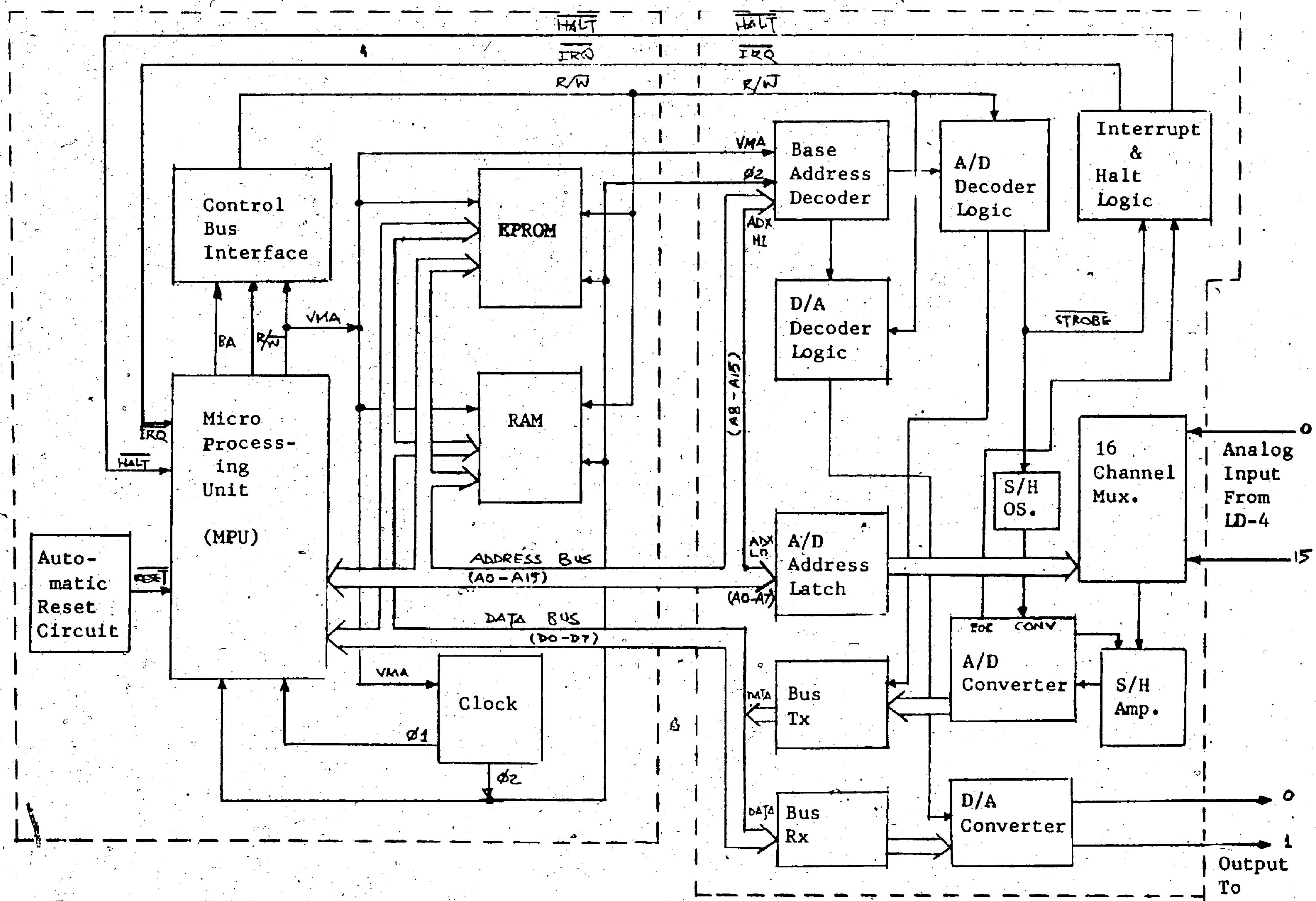


Fig. 3.7 System Block Diagram

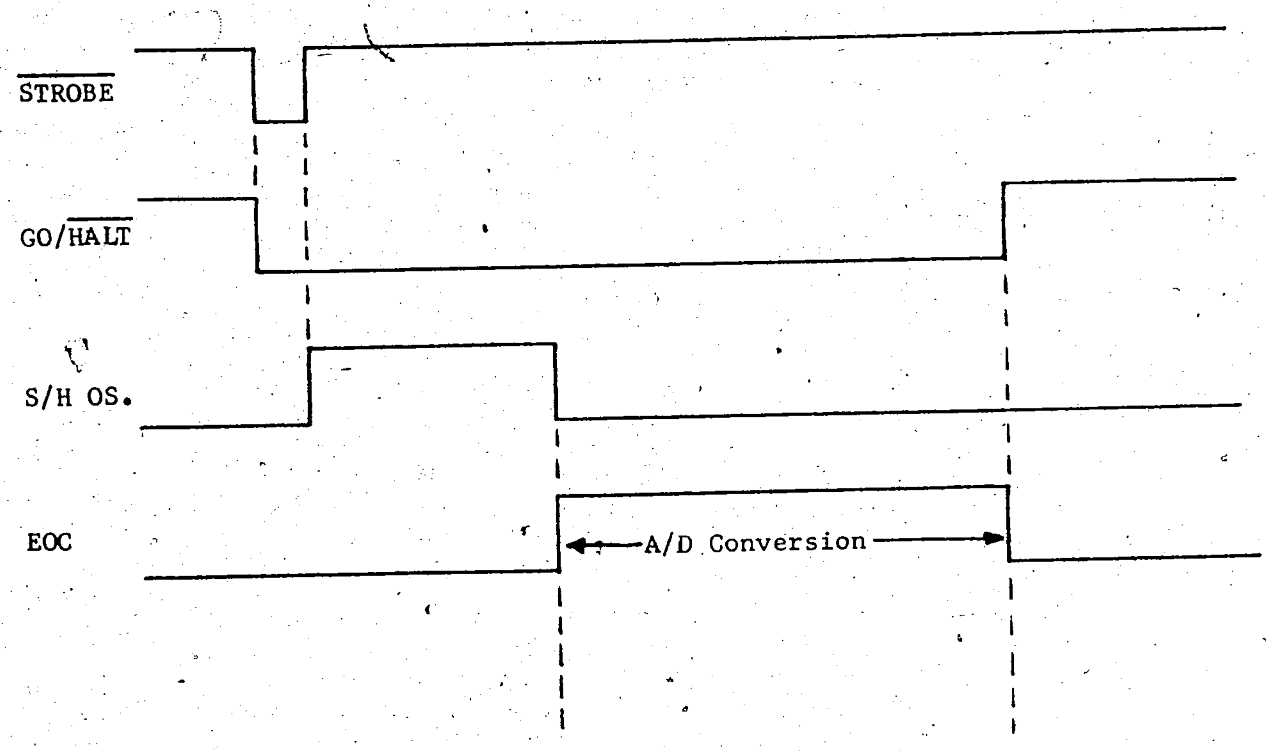


Fig. 3.8 Timing Diagram for A/D Conversion

Qty	Devices
1	MC6800 MPU
1	MCM6830 Read Only Memory (ROM) with JBUG Monitor
3	MCM6810 Random Access Memory (RAM) 128 X 8 bits each
2	MC6820 Peripheral Interface Adapter (PIA)
1	MC6850 Asynchronous Communication Interface Adapter (ACIA)
1	MC6871B Clock Generator

Where the JBUG Monitor is the firmware supplied by the Motorola Inc. which provides the control and diagnostic capability of the system. All these devices are necessary during the development stage although they are not all needed for the final product.

3.4.2 Memory Organization

The addresses of this microcomputer module are not fully decoded and the highest address in the memory field is at \$E3FF. Therefore the JBUG monitor program, which is preprogrammed into a Read Only Memory (ROM), resides at the addresses from \$E000 to \$E3FF in which the reset vector is located at addresses \$E3FE and \$E3FF. However, in order to achieve a power failure automatic reset sequence, an Electrically Programmable Read Only Memory (EPROM) which contains the classification program will have to co-reside at the same addresses (i.e., from \$E000 to \$E3FF). The rest of the memory locations are the same as the standard MEK6800DII module except, as mentioned in section 3.3.3, that memory locations \$4000 through \$4103 are occupied by the ST6800B1A A/D-D/A peripheral system. Figure 3.9 depicts the memory organization of this microcomputer system.

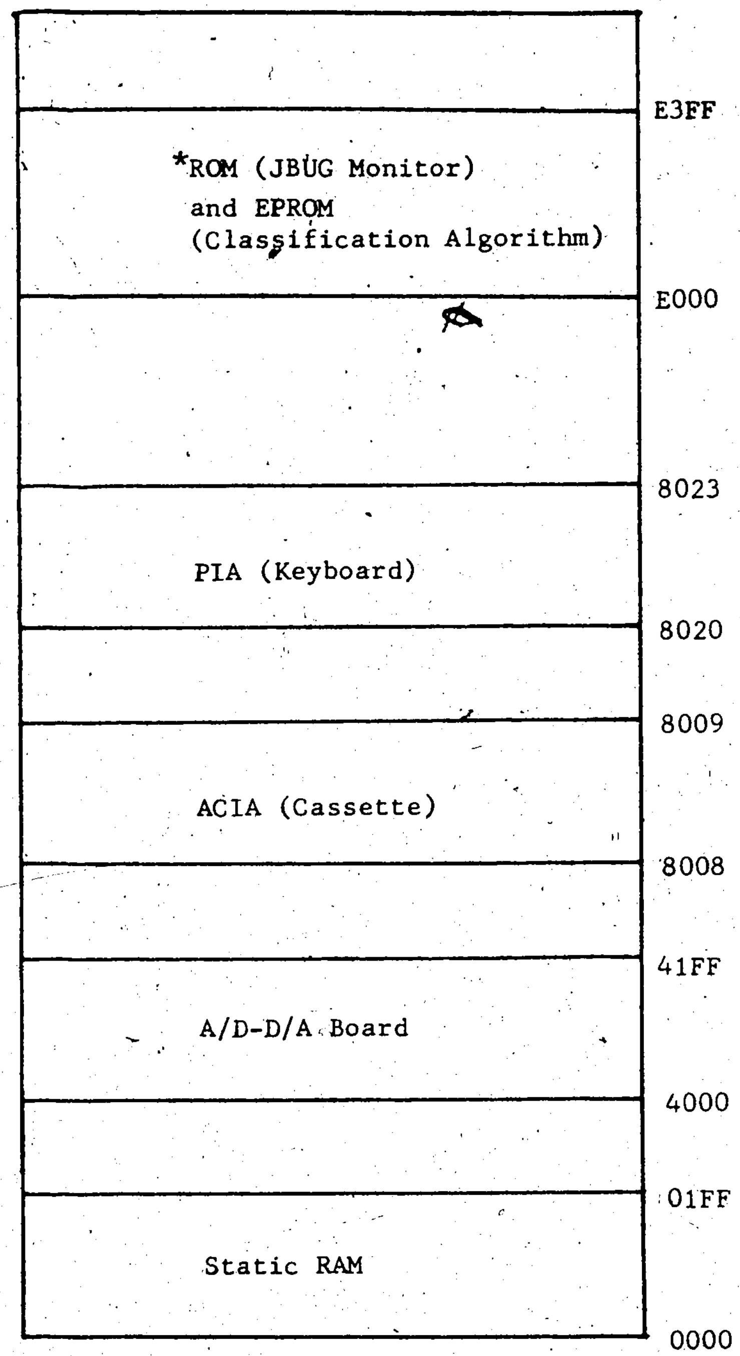


Fig. 3.9 Memory Organization

* One of the two is selected via a toggle switch

3.4.3 Operations

The decision algorithm developed in Chapter 2 is preprogrammed into the EPROM of 1K byte memory. When digitized signals are coming in from the peripheral unit, this program will first extract the features in the same order described by the heirarchical decision tree. It then evaluates the discriminant functions derived from the preceding chapter. If the vehicle is recognized as an ETS bus, the microcomputer module will issue a +10Vdc output via one of the D/A channels from the peripheral unit. This output can then be used to trigger a relay to actual a control device such as a control gate or a bus preemption traffic signal.

3.4.4 Modifications

In order to operate the system in a fully automatic manner, it is necessary to design a power-failure automatic reset circuit (the module has a manual reset circuit only) such that when the power source is up from a failure, the system will be in operation after a prestored reset sequence.

To accomplish such an operation, two start-up criteria must be satified.

1. It must ensure that the power supply to the MPU has reached the minimum required operating voltage of 4.75 Vdc.
2. The $\overline{\text{RESET}}$ line must then be held low for a minimum of 8 complete clock periods.

The circuit in figure 3.10 provides a delay of 300 msec to cover the 8 clock cycles (1 clock cycle is equal to 1.6 msec in this system) with R_2C_2 time constant after the R_1C_1 time constant input has triggered the

MPU insuring the V_{cc} (5 Vdc ± 5%) has reached the minimum required level (Fig. 3.11).

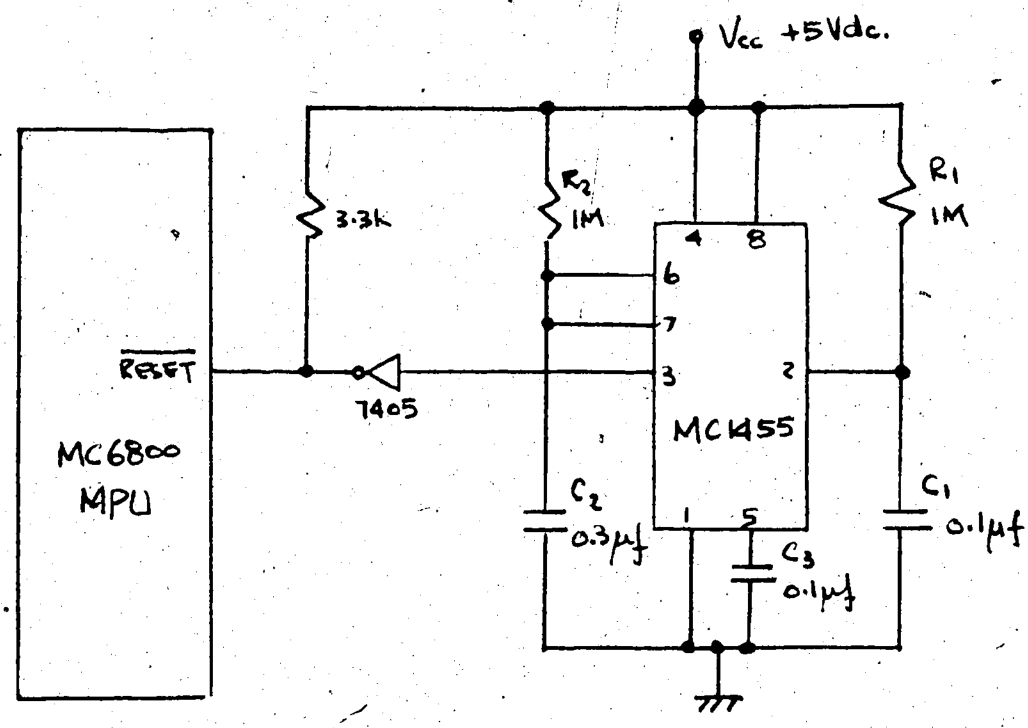


Fig. 3.10 Power Failure Automatic Reset Circuit

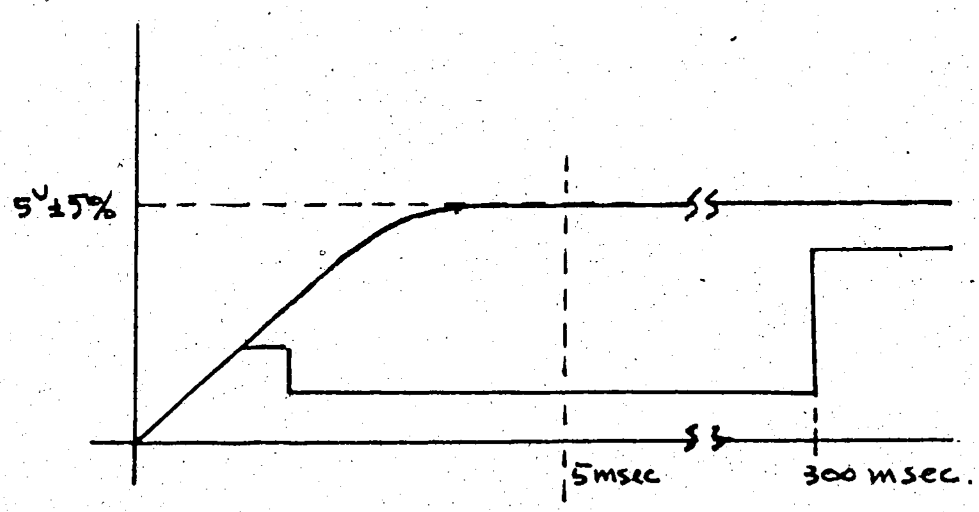


Fig. 3.11 Timing Diagram for Power Start-up

CHAPTER 4 SOFTWARE DEVELOPMENT

4.1 Introduction

Software development very closely follows the development of the classification algorithm. Different routines were designed and implemented for data analysis and parameter designations. Programs were developed in assembler language and were assembled and debugged on the AMDAHL computer via a M6800ASM cross-assembler program. They were then stored, in the form of machine codes, in an audio cassette tape and were loaded into the microcomputer memory for field testing purposes. After the necessary testings, the final program was then "burnt" into an EAROM for actual operation.

These routines and programs were developed in the following order :

1. DATACQ
2. DAC
3. FETD
4. FEATURE
5. CLASSIF

The following sections will describe the logic of each of the above programs.

4.2 DATACQ

This program is developed to store digitized data from the peripheral unit into designated memory locations in the microcomputer module and then transfer them onto the audio cassette tapes via the JBUG monitor residence program. The flow chart in figure 4.1 depicts the logic flow in this program.

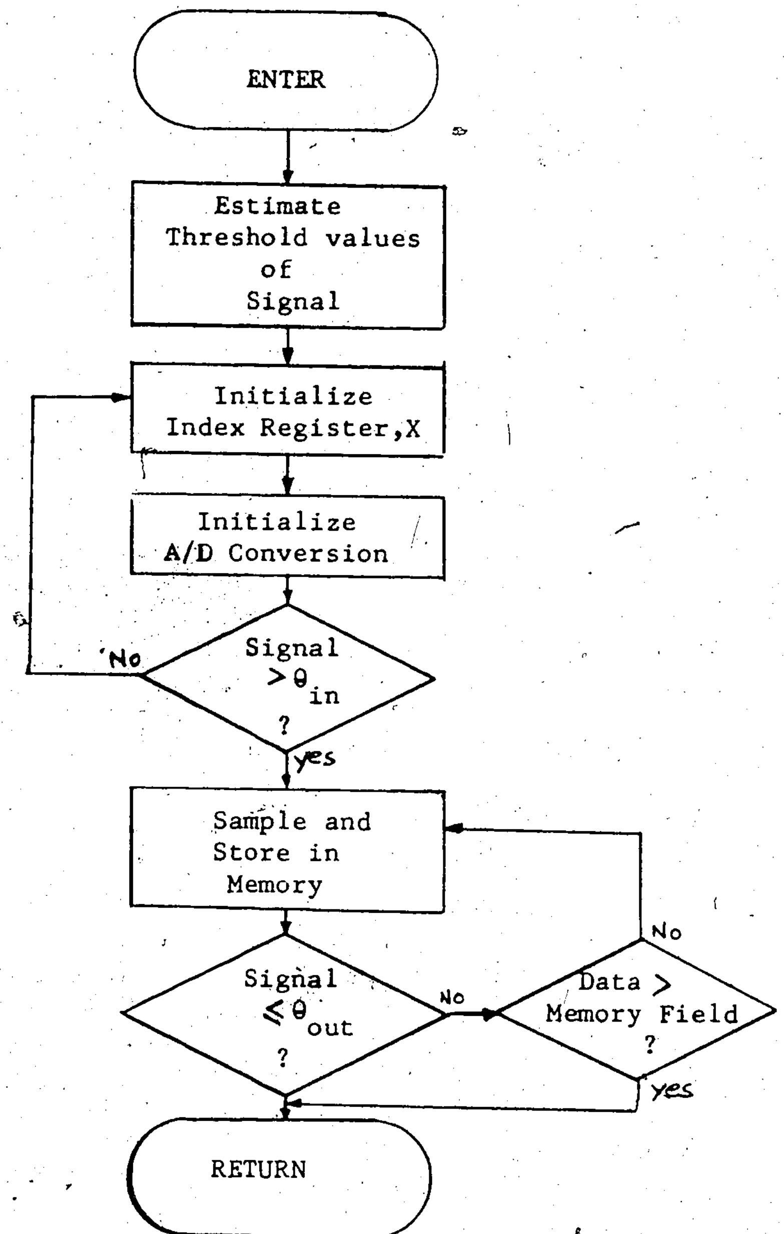


Fig. 4.1 Flow Chart DATACQ

Two parameters were defined to initialize and the operation of the program. They are defined as the input threshold value, θ_{in}, and the output threshold value, θ_{out}. When the digitized signal level is higher than θ_{in} the program will start storing sampled values of the signal until it is lower than θ_{out} or when the designated memory field is full. The sampling rate is controlled by a timing loop subroutine.

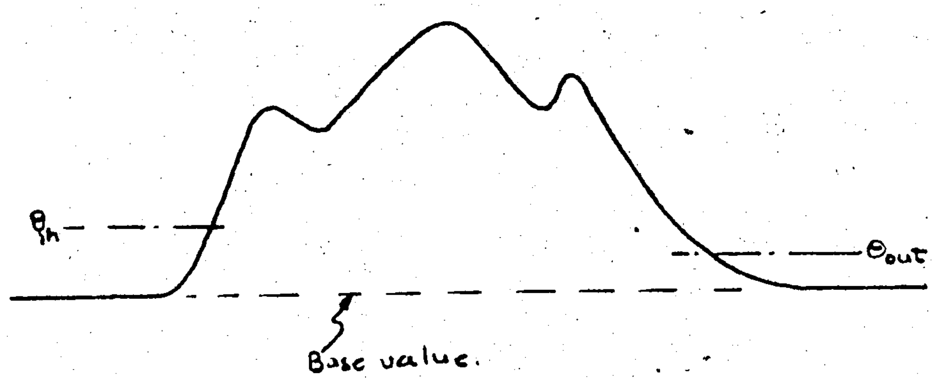


Fig. 4.2 input and output threshold values

The parameters θ_{in} and θ_{out} were rather arbitrarily chosen according to the base value of the signal, that is, signal level when there is no vehicle in the detection zone.

4.3 DAC

This program converts the sampled data stored in the microcomputer memory back into analog signals such that we can plot the signature on a strip chart or observe the signature on an oscilloscope.

4.4 FETD

This is a feature extraction program which extracts the local maxima and the local minima from the stored signature and stores them into designated memory locations.

However, due to the noise that exists in the signal some form of digital filtering is required. After examining the stored data, a set of artificial data was created (fig. 4.4 & Program listing) and a tolerance, ε, was defined. As shown in figure 5.3 below, only a signal variation of more than ε will indicate the existence of a local extremum. Otherwise for any signal variation less than ε, it will be treated as noise and be rejected.

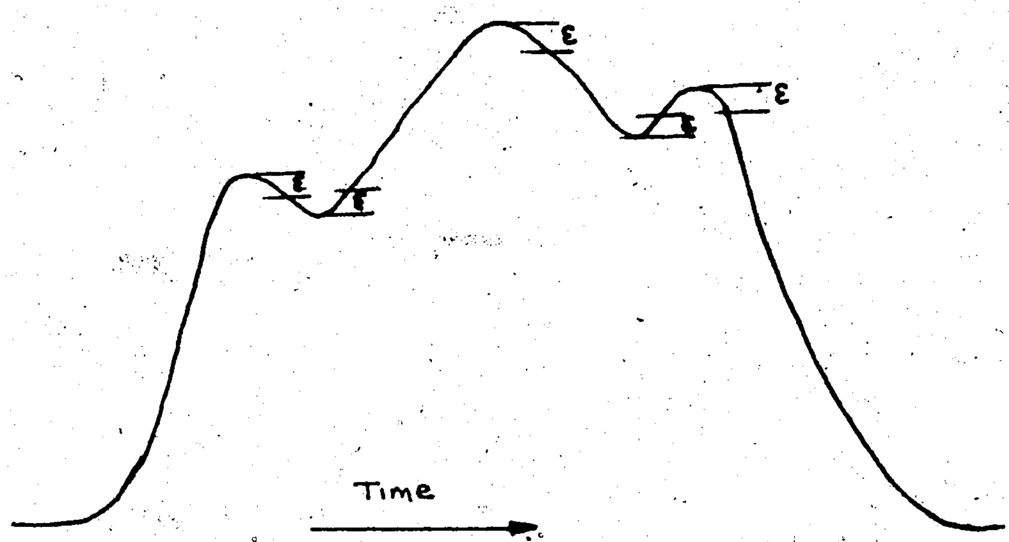


Fig. 4.3 Tolerance value for extremum detection

The following flow charts (Fig. 4.5,4.6) depict the logic flow in this program.

4.5 FEATURE

This program performs the same function as the FETD program (i.e., feature extraction). It basically combines DATACQ and FETD to form a real time program. It extracts and stores only the values of the local extrema

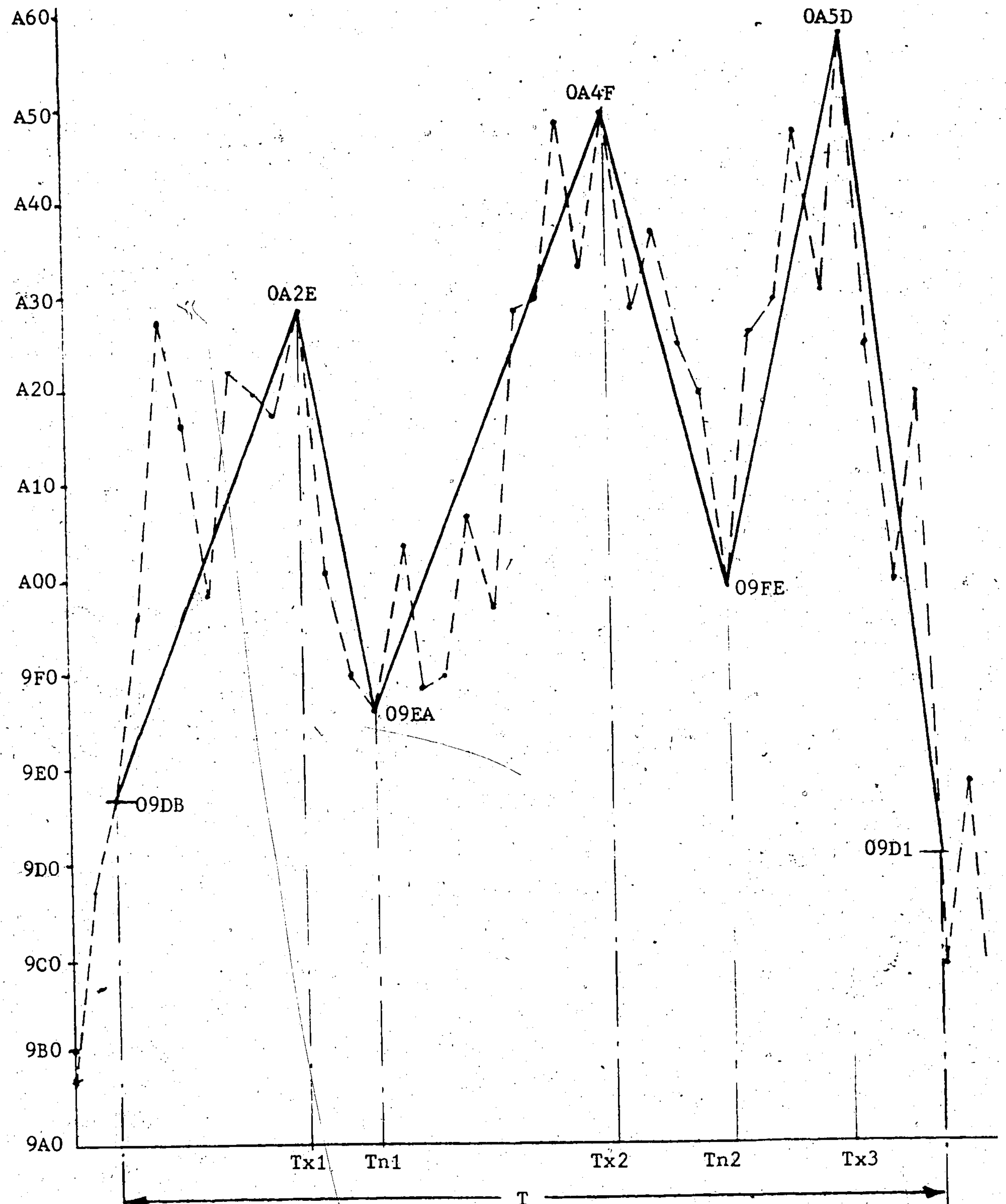
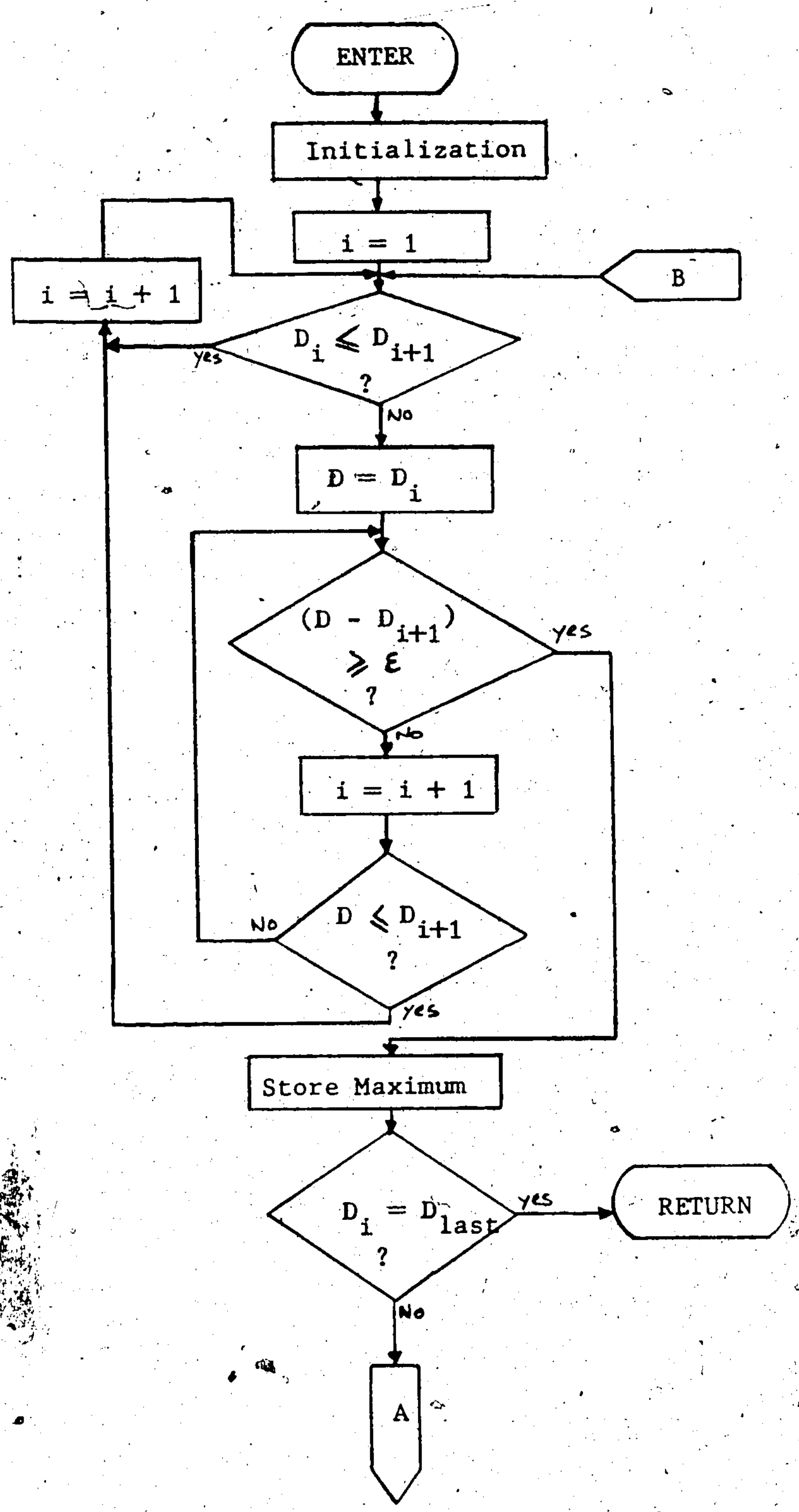


Fig. 4.4 Artificial Test Data

——— After Filtering
------- Digitized Data (Noisy)
θ_{in} = 09DB, θ_{out} = 09D1, ε = 30



Fi[illegible] Flow Chart FETD

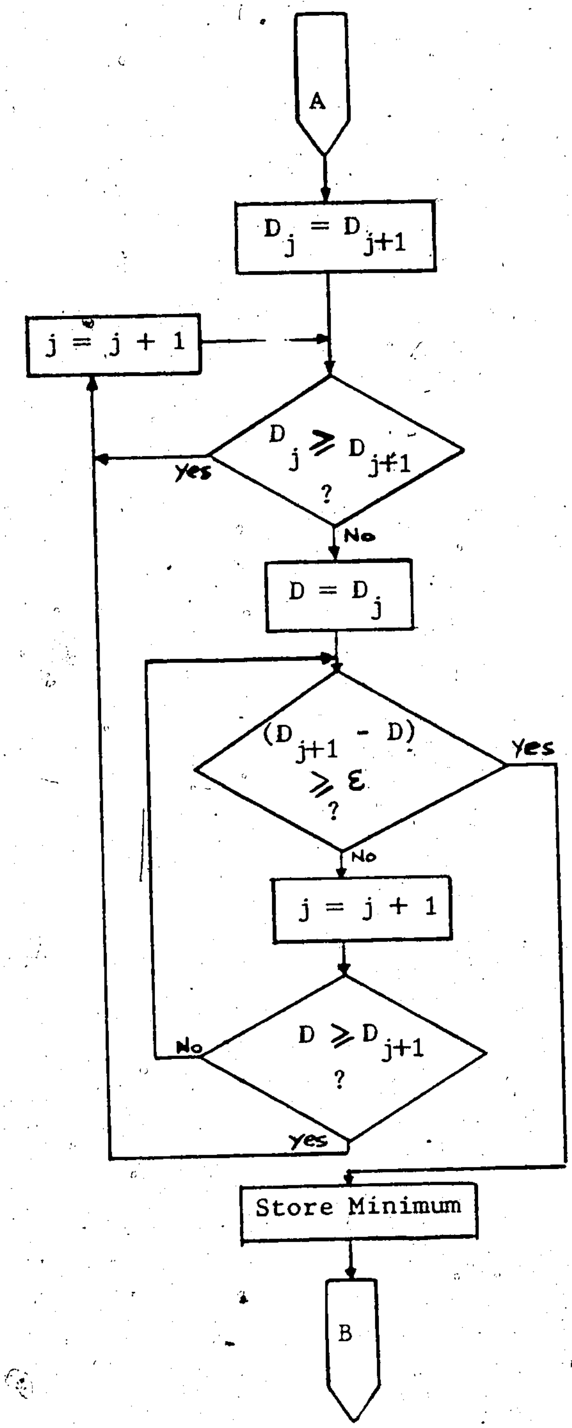


Fig. 4.(Flow Chart TD (Cont'd)

of the signature in the designated memory locations without having to store the whole signature data. Thus it saves considerable memory space . Unlike FETD it only halts when the signal level is lower than the output threshold value, θ_{out}.

