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16. Abstract

This report describes the methods and procedures for upgrading the Surface Dynamics Profilometer owned by the Texas State Department of Highways and Public Transportation. The upgrade performed included the installation of non-contact laser probes used in the process of measuring road profile. The laser probes make the Profilometer more useful for data collection by reducing maintenance problems occurring with the mechanical road-following wheels. The use of non-contact probes in the profilometer is also safer for data collection personnel as greater highway speeds can be used in the measuring process.

The data acquisition and processing capability of the profilometer was also upgraded to reflect more up-to-date technology.

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UPGRADE OF 690D SURFACE DYNAMICS PROFILOMETER FOR NON-CONTACT MEASUREMENTS

by

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The University of Texas at Arlington

Research Report 494-1F

Upgrade Profilometer for Non-Contact Measurements

Research Project 8-10-85-494

conducted for

Texas State Department of Highways and Public Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

JULY 1987

PREFACE

This project report presents results of Research Project 8-10-85-494, "Upgrade Profilometer for Non-Contact Measurements." In this project the 690D Surface Dynamics Profilometer, purchased several years ago, is updated so that profile measurements can be obtained using non-contact probes in addition to the road following wheels. An up-to-date data acquisition system was developed during the project. The on-board computing capability was also updated to provide more rapid and easily obtained PSI roughness measurements.

This project effort was not possible without the close cooperation of State Department personnel, Curtis Goss, Jim Wyatt, Randy Beck, Joe Wise, and Robert Light. The assistance of graduate students, Suhas Pai, Luat Phung, and Richard Pendergast should also be recognized.

Roger S. Walker
John Stephen Schuchman

July 1987

ABSTRACT

This report describes the methods and procedures for upgrading the Surface Dynamics Profilometer owned by the Texas State Department of Highways and Public Transportation. The upgrade performed included the installation of non-contact laser probes used in the process of measuring road profile. The laser probes make the Profilometer more useful for data collection by reducing maintenance problems occurring with the mechanical road-following wheels. The use of non-contact probes in the profilometer is also safer for data collection personnel as greater highway speeds can be used in the measuring process.

The data acquisition and processing capability of the profilometer was also upgraded to reflect more up-to-date technology.

KEY WORDS: Surface Dynamics Profilometer (SDP), Selcom Laser Probes, Present Serviceability Index (PSI), Road Profile.

SUMMARY

The Surface Dynamics Profilometer (SDP) has been used for several years by the Texas State Department of Highways and Public Transportation for obtaining road profile and roughness measurements. The SDP uses two road following wheels, which in conjunction with two corresponding accelerometers provide road profile measurements. A major problem with this device has been the road following wheels and the linear potentiometers, attached to these wheels for providing vertical wheel displacement signals. Maintenance problems with the wheels as well as wheel bounce limit the speed at which measurements can be taken. A second major problem using the profilometer has been the length of time required to process the profile data to obtain various roughness statistics, such as Present Serviceability Index (PSI).

This project was initiated to up-grade the SDP owned by the Department to alleviate or eliminate many of these problems. An earlier study conducted by the University of Texas, Transportation Research Center, had concluded that non-contact laser probes could be used satisfactory in place of the road following wheels. The SDP has been upgraded in this project to include such non-contact probes. Additionally, the on-board computing was updated to include a more recent computer system.

IMPLEMENTATION STATEMENT

The 690D Surface Dynamics Profilometer, owned by the State Department, has been up-graded so that measurements can be used with Selcom laser or non-contact probes in addition to the current road-following wheels. Additionally, the on-board computing capability has been upgraded so that Present Serviceability Index (PSI) roughness measurements can be obtained shortly after the unit is used. The device can be used in its present condition improving previous procedures for road profile and roughness measurements.

ILLUSTRATIONS

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CHAPTER 1

INTRODUCTION

Background

The Surface Dynamics Profilometer (SDP) has been in use for several years by the Texas State Department of Highways and Public Transportation for obtaining road profile measurements. These measurements are then used for obtaining various roughness statistics and for other such things as calibrating the less expensive Mays Ride Meter (MRM), and more recently, the Walker Roughness Device (WRD).