4.6 CLASSIF

In addition to FEATURE, this program consists of all discriminant functions defined in Chapter 2 plus a few more subroutines. This program is responsible for recognizing the ETS busses and outputting a +10Vdc signal to actuate a control device. The other features included in this program are listed as follows:

1. It updates the threshold values in predetermined intervals such that a stalled vehicle in the detection zone will not impair the performance of the system.
2. It resets itself after a vehicle has left the detection zone. (i.e. a new set of threshold values for each vehicle being detected) This subroutine thus compensates the change of base voltage due to the aging of the electronics of the detector; and it also enables the system to operate with different detector units without readjusting the threshold values in the software.
3. A subroutine to detect stalled vehicles in the detection zone is also included such that the system will not be tied up by such vehicles and will automatically go to other channels (other detection zones).
4. It also generates a 1 minute delay after system starts up to allow for the time needed by the LD-4 detector to tune itself.

The following flow charts (Fig. 4.7 through 4.12) show the logic flows in this program.

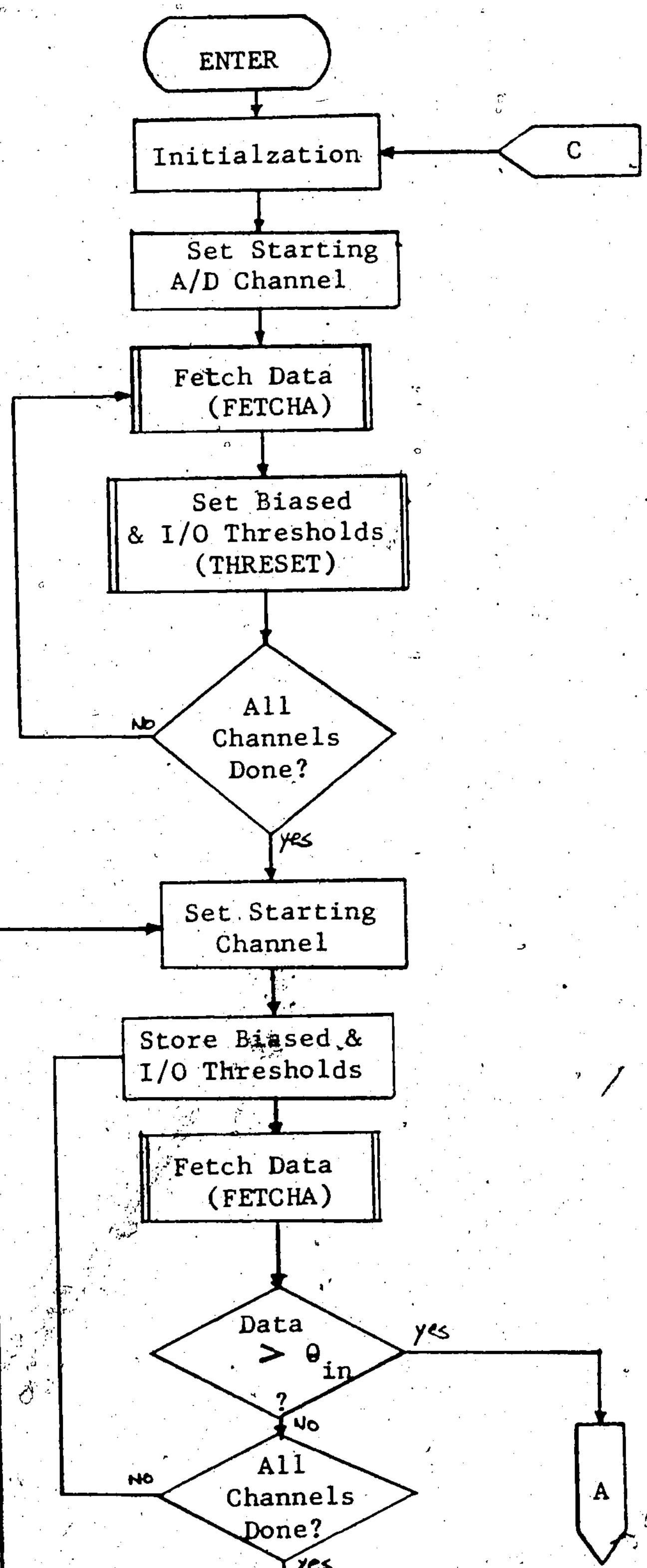


Fig. 4.7 Flow Chart CLASSIF

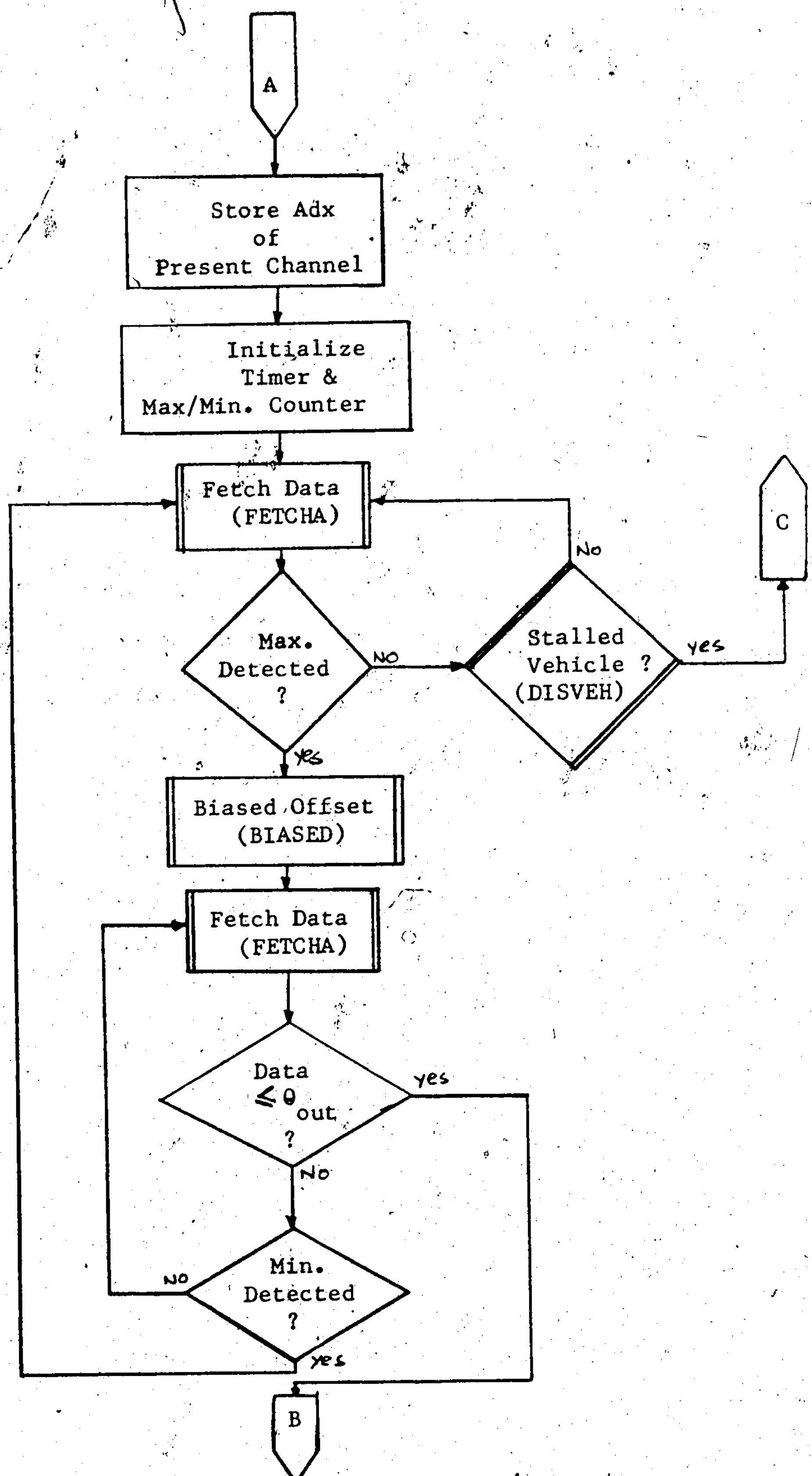


Fig. 4.8 Flow Chart CLASSIF (Cont'd)

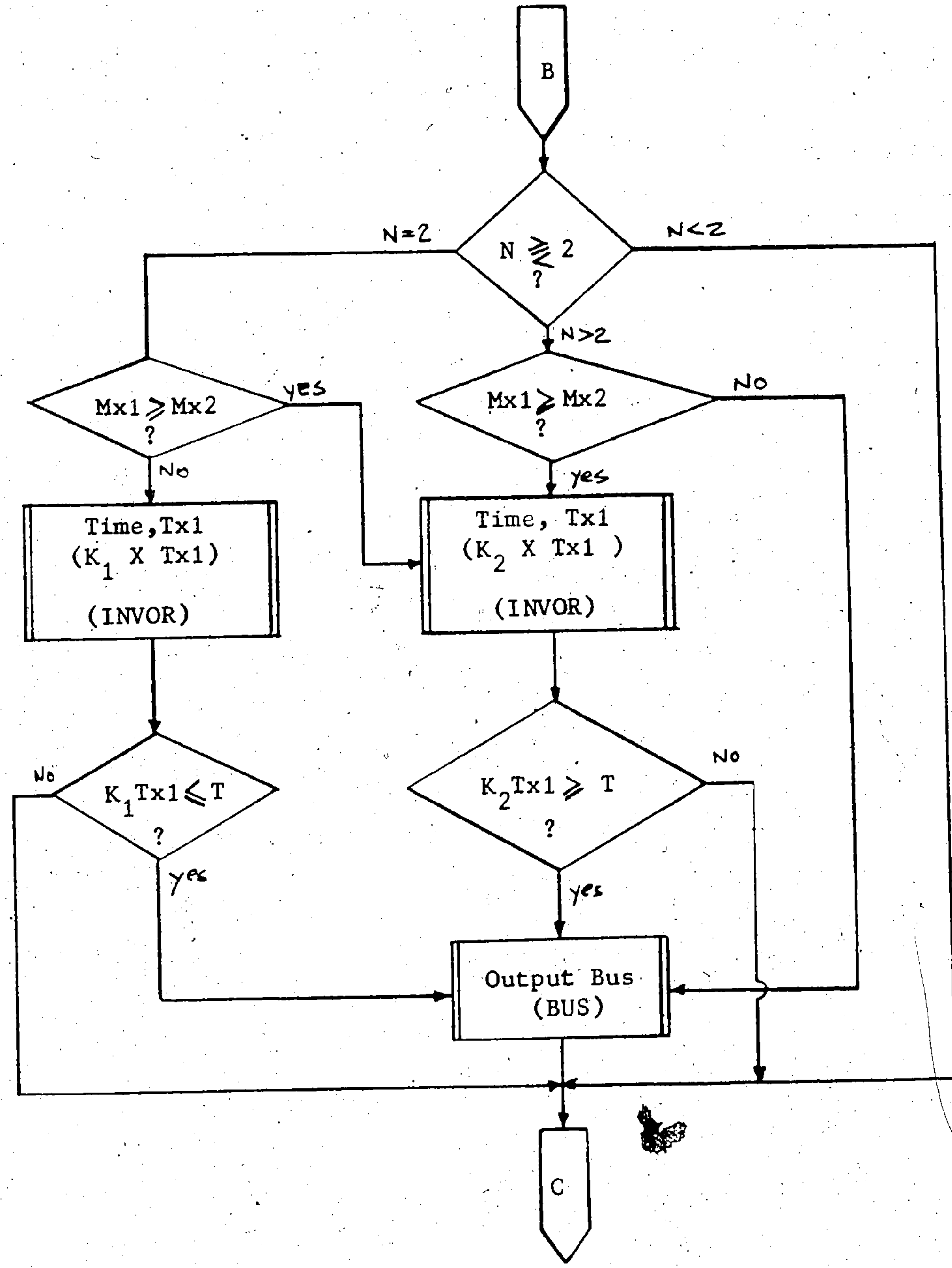


Fig. 4.9 Flow Chart CLASSIF (Cont'd)

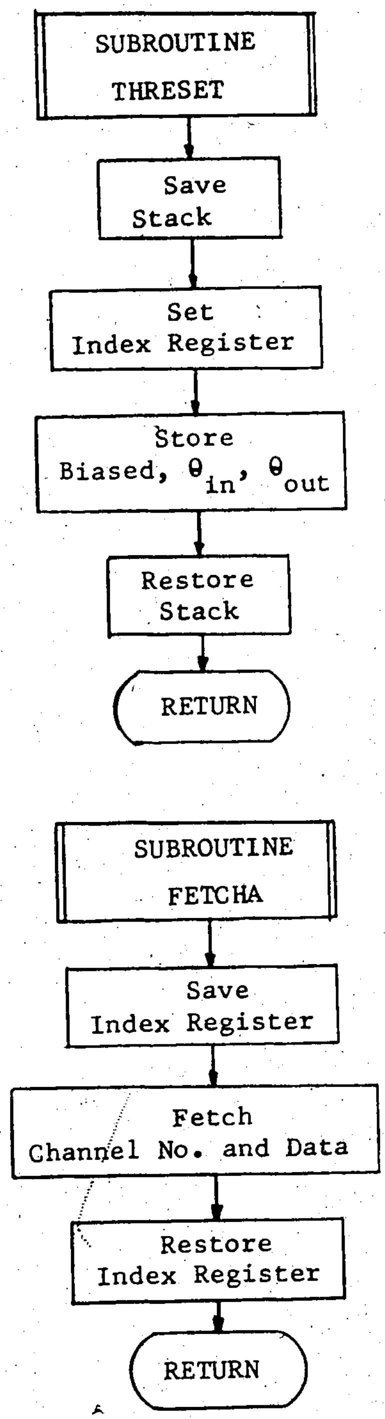
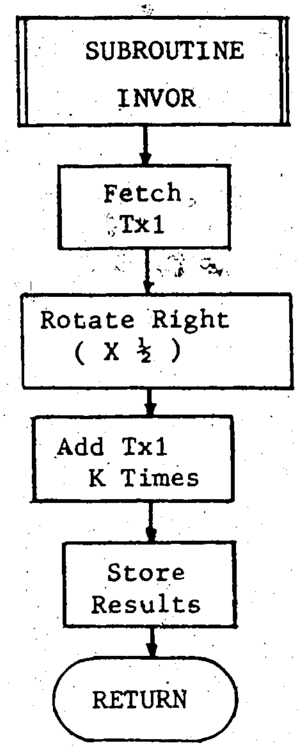


Fig. 4.10 Flow Chart CLASSIF (Cont'd)



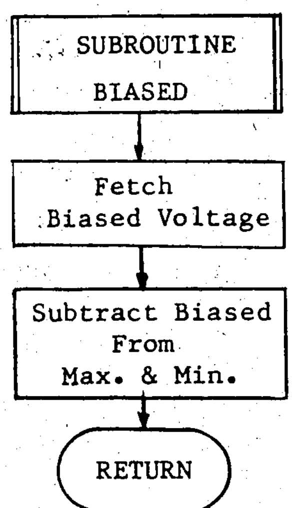


Fig. 4.11 Flow Chart CLASSIF (Cont'd)

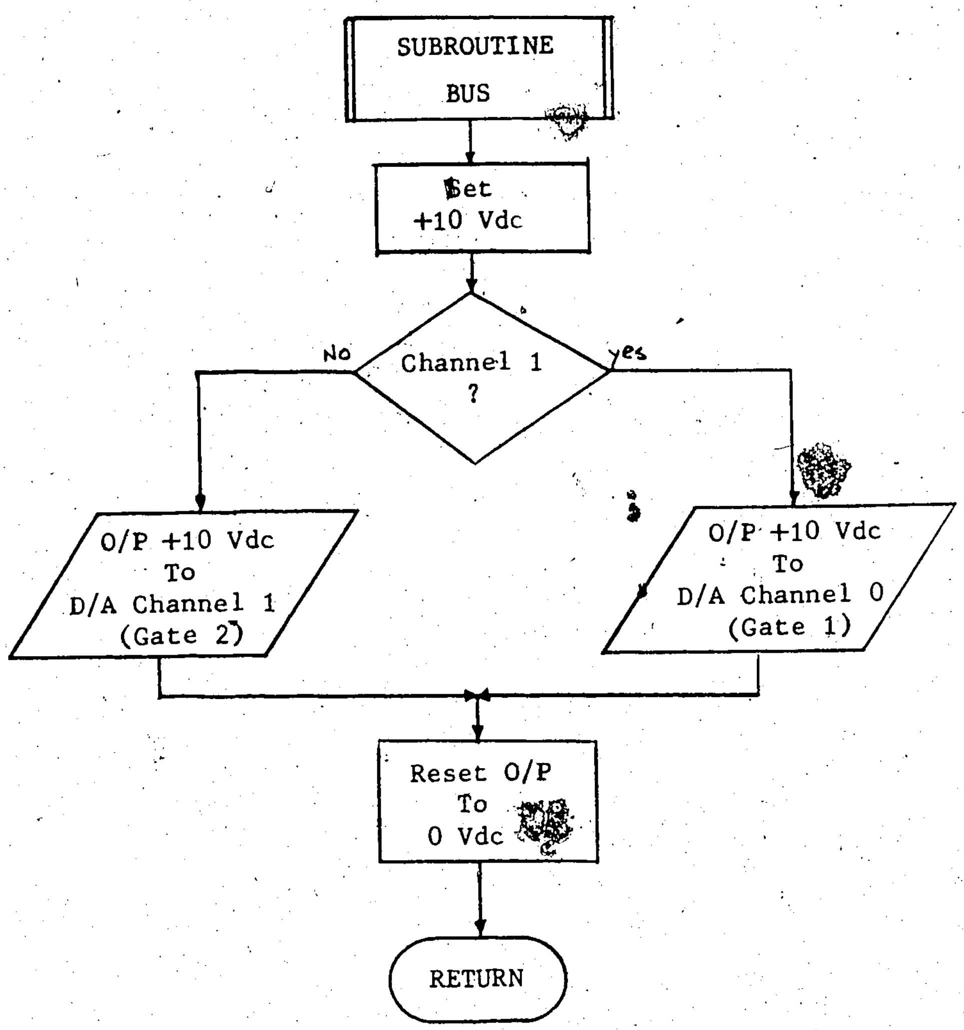


Fig. 4.12 Flow Chart CLASSIF (Cont'd)

CHAPTER 5 CONCLUSION

This chapter includes the field test results, a cost analysis on the systems being used in the City of Edmonton and the areas for possible future developments.

5.1 Field Testing Results

The system was field tested in order to ensure that a high reliability rate could be achieved in an operating environment. Initially the system was capable of classifying ETS busses to a very high degree of accuracy. After the implementation of a LPF, only two (2) passenger cars and four (4) auto-carriers were identified as ETS busses. Adjustments were then made to the algorithm until this problem was eliminated. The testing period monitored a total of 3950 vehicles which included:

2892 cars and vans;

737 trucks, tandems and moving vans;

110 semi-trailers and auto-carriers; anf

191 ETS busses.

The results of these field tests are shown in Tables 5.1, 5.2 and 5.3.

Vehicle Types	No. Detected	Misclassification	accuracy
Cars, vans	868	18	97.9%
Tr.,Tandems,M.V.	348	8	97.7%
Semis.Auto-C.	45	5	88.9%
ETS Busses: Trol.	22	1	95.5%
Dies.	43	1	97.7%
TOTAL	1350	33	97.6%

Table 5.1 Field Test results (Before implementation of LPF)

Vehicle Types	No. Detected	Misclassification	Accuracy
Cars, vans	1653	2	99.9%
Tr.,Tandems,M.V.	387	---	100.0%
Semis.,Auto-C.	120	4*	96.7%
ETS Busses: Trol.	39	---	100.0%
Dies.	70	---	100.0%
TOTAL	2224	6	99.7%

Table 5.2 Field Test Results (After implementation of LPF)
* All four are auto-carriers

Vehicle Types	No. Detected	Misclassification	Accuracy
Cars, vans	271	---	100.0%
Tr.,Tandems,M.V.	78	---	100.0%
Semis.,Auto-C.	8	---	100.0%
ETS Busses: Trol.	6	---	100.0%
Dies.	13	---	100.0%
TOTAL	376	---	100.0%

Table 5.3 Field Test Results (Final Algorithm Installed)

At this point it was felt that the system could be placed into an operating environment for further evaluation particularly during winter conditions. The system has been installed to control gates on a bus only road in Edmonton. The bus only road in question has a high private vehicle volume despite signage forbidding these manoeuvers. A gate was therefore placed at each access of this bus only road. Call on detectors were located such that activation is possible from both directions. The gate closure operated on a timed delay basis. (Fig. 5.1)

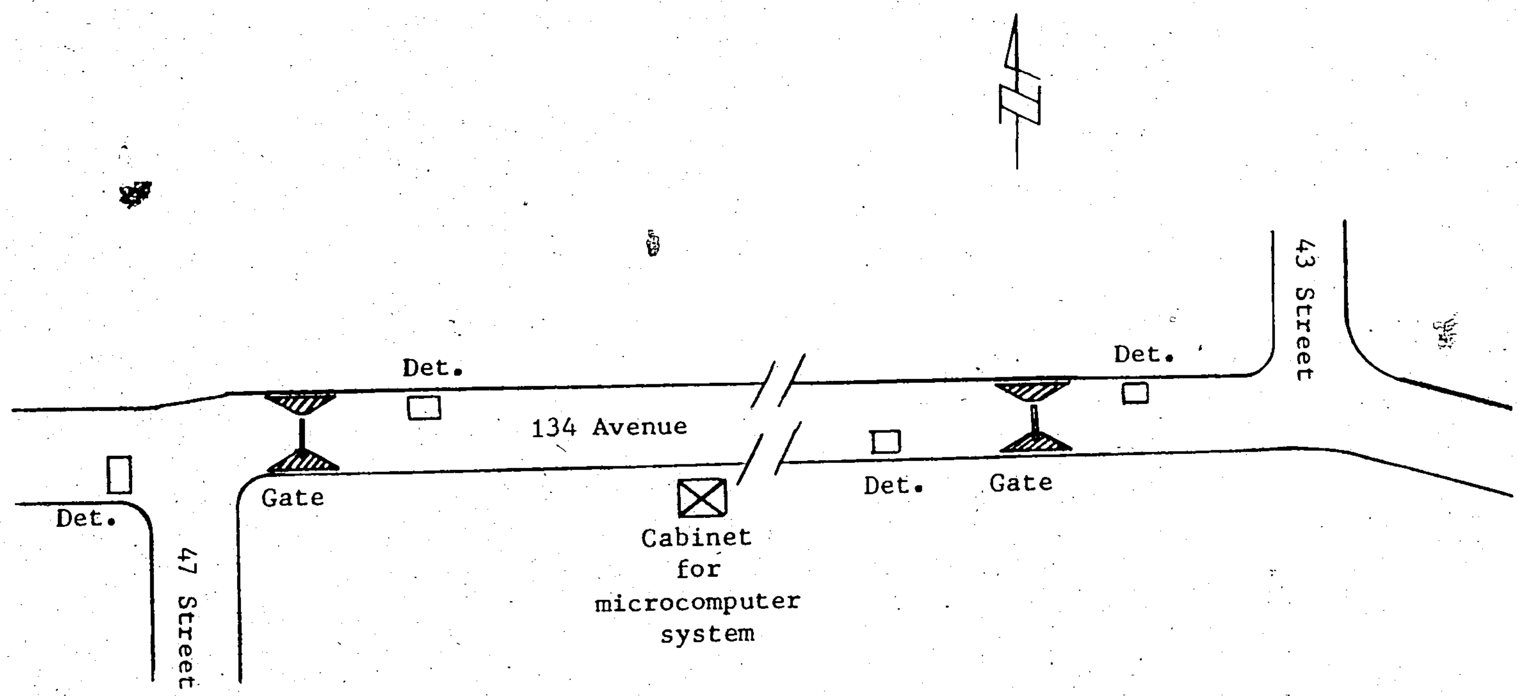


Fig. 5.1 Busway Control Gates in N.E. Edmonton

5.2 Cost Analysis on Existing Systems

As mentioned in Chapter 1 of this thesis, there are presently two other transit actuated systems used in the City of Edmonton, namely the garage door opener type and the vehicle-mounted type. Since it is the policy of the Edmonton Transit System (ETS) that ETS busses rotate their services to every route through the City, all busses will have to be equipped with either of the above devices in addition to the receiving mechanism to be installed on the specific routes that require such detection. Instead, if a passive bus detection system is used, it will be the only device required to be installed on such specific routes.

The system developed in this thesis, a passive bus detection system, offers the following advantages over its counterparts.

1. Lower Operational Costs

   (a) Installation and Equipment Costs:

   The installation and equipment cost for each garage door opener is $50.00 and for the vehicle-mounted transmitter is $120.00. There are a total of 650 busses approximately. Therefore, a cost of $32,500.00 will be incurred to equip all busses using the garage door opener type and $78,000.00 using the vehicle-mounted type of transmitters. In addition, costs for the receiving mechanism are $700.00 per intersection. The costs for the passive bus detector developed in this project are approximately $2,500.00 per intersection. The City of Edmonton indicates that 15 intersections will require such kind of detection in the next two years. Table 5.4 shows a comparison in the costs incurred for the three systems.

System	Tx. Devices	Rx. Devices	Total Cost
Garage Door Opener	$32,500.00	$10,500.00	$43,000.00
Vehicle-mounted Tx.	$78,000.00	$10,500.00	$88,500.00
Passive Bus Det.	----------	$37,500.00	$37,500.00

Table 5.4 Cost Estimations for 15 Intersections

(b) Maintenance Costs:

There are only 15 devices to be maintained vs 650 + 15 devices which means that a substantial amount of man-hours will be saved in maintenance if the passive bus detectors are used.

2. Better Reliability

The garage door opener type and the vehicle-mounted transmitters are more vulnerable to damage than the passive bus detector since the latter is housed in a steel cabinet.

3. Easier to Manage

Transit operators do not have to remember to carry the garage door openers when they are on duty or to return them when they are off.

5.3 Conclusion and Future Developments

After the field testing and the early stage of operation, the sytem appears to be highly reliable (no system failure since the installation of the system on February 8, 1979). However, some arbitrarinesses still exist in the designation of the parameters such as the input threshold, θ_{in}, the output threshold, θ_{out}, and the tolerance value ε. Until a much larger data set is obtained, it is very difficult, if possible at all, to adjust these parameters to render an optimal operation.

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APPENDIX 1 MAXIMUM LIKELIHOOD ESTIMATION

Consider a Normal distribution probability density function described by,

$$p(\underline{Y}; \mu, \sigma) = f(\underline{Y}) = \frac{e^{-(\underline{Y}-\mu)^2/2\sigma^2}}{\sigma\sqrt{2\pi}},$$

where μ is the mean value and σ is the standard deviation of the data set.

Let $\theta_1 = \mu$ and $\theta_2 = \sigma^2$ be the components of a parameter vector, $\underline{\theta}$, and $\underline{Y}$ be the union of all data points, i.e.,

$$\underline{Y} = \bigcup_{i=1}^{n} y_i,$$ where n is the number of components.