The SDP uses two road following wheels, which in conjunction with two linear potentiometers and corresponding accelerometers provide road profile measurements (1). These wheels are held firmly against the road surface as the vehicle on which the unit is installed is driven down the road. Two linear potentiometers mounted between the sensor wheel and the vehicle body are used to provide a voltage proportional to the difference between the vehicle frame and the road surface (W-Z) as illustrated in Figure 1.1. The accelerometers, mounted directly above their respective potentiometer, provides the vertical vehicle body acceleration. This acceleration is digitized by a profile computer and summed with the digitized potentiometer signal resulting in the road profile, W as illustrated. A high pass filter is then used to filter the low-frequency or long-wavelength profiles, such as hills. The two independent measuring subsystems thus provide a profile for both the right and left wheel paths.

A major problem with this device is the road following wheels and potentiometers. The wheels limit the speed at which measurements can be taken because of wheel bounce. Measurements are usually taken at speeds of 20 MPH. Additionally, the wheels and potentiometers are easily damaged by rough road surfaces.

A study conducted in 1978-1979, by the University of Texas at Austin for the Department (4), investigated the use of non-contact probes in place of the road following wheels. This study concluded that many of the problems occurring with the SDP could be solved by using non-contract probes in place of these road following or profiling wheels. The study

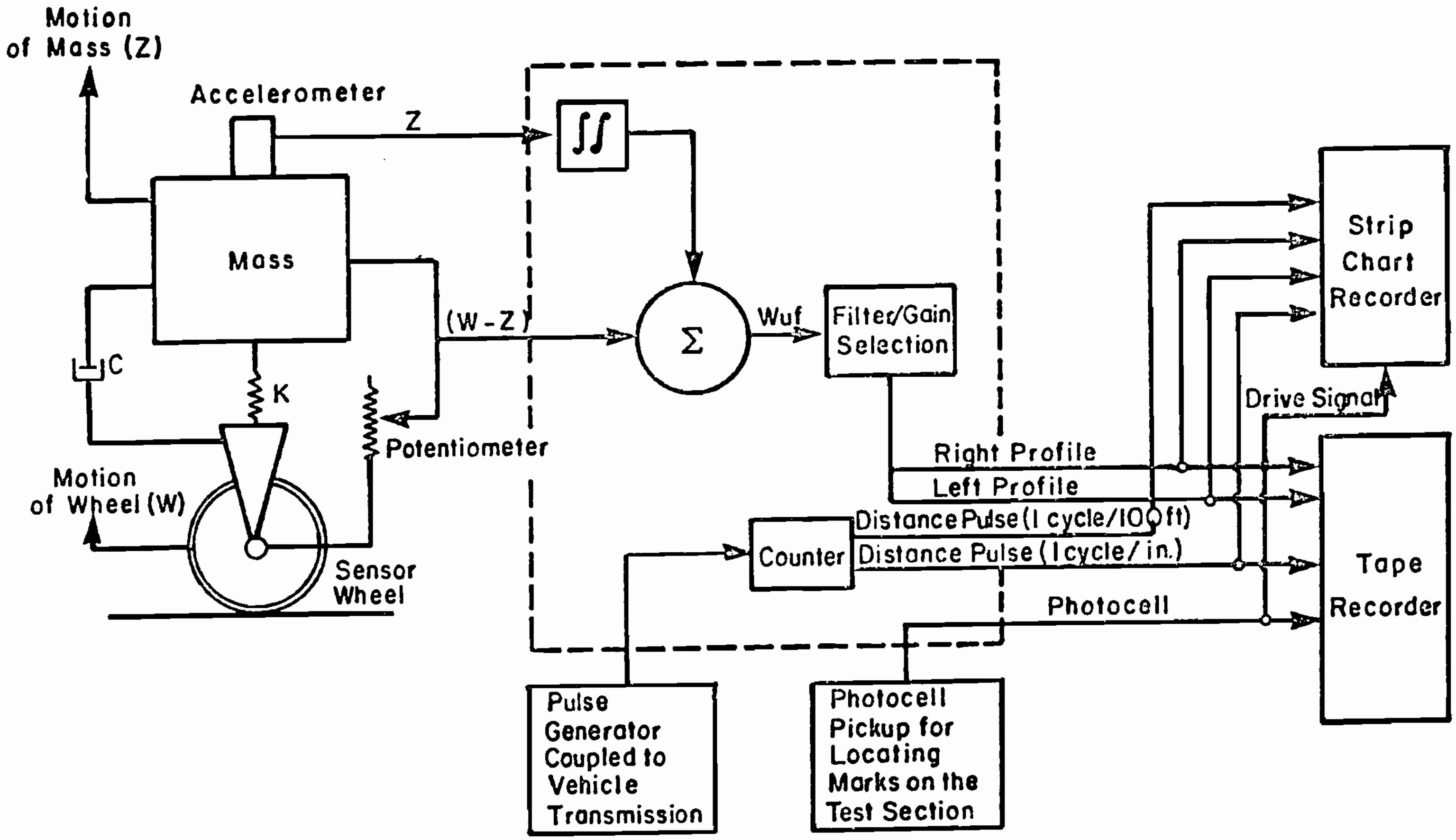

Figure 1.1. Block Diagram of the Surface Dynamics Profilometer.

recommended that non-contact probes such as the Selcom laser units be used.

A second major problem using the Profilometer is the length of time required to process the data. Profile data is obtained by the on-board computer system and this data written to a magnetic tape unit in the vehicle. The tape is then brought back to the Department where a often lengthy data processing operation is involved in order to routinely process this data. A turn-around time of several days is typically expected before any useful information from this data can be obtained, such as the often desired present serviceability index (PSI).

Although, once a very popular and up-to-date system, the computer system used in the 690D profilometer is outdated. It was one of the better systems at the time, but is not really suited to the typical profilometer operating environment. Advances in computer technology have now resulted in systems more acceptable to profilometer applications. These newer systems are typically more reliable, smaller in size, require less power, and are less expensive. The newer systems also have the necessary resources to permit much of the data processing on these same systems. Thus turn-around on such information as road profile and pavement roughness can be provided in minutes.

As will be discussed in the next section, the objective of this project is to up-grade the Department's SDP with the non-contact probes and a newer computer system to reduce or eliminate the above problems.

Study Objectives