Then

$$p(y_i/\underline{\theta}) = \frac{\exp\left(-(y_i - \theta_1)^2/2\theta_2\right)}{\sqrt{2\pi\theta_2}} \quad \text{.........................(1)}$$

The likelihood of $\underline{\theta}$ is defined as

$$p(\underline{Y}/\underline{\theta}) = \prod_{i=1}^{n} p(y_i/\underline{\theta})$$

Therefore, for maximum likelihood

$$\nabla_{\underline{\theta}} \left[\prod_{i=1}^{n} p(y_i/\underline{\hat{\theta}}) \right] = \underline{0}$$

where $\underline{\hat{\theta}}$ is the maximun likelihood estimate of $\underline{\theta}$.

Now, since ln p is a monotonic function of p, the vector that maximizes ln p should also maximizes p.

Hence, let

$$\nabla_{\underline{\theta}} \left[\ln\left(\prod_{i=1}^{n} p(y_i/\underline{\hat{\theta}}) \right) \right] = \underline{0}$$

i.e.,

$$\nabla_{\underline{\theta}} \left[\sum_{i=1}^{n} \ln p(y_i/\hat{\underline{\theta}}) \right] = \underline{0}$$

or

$$\sum_{i=1}^{n} \left[\nabla_{\underline{\theta}} \ln p(y_i/\hat{\underline{\theta}}) \right] = \underline{0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From (1), we have

$$\ln p(y_i/\underline{\theta}) = -\frac{1}{2} \ln (2 \quad \theta_2) - \frac{1}{2\theta_2} (y_i - \theta_1)^2$$

Thus (2) becomes

$$\sum_{i=1}^{n} \left[\nabla_{\underline{\theta}} \ln p\, (y_i/\hat{\underline{\theta}}) \right] = \sum_{i=1}^{n} \begin{bmatrix} \dfrac{1}{\hat{\theta}_2} (y_i - \hat{\theta}_1) \\ -\dfrac{1}{2\hat{\theta}_2} + \dfrac{(y_i - \hat{\theta}_1)^2}{2\hat{\theta}_2^2} \end{bmatrix} = \underline{0}$$

i.e.,

$$\sum_{i=1}^{n} \frac{1}{\hat{\theta}_2} (y_i - \hat{\theta}_1) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

and

$$\sum_{i=1}^{n} \left[-\frac{1}{2\hat{\theta}_2} + \frac{(y_i - \hat{\theta}_1)^2}{2\,\hat{\theta}_2^2} \right] = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where θ_1 and θ_2 are the maximum likelihood estimates for θ_1 and θ_2 respectively.

From (3), we have

$$n\,\hat{\theta}_1 = \sum_{i=1}^{n} y_i$$

i.e.,

$$\hat{\theta}_1 = \frac{1}{n} \sum_{i=1}^{n} y_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

and from (4)

$$n\,\hat{\theta}_2 = \sum_{i=1}^{n} (y_i - \hat{\theta}_1)^2$$

i.e.,

$$\hat{\theta}_2 = \frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{\theta}_1)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Substituting $\hat{\mu}$ and $\hat{\sigma}^2$ into $\hat{\theta}_1$ and $\hat{\theta}_2$ respectively, (5) and (6) become,

$$\hat{\mu} = \frac{1}{n} \sum_{i=1}^{n} y_i$$

and

$$\hat{\sigma}^2 = \frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{\mu})^2.$$

Expand these results into the multivariate case, we have

$$\hat{\underline{\mu}} = \frac{1}{n} \sum_{i=1}^{n} \underline{y}_i$$

and

$$\hat{\Sigma} = \frac{1}{n} \sum_{i=1}^{n} (\underline{y}_i - \hat{\underline{\mu}})(\underline{y}_i - \hat{\underline{\mu}})^T$$

where $\hat{\Sigma}$ is the estimated covariant matrix and superscript T indicates matrix transpose.

APPENDIX 2 STORED VEHICLE SIGNATURES

This appendix includes all stored vehicle signatures and their corresponding features extracted by the program FETD described in Chapter 4.

Note that values of data and parameters shown are in hexadecimal numbers, and that the values chosen for the parameters are as follows:

Input threshold	θ_{in} = 09DB
Output threshold	θ_{out} = 09C7
Sample timing	T_s = 70
Tolerance	ε = 28

unless otherwise stated.

[N.B.] Time scale is reversed (i.e., from right to left) on all charted signatures

T5S1	#Mx	#Mn	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
1	3	2	0A1C	1444	09F0	15A6	0A4F	1746	0A0B	1978	0A42	1A4A	1D62
2	3	2	0A50	03E0	0927	0486	0A3B	0498	0A0A	0556	0A42	0600	06DC
3	-	-	----	----	----	----	----	----	----	----	---	---	----
4	4	3	0A2F	0174	0907	0242	0AD4	040A	0A16	059A	0A53	0642	073A
5	3	2	0A7F	01A8	0957	0246	0AC2	048A	0A66	062A	0AB1	06D0	07DE
6	4	3	0A0E	0166	09E3	02A8	0A2F	0402	0904	06EA	0A17	06EC	0784
7	3	2	0A4B	018A	0923	0210	0A8C	040A	0A34	05AA	0A76	063E	072A
8	3	2	0A1B	018E	09EE	02CE	0A4D	045C	0A03	067E	0A38	0722	0836
T5S2													
1	2	1	0AEA	0290	09B8	0332	0AC7	0334	----	----	----	----	0432
2	4	3	0A13	01EA	09DB	0368	0A17	0444	09E1	08EE	0A1D	09E0	0B62
3	4	3	0A32	0252	0909	02F2	0A1C	02F8	09E1	065E	0A0A	06D2	0764
4	3	2	0A27	01D6	09FD	0328	0A63	053C	0A12	07D2	0A4F	08A2	0A22
5	1	0	0B0E	0270	----	----	----	----	----	----	----	----	0412
6	-	-	----	----	----	----	----	----	----	----	----	----	----
7	-	-	----	----	----	----	----	----	----	----	----	----	----
8	2	1	0A38	0218	090F	0322	0A26	032E	----	----	----	----	041E
9	3	2	0A46	01B0	091E	022A	0A90	0450	0A3B	062C	0A88	06E2	07F0
10	1	0	0A01	046A	----	----	----	----	----	----	----	----	089C
11	3	2	0A35	023C	090B	0278	0A1C	027A	09DA	0436	0A17	0684	072A
12	3	2	0A27	0204	09D6	03DE	0AFF	04E4	09EC	04EC	0A2C	0580	06A6
13	3	2	0A52	0196	0928	021E	0AA1	0400	0A47	0592	0A94	062E	0724

Parameters:

θ_{in} = 09DB (input threshold)

θ_{out} = 09C7 (output threshold)

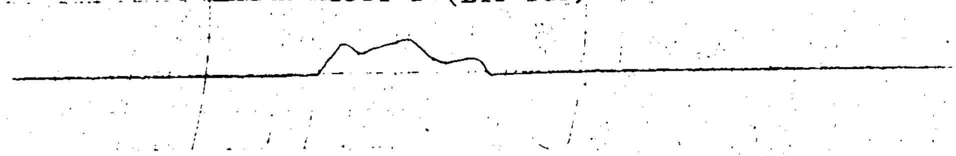
T_s = 70 (sample timing)

ε = 28 (tolerance)

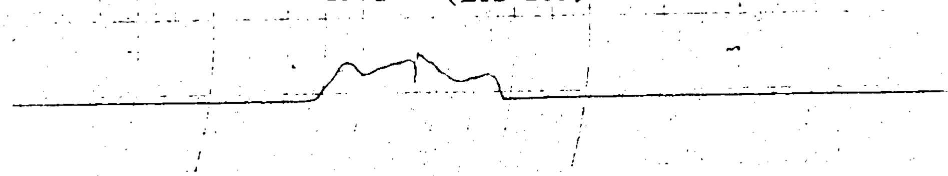
[N.B.] Data and parameter values are in hexadecimal

T5S1-1 (ETS Bus)

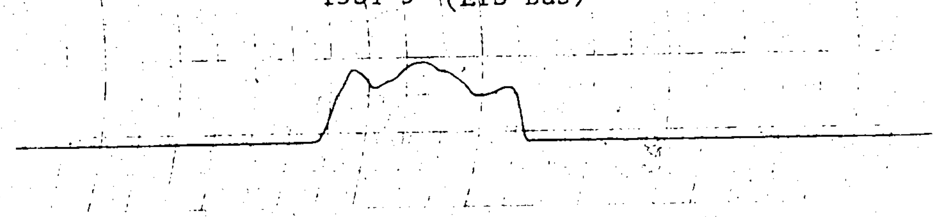
T5S1-2 (ETS Bus)



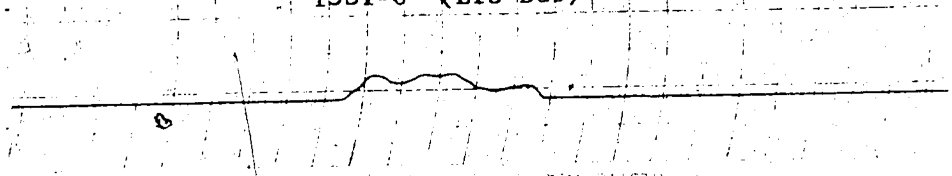
T5S1-4 (ETS Bus)

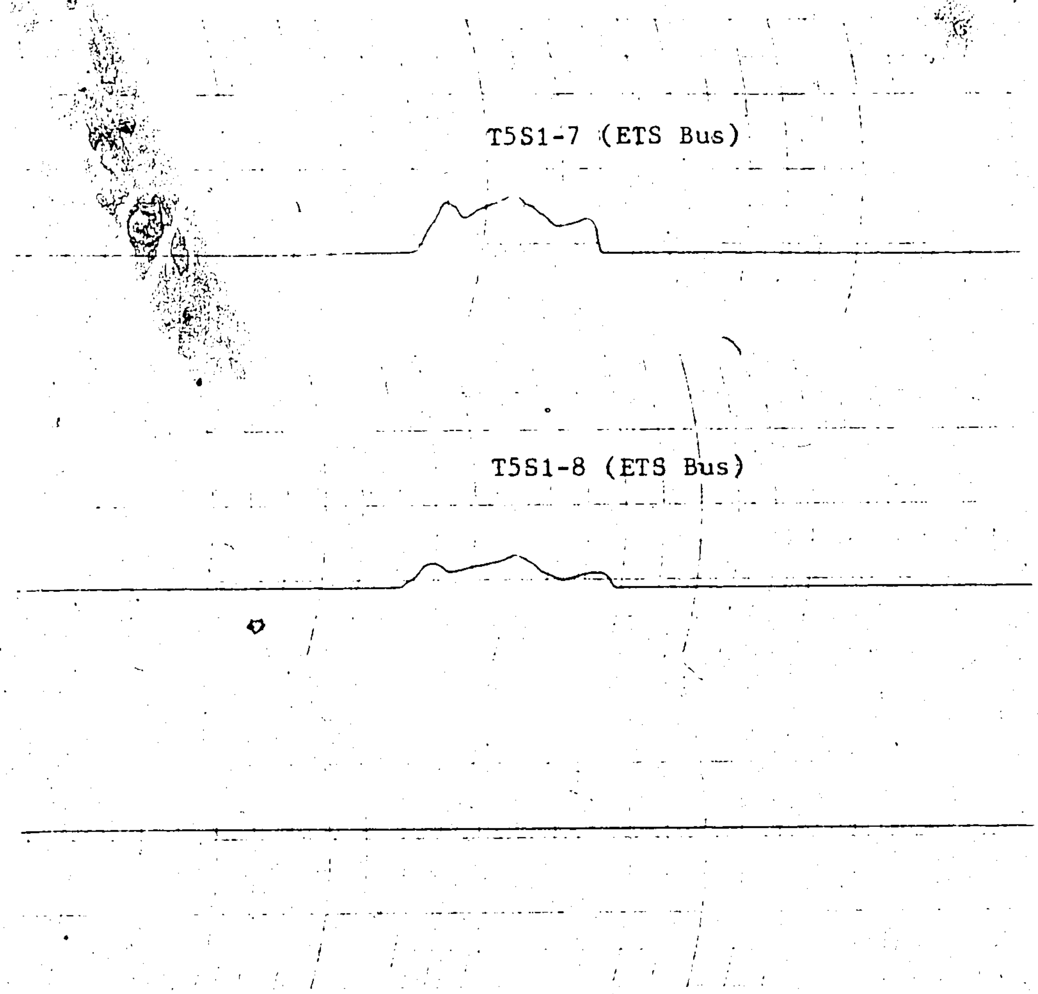


T5S1-5 (ETS Bus)

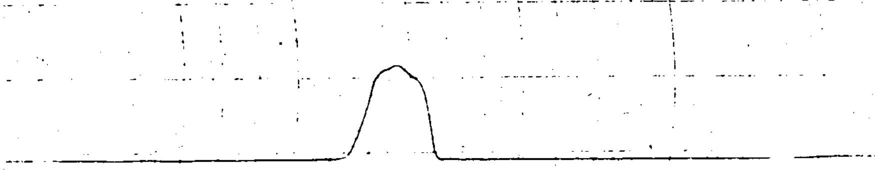


T5S1-6 (ETS Bus)

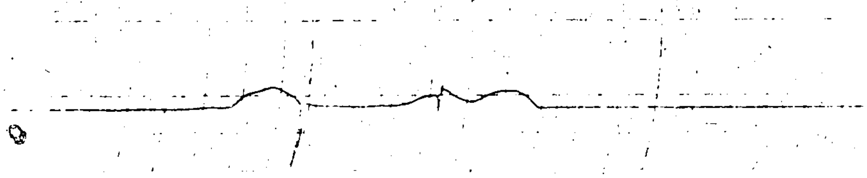



T5S1-7 (ETS Bus)
T5S1-8 (ETS Bus)

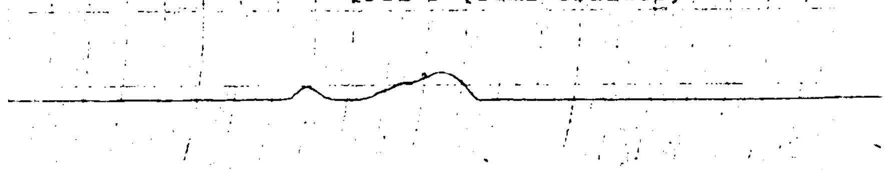
T5S2-1 (Car)



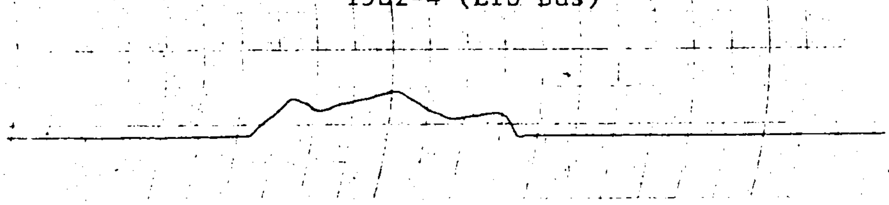
T5S2-2 (Semi-trailer)



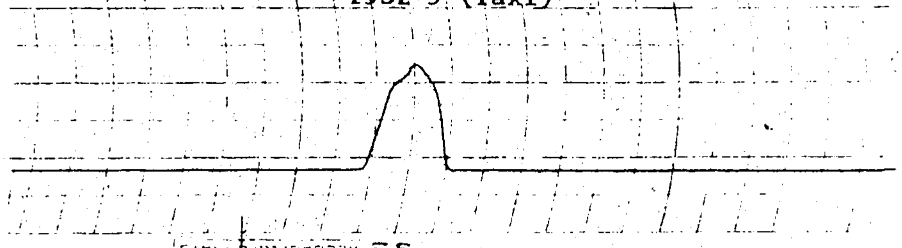
T5S2-3 (Semi-trailer)



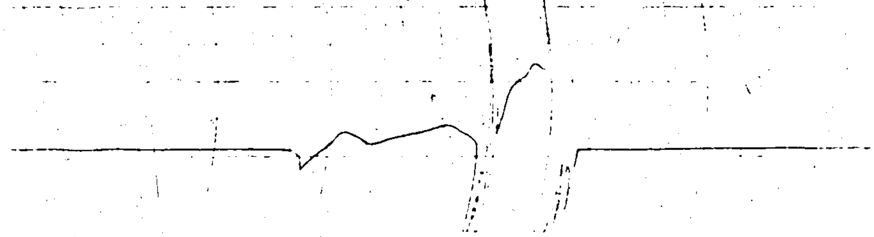
T5S2-4 (ETS Bus)



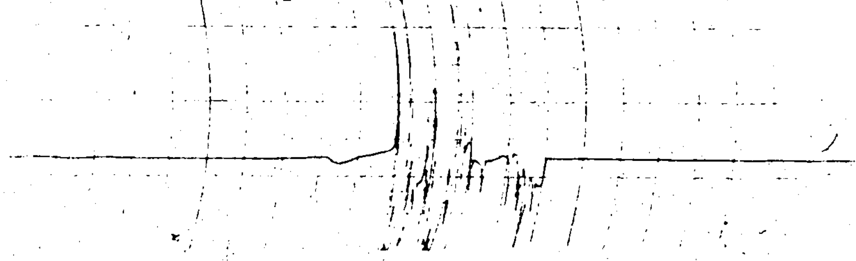
T5S2-5 (Taxi)



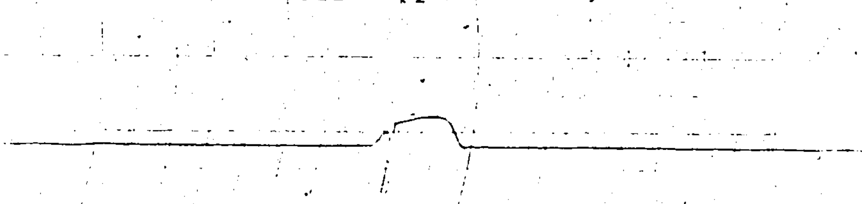
T5S2-6 (Semi-trailer)



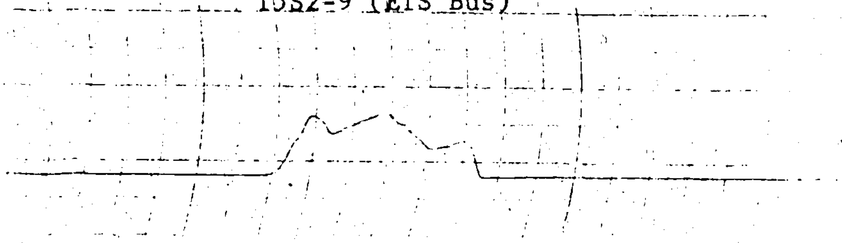
T5S2-7 (Semi-trailer)



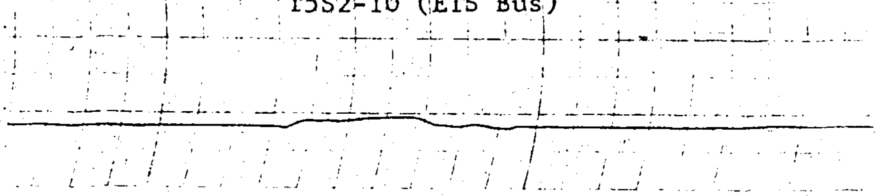
T5S2-8 (½ Ton Truck)



T5S2-9 (ETS Bus)



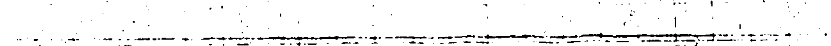
T5S2-10 (ETS Bus)



T5S2-11 (Gas Tanker in Tandem)

T5S2-12 (Semi-trailer)

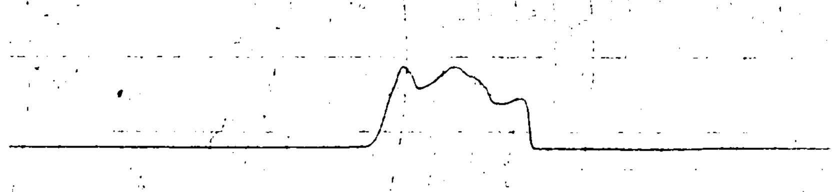
T5S2-13 (ETS Bus)



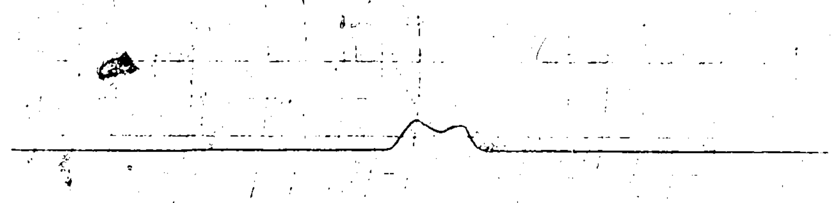
T6S1	#Mx	#Mn	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
1	3	2	0A6C	019E	0942	0212	0AC2	03D2	0A6A	04F6	0AC1	059C	067A
2	3	2	0A4A	01E0	0916	0200	0A23	020A	09FB	0282	0A38	0356	042C
3	5	4	0A4A	01E0	0922	021C	0A33	0224	09F0	065E	0A29	06DC	07FE
4	5	4	0A4E	021A	0926	0276	0A3A	027C	09DE	058A	0A24	072E	0834
5	5	4	0A37	02D6	090E	0328	0A22	032E	090C	032E	0A1B	07FC	089C
6	3	2	0A12	0190	09CC	04D0	0AF5	0574	09E2	0582	0A0F	0604	06FE
7	3	2	0A4C	01BA	0924	0224	0A88	0498	0A34	0678	0AAD	06CA	086C
8	-	-	----	----	----	----	----	----	----	----	----	----	----
9	3	2	0AAF	0448	0987	053C	0A8C	0544	0A5D	0604	0AA6	06C4	07CC
10	3	2	0A40	0188	0914	020A	0A7D	0432	0A2C	05C0	0A78	0674	076A
11	-	-	----	----	----	----	----	----	----	----	----	----	----
12	-	-	----	----	----	----	----	----	----	----	----	----	----
13	3	2	0A7E	01B4	0956	022E	0ABD	0484	0A61	063C	0AB0	06D2	0800
14	-	-	----	----	----	----	----	----	----	----	----	----	----

T6S2													
1	3	2	0A53	[illegible]	[illegible]	0426	0A3D	0456	0A0E	0526	0A47	05B8	0692
2	2	1	[illegible]	[illegible]	[illegible]	0358	0A7E	0440	----	----	----	----	0512
3	4	3	[illegible]	[illegible]	091F	02B6	0A39	035A	0901	0628	0A11	0630	06B0
4	3	2	0A62	01D4	0939	0256	0AA9	04E8	0A53	06F6	0AA8	07AA	0912
5	5	4	0A33	01D0	0907	0244	0A1B	0246	09D1	04C0	0A17	069C	0728
6	5	4	0A4F	0200	0925	0248	0A36	024A	09DC	058C	0A1E	07FE	08F0
7	4	3	0A2A	01B2	0901	028C	0A61	0486	0A13	0688	0A4C	071A	0866
8	6	5	0A37	020C	090F	0258	0A25	025A	0907	091E	0A1C	0920	0964
9	1	0	0A0A	044C	----	----	----	----	----	----	----	----	0826
10	2	1	0A24	029C	09EC	040E	0A3D	063C	----	----	----	----	07C0
11	3	2	0A83	0466	095B	0568	0A69	057A	0A38	0632	0A87	06E4	0802
12	4	3	0A3F	020A	0914	02CC	0A2B	032A	0900	0808	0A0A	0814	086C
13	3	2	0A1F	01DA	09CD	048A	0AF7	04DC	09E7	04E0	0A47	078E	08D0
14	-	-	----	----	----	----	----	----	----	----	----	----	----

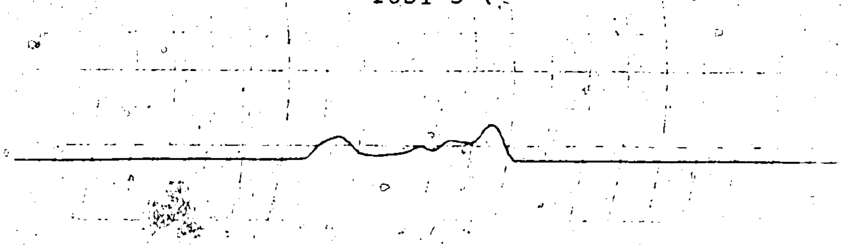
T6S1-1 (ETS Bus)



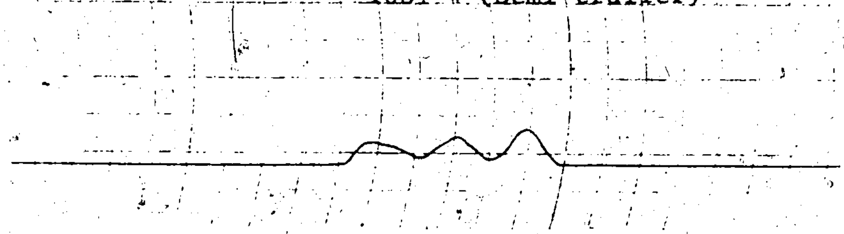
T6S1-2 (Dump Truck)



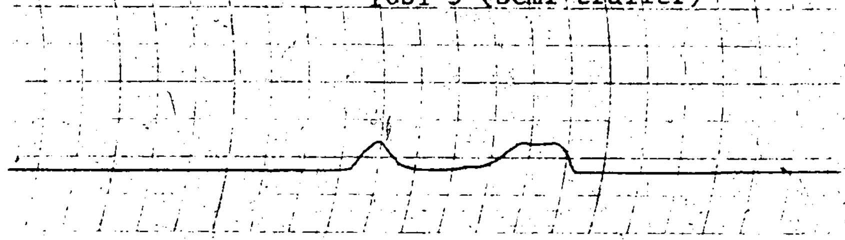
T6S1-3 (Semi-trailer)



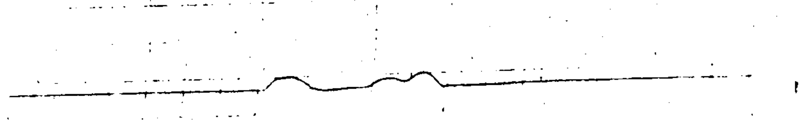
T6S1-4 (Semi-trailer)



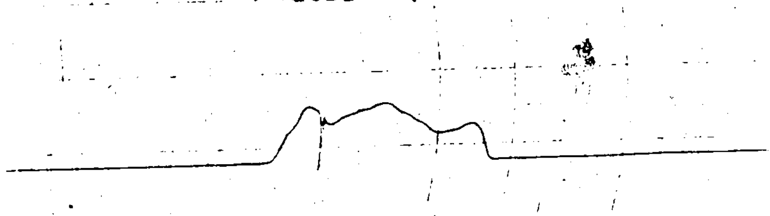
T6S1-5 (Semi-trailer)



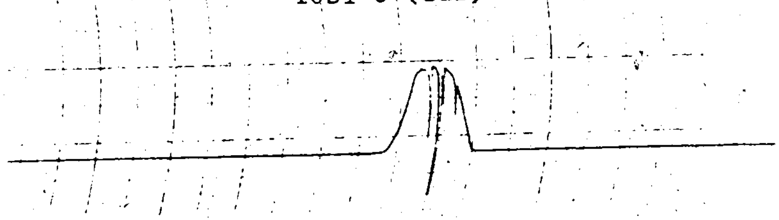
T6S1-6 (Semi-trailer)



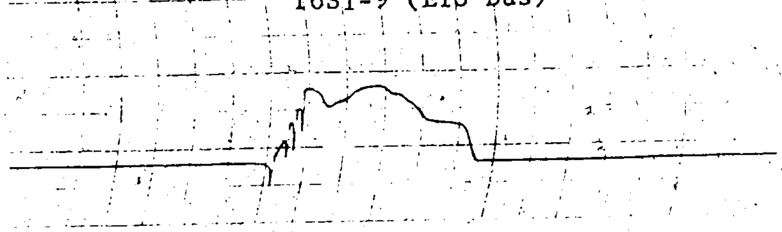
T6S1-7 (ETS Bus)



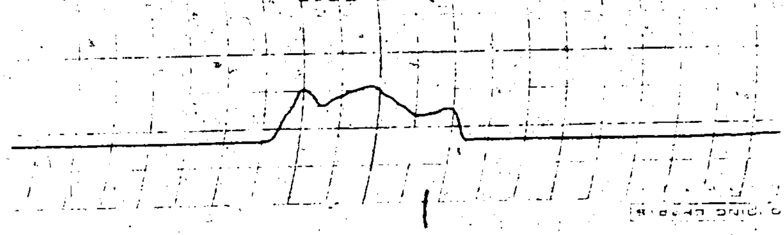
T6S1-8 (Car)



T6S1-9 (ETS Bus)

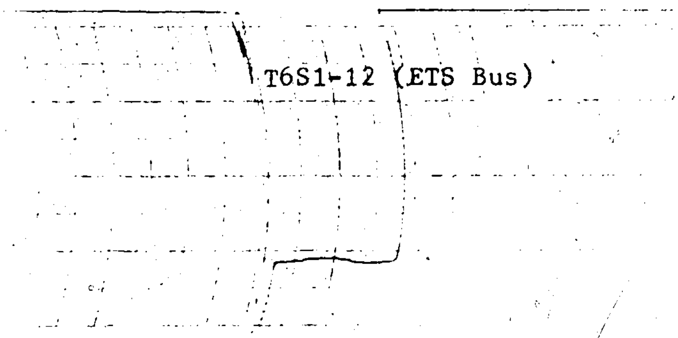


T6S1-10 (ETS Bus)

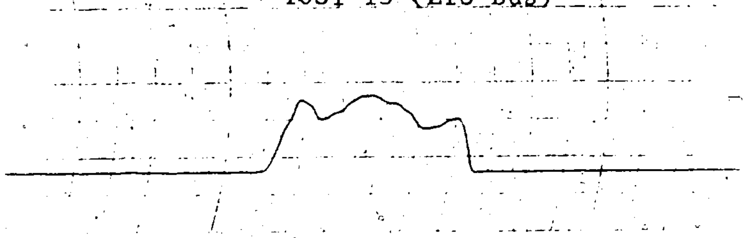


T6S1-11 (ETS Bus)

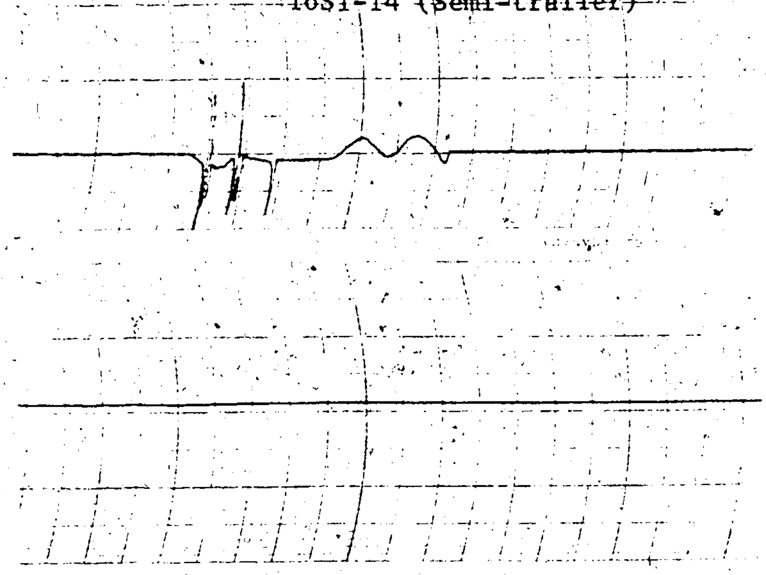
T6S1-12 (ETS Bus)