The main objective of Project 494 is to update the current profilometer by providing the use of laser sensors in place of the road following wheels, to upgrade the data acquisition capability, and to permit more on-board computing. Such upgrade will result in a more reliable system and reduce the dependence on the Department's main frame systems and thus reduce data reduction costs and turn-around time. Specifically, these objectives are:

1. Purchase and install the appropriate Selcom laser probes.
2. Obtain and install the appropriate accelerometers and interface circuitry.
3. Perform appropriate tests on data obtained from the non-contact measuring system to insure its validity.

4. Obtain up-to-date computing hardware and software to permit more on-board computing and increase system reliability.

Research Plan and Report Scope

The appropriate Selcom laser probes were obtained and installed and are described in Chapter 2. Two accelerometers were also obtained and necessary interface circuitry built. The accelerometers were then installed providing a separate non-contact sensor capability.

In the initial plans to upgrade the computing capability, a computer system such as used by the WRD was considered. However, after the project began, it was decided to use one or more Motorola VME boards for the data acquisition and profile computing. Other on board computing and data storage would then be done by a Compaq portable 286 PC.

Work began as planned obtaining a Motorola 68020 system and supporting hardware. The Motorola data acquisition developed is described in Chapters 3 and 4.

Unfortunately, during the testing phases of the lasers, a major hardware problem occurred in the SDP computer. Additionally, the left accelerometer failed. A power problem within the PDP 11 affected a number of the computer and profilometer interface boards. Because of the costs and time estimated by Digital maintenance personnel to fix the system, and because other non-Digital boards were affected, it was decided to use the Compaq 286 for an intermediate solution to all computing.

An available Data Translation A/D board was installed in the Compaq and the necessary software developed so that the SDP could continue field use. The A/D board was later replaced with a faster unit also available from Data Translation. The Compaq 286 system and software developed are described in Chapter 5. An on-board VERTAC program which computes the Present Serviceability Index from the road profile was also developed and is described in the Appendix. Because of the problems in updating the computing capability sooner than planned, the system is currently operational with the Compaq 286 unit. Because of the efforts to get the Compaq 286 system operational the Development of the Motorola based 68020 system was not completed but has continued in the implementation of this equipment. Operations of the Compaq 286 system include usage of both the road following wheels and laser system.

Chapter 7 provides a summary and conclusions of the project.

CHAPTER 2

NON-CONTACT PROBE

Introduction

It was desired to upgrade the road profilometer by replacing the road-following wheel and linear potentiometer with a non-contact probe. Two types were tested to determine their accuracy in measuring the distance from the vehicle body to the road surface. The tested units were compared to each other and to the original mechanical system. A report by Claros, Hudson, and Lee published in April of 1985 gives the results of those tests (4).