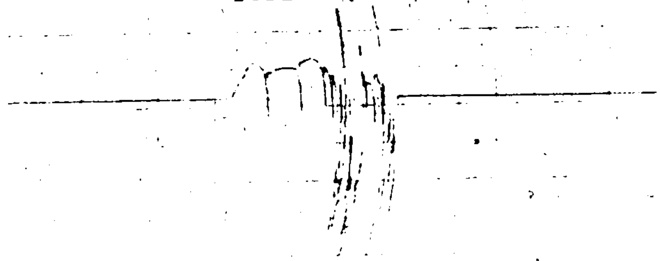
T6S1-13 (ETS Bus)



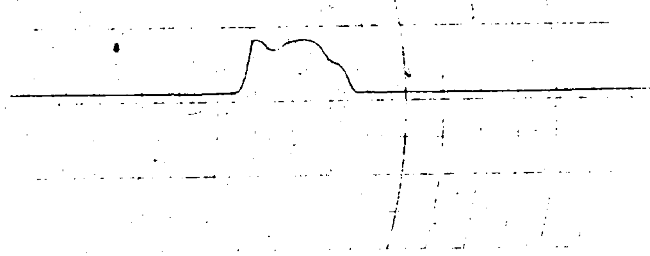
T6S1-14 (Semi-trailer)



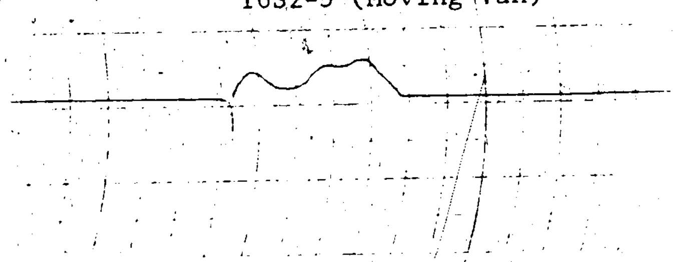
T6S2-1 (ETS Bus)



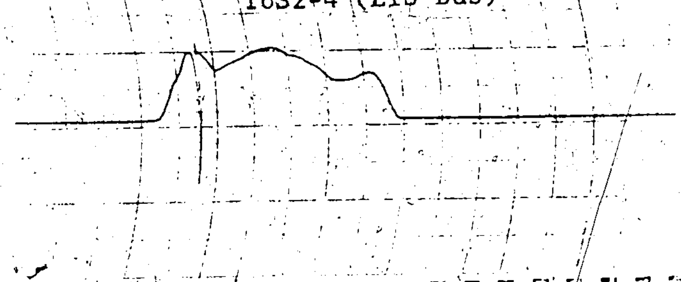
T6S2-2 (Fire Truck)



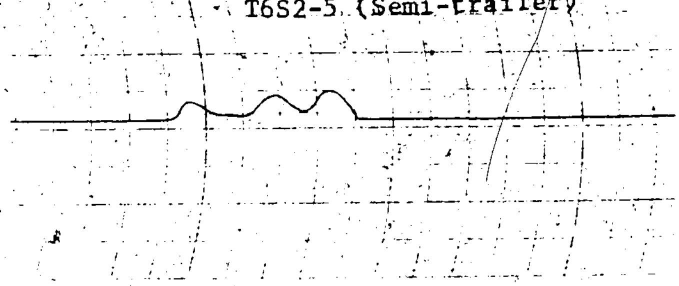
T6S2-3 (Moving Van)



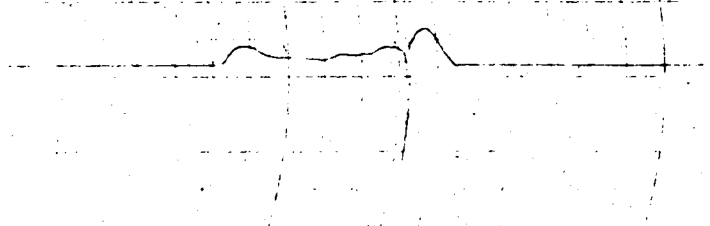
T6S2-4 (ETS Bus)



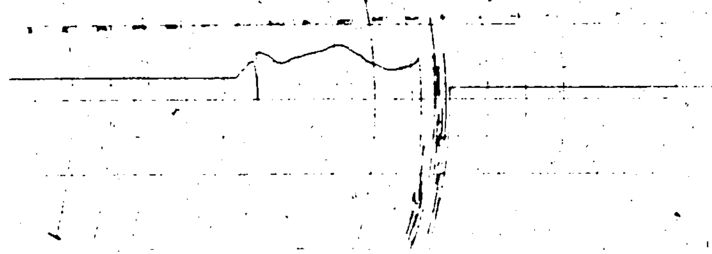
T6S2-5 (Semi-trailer)



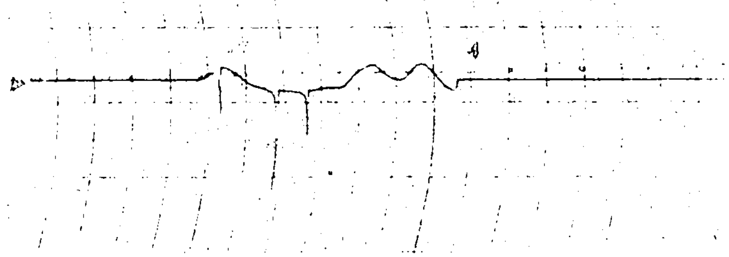
T6S2-6 (Semi-trailer)



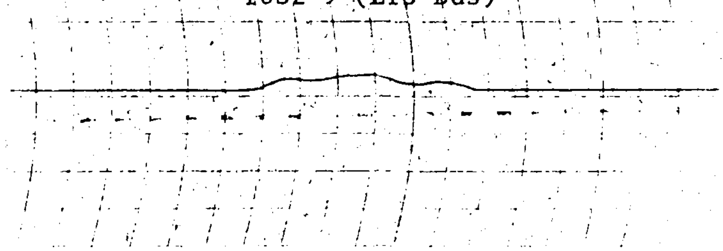
T6S2-7 (ETS Bus)



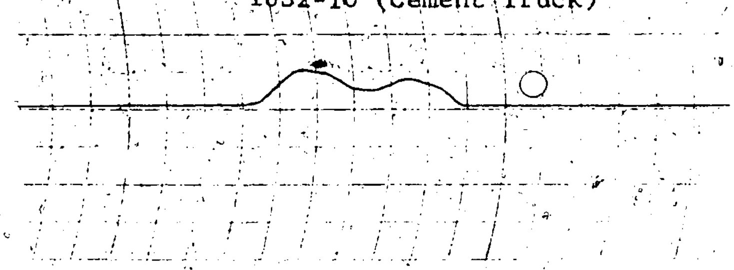
T6S2-8 (Semi-trailer)



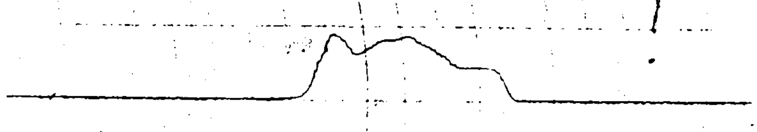
T6S2-9 (ETS Bus)



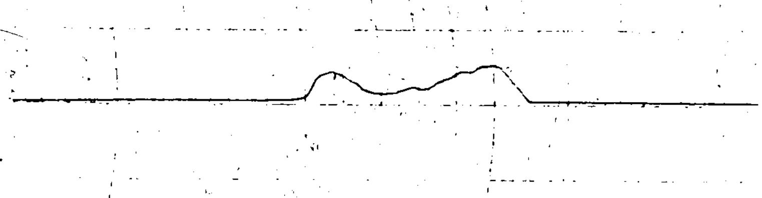
T6S2-10 (Cement Truck)



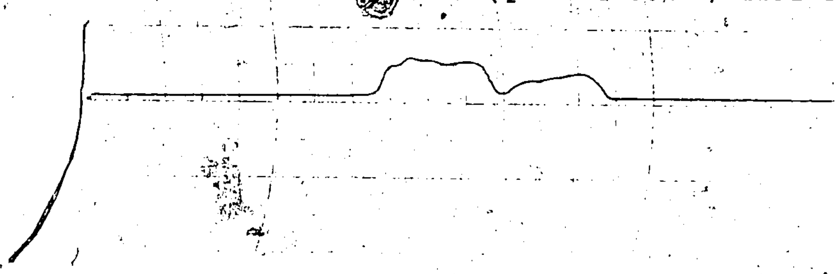
T6S2-11 (ETS Bus)



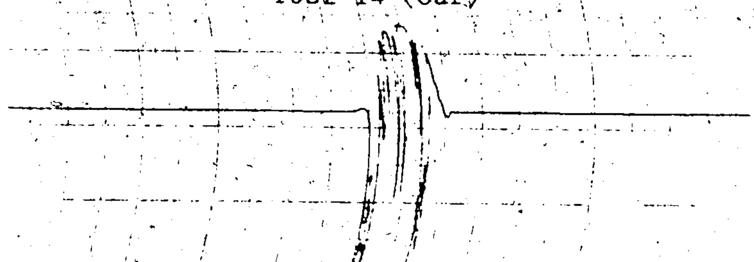
T6S2-12 (Semi-trailer)

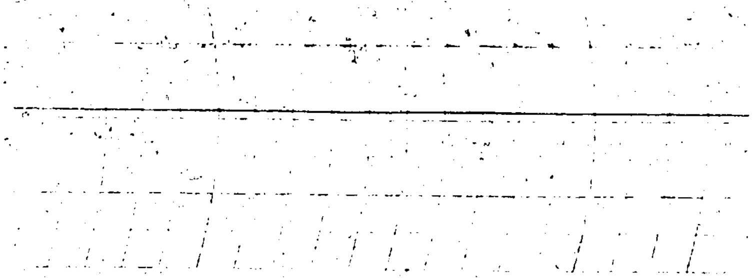


T6S2-13 (½ Ton Truck w/ Trailer)



T6S2-14 (Car)

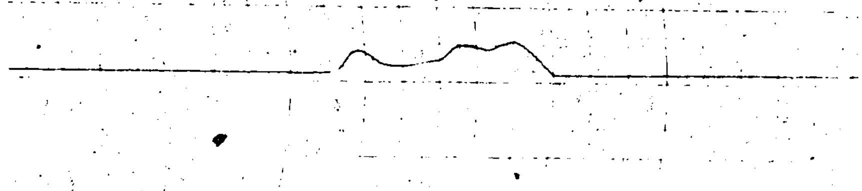




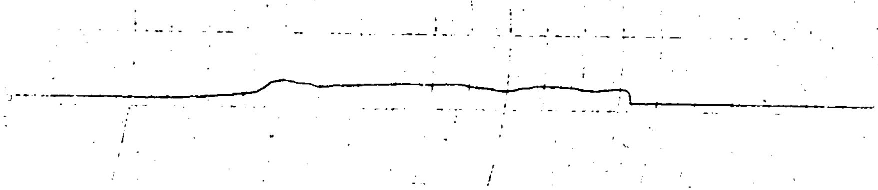
T7S1	#Mx	#Mn	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
1	3	2	0A38	023C	0910	02D6	0A29	03D2	09DA	060C	0A1C	0768	082E
2	1	0	0939	0C6A	----	----	----	----	----	----	----	----	0FA8
3	4	3	0A43	020C	0919	02E2	0A37	0358	0913	080E	0A26	0810	08B6
4	3	2	0A4E	010A	0A26	01CA	0A9D	03CE	0A3D	05DE	0A81	06B2	07FA
5	3	2	0A2C	0338	0902	038C	0A16	0392	09D1	04EE	0AFA	057A	0676
6	4	3	0A77	01BC	094F	0226	0A9C	03D0	0A5B	0644	0AAA	0710	083E
7	3	2	0A59	0430	0930	04C0	0A44	04CC	0A0F	05EA	0A51	06AF	07B4
8	2	1	0A50	0230	0928	0334	0A3B	034E	----	----	----	----	05D4
9	1	0	0A07	0418	----	----	----	----	----	----	----	----	07C0
10	4	3	0A2A	01A2	0902	0270	0A5F	044C	0A0E	0612	0A4A	06D0	07E2
11	1	0	0A18	049A	----	----	----	----	----	----	----	----	086C
12	4	3	0A29	01FC	0901	0336	0A15	0338	0901	063C	0A17	0644	0720

T7S2													
1	4	3	0A4A	02FC	0920	03A8	0B02	061A	0A24	09CE	0A51	0B8C	0C48
2	3	2	0A79	01B2	0950	020E	0AB6	0434	0A5F	05C4	0AAC	066E	0770
3	3	2	0A89	042E	095F	051E	0A6F	052C	0A3B	05D8	0A92	0674	0790
4	1	0	0A27	03E8	----	----	----	----	----	----	----	----	0742
5	3	2	0A7B	01A0	0953	01FC	0ABE	0436	0A61	057E	0AAF	0624	0722
6	3	2	0A47	01AC	091E	0234	0A8D	047C	0A31	0650	0A7D	0720	082E
7	3	2	0A77	01B8	094F	01F4	0AB1	0464	0A5C	0602	0AB0	06AA	07B6
8	3	2	0A9B	03EB	0970	049C	0A7C	049E	0A4E	052E	0AA9	05CA	06D0
9	1	0	0A04	03EC	----	----	----	----	----	----	----	----	0758
10	5	4	0A5D	01FE	0931	0232	0A3F	0234	09EE	07C8	0A2C	0870	091E
11	3	2	0A5D	01FE	0931	0232	0A3F	0234	09DC	02EA	0A18	0384	06A0
12	5	4	0A37	0418	090F	04B0	0A21	04B2	0904	0B10	0A18	0B12	0C3A
13	4	3	0A8F	019C	0967	01DC	0A71	01E0	0A4E	04FE	0AB8	064A	0728

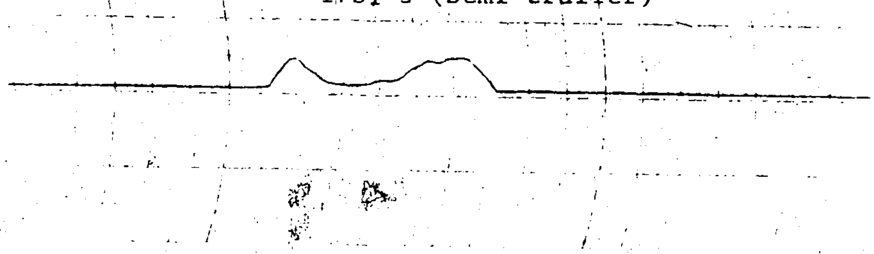
T7S1-1 (Semi-trailer)



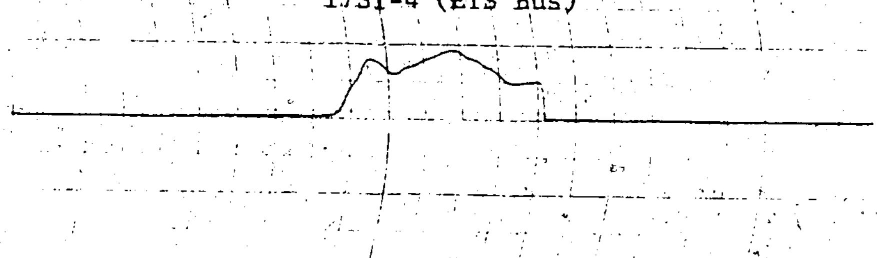
T7S1-2 (ETS Bus)



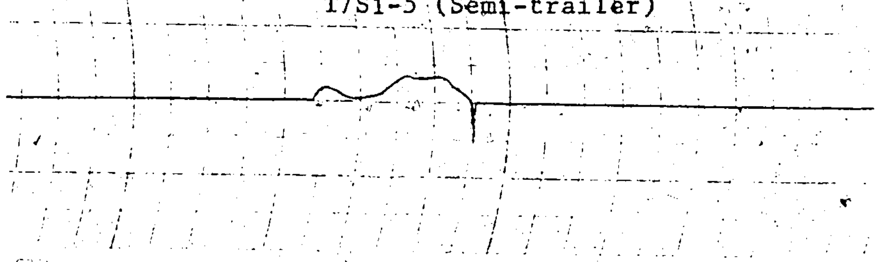
T7S1-3 (Semi-trailer)



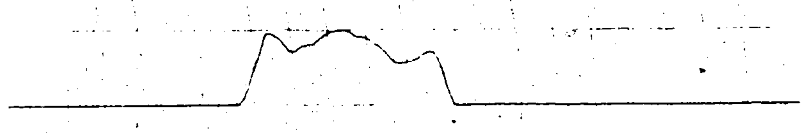
T7S1-4 (ETS Bus)



T7S1-5 (Semi-trailer)

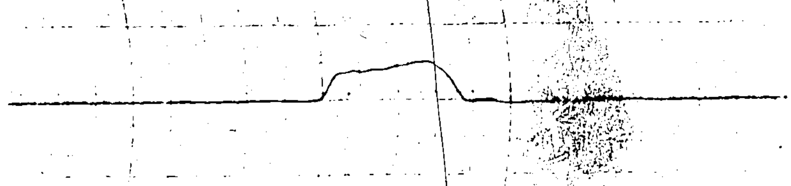


T7S1-6 (ETS Bus)

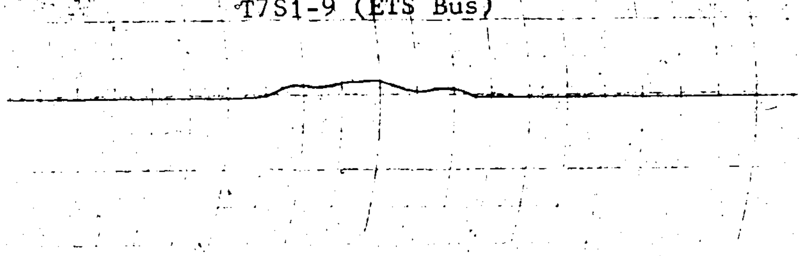


T7S1-7 (ETS Bus)

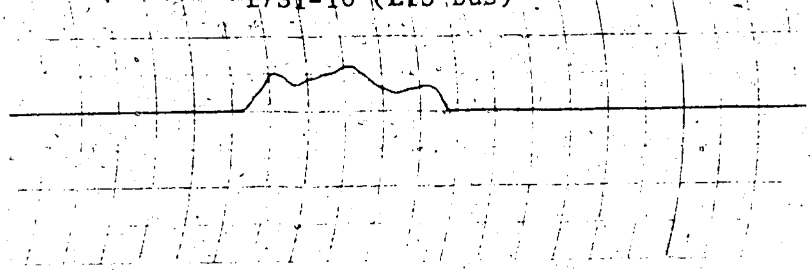
T7S1-8 (School Bus)



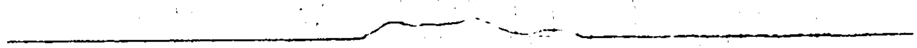
T7S1-9 (ETS Bus)



T7S1-10 (ETS Bus)

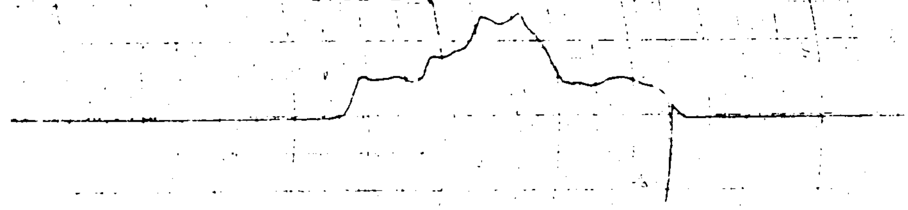


T7S1-11 (ETS Bus)

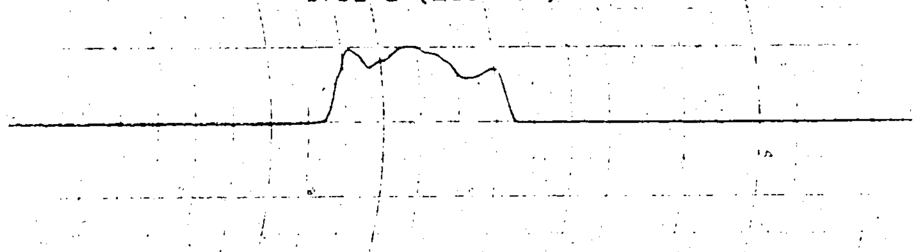


T7S1-12 (Semi-trailer)

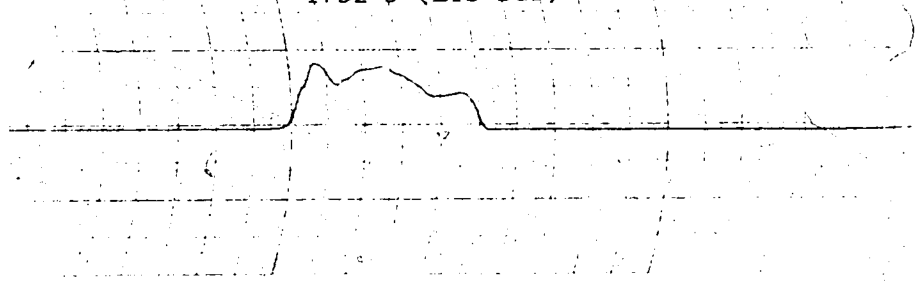
T7S2-1 (Auto Carrier)



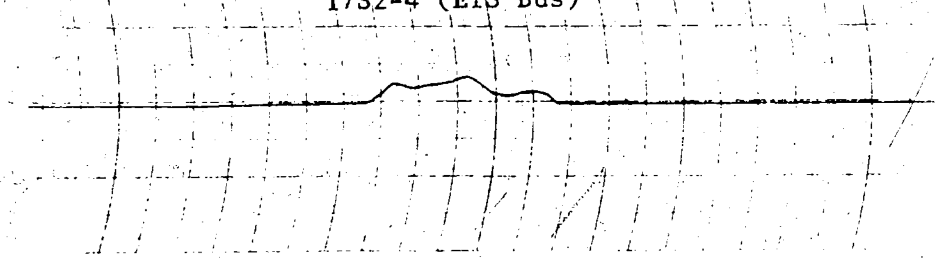
T7S2-2 (ETS Bus)



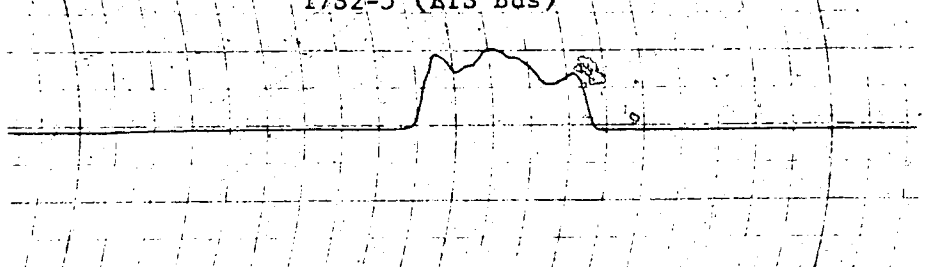
T7S2-3 (ETS Bus)



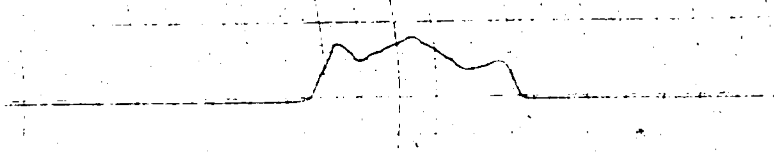
T7S2-4 (ETS Bus)



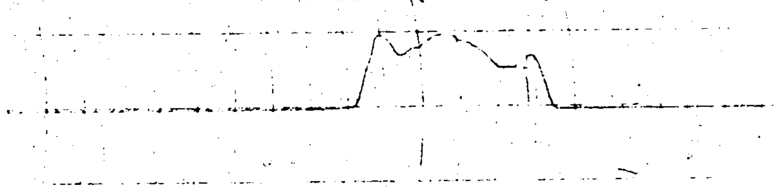
T7S2-5 (ETS Bus)



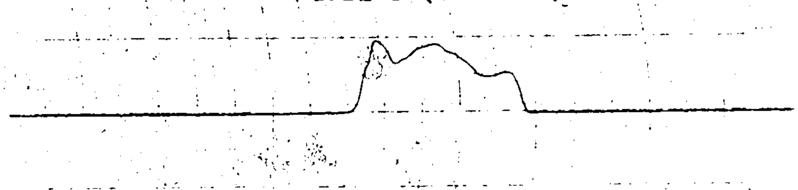
T7S2-6 (ETS Bus)



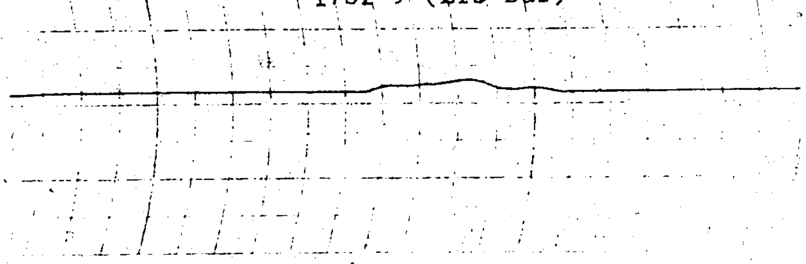
T7S2-7 (ETS Bus)



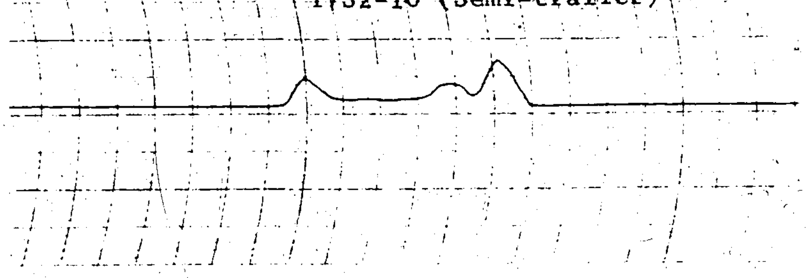
T7S2-8 (ETS Bus)



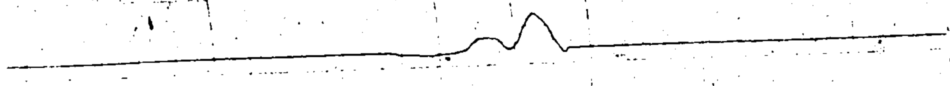
T7S2-9 (ETS Bus)



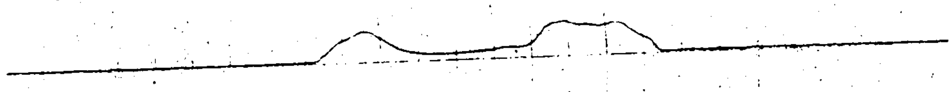
T7S2-10 (Semi-trailer)



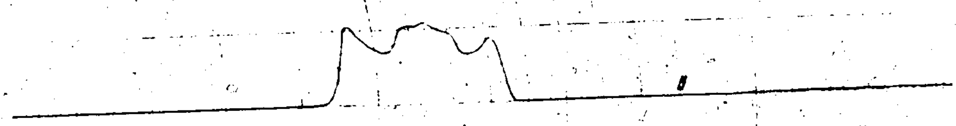
T7S2-11 (Semi-trailer)



T7S2-12 (Semi-trailer)



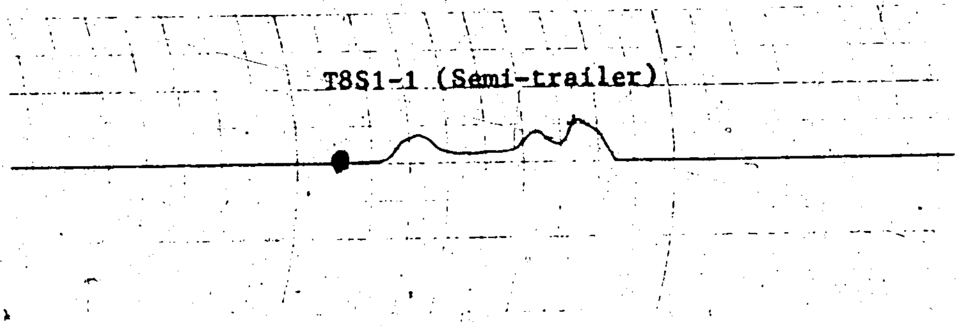
T7S2-13 (ETS Bus)

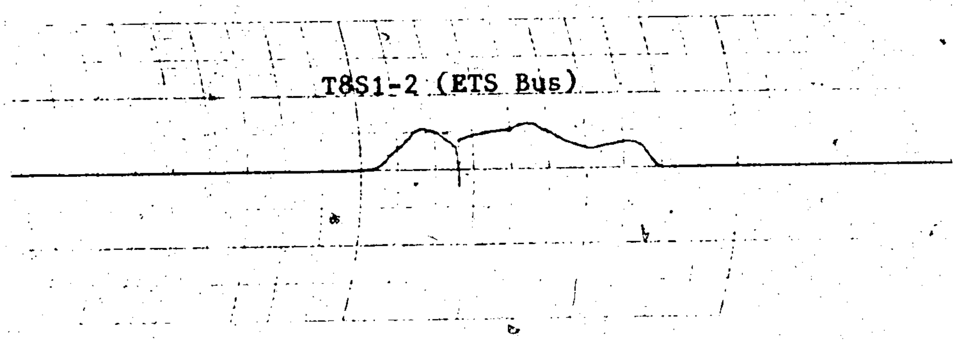


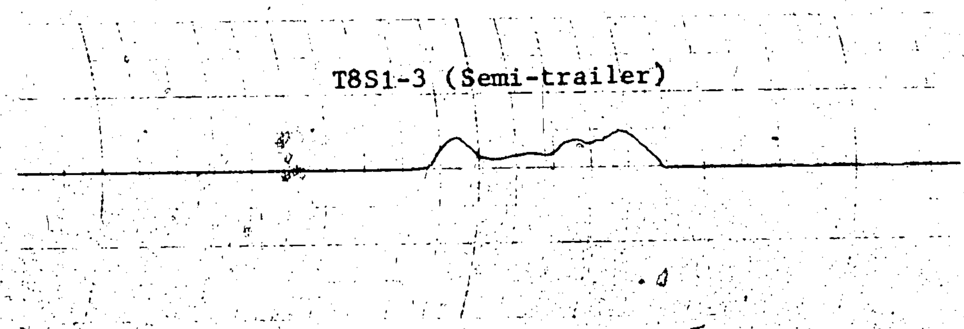
T8S1	#Mx	#Mn	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
1	5	4	0A4D	0238	0923	026E	0A32	0272	09D7	0642	0A27	077C	088A
2	3	2	0A23	01FE	09F7	033A	0A5A	0532	0A0F	07B6	0A4D	08C6	0A5A
3	4	3	0A3B	0258	0912	02BE	0A28	02C2	0906	081A	0A18	081C	08B0
4	5	4	0A4B	01E2	0922	022E	0A3A	0232	09E7	076E	0A27	081E	0944
5	3	2	0A26	01E2	09D3	06B6	0AFD	06C8	09ED	06CE	0A1C	0766	0866
6	-	-	----	----	----	----	----	----	----	----	----	----	----
7	3	2	0A28	01DC	09FF	0330	0A67	055A	0A1B	07E0	0A5D	08C8	0A34
8	-	-	----	----	----	----	----	----	----	----	----	----	----
9	1	0	0A17	03D4	----	----	----	----	----	----	----	----	070A
10	4	3	0A38	0216	090F	02AE	0A37	038E	09EA	07CE	0A1D	0886	0974
11	3	2	0A6C	01B2	0944	0200	0AA6	0430	0A4E	05D4	0AA1	067C	078C
12	1	0	0A18	03C8	----	----	----	----	----	----	----	----	06FE

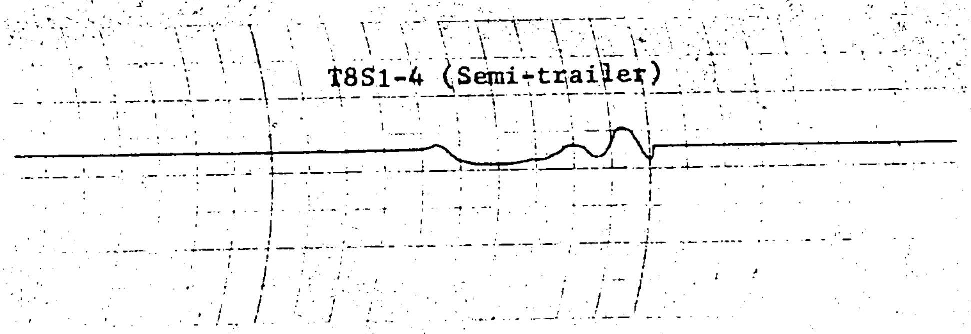
*T8S2													
1	2	1	0ABC	0454	0A6D	0630	0AB8	06A0	----	----	----	----	07F4
2	-	-	----	----	----	----	----	----	----	----	----	----	----
3	-	-	----	----	----	----	----	----	----	----	----	----	----
4	3	2	0A34	0186	0A16	0260	0A7A	03B6	0A33	0542	0A71	05D0	06D6
5	3	2	0A27	0186	0A0C	0276	0A6A	03E4	0A29	0570	0A61	0600	0720
6	1	0	0A10	046E	----	----	----	----	----	----	----	----	0888
7	3	2	0A77	01A2	0A51	0262	0AB7	03F0	0A63	0560	0AA9	05EE	0726
8	1	0	0A11	03CE	----	----	----	----	----	----	----	----	076C
9	3	2	0A3A	019A	091F	0210	0A73	047E	0A2E	053C	0A79	0698	079A
10	-	-	----	----	----	----	----	----	----	----	----	----	----
11	-	-	----	----	----	----	----	----	----	----	----	----	----
12	-	-	----	----	----	----	----	----	----	----	----	----	----
13	4	3	0A4F	01A4	0A31	0278	0A93	0406	0A46	05C4	0A8F	0684	07BE

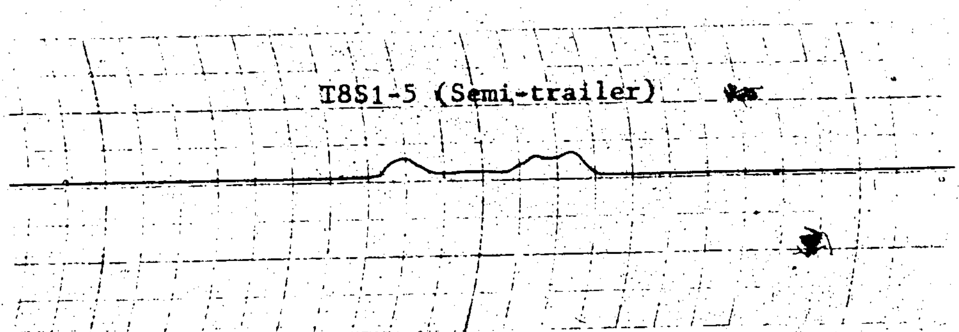
* Tolerance value is changed to ϵ = 1B


T8S1-1 (Semi-trailer)

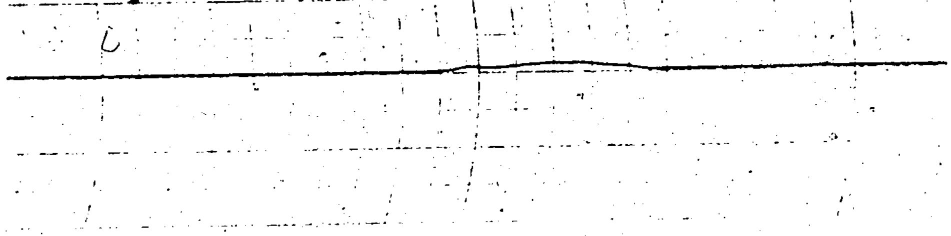

T8S1-2 (ETS Bus)


T8S1-3 (Semi-trailer)

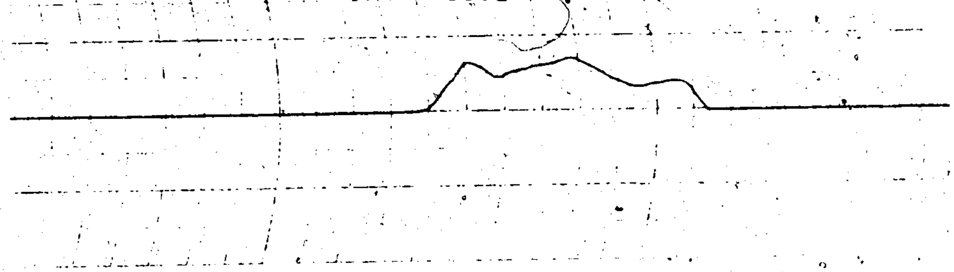

T8S1-4 (Semi-trailer)


T8S1-5 (Semi-trailer)

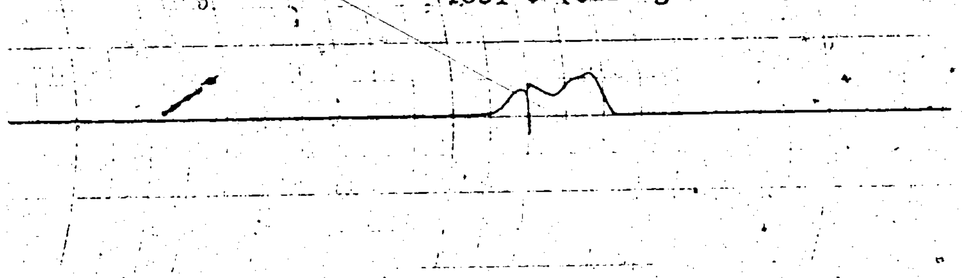
T8S1-6 (ETS Bus)



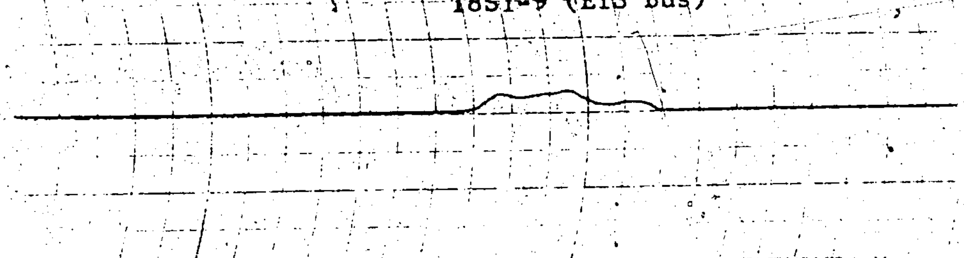
T8S1-7 (ETS Bus)



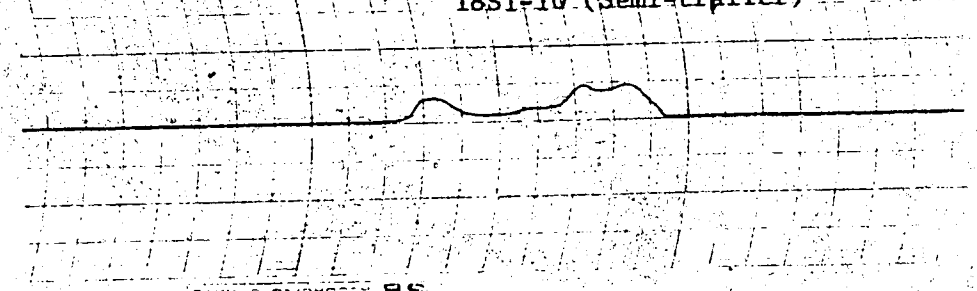
T8S1-8 (Garbage Truck)



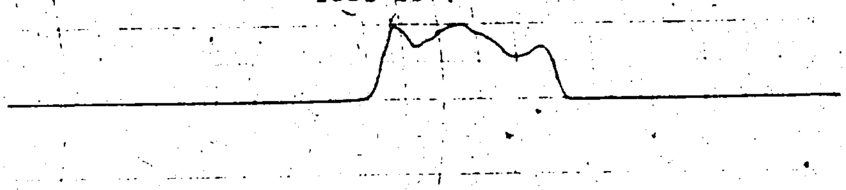
T8S1-9 (ETS Bus)



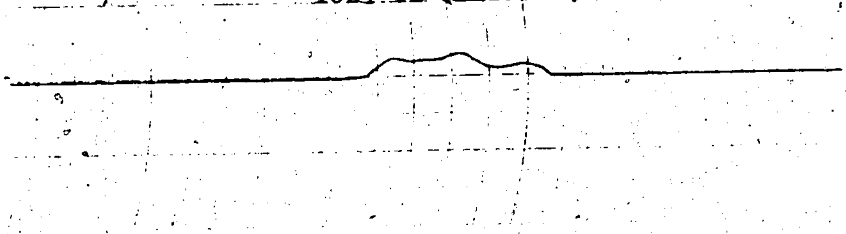
T8S1-10 (Semi-trailer)

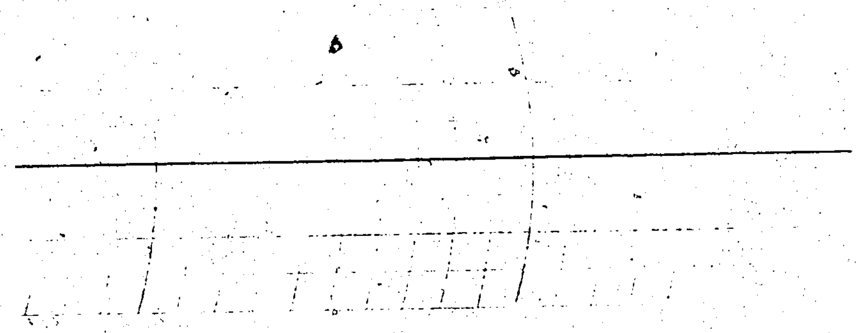


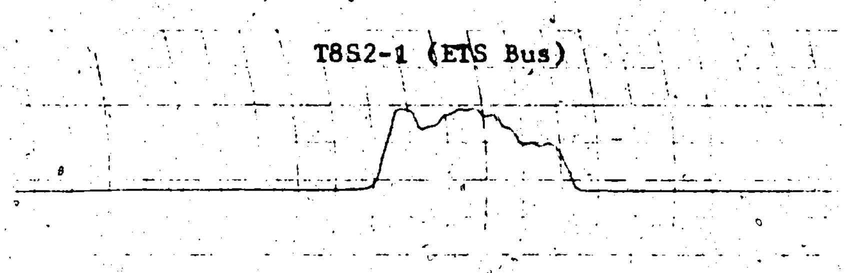
T8S1-11 (ETS Bus)

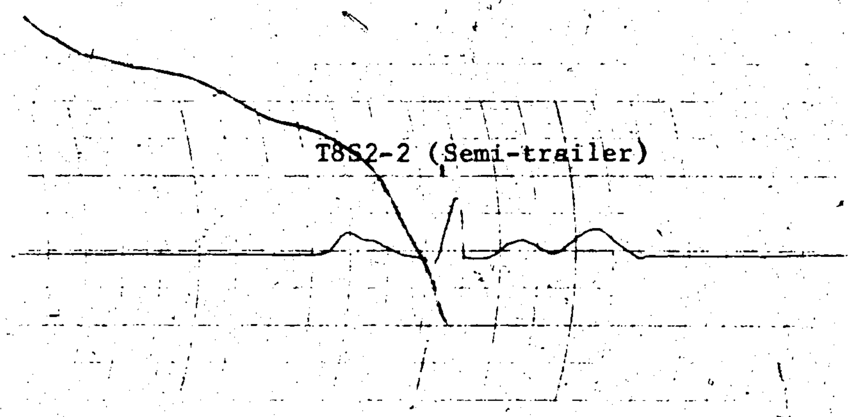


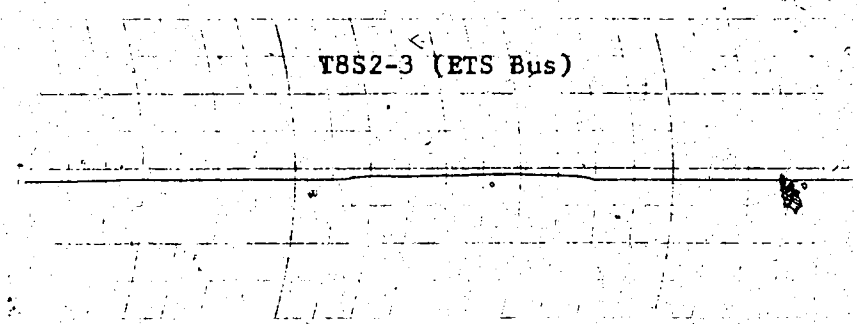
T8S1-12 (ETS Bus)

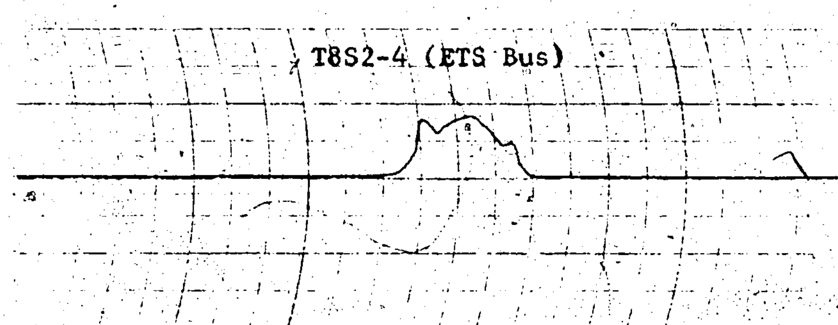


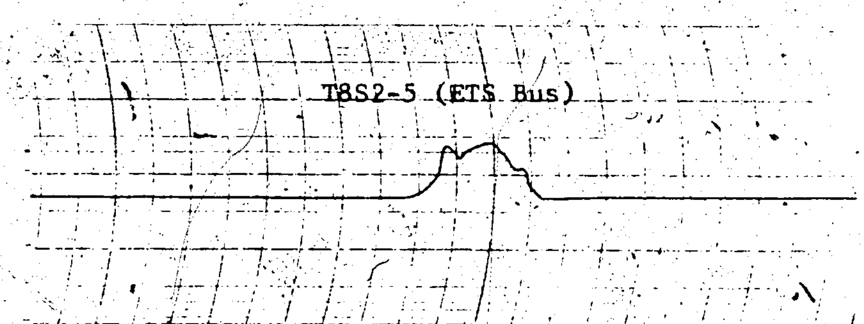



T8S2-1 (ETS Bus)

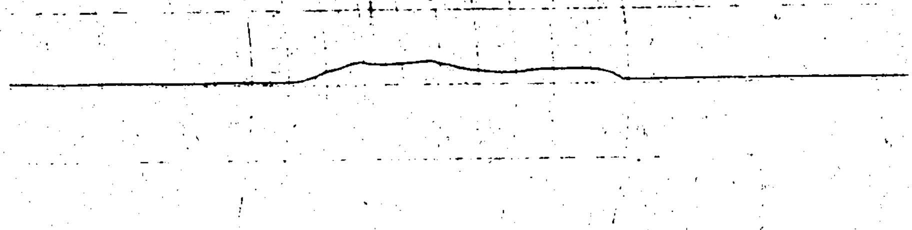

T8S2-2 (Semi-trailer)


T8S2-3 (ETS Bus)


T8S2-4 (ETS Bus)

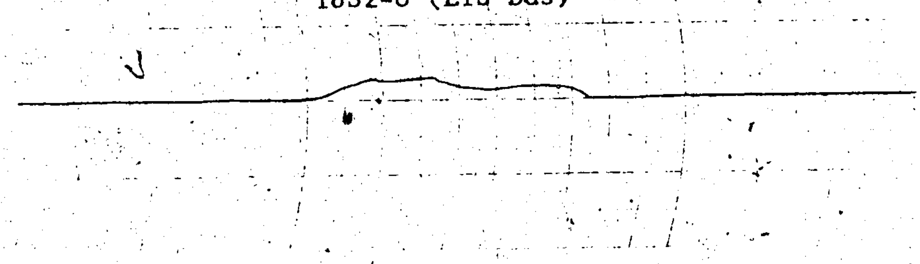

T8S2-5 (ETS Bus)

T8S2-6 (ETS Bus)

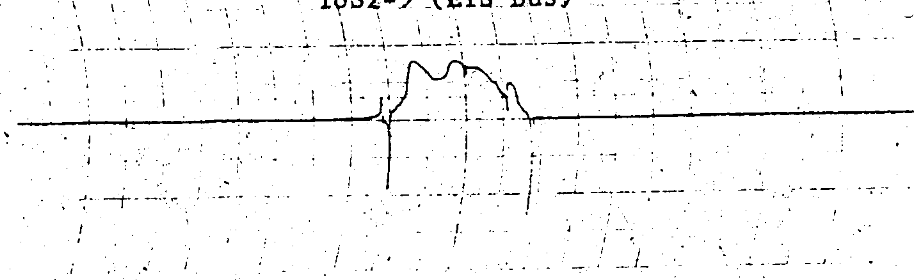


T8S2-7 (ETS Bus)

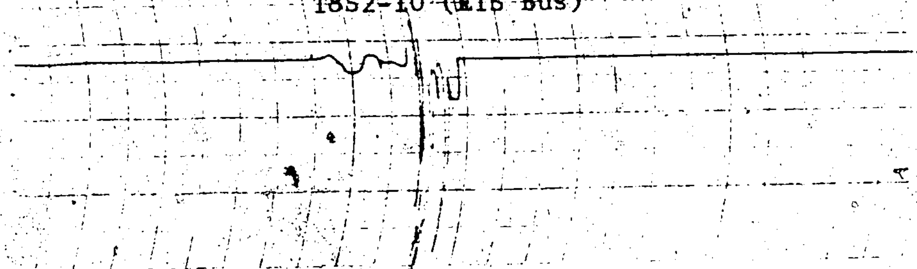
T8S2-8 (ETS Bus)



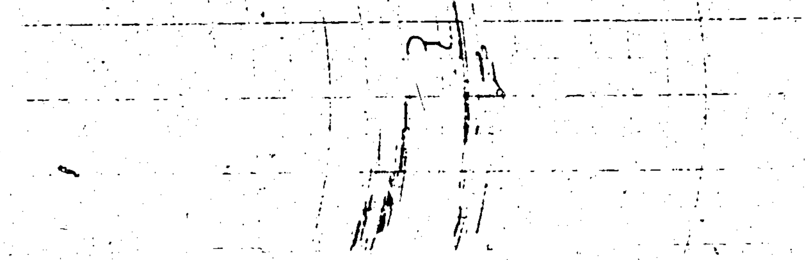
T8S2-9 (ETS Bus)



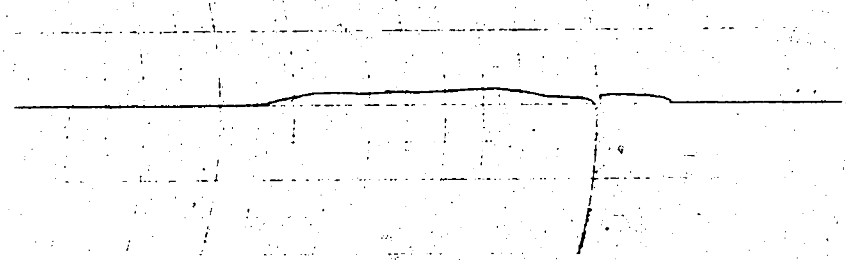
T8S2-10 (ETS Bus)



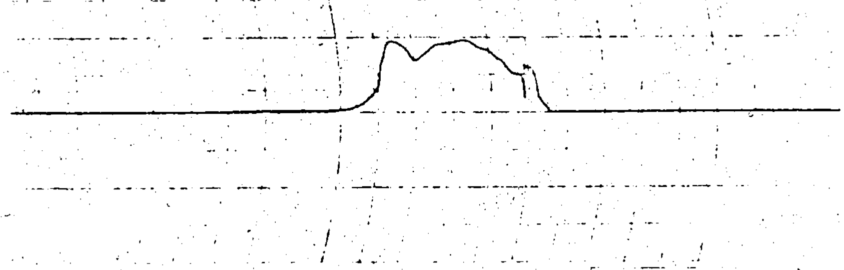
T8S2-11 (ETS Bus)

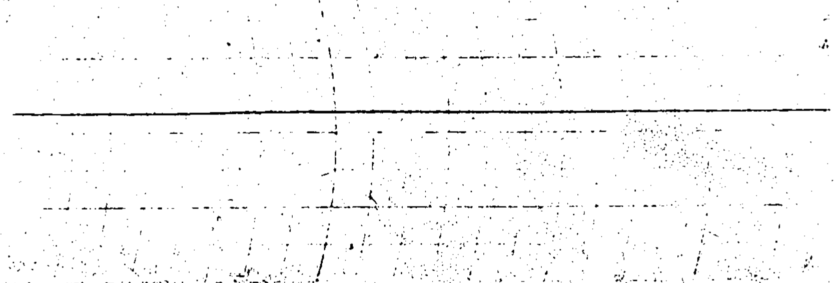


T8S2-12 (ETS Bus)



T8S2-13 (ETS Bus)



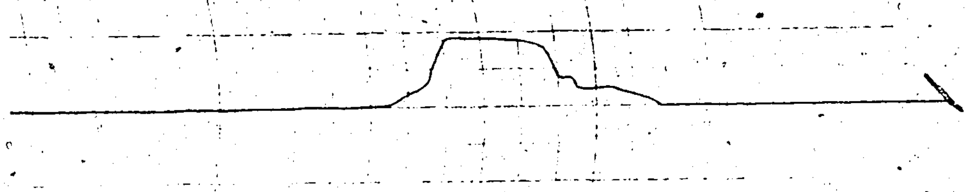


*T9S1	#Mx	#Mn	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
1	2	1	0A8B	07DE	0970	0832	0A70	0834	----	----	----	----	0A10
2	3	2	0A3E	0208	0922	0242	0A1F	0244	09E6	065C	0A18	07CE	08A6
3	3	2	0A70	019E	0A4C	0276	0AB5	0402	0A69	0574	0AAD	0618	0722
4	5	4	0A47	0234	092C	0288	0A2B	028A	0A12	0820	0A3D	08AC	0950
5	3	2	0A7E	019E	0A4C	0276	0AB5	0432	0A67	0576	0A9F	0618	0734
6	3	2	0A23	01BC	09D9	05DE	0AF5	0686	09F2	0694	0A17	0738	07F2
7	3	2	0A40	018C	0925	0210	0A89	040A	0A3E	05AE	0A81	0607	076E
8	3	2	0A83	01A8	0A50	029A	0AB9	0406	0A65	0594	0AC3	06D4	0810
9	3	2	0A68	018A	0A46	0266	0AAC	03EA	0A5B	0546	0A9D	05D4	06F2
10	3	2	0A6C	01D0	0A49	02EE	0AB7	0564	0A6B	07A2	0AB3	0894	0A68
11	3	2	0A78	01B6	0A4F	028C	0AB5	047E	0A6E	060C	0AAC	06AC	07F0
12	1	0	0A07	0404	----	----	----	----	----	----	----	----	07D4

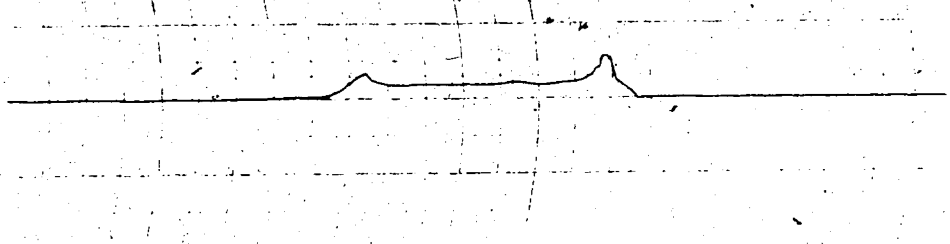
*T9S2													
1	3	2	0A73	0186	0958	01C6	0AD1	0394	0A67	0514	0AAB	059E	06AC
2	1	0	0B00	0430	----	----	----	----	----	----	----	----	0702
3	1	0	0A26	0416	----	----	----	----	----	----	----	----	07D6
4	3	2	0A26	0182	0A0A	0298	0A65	0404	0A24	05BE	0A51	066A	0788
5	2	1	0A1E	039E	0903	0472	0A11	0586	----	----	----	----	068C
6	1	0	09E8	03B4	----	----	----	----	----	----	----	----	081E
7	3	2	0A51	0412	0936	04C0	0A3B	04E2	0A15	05D6	0A3D	067A	07A0
8	3	2	0A73	0190	0A4A	024E	0AB1	03E2	0A63	0568	0A9C	05F8	06F8
9	3	2	0A6B	01A4	0A45	0278	0AAD	0420	0A62	05C0	0AAB	066A	0788
10	1	0	0A0A	03EC	----	----	----	----	----	----	----	----	0774
11	3	2	0A69	01C8	0A3E	02D6	0AA7	04DE	0A5B	06F0	0A98	07C6	0932
12	3	2	0A67	018C	0A45	024A	0AB4	0406	0A67	055C	0AB0	0604	070C

* Tolerance value ε = 1B

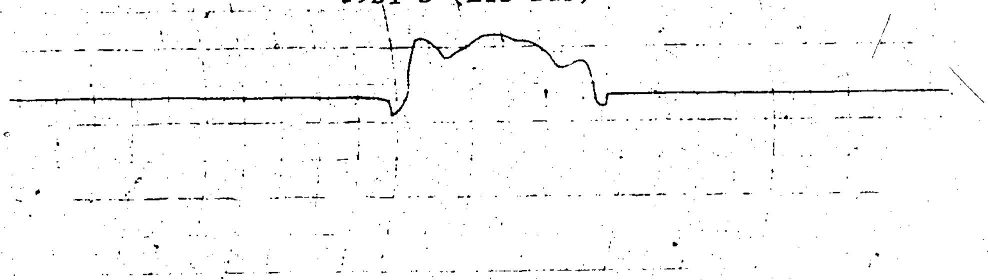
T9S1-1 (Semi-trailer)



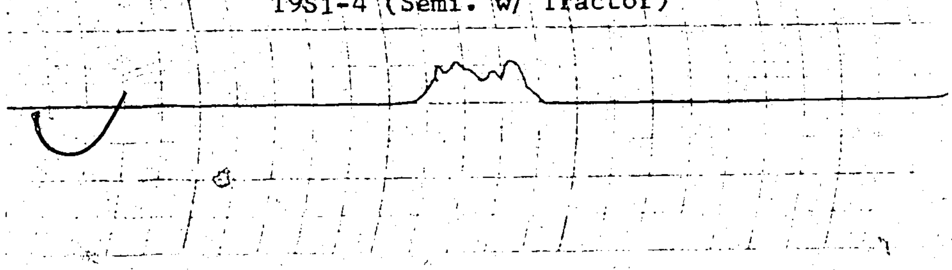
T9S1-2 (Semi-trailer)



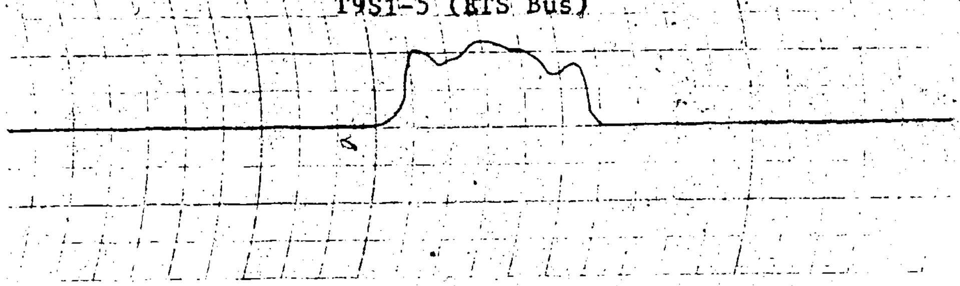
T9S1-3 (ETS Bus)



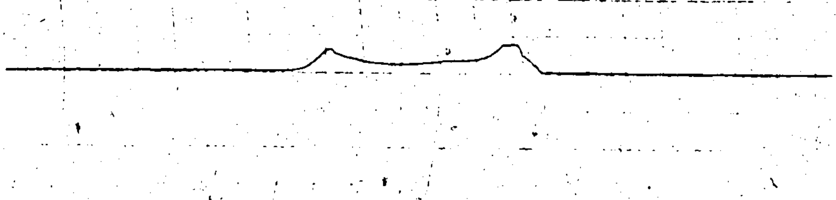
T9S1-4 (Semi. w/ Tractor)



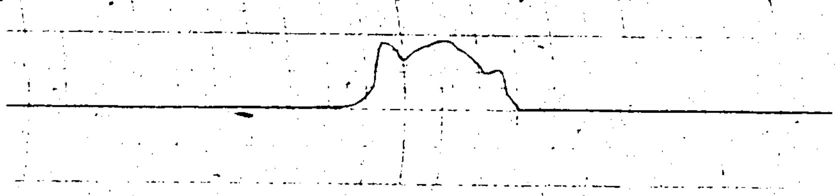
T9S1-5 (ETS Bus)



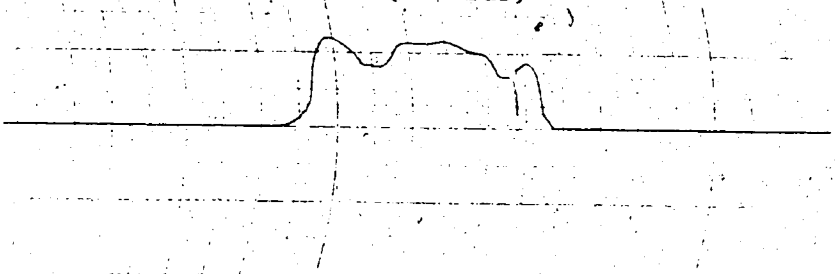
T9S1-6 (Semi-trailer)



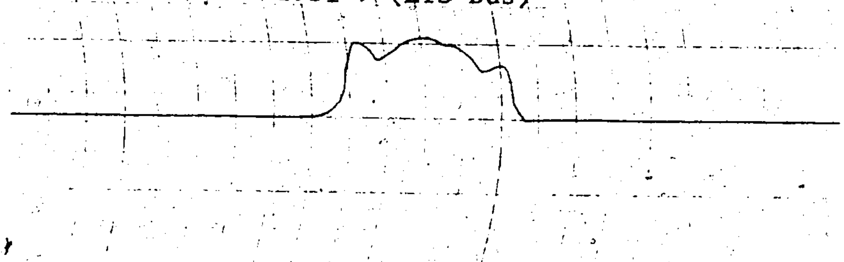
T9S1-7 (ETS Bus)



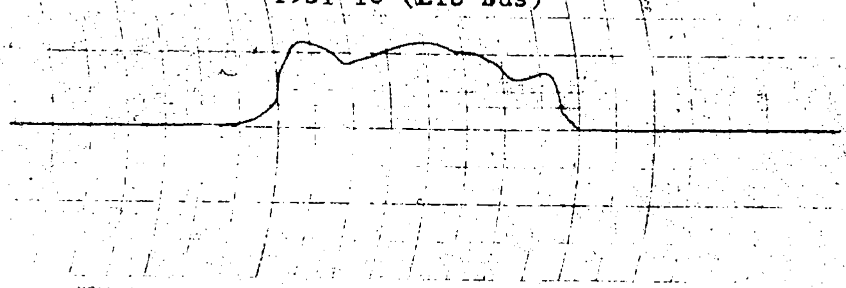
T9S1-8 (ETS Bus)