The two non-contact probes evaluated were the Selcom laser Optocator, and the Infrared-Light Linear Transducer developed in cooperation between the Federal Highway Administration and the Southwest Research Institute. Chapter four of their study presents the test results. It was determined that the Selcom unit and the Infrared system could replace the profiling wheels without loss of accuracy. Because the Selcom unit was commercially available, could be easily mounted on the vehicle, and produced good results the Texas Highway Department chose it to replace the wheel and potentiometer combination. This would permit profile measurements to be made at normal highway speeds instead of the twenty mile per hour limit of the wheel device.

Description of the Selcom Optocator

The Selcom Optocator is a distance measuring device using the small beam diameter of a laser to achieve high accuracy. Details of the unit's design and operation can be found in the Optocator Users Manual (5). The basic principle of operation is shown in Figure 2.1. The source of light is a laser diode which has high output and can be focused into a very tight beam. The spot of light is reflected by the road surface through the receiving lens into the detector. The position of the light on the detector surface is a function of the distance to the road surface. Additional processing can easily produce a direct readout of that distance. A block diagram of the Optocator is shown in Figure 2.2.

The Selcom Optocator comes in two main parts.

(1) The probe unit which makes the raw measurement. It consists of the laser light source, the camera unit with lens and detector, and the signal processing electronics.

(2) The central processing unit which receives and processes the reading from the probe unit and makes it available to the profilometer computer. It also contains power supplies for itself and the probe.

Operation of the Optocator

The beam of laser light generated inside the probe unit is focused to a spot 3/8-inch by 1/8-inch on the road surface. The light source is regulated to maintain a constant intensity when reflected back to the detector surface. This permits wide variations in the texture, color, and reflectivity of the surface without affecting the accuracy of the distance reading. In order to allow the detector to distinguish between the laser and unwanted light sources, the laser light is turned on and off at a rate of 32,000 times a second.

The probe unit updates the distance reading sent to the processor every 62.5 microseconds. Inside the processing unit a selectable number of readings from the probe can be averaged. This prevents cracks or irregularities in the road surface from distorting the data. The processor makes a new reading available to the profilometer computer as soon as the required number of readings from the probe have been averaged. The distance readings are transmitted to the profilometer as twelve parallel bits plus a flag bit that indicates an error condition in the Optocator. These readings are sent continuously as long as the unit is running. No handshaking is required between the Optocator and the profilometer computer. The probe unit and the processor also make available analog data indicating the distance being measured, however only the twelve-bit parallel data is used by the profilometer.

Installation of the Optocator

For testing and comparison purposes it was desired to be able to operate the profilometer with either the mechanical wheel or the non-contact probes. Provision was made to have

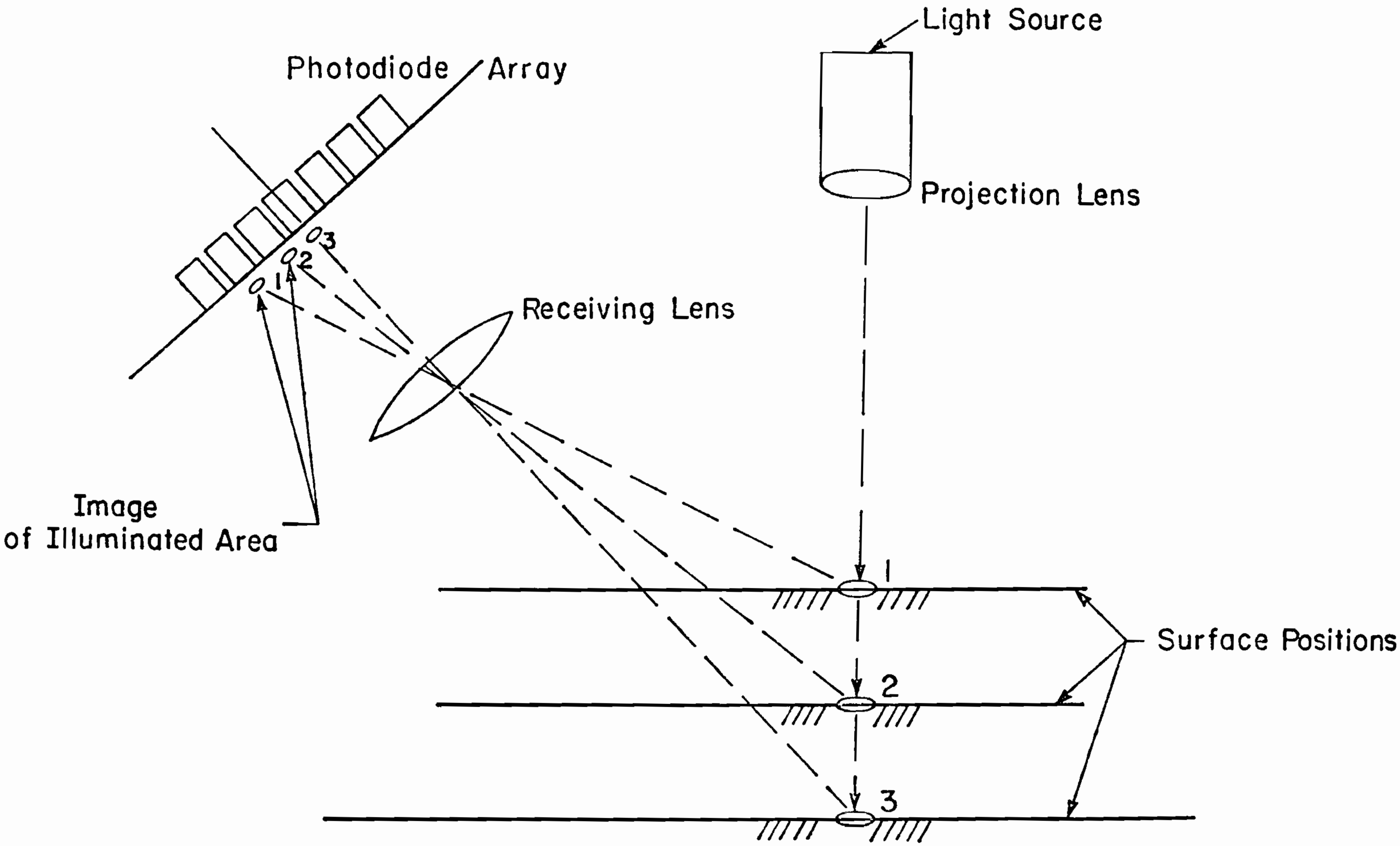

Figure 2.1. Selcom Optocator Basic Operating Principle.