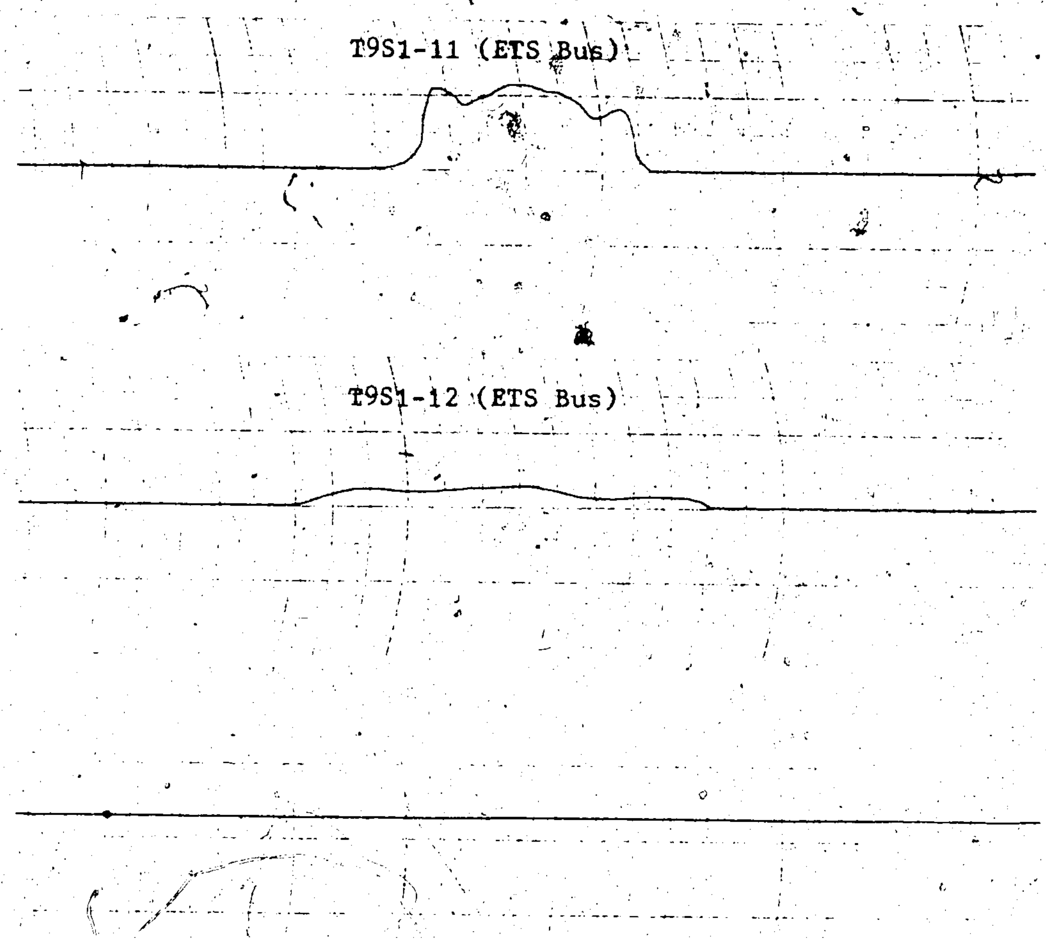


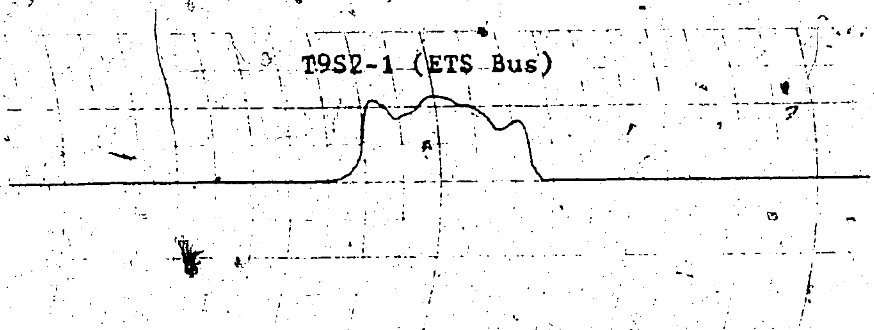
T9S1-9 (ETS Bus)

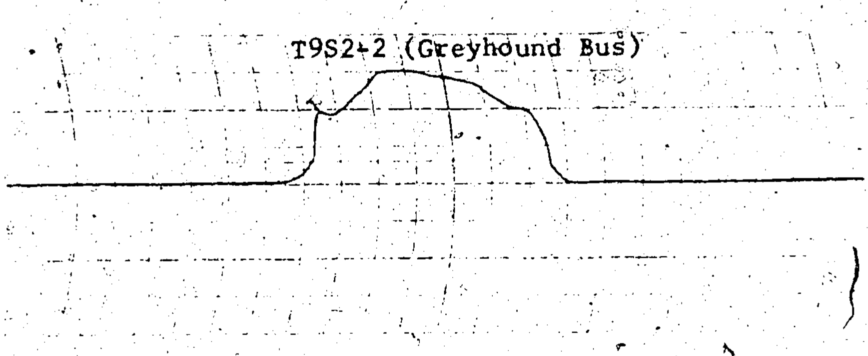


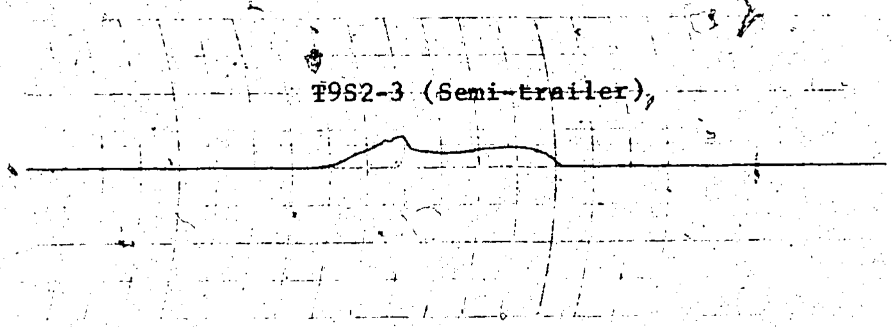
T9S1-10 (ETS Bus)

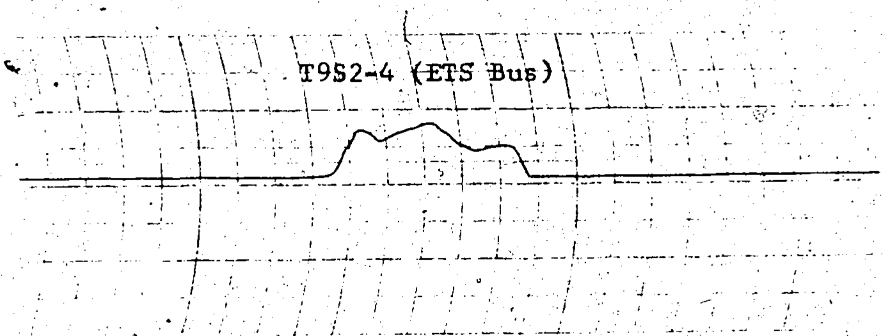


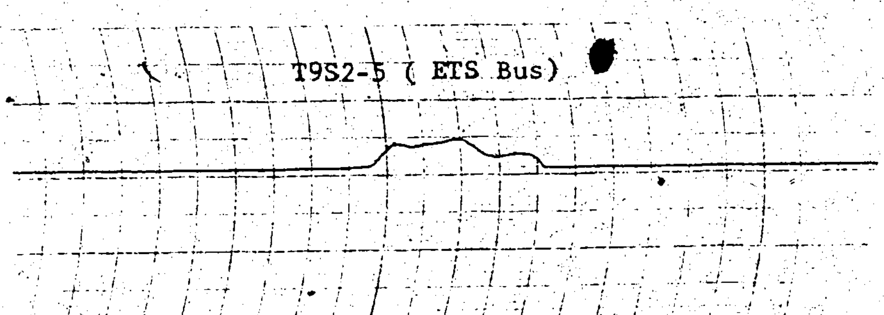

T9S1-11 (ETS Bus)
T9S1-12 (ETS Bus)

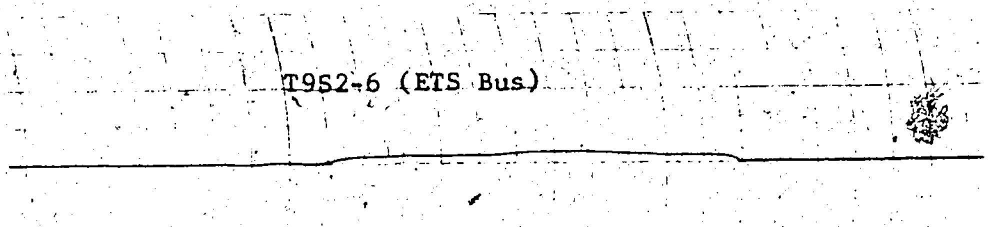

T9S2-1 (ETS Bus)

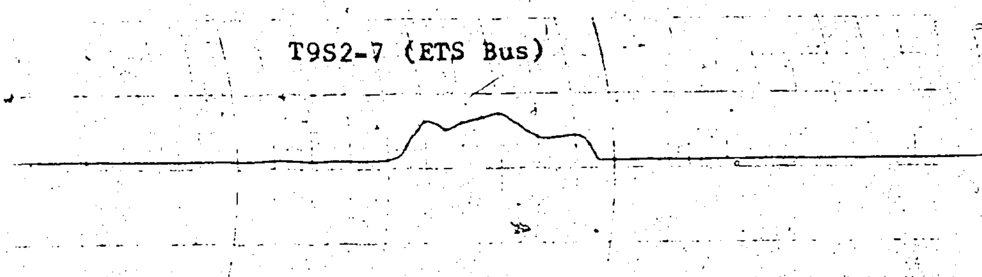

T9S2-2 (Greyhound Bus)

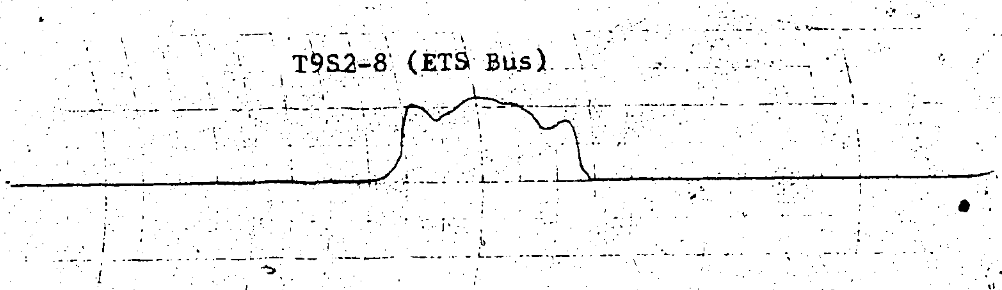

T9S2-3 (Semi-trailer)

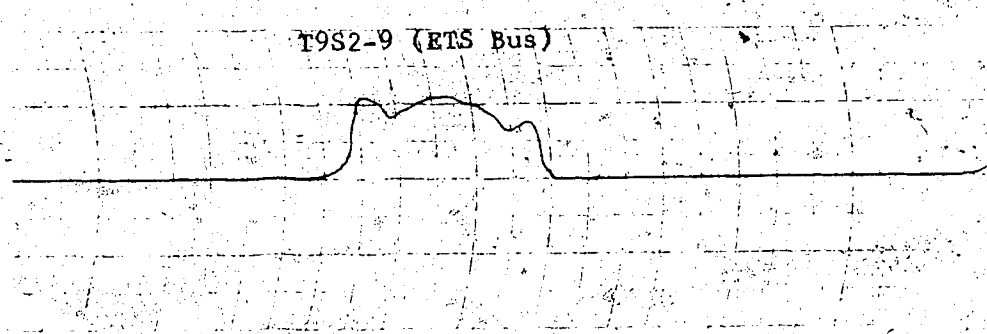

T9S2-4 (ETS Bus)

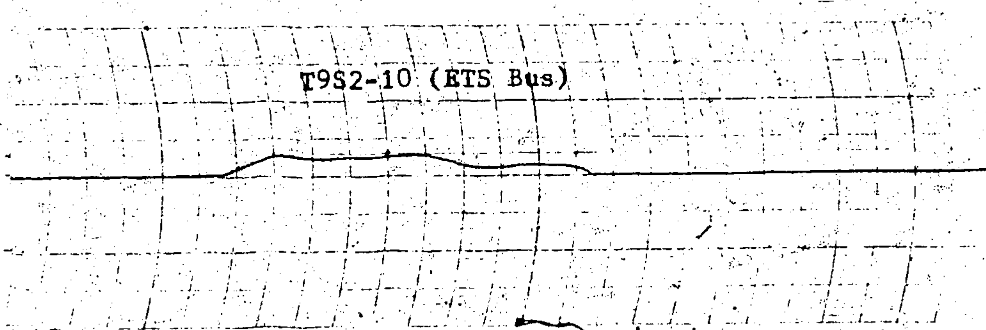

T9S2-5 (ETS Bus)


T9S2-6 (ETS Bus)

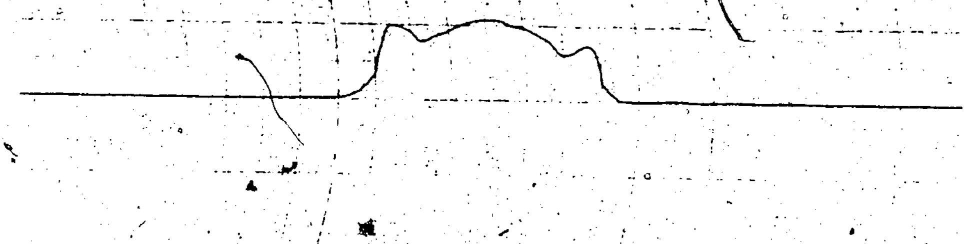

T9S2-7 (ETS Bus)


T9S2-8 (ETS Bus)

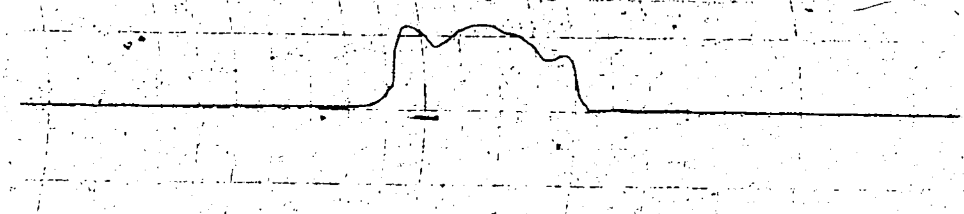

T9S2-9 (ETS Bus)

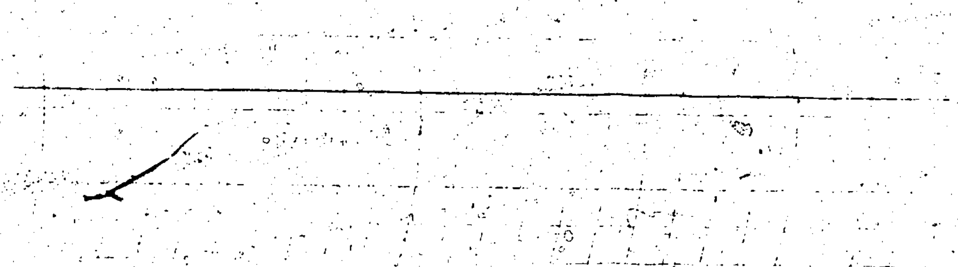

T9S2-10 (ETS Bus)

T9S2-11 (ETS Bus)



T9S2-12 (ETS Bus)

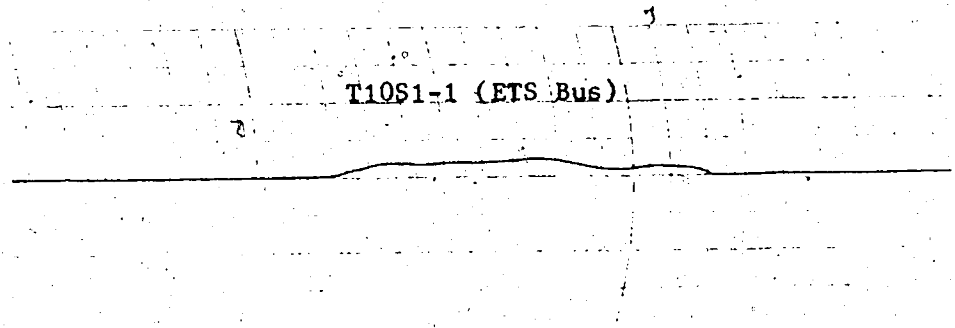




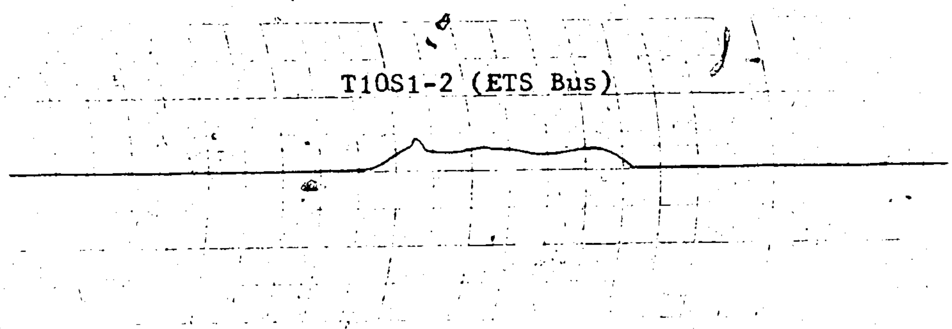
*T10S1	#Mx	#Mn	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
1	1	0	09FD	0398	----	----	----	----	----	----	----	----	0722
2	3	2	0A06	019E	09EA	02AA	0A0F	03EC	09F0	05A8	0A2B	074F	085A
3	3	2	0A13	01A0	09F8	02E0	0A4B	0484	0A10	06A8	0A3B	079A	08F0
4	4	3	0A4A	0222	0A01	032E	0A31	03EC	0A17	07F6	0A42	0868	091E
5	1	0	0A49	03D0	----	----	----	----	----	----	----	----	05D4
6	3	2	0A25	0452	090A	0542	0A1B	0736	0900	0788	09FF	078A	0858
7	1	0	0A0A	03EA	----	----	----	----	----	----	----	----	0760
8	4	3	0A2B	02B2	090F	0336	0A10	0348	099E	0652	0A0F	065C	074A
9	3	2	0A2D	0234	0912	0406	0A10	040A	09D4	0686	0A13	087A	09CE
10	1	0	09E8	0302	----	----	----	----	----	----	----	----	0684
11	3	2	0A68	0186	094D	01C8	0AB1	03A0	0A63	04FC	0AA7	0582	068A
12	2	1	0A20	043C	09FD	0600	0A1B	06A0	----	----	----	----	07D4

*T10S2													
1	1	0	09EE	031C	----	----	----	----	----	----	----	----	063E
2	3	2	0A32	01A0	0917	02C0	0A7B	0482	0A32	068E	0A65	0766	08D2
3	4	3	0A1D	026E	0902	02F2	0A00	0306	09D6	0874	0A14	0B00	0C54
4	1	0	09F0	0432	----	----	----	----	----	----	----	----	08A2
5	1	0	09F1	0382	----	----	----	----	----	----	----	----	073E
6	7	6	0A46	0200	092A	0270	0A59	0466	0A49	08BE	0A93	0964	0A52
7	3	2	0A47	01EC	09E7	043E	0A3C	05E8	0920	0620	0A1F	0622	06EE
8	3	2	0A1C	01B8	09FF	02F8	0A57	04E6	0A16	070E	0A41	07E4	0956
9	1	0	0A07	046C	----	----	----	----	----	----	----	----	088E
10	1	0	09E5	02C8	----	----	----	----	----	----	----	----	068C
11	1	0	09F5	0780	----	----	----	----	----	----	----	----	0556
12	1	0	09E5	02CA	----	----	----	----	----	----	----	----	05EC
13	2	1	09FF	0334	09CD	05D8	0A00	084A	----	----	----	----	096A

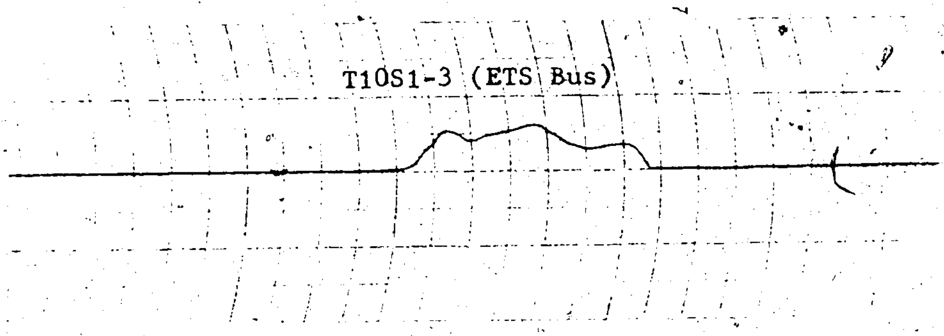
* Tolerance value $\epsilon = 1B$



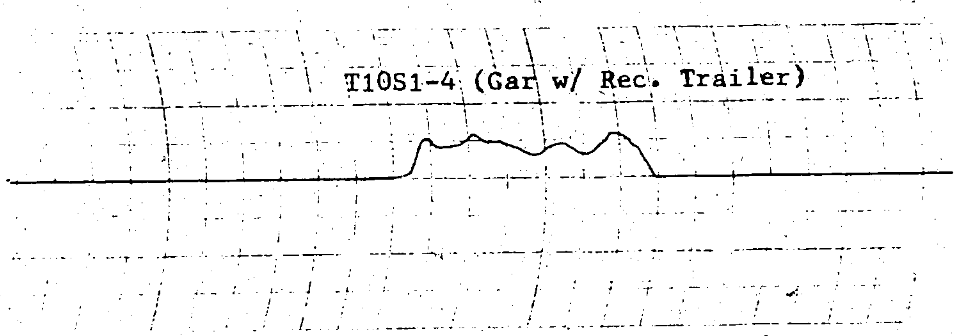
T10S1-1 (ETS Bus)



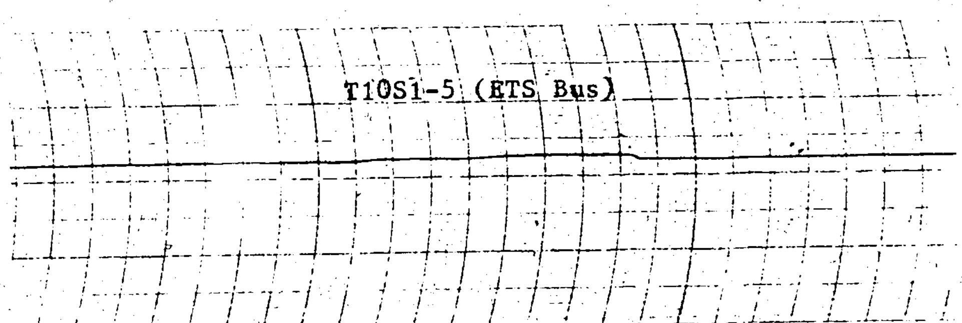
T10S1-2 (ETS Bus)



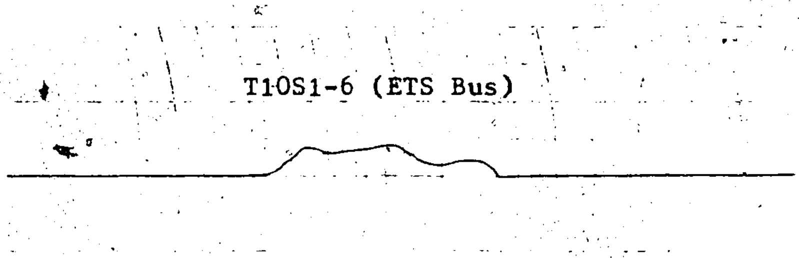
T10S1-3 (ETS Bus)



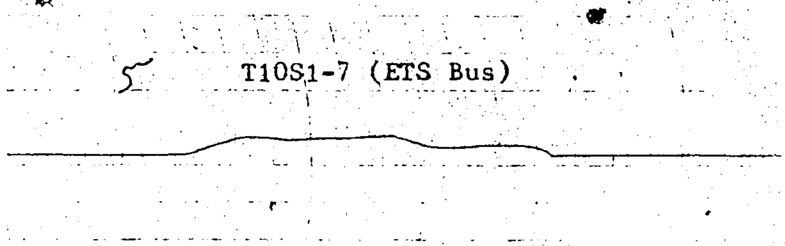
T10S1-4 (Car w/ Rec. Trailer)



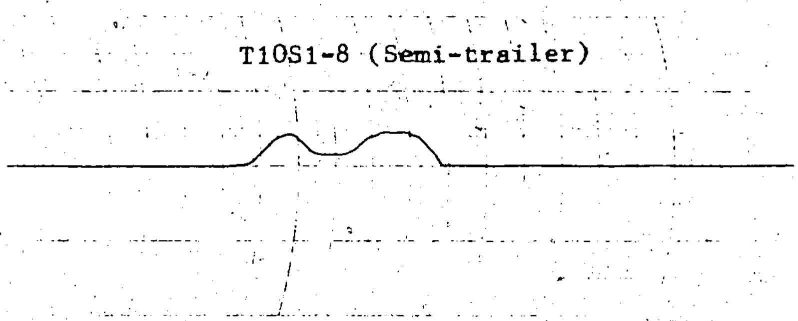
T10S1-5 (ETS Bus)



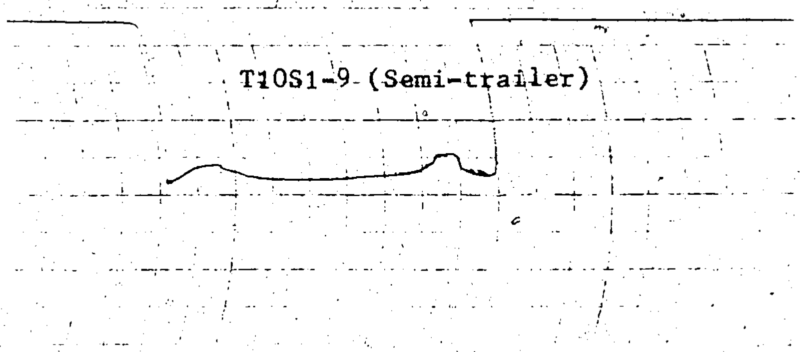
T10S1-6 (ETS Bus)



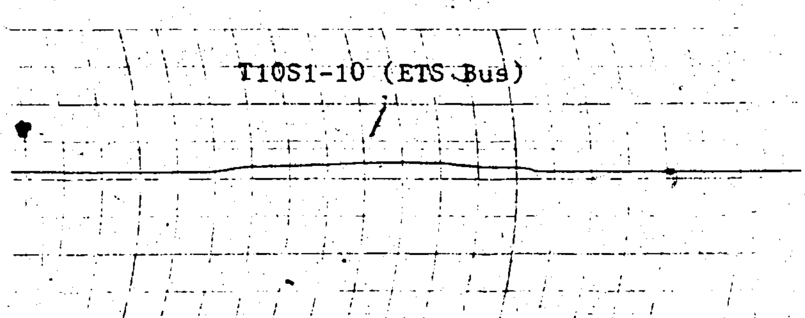
T10S1-7 (ETS Bus)



T10S1-8 (Semi-trailer)



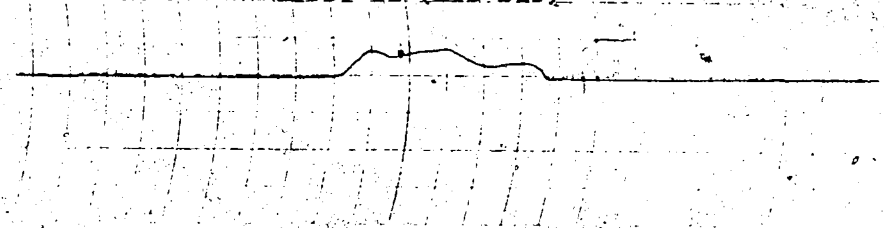
T10S1-9 (Semi-trailer)

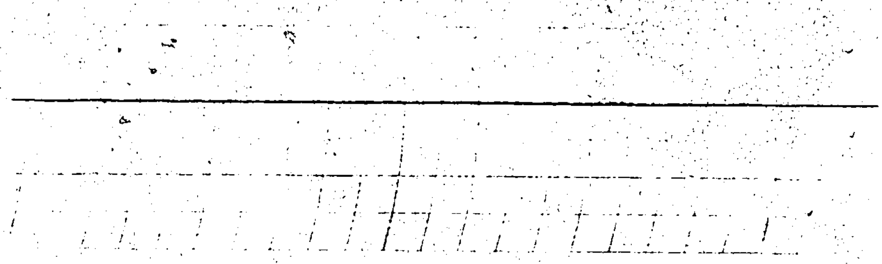


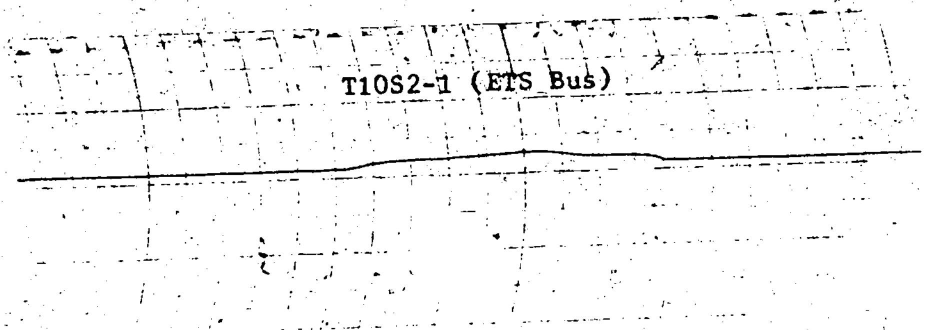
T10S1-10 (ETS Bus)

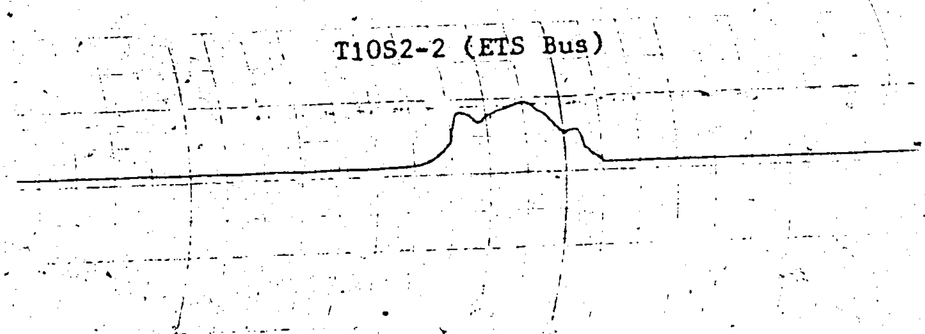
T10S1-11 (ETS Bus)