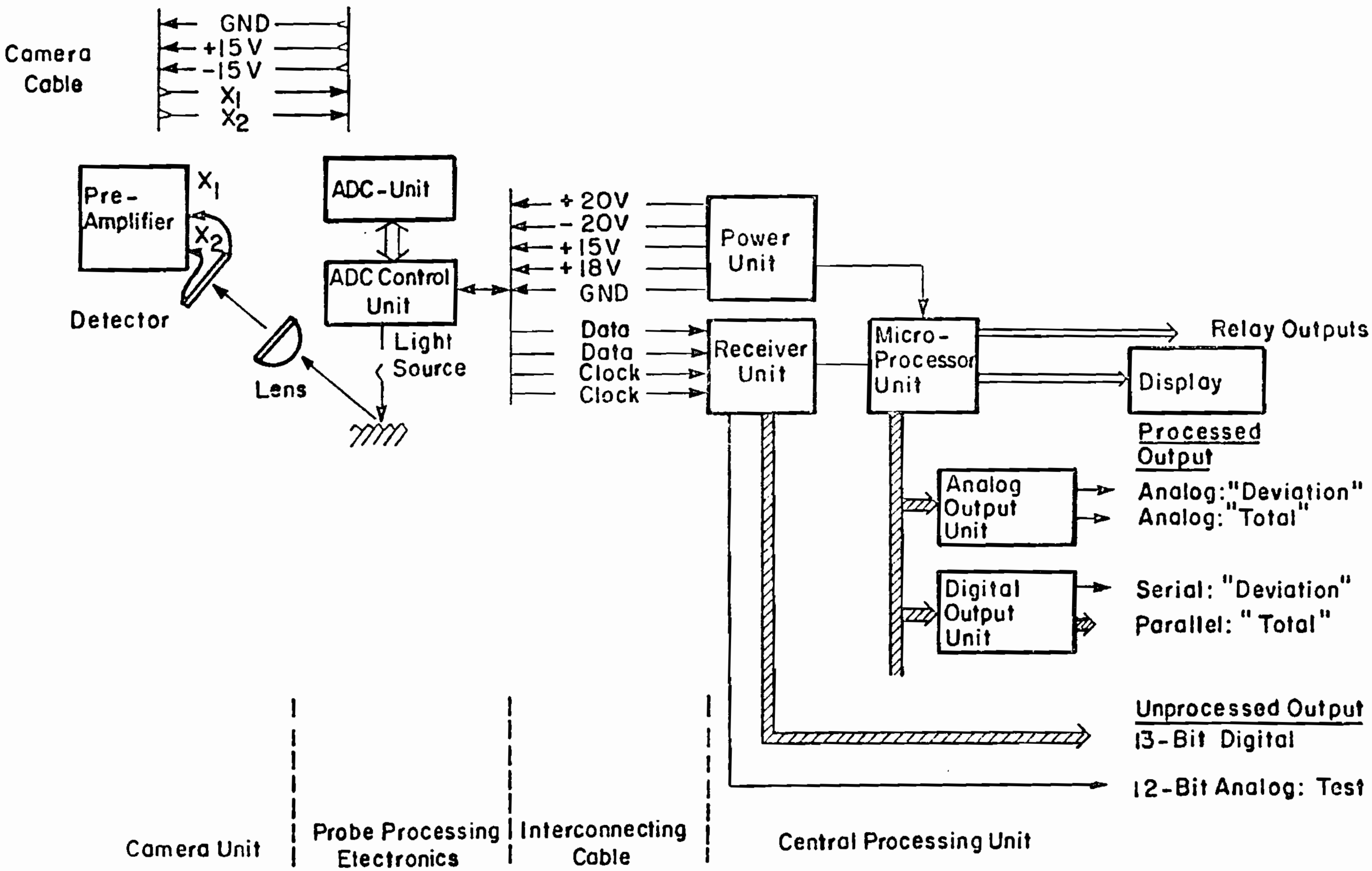

Figure 2.2. Block Diagram of Selcom Optocator.

both types of distance measuring devices operating at the same time. Figure 2.3 shows the installation position of the non-contact probe in the van relative to the wheel assembly. Since the accelerometer must be mounted directly above the point at which distance to the road surface is being measured, a separate accelerometer for the non-contact probe is used. Its location is also indicated in Figure 2.3. If desired, the wheel assembly can be removed from the van once testing has been completed. During the testing phase only a single Selcom device was mounted in the van but for actual operation two Optocators will be used, one for each of the left and right wheel tracks of the vehicle.

Conclusion

Tests have proved the ability of the non-contact probe to take accurate distance measurements at normal highway speeds. This promises to deliver savings of time and money and to increase the operational safety of the profilometer. The increased data rate, however, indicates the need to augment the processing capacity of the profilometer computer in order to fully exploit the advantages of the non-contact probes.