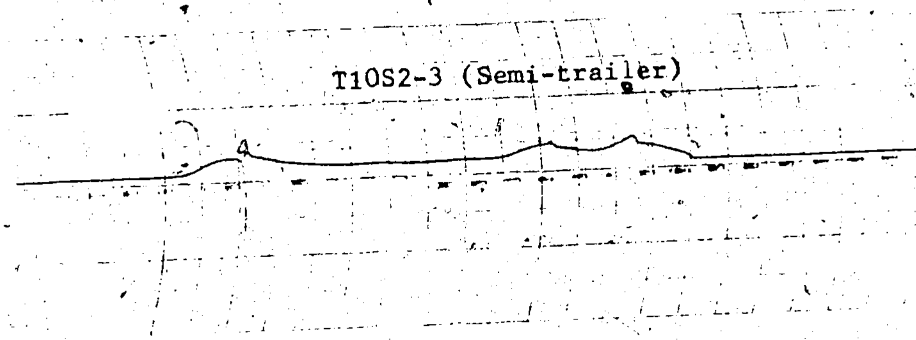
T10S1-12 (ETS Bus)

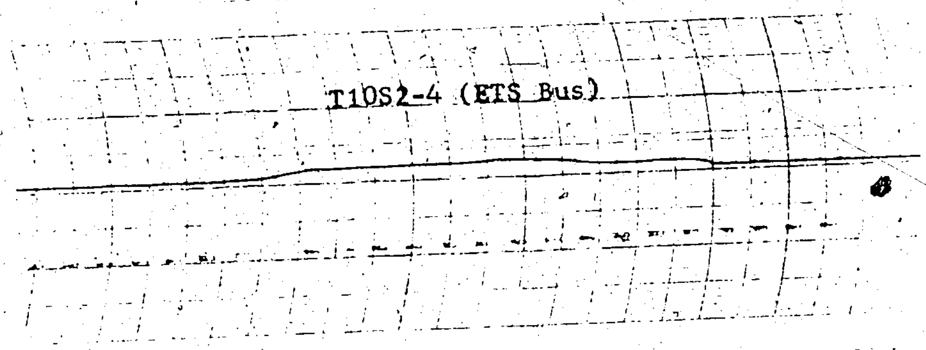


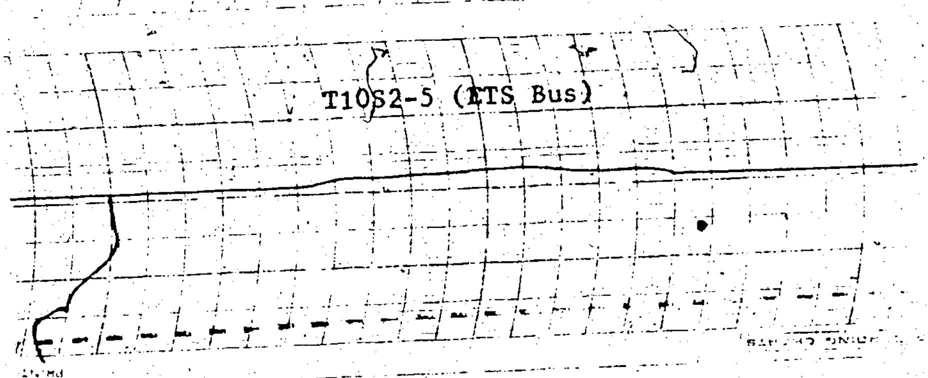



T10S2-1 (ETS Bus)

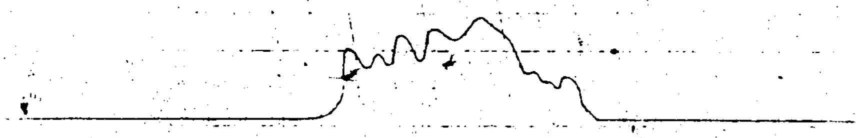

T10S2-2 (ETS Bus)


T10S2-3 (Semi-trailer)

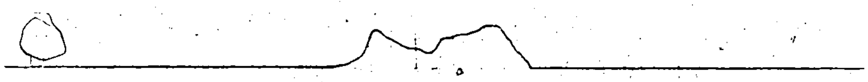

T10S2-4 (ETS Bus)


T10S2-5 (ETS Bus)

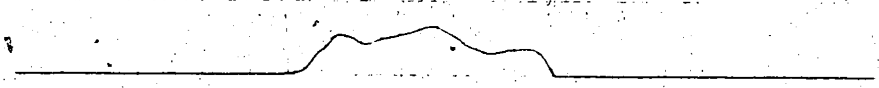
T10S2-6 (Auto Carrier)



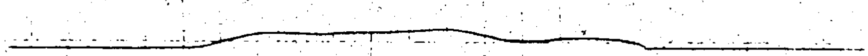
T10S2-7 (Semi-trailer)



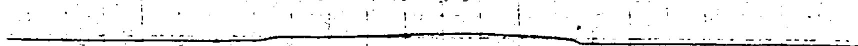
T10S2-8 (Ets Bus)



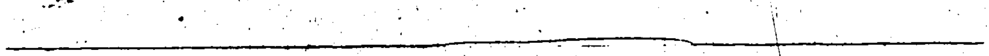
T10S2-9 (ETS Bus)



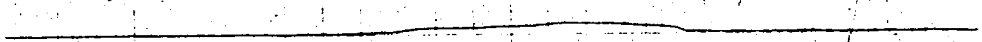
T10S2-10 (ETS Bus)



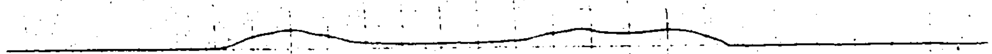
T10S2-11 (ETS Bus)



T10S2-12 (ETS Bus)



T10S2-13 (Semi-trailer)

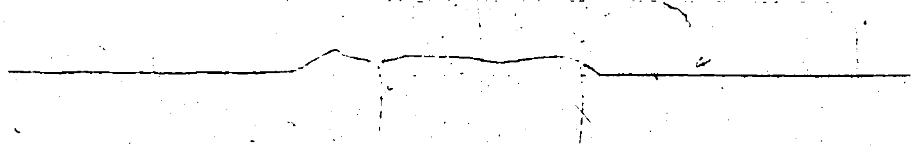


*T11S1	#Mx	#Mn	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
1	-	-	----	----	----	----	----	----	----	----	----	----	----
2	2	1	0AA0	03E2	0A55	0556	0A9F	05E2	----	----	----	----	0700
3	3	2	0A58	0172	0A36	022E	0AA1	0354	0A56	0498	0A95	051A	05FC
4	1	0	0A19	0354	----	----	----	----	----	----	----	----	0630
5	3	2	0A7A	0250	0A44	0422	0AAD	0830	0A5D	0C20	0AA0	0DAA	1050
6	3	2	0A26	0198	0A09	0290	0A63	03F8	0A22	05A0	0A56	0646	076A
7	3	2	0A33	0192	0A18	0280	0A7D	03D8	0A33	0578	0A6E	0608	0712
8	-	-	----	----	----	----	----	----	----	----	----	----	----
9	1	0	09EE	0364	----	----	----	----	----	----	----	----	06F0
10	3	2	0A5C	017C	0A3B	0226	0AA3	0380	0A5A	048A	0A9B	0514	05EE
11	-	-	----	----	----	----	----	----	----	----	----	----	----
12	-	-	----	----	----	----	----	----	----	----	----	----	----
13	3	2	0A69	0184	0A49	022C	0AB8	0368	0A6E	04A2	0ABA	0518	0606

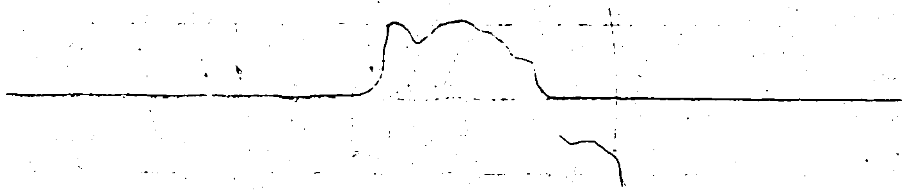
*T11S2													
1	3	2	0A5C	018A	0A33	0246	0A9B	03D8	0A51	0562	0A93	05F0	070E
2	1	0	0A0F	03EA	----	----	----	----	----	----	----	----	075A
3	1	0	09E9	0302	----	----	----	----	----	----	----	----	0652
4	2	1	0A2A	044E	090E	05D4	0A29	06FE	----	----	----	----	0836
5	1	0	0A16	03B2	----	----	----	----	----	----	----	----	06C2
6	3	2	0A83	01C0	0A4F	02B2	0AB7	0486	0A66	0660	0AAB	0720	088C
7	3	2	0A3C	019A	0A1D	0274	0A86	0400	0A38	05A4	0A70	064E	0770
8	2	1	0A2D	0488	0912	057A	0A24	0768	----	----	----	----	08BE
9	1	0	0A1B	03D6	----	----	----	----	----	----	----	----	0760
10	3	2	0A36	01A0	0A13	02A6	0A73	0436	0A2E	05F8	0A64	06B6	07EE
11	2	1	0ABC	03D0	0A67	0526	0AB3	05CE	----	----	----	----	06D6
12	1	0	09FF	03B0	----	----	----	----	----	----	----	----	071E
13	3	2	0A0E	01A2	09F3	02E2	0A35	04A0	0A0A	06AA	0A33	0784	08DA

* Tolerance value ε = 1B

T11S1-1 (ETS Bus)



T11S1-2 (ETS Bus)



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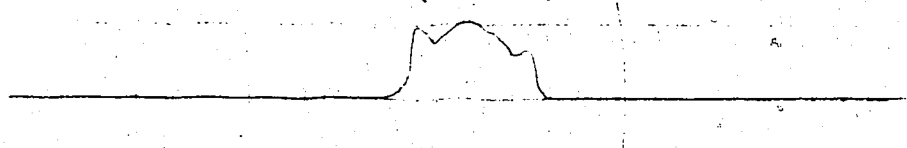

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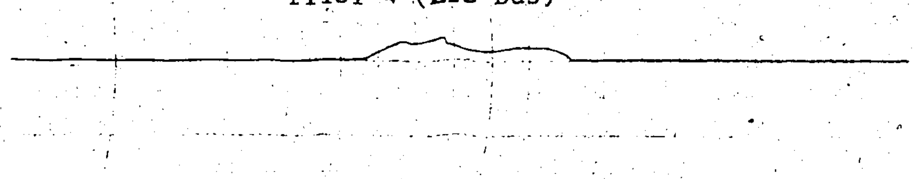

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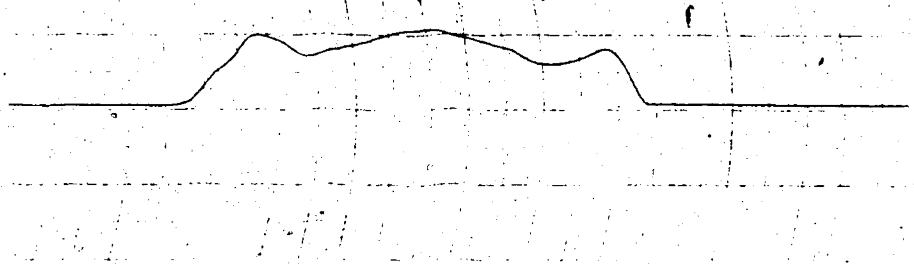
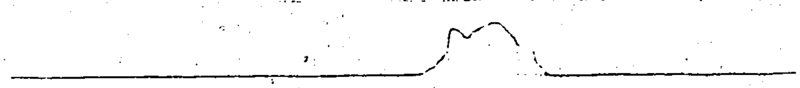
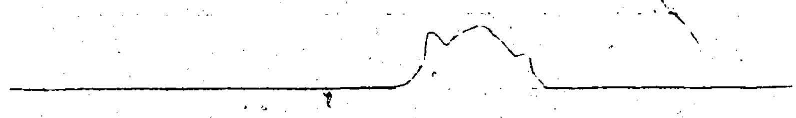


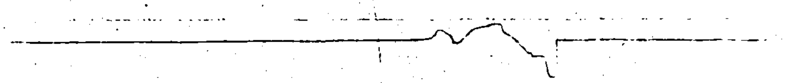
T11S1-6 (ETS Bus)



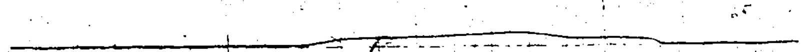
T11S1-7 (ETS Bus)



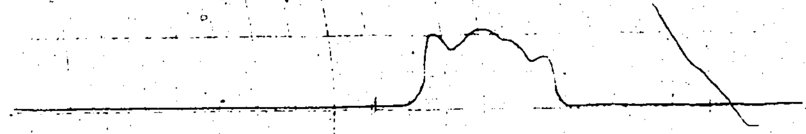
T11S1-8 (ETS Bus)



T11S1-9 (ETS Bus)

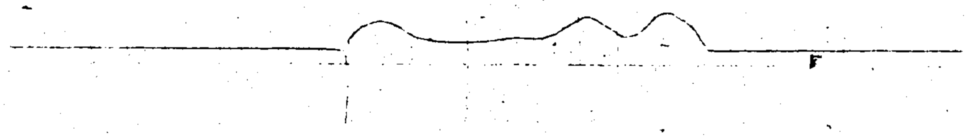


T11S1-10 (ETS Bus)

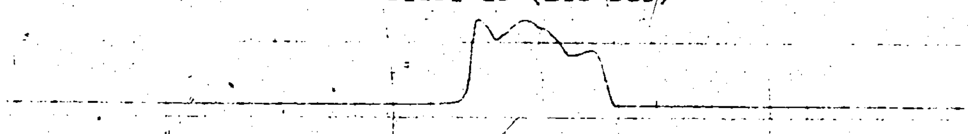


T11S1-11 (ETS Bus)

T11S1-12 (Semi-trailer)

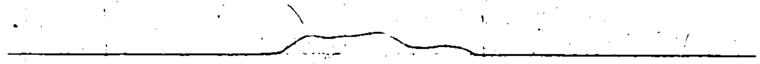


T11S1-13 (ETS Bus)

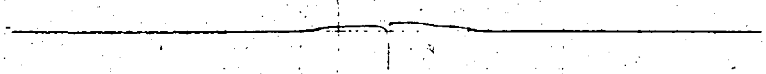


T11S2-1 (ETS Bus)

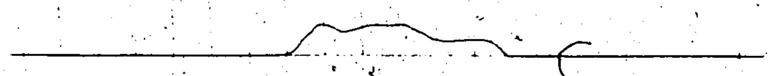
T11S2-2 (ETS Bus)



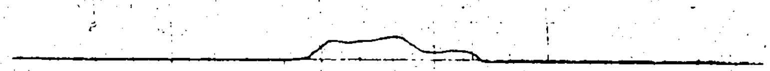
T11S2-3 (ETS Bus)



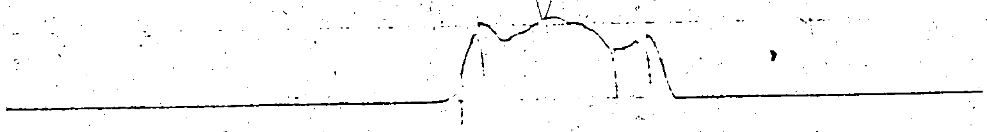
T11S2-4 (ETS Bus)



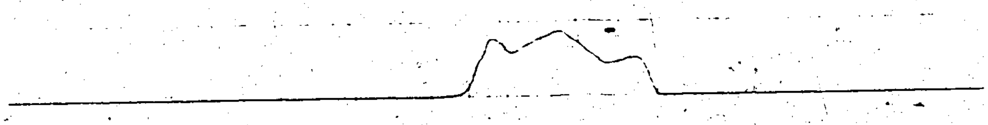
T11S2-5 (ETS Bus)



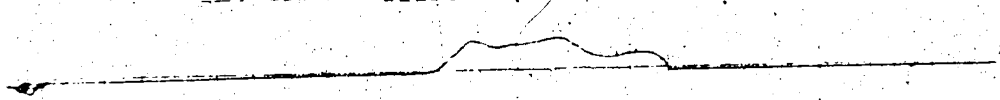
T11S2-6 (ETS Bus)



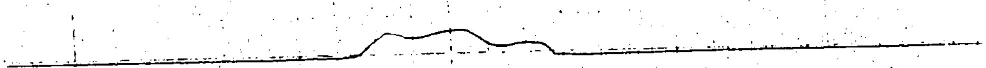
T11S2-7 (ETS Bus)



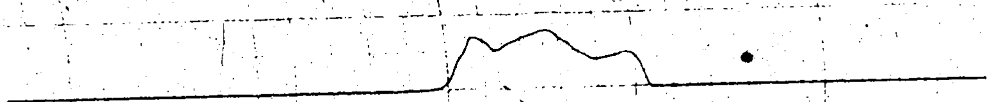
T11S2-8 (ETS Bus)



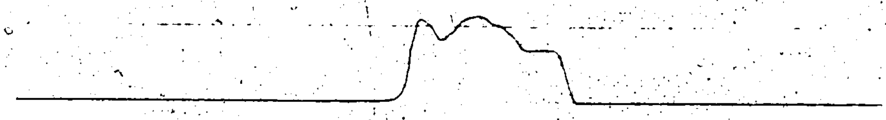
T11S2-9 (ETS Bus)



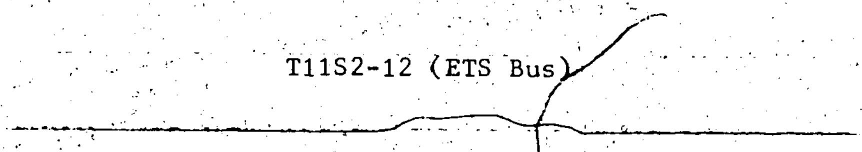
T11S2-10 (ETS Bus)



T11S2-11 (ETS Bus)



T11S2-12 (ETS Bus)



T11S2-13 (ETS Bus)

APPENDIX 3 DATA ACQUIRED VIA FEATURE

This appendix includes data acquired via the program FEATURE which extracts real-time features and stores them into designated memory locations.

No.	Veh.Type	#Mx	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
1	ETS Bus	3	0080	0198	FF65	01E7	006A	01FC	004E	0273	006F	02D1	02F0
2	Car	1	0100	009D	----	----	----	----	----	----	----	----	00E2
3	Car	1	0143	00A1	----	----	----	----	----	----	----	----	00BB
4	Stn.Wgn.	1	0111	00A8	----	----	----	----	----	----	----	----	00EB
5	½ Ton Tr.	1	00BA	0077	----	----	----	----	----	----	----	----	00C4
6	Van	1	00EB	007B	----	----	----	----	----	----	----	----	00CA
7	ETS Bus	1	004D	01A6	----	----	----	----	----	----	----	----	028D
8	½ Ton Tr.	1	00B2	008A	----	----	----	----	----	----	----	----	00B6
9	½ Ton Tr.	1	00CA	007A	----	----	----	----	----	----	----	----	00A0
10	Dairy Van	1	00DD	008D	----	----	----	----	----	----	----	----	00B8
11	Police C.	1	00F9	0085	----	----	----	----	----	----	----	----	00CA
12	Moving V.	2	0070	0069	FF54	00C8	005C	015A	----	----	----	----	01B8
13	Semi-T.	3	0089	0099	001B	01A7	0037	0234	0035	0238	0051	0265	028B
14	ETS Bus	2	006F	01EF	FF54	025C	0066	0377	----	----	----	----	03A4
15	Semi-T.	4	0064	0081	FF49	00FA	004F	0100	0026	0264	005A	0330	0381
16	ETS Bus	2	0060	0151	FF45	01D4	0055	0267	----	----	----	----	0293
17	ETS Bus	3	0095	0067	FF19	00A1	00DB	01E4	0090	02C6	00D2	0336	0352
18	Deli. Van	2	0077	0076	FF5C	00D3	006D	01BD	----	----	----	----	01F5
19	Moving V.	2	0089	006B	0025	01E8	0055	0269	----	----	----	----	028C
20	Semi-T.	5	0062	0090	FF47	00E9	0046	00EF	FF59	053F	005F	0546	058B
21	ETS Bus	2	0041	004B	0026	00DC	0061	0191	----	----	----	----	01E3
22	Semi-T.	4	004D	00D0	0010	0232	0049	0371	FF47	0B6E	004D	0B74	0BD0
23	Semi-T.	3	0082	0CCC	FF67	0D00	0072	0D49	0031	0DE6	0080	0EB6	0EEC
24	ETS Bus	2	006D	018E	FF50	01DC	005A	02D4	----	----	----	----	02FE
25	Semi-T.	2	009C	008F	0026	01FE	0057	0267	----	----	----	----	028F
26	Dump Tr.	3	0087	009C	FF6A	00EA	006D	00EB	004C	012F	0080	01C9	01F3
27	Dump Tr.	3	0080	0081	FF65	00B8	0068	00B9	0042	0106	006A	01A2	01CB
28	Dump Tr.	2	004F	006A	002F	00D6	004D	014B	----	----	----	----	017F
29	Semi-T.	4	00A8	00B4	FF8D	00F9	0092	0101	008F	06AB	00C6	07C8	080D
30	ETS Bus	3	0073	0048	FF57	00B1	00AE	0184	0068	0260	0092	02B2	02CD
31	ETS Bus	2	006B	0176	FF50	01EC	0061	028A	----	----	----	----	02CA
32	Semi-T.	4	005F	0082	FF00	00B7	0045	00B8	0020	0219	004E	02CD	031D
33	ETS Bus	3	00AD	005B	FF92	0084	00DC	01C9	0097	02A5	00D5	0302	031A
34	ETS Bus	3	0073	0042	004B	00BA	00A4	01A3	0065	01F5	00A9	0286	029F

No.	Veh.Type	#Mx	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
35	Car	1	0118	006C	----	----	----	----	----	----	----	----	0096
36	ETS Bus	3	007D	01A4	FF62	01EA	0068	01F0	004D	028E	0070	02DF	0305
37	Car	1	012E	0159	----	----	----	----	----	----	---	----	0186
38	ETS Bus	3	0089	01D4	FF6E	0224	0073	022C	0052	02D8	0077	0340	036B
39	Dump Tr.	2	0072	0073	FF57	0095	0077	0125	----	----	----	----	0141
40	Semi-T.	3	0059	0123	FF3E	0164	003D	0165	0022	01B5	004D	023E	0272
41	Car	1	0110	009C	----	----	----	----	----	----	----	----	00DE
42	½ Ton Tr.	2	00D4	006D	FFB9	00BB	00B8	00C4	----	----	----	----	00E2
43	Moving V.	2	0068	006D	FF4C	00A2	005C	011F	----	----	----	----	0177
44	Semi-T.	4	0074	008F	FF59	00C8	0069	014D	0039	0332	006F	0392	03BA
45	Car-on-Tow	2	00AA	0077	0029	0153	0101	023E	----	----	----	----	0264
46	ETS Bus	3	004E	0067	0030	011E	0071	0229	0047	0378	0068	03F0	0433
47	Semi-T.	3	0096	005E	FF7B	007B	0078	007D	0024	01C1	004F	02CB	02F4
48	ETS Bus	3	00BC	0080	FFA1	00AA	00ED	0222	00AC	0323	00E6	038E	03AE
49	Semi-T.	5	0085	0086	FF6A	00AA	006A	00AC	FF58	035E	005B	0362	0377
50	Semi-T.	3	007B	0075	FF5E	00AD	0061	00B3	0019	01CB	00B5	0211	0212
51	Semi-T.	3	007F	009B	001D	01B4	013B	0231	FF3D	0233	0053	0268	0291
52	Dump Tr.	2	006B	007F	FF4F	00B8	006C	016E	----	----	----	----	0198
53	Car	1	011C	009D	----	----	----	----	----	----	----	----	00BE
54	ETS Bus	3	0058	005C	003C	00DF	008E	01D2	0059	02D3	0086	033D	0369
55	ETS Bus	4	00B9	005C	FF9D	007A	009B	0083	0091	0280	00E1	031F	033B
56	Semi-T.	3	006C	0074	FF50	00DE	0063	0118	002C	0183	0058	0206	023B
57	Semi-T.	4	007B	009C	FF5F	00D0	0072	0159	FF3E	0374	0061	03DF	0435
58	ETS Bus	3	0055	0052	0038	00FB	0084	01B0	004C	02CD	006F	0338	0358
59	Van	1	00D7	0078	----	----	----	----	----	----	----	----	00F0
60	Cement Tr.	3	0059	008D	FF3D	00B9	0040	00BF	001F	011F	0066	01AD	01E6
61	Tr.&Trailr	3	00C5	00DB	FFA8	0131	00A8	0132	0031	02BC	009E	040F	0444
62	ETS Bus	3	008D	0088	006B	0147	00D3	029D	008C	03EE	00CD	0477	0496
63	ETS Bus	2	00F3	02A6	00A7	03CD	00EC	0457	----	----	----	----	0483
64	Dump Tr.	3	0075	00C7	FF5A	010E	005D	011A	0034	019E	0070	0274	02B4
65	Semi-T.	4	005E	025C	FF43	02A5	0049	02B1	FF40	06FB	0045	0705	0733
66	Dump Tr.	2	00AE	0100	FF92	0143	0093	0153	----	----	----	----	01D6
67	Tr.&Trailr	2	00A6	00DA	FF8B	01BE	008C	01BF	----	----	----	----	01D9
68	ETS Bus	2	0061	027D	0040	03C1	005D	045B	----	----	----	----	0494

No.	Veh.Type	#Mx	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
69	ETS Bus	3	003D	0094	0022	016D	0064	02A5	FF48	037D	005F	04C1	0507
70	Dump Tr.	3	0081	00DC	FF65	011F	0066	0121	0043	0173	0075	023A	027C
71	Semi-T.	4	0069	01A8	FF4E	0202	005B	03ED	0022	0746	0055	0960	09D3
72	Semi-T.	5	0064	00B3	FF48	00F8	004B	00FE	002E	0535	0076	05E3	0614
73	ETS Bus	3	004F	0084	0029	0159	005B	030E	003D	0397	0067	0500	0535
74	ETS Bus	3	004F	009A	002E	0194	0074	02EA	0046	04A3	0068	0553	05A9
75	Car	1	011F	00FF	----	----	----	----	----	----	----	----	0132
76	Dump Tr.	3	0062	0118	FF44	016E	0047	016F	0029	01EE	004E	02EA	034A
77	ETS Bus	3	0068	006A	FF4D	0119	009F	025C	0061	039D	0094	0420	044F
78	Semi-T.	4	0090	0122	00C3	0212	0065	02A7	003B	060B	0070	068B	06FA
79	Semi-T.	5	009D	00C9	FF82	0107	0083	0108	003E	04C2	0066	0541	05B0
80	ETS Bus	3	00BF	00A7	0097	0157	00F5	02C1	00AD	03FF	00EA	049A	04C2
81	ETS Bus	3	0089	009C	005A	0185	00B6	0343	0072	041C	00B5	0545	0573
82	ETS Bus	3	006A	031B	FF4F	03F7	005F	0443	0043	0503	0062	05B1	0609
83	½Ton Tr.	2	00C5	00Ac	FFAA	00DF	00A9	00E1	----	----	----	----	09BA
84	Semi-T.	5	008C	00A9	002C	0147	0082	01E4	0039	0463	0076	0500	054F
85	Semi-T.	5	0087	0090	FF68	00AA	006B	00AB	0021	02D1	003D	031D	031E
86	Moving V.	2	006A	0080	0021	019B	013E	021B	----	----	----	----	021C
87	Semi-T.	2	0064	006F	0020	01EE	013C	9232	----	----	----	----	09C0
88	Car	1	00FA	009F	----	----	----	----	----	----	----	----	00E5
89	ETS Bus	2	0065	021C	FF49	0305	0065	03B3	----	----	----	----	03EA
90	Semi-T.	3	0077	006E	002F	00CD	004C	0128	0024	01CD	0042	023B	0264
91	Semi-T.	4	0071	010E	FF56	0139	0058	0140	FF47	03AC	0046	03AD	03C4
92	Garbage Tr.	3	008E	0051	FF73	0088	007A	0090	0047	00E4	0074	0143	016D
93	ETS Bus	2	005C	0190	FF41	0208	004E	02CD	----	----	----	----	0305
94	Semi-T.	4	0081	0085	FF66	00B4	0064	00B6	002B	0231	0069	02D0	0317
95	ETS Bus	3	0081	0066	0058	0113	00C1	0217	0078	0325	00B0	039D	03B9
96	Dump Tr.	2	0068	0066	0040	00C4	0062	0124	----	----	----	----	014C
97	ETS Bus	3	0095	0054	0076	00BE	00D7	0184	0090	023A	00CF	028D	02A1
98	ETS Bus	2	0043	0083	0028	015D	0063	0284	----	----	----	----	0355
99	ETS Bus	3	00BA	0055	0090	00B0	00EF	0199	00AB	024F	00EB	02A3	02B6
100	Moving V.	2	008B	009C	0041	01C4	0080	02A3	----	----	----	----	02D0
101	Moving V.	2	005F	0076	FF44	00AF	0054	0133	----	----	----	----	018D
102	ETS Bus	3	00AE	0056	FF93	00A1	00EE	0199	00AC	025D	00ED	02AE	02D4

No.	Veh.Type	#Mx	Mx1	Tx1	Mn1	Tn1	Mx2	Tx2	Mn2	Tn2	Mx3	Tx3	T
103	G.H. Bus	2	00C9	0137	005C	02B8	0078	0316	----	----	----	----	0360
104	Semi-T.	3	008A	00C1	001E	0307	013A	0388	FF43	0394	0079	03FA	0432
105	Semi-T.	4	008C	0073	002B	00EE	005A	013F	0033	0327	0065	0386	03CB
106	ETS Bus	3	00A0	005B	FF85	00AB	00E3	01B3	009C	0276	00DF	02D4	02F2
107	ETS Bus	3	00A6	0047	0089	0099	00E8	016C	00AA	0209	00EB	024D	0267
108	ETS Bus	3	0088	018F	FF6D	01DC	0073	01F0	0054	0275	0077	02C7	02E6
109	ETS Bus	3	00BC	004D	008D	009F	00F4	016E	00AC	01E9	00DD	022C	0249
110	Semi-T.	4	0065	007E	FF4A	00D2	0056	013F	FF40	0418	0040	041E	0439
111	ETS Bus	3	008E	0041	FF73	00A9	00D1	0161	008A	021A	00CB	0261	0278
112	Garbage Tr.	2	008B	0052	0043	00F0	0072	014F	----	----	----	----	0183
113	ETS Bus	2	0073	01F1	FF58	026C	0064	0395	----	----	----	----	03C9
114	Schl. Bus	2	0087	00A5	FF6B	0139	0078	017C	----	----	----	----	01C0
115	ETS Bus	3	00A1	0044	0075	0098	00E0	0158	0095	01B8	00D8	0226	023C
116	Semi-T.	3	0080	008A	FF64	00D2	0070	010B	002A	02C5	0060	03DC	041F
117	Semi-T.	4	006E	00aa	FF53	013A	0055	013D	0035	02B5	0075	0300	0328
118	ETS Bus	3	008D	0050	006C	0094	00D3	0175	0088	0238	00CC	0287	029D
119	Semi-T.	3	0095	009B	0043	00EF	0068	015B	0024	0229	0076	0369	039E
120	ETS Bus	2	0072	0168	FF57	01F8	0071	027F	----	----	----	----	029E
121	ETS Bus	3.	0062	0054	0046	00D8	009D	019C	005F	027B	008F	02D9	02F9
122	ETS Bus	3	00AA	00B8	FF8F	00C7	00E6	01FE	009B	02F7	00D3	0352	036F
123	ETS Bus	3	0058	005B	003B	00ED	0088	01C6	0051	02D4	0077	0326	035E
124	Semi-T.	4	008B	0090	FF70	00C7	0070	00C9	0029	025C	0066	031E	037B
125	Semi-T.	4	0078	0084	FF5B	00AB	0059	00AD	002D	0233	0054	029C	02DF
126	ETS Bus	2	0059	0203	FF3E	02CD	0050	03BF	----	----	----	----	03FB
127	ETS Bus	3	0061	0036	FF45	007D	0075	0174	FF59	01AE	007B	0263	0287
128	Van	1	00B0	0084	----	----	----	----	----	----	----	----	00D0

APPENDIX 4 PROGRAM LISTING

This appendix includes:

1. Data used in Fig. 4.4 Artificial Test Data in Chapter 4, and the emulated result (underlined) from FETD using the Motorola M6800 Emulator via the AMDAHL computer.