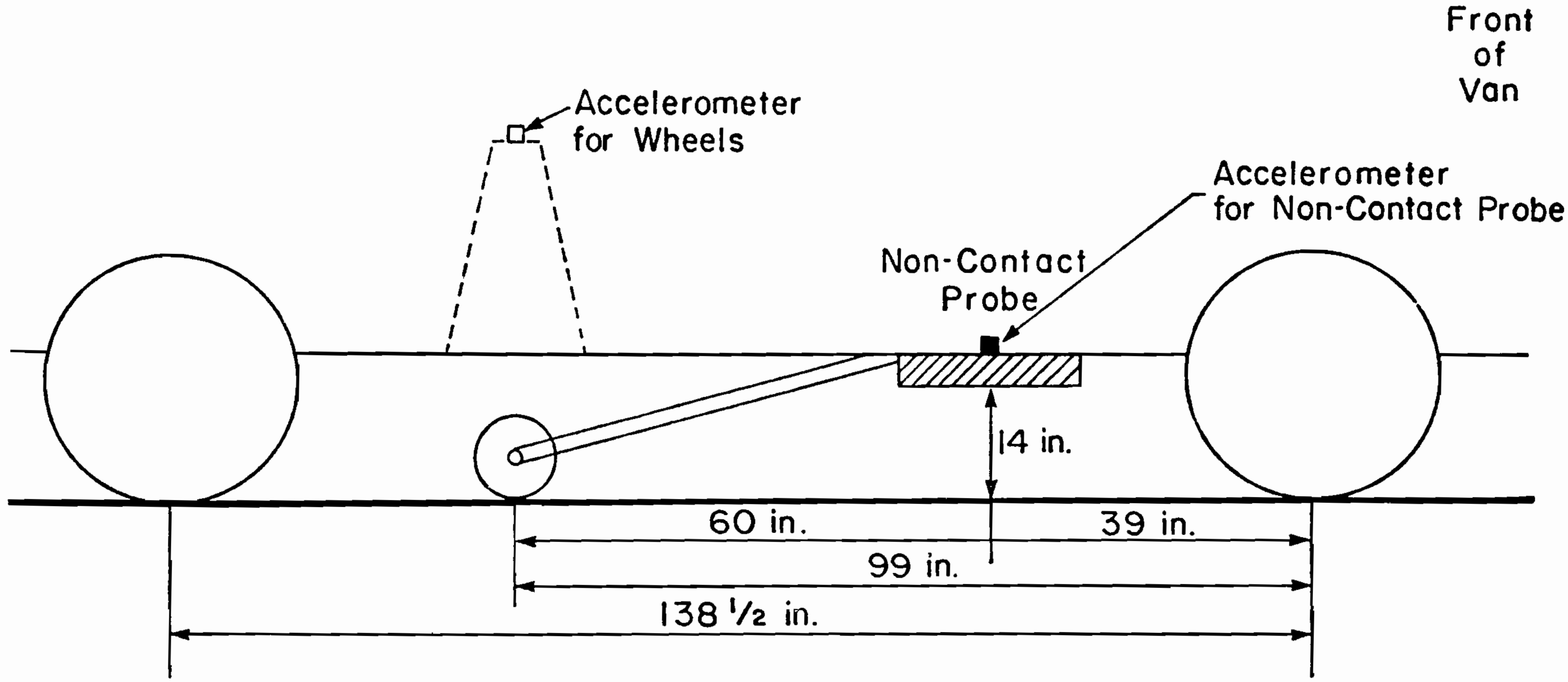

Figure 2.3. Diagram of Non-Contact Probe Installation.

CHAPTER 3

AN ENHANCED PROFILOMETER COMPUTER

Overview of the System

In order to take advantage of the higher profile measurement speeds that will be permitted by the use of non-contact probes, adequate computational speed must be designed into the profile computer. Several other improvements and capabilities have been suggested for the computer, such as a voice synthesizer to inform the operator or driver of system status and potential problems. Greater processing speed will also allow more real-time analysis of the collected data. This will permit measurement errors to be detected at once so that a bad section could be repeated immediately.

The profile computer must interface with a variety of devices and data formats. It will be receiving both digital and analog data from the sensors. It will send processed data to and receive commands from a host computer via RS-232 serial ports. It will also provide analog outputs to a two-channel strip chart recorder as well as issuing digital commands to the same. Several internal circuit adjustments such as the cut-off frequencies of hardware filters and DC offset adjustments are made by the profile computer by means of parallel data commands.

Figure 3.1 shows the world as seen by the profile computer. It gives examples of the variety of inputs and outputs with which the profile computer must be able to interface.

Profile Computer Subsystems

There are three main subsystems making up the profile computer. Each one is described below.

(1) The Central Processing Unit (CPU) is where the actual computations are done. It is built around the Motorola VME-131 processor board which features the 68020 microprocessor and the 68881 math co-processor.