2. Program listing of CLASSIF.

```
IM
SM 0016,01,4E
SM 0018,30
SM 0100,09 0AC,09,0CB,09,0DB,09,0FA,0A,2C,0A,1B,09,0FE,0A,24
SM 0110,0A,20,0A,1B,0A,2E,0A,02,09,0F0,09,0EA,0A,06,09,0EE
SM 0120,09,0F0,0A,0B,09,0FB,0A,2E,0A,30,0A,4E,0A,35,0A,4F
SM 0130,0A,2E,0A,3B,0A,28,0A,20,09,0FE,0A,2A,0A,30,0A,4C
SM 0140,0A,32,0A,5D,0A,28,0A,00,0A,20,09,0BE,09,0DD,09,77
DM 0000,30
DM 0100,50
SR P 3000
R 389
DM 0000,30
EX
```

Data values (artificial) in Fig. 4.4 of Chapter 4.

```
     M68EML is the property of Motorola Spd, Inc.
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          Motorola M6800 Emulator, Release 1.0

 HH IA   OC    EA    P     X    A   B    C      S      T
  0000 ***    0000 0000 0000 00 00 000000 0000 0000000
 0000 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
 0010 00 00 00 00 00 00 01 4E 30 00 00 00 00 00 00 00 .....
 0020 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
 0100 09 AC 09 CB 09 DB 09 FA 0A 2C 0A 1B 09 FE 0A 24 .....
 0110 0A 20 0A 1B 0A 2E 0A 02 09 F0 09 EA 0A 06 09 EE . ...
 0120 09 F0 0A 0B 09 FB 0A 2E 0A 30 0A 4E 0A 35 0A 4F .....
 0130 0A 2E 0A 3B 0A 28 0A 20 09 FE 0A 2A 0A 30 0A 4C .....
 0140 0A 32 0A 5D 0A 28 0A 00 0A 20 09 BE 09 DD 09 77 .2.~.
 Memory Fault at FFFA
 *3123 SWI   *7FFB 0000*014E*01*4E 0I0Z00*FFF9 0003425
 0000 24 02 0A 2E 01 14 09 EA 01 1A 0A 4F 01 2E 09 FE $....
 0010 01 38 0A 5D 01 42 01 4E 30 09 BE 0A DD CE 01 4A .8.~.
 0020 01 4E 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .N...
#10:50:58  T=.785  RC=0
#
```

Emulated result from FETD.

[N.B.] Underlined values are the local maxima and the local minima extracted by FETD.

Motorola M6800 Cross Assembler, Release 1.1

```
                    NAM    CLASSIF
               *
               *    DATA STORAGE
               *
0000 0001      MXCNT  RMB    $1        # OF MAXIMA DETECTED
0001 0001      MNCNT  RMB    $1        # OF MINIMA DETECTED
0002 0001      MX1H   RMB    $1        MSB OF 1ST MAX
0003 0001      MX1L   RMB    $1        LSB OF 1ST MAX
0004 0002      TMX1   RMB    $2        TIME OF THE 1ST MAX
0006 0001      MN1H   RMB    $1        MSB OF 1ST MIN
0007 0001      MN1L   RMB    $1        LSB OF 1ST MIN
0008 0002      TMN1   RMB    $2        TIME OF THE 1ST MIN
000A 0001      MX2H   RMB    $1        MSB OF 2ND MAX
000B 0001      MX2L   RMB    $1        LSB OF 2ND MAX
000C 0002      TMX2   RMB    $2        TIME OF THE 2ND MAX
000E 0001      MN2H   RMB    $1        MSB OF 2ND MIN
000F 0001      MN2L   RMB    $1        LSB OF 2ND MIN
0010 0002      TMN2   RMB    $2        TIME OF THE 2ND MIN
0012 0001      MX3H   RMB    $1        MSB OF 3RD MAX
0013 0001      MX3L   RMB    $1        LSB OF 3RD MAX
0014 0002      TMX3   RMB    $2        TIME OF THE 3RD MAX
0016 0001      LADXH  RMB    $1        LAST ADX OF DATA (HIGH)
0017 0001      LADXL  RMB    $1        LAST ADX OF DATA (LOW)
0018 0001      EPSILO RMB    $1        TOLERANCE VALUE ($1B)
0019 0001      BIASH  RMB    $1        MSB OF BIASED VOLTAGE
001A 0001      BIASL  RMB    $1        LSB OF BIASED VOLTAGE
001B 0001      HITHD  RMB    $1        MSB OF INPUT THRESHOLD
001C 0001      LITHD  RMB    $1        LSB OF INPUT THRESHOLD
001D 0001      HOTHD  RMB    $1        MSB OF OUTPUT THRESHOLD
001E 0001      LOTHD  RMB    $1        LSB OF OUTPUT THRESHOLD
001F 0001      TIME   RMB    $1        SAMPLING TIMER ($E0)
0020 0001      XHI1   RMB    $1        DATA SCRATCH
0021 0001      XLI1   RMB    $1        DATA SCRATCH
0022 0001      XTHI   RMB    $1        DATA SCRATCH
0023 0001      XTLI   RMB    $1        DATA SCRATCH
0024 0001      XT     RMB    $1        DATA SCRATCH
0025 0001      TSX1   RMB    $1        DATA SCRATCH
0026 0001      TSX2   RMB    $1        DATA SCRATCH
0027 0001      TSX3   RMB    $1        DATA SCRATCH
0028 0001      TSX4   RMB    $1        DATA SCRATCH
0029 0001      MULT   RMB    $1        MUXN FACTOR (SCRATCH)
002A 0001      TT22   RMB    $1        MUXN FACTOR ,K-1 (1,2)
002B 0001      TT21   RMB    $1        MUXN FACTOR ,K-1  (5)
002C 0001      TT3    RMB    $1        MUXN FACTOR ,K-1 (1,2)
002D 0001      INVTXH RMB    $1        TIMING (K X TMX1-H)
```

```
002E 0001        INVTXL RMB    $1       TIMING (K X TMX1-L)
002F 0002        STORE  RMB    $2       DATA SCRATCH
0031 0001        TEMP1  RMB    $1       DATA SCRATCH
0032 0002        XTEMP  RMB    $2       DATA SCRATCH
0034 0002        DTEMP1 RMB    $2       PRESENT CHANNEL
0036 0002        DTEMP2 RMB    $2       DATA SCRATCH
0038 0002        TEMP20 RMB    $2       OUTPUT TIMER (FFFF)
003A 0001        IPTHR  RMB    $1       INPUT THRESHOLD ($1B)
003B 0001        OPTHR  RMB    $1       OUTPUT THRESHOLD ($0E)
003C 0002        DTEMP3 RMB    $2       DATA SCRATCH
003E 0002        DTEMP4 RMB    $2       DATA SCRATCH
0040 0001        TEMP5  RMB    $1       DATA SCRATCH
                 *
                 *    THIS PROGRAMME SCANS TWO INPUT A/D CHAN-
                 *    NELS (ONE FROM EACH LOOP) AND TWO
                 *    OUTPUT D/A CHANNELS ($4100 AND
                 *    $4101, $4102 AND $4103) TO ACTUATE
                 *    TWO CONTROL DEVICES
                 *
                 *        GATE 1
                 *          CHANNEL 1  $0050 TO $0055
                 *        GATE 2
                 *          CHANNEL 2  $0058 TO $005D
                 *
E000                    ORG    $E000
                 *
                 *    INPUT AND OUTPUT THRESHOLD VALUES SETTING
                 *
E000 8E 00FF     NEW    LDS    #$00FF
E003 CE 0800            LDX    #$0800
E006 FF 4100            STX    $4100
E009 FF 4102            STX    $4102
E00C 86 10              LDA A  #$10
E00E 97 31              STA A  TEMP1
                 *
E010 CE 4000     AVG    LDX    #$4000
E013 86 50              LDA A  #$50
                 *
E015 7F 002F     SCAN   CLR    STORE
E018 97 30              STA A  STORE+1
E01A A7 00              STA A  00,X
E01C 01                 NOP
E01D A6 00              LDA A  00,X
E01F E6 01              LDA B  01,X
E021 BD E296            JSR    THRESET
E024 08                 INX
E025 08                 INX
E026 96 30              LDA A  STORE+1
E028 8B 08              ADD A  #$08
E02A 8C 4004            CPX    #$4004
```

```
E02D 26 E6              BNE    SCAN
E02F 7A 0031            DEC    TEMP1
E032 26 DC              BNE    AVG
                   *
                   *    INPUT THRESHOLD TESTING (VEHICLE PRESENT ?)
                   *
                   *    A THRESHOLD UPDATE SEQUENCE AT 0.12
                   *    SEC INTERVALS IS INCLUDED TO RESET
                   *    THE THRESHOLD VALUES AFTER A DISABLE
                   *    VEHICLE LEAVES THE DETECTION ZONE
                   *
E034 86 FF              LDA A  #$FF
E036 97 40              STA A  TEMP5
E038 CE 4000  STARTQ    LDX    #$4000
E03B 7F 002F  CHGE      CLR    STORE
E03E 86 50              LDA A  #$50
E040 97 30              STA A  STORE+1
                   *
E042 DF 32    START1    STX    XTEMP
E044 DE 2F              LDX    STORE
E046 A6 00              LDA A  00,X
E048 E6 01              LDA B  01,X
E04A 97 19              STA A  BIASH
E04C D7 1A              STA B  BIASL
E04E A6 02              LDA A  02,X
E050 E6 03              LDA B  03,X
E052 97 1B              STA A  HITHD
E054 D7 1C              STA B  LITHD
E056 A6 04              LDA A  04,X
E058 E6 05              LDA B  05,X
E05A 97 1D              STA A  HOTHD
E05C D7 1E              STA B  LOTHD
E05E DE 32              LDX    XTEMP
E060 A7 00              STA A  00,X
E062 01                 NOP
E063 A6 00              LDA A  00,X
E065 91 1B              CMP A  HITHD
E067 2D 0A              BLT    NEXT
E069 2E 1D              BGT    CONV
E06B E6 01              LDA B  01,X
E06D D1 1C              CMP B  LITHD
E06F 22 17              BHI    CONV
E071 27 15              BEQ    CONV
E073 96 30    NEXT      LDA A  STORE+1
E075 8B 08              ADD A  #$08
E077 97 30              STA A  STORE+1
E079 08                 INX
E07A 08                 INX
E07B 8C 4004            CPX    #$4004
E07E 26 C2              BNE    START1
```

```
E080 7A 0040                DEC      TEMP5
E083 26 B3                  BNE      STARTO
E085 7E E000                JMP      NEW
                *
E088 DF 34      CONV        STX      DTEMP1
                *
                *    INITIALIZATION
                *
E08A CE 0000                LDX      #$0000    (RESET TIME COUNTER)
E08D 7F 0000                CLR      MXCNT     (RESET MAXIMA COUNTER)
E090 7F 0001                CLR      MNCNT     (RESET MINIMA COUNTER)
E093 BD E2B7                JSR      FETCHA
                *
                *    MAXIMA DETECTION
                *
E096 97 20      MXD         STA A    XHI1
E098 D7 21                  STA B    XLI1
E09A DF 25                  STX      TSX1
E09C 08         FLSMX       INX
E09D BD E277                JSR      TL1
E0A0 BD E2B7                JSR      FETCHA
E0A3 91 20                  CMP A    XHI1
E0A5 2E EF                  BGT      MXD       (A>XHI1)
E0A7 2D 10                  BLT      LESS
E0A9 D1 21                  CMP B    XLI1      (A=XHI1)
E0AB 22 E9                  BHI      MXD       (B> OR = XLI1)
E0AD 27 E7                  BEQ      MXD
E0AF D7 23                  STA B    XTLI      (B<XLI1)
E0B1 CB 1B                  ADD B    #$1B
E0B3 25 E7                  BCS      FLSMX
E0B5 D1 21                  CMP B    XLI1
E0B7 20 17                  BRA      CMPMX
E0B9 97 22      LESS        STA A    XTHI      (A<XHI1)
E0BB D7 23                  STA B    XTLI
E0BD D1 21                  CMP B    XLI1
E0BF 23 11                  BLS      STRMX     (B< OR = XLI1)
E0C1 D0 21                  SUB B    XLI1      (B>XLI1)
E0C3 5A                     DEC B
E0C4 D7 24                  STA B    XT
E0C6 C6 FF                  LDA B    #$FF
E0C8 D0 24                  SUB B    XT
E0CA C1 1B                  CMP B    #$1B
E0CC 2D CE                  BLT      FLSMX
E0CE 20 02                  BRA      STRMX
E0D0 22 CA      CMPMX       BHI      FLSMX
E0D2 7C 0000    STRMX       INC      MXCNT
E0D5 D6 00                  LDA B    MXCNT
E0D7 C1 02                  CMP B    #$02
E0D9 27 17                  BEQ      NDMX
E0DB 22 2A                  BHI      RDMX
```

```
E0DD 96 20            LDA A  XHI1      (STORE 1ST MAX.)
E0DF D6 21            LDA B  XLI1
E0E1 BD E27D          JSR    BIASED
E0E4 97 02            STA A  MX1H
E0E6 D7 03            STA B  MX1L
E0E8 DF 27            STX    TSX3
E0EA DE 25            LDX    TSX1
E0EC DF 04            STX    TMX1
E0EE DE 27            LDX    TSX3
E0F0 20 28            BRA    CONTD
E0F2 96 20    NDMX    LDA A  XHI1      (STORE 2ND MAX.)
E0F4 D6 21            LDA B  XLI1
E0F6 BD E27D          JSR    BIASED
E0F9 97 0A            STA A  MX2H
E0FB D7 0B            STA B  MX2L
E0FD DF 27            STX    TSX3
E0FF DE 25            LDX    TSX1
E101 DF 0C            STX    TMX2
E103 DE 27            LDX    TSX3
E105 20 13            BRA    CONTD
E107 96 20    RDMX    LDA A  XHI1      (STORE 3RD MAX.)
E109 D6 21            LDA B  XLI1
E10B BD E27D          JSR    BIASED
E10E 97 12            STA A  MX3H
E110 D7 13            STA B  MX3L
E112 DF 27            STX    TSX3
E114 DE 25            LDX    TSX1
E116 DF 14            STX    TMX3
E118 DE 27            LDX    TSX3
E11A 96 22    CONTD   LDA A  XTHI
E11C D6 23            LDA B  XTLI
              *
              *   MINIMA DETECTION
              *
E11E 97 20    MND     STA A  XHI1
E120 D7 21            STA B  XLI1
E122 DF 25            STX    TSX1
E124 08       FLSMN   INX
              *
              *   OUTPUT THRESHOLD TESTING
              *
E125 96 1D            LDA A  HOTHD
E127 91 20            CMP A  XHI1
E129 2E 08            BGT    STLST     (HOTHD>XHI1)
E12B 2D 0C            BLT    CONTD2    (HOTHD<XHI1)
E12D D6 1E            LDA B  LOTHD     (HOTHD=XHI1)
E12F D1 21            CMP B  XLI1
E131 2D 06            BLT    CONTD2    (LOTHD<XLI1)
E133 DE 27    STLST   LDX    TSX3      (LOTHD>XLI1)
E135 DF 16            STX    LADXH
```

```
E137 20 76            BRA     EXIT
                *
E139 BD E277  CONTD2  JSR     TL1
E13C BD E2B7          JSR     FETCHA
E13F 91 20            CMP A   XHI1
E141 2D DB            BLT     MND       (A<XHI1)
E143 2E 0E            BGT     GRE
E145 D1 21            CMP B   XLI1      (A=XHI1)
E147 23 D5            BLS     MND       (B< OR =XLI1)
E149 D7 23            STA B   XTLI      (B>XLI1)
E14B C0 1B            SUB B   #$1B
E14D 25 D5            BCS     FLSMN
E14F D1 21            CMP B   XLI1
E151 20 1D            BRA     CMPMN
E153 97 22    GRE     STA A   XTHI      (A>XHI1)
E155 D7 23            STA B   XTLI
E157 D1 21            CMP B   XLI1
E159 22 17            BHI     STRMN     (B> OR = XLI1)
E15B 27 15            BEQ     STRMN
E15D D7 24            STA B   XT        (B<XLI1)
E15F D6 21            LDA B   XLI1
E161 D0 24            SUB B   XT
E163 D7 24            STA B   XT
E165 C6 FF            LDA B   #$FF
E167 D0 24            SUB B   XT
E169 5C               INC B
E16A C1 1B            CMP B   #$1B
E16C 23 B6            BLS     FLSMN
E16E 20 02            BRA     STRMN
E170 23 B2    CMPMN   BLS     FLSMN
E172 7C 0001  STRMN   INC     MNCNT
E175 D6 01            LDA B   MNCNT
E177 C1 01            CMP B   #$01
E179 26 1A            BNE     NDMN
E17B 96 20            LDA A   XHI1      (STORE 1ST MIN.)
E17D D6 21            LDA B   XLI1
E17F BD E27D          JSR     BIASED
E182 97 06            STA A   MN1H
E184 D7 07            STA B   MN1L
E186 DF 27            STX     TSX3
E188 DE 25            LDX     TSX1
E18A DF 08            STX     TMN1
E18C DE 27            LDX     TSX3
E18E 96 22            LDA A   XTHI
E190 D6 23            LDA B   XTLI
E192 7E E096          JMP     MXD
E195 96 20    NDMN    LDA A   XHI1      (STORE 2ND MIN.)
E197 D6 21            LDA B   XLI1
E199 BD E27D          JSR     BIASED
E19C 97 0E            STA A   MN2H
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E19E D7 0F          STA B   MN2L
E1A0 DF 27          STX     TSX3
E1A2 DE 25          LDX     TSX1
E1A4 DF 10          STX     TMN2
E1A6 DE 27          LDX     TSX3
E1A8 96 22          LDA A   XTHI
E1AA D6 23          LDA B   XTLI
E1AC 7E E096        JMP     MXD
               *
               *    CLASSIFICATION ROUTINE
               *    THE ALGORITHM IS BASED ON THE NUMBER
               *    OF MAXIMA, THE RATIO BETWEEN THE TIME
               *    THE FIRST MAXIMUM IS DETECTED AND THE
               *    DURATION OF THE SIGNATURE, AND THE
               *    MAGNITUDE OF THE FIRST MAXIMUM COM-
               *    PARED TO THE MAGNITUDE OF THE SECOND
               *    MAXIMUM
               *
E1AF 96 00     EXIT     LDA A   MXCNT
E1B1 81 02              CMP A   #$02
E1B3 2D 6F              BLT     RETURN
E1B5 27 2A              BEQ     NEQ2
E1B7 81 04              CMP A   #$04
E1B9 22 69              BHI     RETURN
               *
E1BB 96 02     NEQ3     LDA A   MX1H
E1BD 91 0A              CMP A   MX2H
E1BF 22 16              BHI     TMTST3
E1C1 27 06              BEQ     LBTST3
E1C3 BD E244            JSR     BUS
E1C6 7E E224            JMP     RETURN
               *
E1C9 D6 03     LBTST3   LDA B   MX1L
E1CB D1 0B              CMP B   MX2L
E1CD 22 08              BHI     TMTST3
E1CF 27 06              BEQ     TMTST3
E1D1 BD E244            JSR     BUS
E1D4 7E E224            JMP     RETURN
               *
E1D7 86 02     TMTST3   LDA A   #$02
E1D9 97 29              STA A   MULT
E1DB BD E2C5            JSR     HALF      (2)
E1DE 7E E204            JMP     HI12
               *
E1E1 96 02     NEQ2     LDA A   MX1H
E1E3 81 01              CMP A   #$01
E1E5 27 3B              BEQ     RETURN
E1E7 91 0A              CMP A   MX2H
E1E9 22 12              BHI     TMTST2
E1EB 27 0A              BEQ     LBTST2
```

```
                    *
E1ED 86 05     BACK    LDA A   #$05        (MX1H<MX2H)
E1EF 97 29             STA A   MULT
E1F1 BD E22A           JSR     INVNOR
E1F4 7E E215           JMP     LO12
                    *
E1F7 D6 03     LBTST2  LDA B   MX1L
E1F9 D1 0B             CMP B   MX2L
E1FB 23 F0             BLS     BACK
                    *
E1FD 86 02     TMTST2  LDA A   #$02        (MX1>MX2)
E1FF 97 29             STA A   MULT
E201 BD E2C5           JSR     HALF        (2)
                    *
E204 91 16     HI12    CMP A   LADXH
E206 22 08             BHI     HIBUS
E208 27 02             BEQ     HIEQU
E20A 20 18             BRA     RETURN
E20C D1 17     HIEQU   CMP B   LADXL
E20E 23 14             BLS     RETURN
E210 BD E244   HIBUS   JSR     BUS         (K X TMX1>LADXH)
E213 20 0F             BRA     RETURN
                    *
E215 91 16     LO12    CMP A   LADXH
E217 22 0B             BHI     RETURN
E219 27 02             BEQ     LOEQU
E21B 20 04             BRA     LOBUS
E21D D1 17     LOEQU   CMP B   LADXL
E21F 22 03             BHI     RETURN
E221 BD E244   LOBUS   JSR     BUS         (K X TMX1< OR = LADXH)
E224 BD E2E1   RETURN  JSR     LEFT
E227 7E E000           JMP     NEW
                    *
                    *     SUBROUTINE INVNOR
                    *     THIS SUBROUTINE MULTIPLIES TMX1 BY
                    *     A FACTOR N SUCH THAT WE CAN DETER-
                    *     MINE WHERE THE FIRST MAXIMUM IS
                    *     COMPARING TO THE TOTAL DURATION OF
                    *     THE SIGNATURE
                    *
E22A 96 04     INVNOR  LDA A   TMX1
E22C D6 05             LDA B   TMX1+1
E22E 0C                CLC
E22F DB 05     ADB     ADD B   TMX1+1
E231 25 09             BCS     CARRY
E233 9B 04     ADA     ADD A   TMX1
E235 7A 0029           DEC     MULT
E238 26 F5             BNE     ADB
E23A 20 03             BRA     KEEP
E23C 4C        CARRY   INC A
```

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E23D 20 F4              BRA      ADA
E23F 97 2D     KEEP     STA A    INVTXH
E241 D7 2E              STA B    INVTXL
E243 39                 RTS
               *
               *         SUBROUTINE BUS
               *    THIS ROUTINE OUTPUTS A VOLTAGE OF
               *    +10 VDC TO THE ANALOG OUTPUT OF THE
               *    ST6800 D/A-A/D BOARD TO INDICATE
               *    THAT A BUS IS DETECTED
               *
E244 96 35     BUS      LDA A    DTEMP1+1
E246 81 02              CMP A    #$02
E248 26 0C              BNE      GATE1
E24A 86 0F              LDA A    #$0F
E24C C6 FF              LDA B    #$FF
E24E B7 4102            STA A    $4102
E251 F7 4103            STA B    $4103
E254 20 0A              BRA      TIMER1
E256 86 0F     GATE1    LDA A    #$0F
E258 C6 FF              LDA B    #$FF
E25A B7 4100            STA A    $4100
E25D F7 4101            STA B    $4101
E260 CE 2000   TIMER1   LDX      #$2000
E263 09        TIMER    DEX
E264 26 FD              BNE      TIMER
E266 86 08              LDA A    #$08
E268 C6 00              LDA B    #$00
E26A B7 4100            STA A    $4100
E26D B7 4102            STA A    $4102
E270 F7 4101            STA B    $4101
E273 F7 4103            STA B    $4103
E276 39        OUT      RTS
               *
               *    TIMING LOOP
               *
E277 C6 E0     TL1      LDA B    #$E0
E279 5A        LOOP1    DEC B
E27A 26 FD              BNE      LOOP1
E27C 39                 RTS
               *
               *    THIS ROUTINE OFFSETS THE BIASED
               *    VOLTAGE LEVEL BY SUBTRACTING THIS
               *    VOLTAGE LEVEL FROM THE DETECTED
               *    MAXIMA AND MINIMA
               *
E27D D1 1A     BIASED   CMP B    BIASL
E27F 23 04              BLS      HI
E281 D0 1A              SUB B    BIASL
E283 20 0E              BRA      AL1
```

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E285 D7 24    HI      STA B   XT
E287 D6 1A            LDA B   BIASL
E289 D0 24            SUB B   XT
E28B 5A               DEC B
E28C D7 24            STA B   XT
E28E C6 FF            LDA B   #$FF
E290 D0 24            SUB B   XT
E292 4A               DEC A
E293 90 19    AL1     SUB A   BIASH
E295 39               RTS
              *
              *       SUBROUTINE THRESET
              *       THIS SUBROUTINE SETS THE BIASED
              *       VOLTAGE LEVEL, THE INPUT AND THE
              *       OUTPUT THRESHOLD VALUES FOR THE
              *       MULTIPLEXED A/D CHANN'LS
              *
E296 DF 32    THRESE  STX     XTEMP
E298 DE 2F            LDX     STORE
E29A A7 00            STA A   00,X
E29C E7 01            STA B   01,X
E29E CB 1B            ADD B   #$1B
E2A0 24 01            BCC     LTAVI
E2A2 4C               INC A
E2A3 A7 02    LTAVI   STA A   02,X
E2A5 E7 03            STA B   03,X
E2A7 A6 00            LDA A   00,X
E2A9 E6 01            LDA B   01,X
E2AB CB 0E            ADD B   #$0E
E2AD 24 01            BCC     LTAVO
E2AF 4C               INC A
E2B0 A7 04    LTAVO   STA A   04,X
E2B2 E7 05            STA B   05,X
E2B4 DE 32            LDX     XTEMP
E2B6 39               RTS
              *
              *       SUBROUTINE FETCHA
              *       THIS SUBROUTINE FETCHES THE INPUT
              *       DATA FROM EACH OF THE INPUT A/D
              *       CHANNELS
              *
E2B7 DF 36    FETCHA  STX     DTEMP2
E2B9 DE 34            LDX     DTEMP1
E2BB A7 00            STA A   00,X
E2BD 01               NOP
E2BE A6 00            LDA A   00,X
E2C0 E6 01            LDA B   01,X
E2C2 8D 6E            BSR     DISVEH
E2C4 39               RTS
              *
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```
                    *     SUBROUTINE HALF
                    *     THIS SUBROUTINE DOES THE SAME FCN
                    *     AS INVNOR EXCEPT THAT HALF VALUE
                    *     OF TMX1 IS INCLUDED TO GENERATE A
                    *     DECISION LINE AT 0.4T
                    *
E2C5 96 04          HALF   LDA A   TMX1
E2C7 D6 05                 LDA B   TMX1+1
E2C9 46                    ROR A
E2CA 56                    ROR B
E2CB 0C                    CLC
E2CC DB 05          HADB   ADD B   TMX1+1
E2CE 25 09                 BCS     HCARY
E2D0 9B 04          HADA   ADD A   TMX1
E2D2 7A 0029               DEC     MULT
E2D5 26 F5                 BNE     HADB
E2D7 20 03                 BRA     HEEP
E2D9 4C             HCARY  INC A
E2DA 20 F4                 BRA     HADA
E2DC 97 2D          HEEP   STA A   INVTXH
E2DE D7 2E                 STA B   INVTXL
E2E0 39                    RTS
                    *
                    *     SUBROUTINE LEFT
                    *
                    *     THIS SUBROUTINE ENSURES THAT THE
                    *     VEHICLE HAS LEFT THE DETECTION
                    *     ZONE BEFORE THE RESET OF THE I/O
                    *     THRESHOLD BARAMETERS
                    *
E2E1 DE 34          LEFT   LDX     DTEMP1
E2E3 86 40                 LDA A   #$40
E2E5 97 31                 STA A   TEMP1
E2E7 96 1D                 LDA A   HOTHD
E2E9 D6 1E                 LDA B   LOTHD
E2EB 97 3C                 STA A   DTEMP3
E2ED D7 3D                 STA B   DTEMP3+1
E2EF A7 00          HIGH   STA A   00,X
E2F1 01                    NOP
E2F2 A6 00                 LDA A   00,X
E2F4 E6 01                 LDA B   01,X
E2F6 91 3C                 CMP A   DTEMP3
E2F8 22 F5                 BHI     HIGH
E2FA 27 02                 BEQ     EQU
E2FC 20 06                 BRA     NOTYET
E2FE D1 3D          EQU    CMP B   DTEMP3+1
E300 22 ED                 BHI     HIGH
E302 27 09                 BEQ     READY
E304 97 3C          NOTYET STA A   DTEMP3
E306 D7 3D                 STA B   DTEMP3+1
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```
E308 7A 0031          DEC     TEMP1
E30B 26 E2            BNE     HIGH
E30D 97 19    READY   STA A   BIASH
E30F 96 35            LDA A   DTEMP1+1
E311 81 00            CMP A   #$00
E313 27 08            BEQ     CH1
E315 96 19            LDA A   BIASH
E317 97 58            STA A   $58
E319 D7 59            STA B   $59
E31B 20 06            BRA     OK
E31D 96 19    CH1     LDA A   BIASH
E31F 97 50            STA A   $50
E321 D7 51            STA B   $51
E323 39       OK      RTS
              *
              *       THIS IS A TIME DELAY PROGRAMME
              *       THIS ROUTINE DELAYS THE START OF
              *       SAMPLING INPUT DATA IN ORDER TO
              *       ALLOW THE DETECTOR/AMPLIFIFR TO
              *       TO SETTLE DOWN
              *
E324 86 40    RESTAR LDA A   #$40
E326 CE FFFF  LX      LDX     #$FFFF
E329 09       DX      DEX
E32A 26 FD            BNE     DX
E32C 4A               DEC A
E32D 26 F7            BNE     LX
E32F 7E E000          JMP     NEW
              *       SUBROUTINE DISVEH
              *       THIS SUBROUTINE TESTS FOR VEHICLES
              *       WHICH OCCUPY ONE OF THE LOOPS FOR
              *       MORE THAN A PREDEFINED PERIOD OF
              *       TIME (7 SECONDS, I.E., EQUIVALENT
              *       TO A BUS TRAVELLING AT LESS THAN
              *       8 KM/HR) IF THIS PERIOD IS EXPIRED
              *       THE SYSTEM WILL DISCARD THE LOOP
              *       AND CONSIDERS ONLY THE UNOCCUPIED
              *       LOOP
              *
E332 97 3E    DISVEH STA A   DTEMP4
E334 D7 3F            STA B   DTEMP4+1
E336 96 36            LDA A   DTEMP2
E338 81 16            CMP A   #$16
E33A 2D 11            BLT     OKAY
E33C C6 00            LDA B   #$00
E33E D1 35            CMP B   DTEMP1+1
E340 27 04            BEQ     CHNL2
E342 D7 35            STA B   DTEMP1+1
E344 20 04            BRA     JUMP
E346 C6 02    CHNL2   LDA B   #$02
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E348 D7 35              STA B   DTEMP1+1
E34A 7E E000 JUMP       JMP     NEW
E34D DE 36   OKAY       LDX     DTEMP2
E34F 96 3E              LDA A   DTEMP4
E351 D6 3F              LDA B   DTEMP4+1
E353 39                 RTS
             *     RESTART VECTOR SETTING
             *
E3FE                    ORG     $E3FE
E3FE E324               FDB     RESTART    (RESTART INTERRUPT VECTOR
                        FDB     RESTART    (RESTART INTERRUPT VECTOR
```