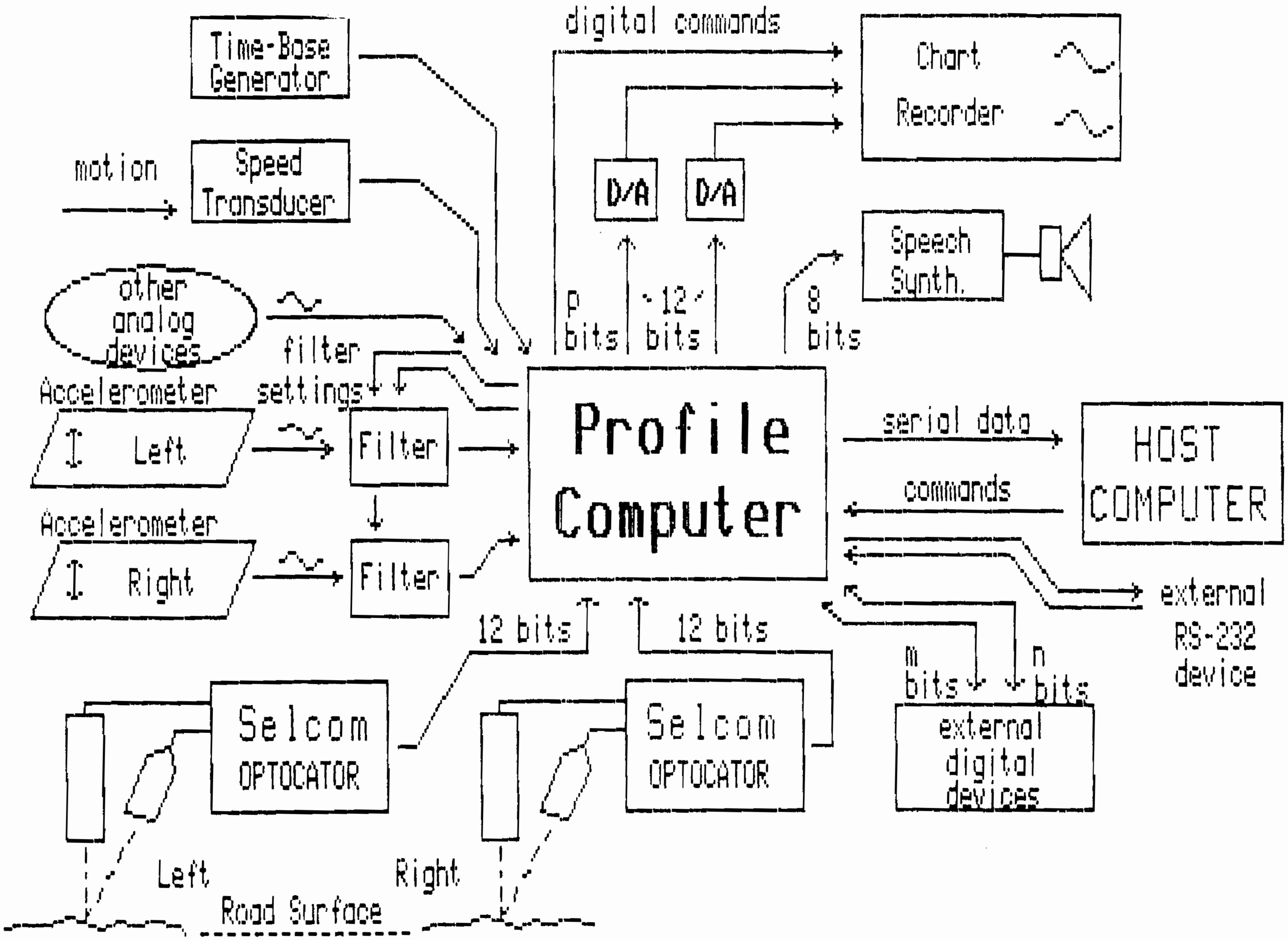

Figure 3.1. The World According to the CPU.

(2) The I/O (input/output) subsystem is the interface between the CPU and the outside world. It is responsible for gathering data from the external devices and making it available to the CPU. It also passes commands from the CPU to the outside.
(3) The power supply subsystem provides operating voltages to the several elements of the profile computer. It must protect itself and the units it is serving from various fault conditions.

The profile computer can be thought of as a 'black-box'. If designed properly it should completely isolate the operator from the details of each of the input and output devices connected to it. The operator would communicate with the profile computer through the host computer. The profile computer would process data from all inputs and pass it in some standard format to the host computer for storage.

The central processing unit

The CPU of the profile computer is built around the Motorola MVME-131 processor board. This uses the well-defined VME bus standard to insure compatibility among boards on the bus. The processor board includes the 68020 32-bit microprocessor and the 68881 math coprocessor; both true state-of-the-art devices. The board has sockets for four memory chips; two hold the ROM monitor and the other two are used for 8Kbyte RAM chips. The profile computer does not need very much RAM space, so this is sufficient. Details on the processor board can be found in the MVME-131 Users Manual (6).

While there is sufficient RAM on the processor board, the profile computer does require additional space for EPROM to hold the necessary code. A Motorola MVME-211 memory board provides for up to sixteen 28-pin memory chips to be accessed by the processor. This board is also compatible with the VME bus and permits 24-bit addressing and 16-bit wide data transfers. More information can be found in the MVME-211 Users Manual (7).

The object code running on the profile computer is held on EPROM chips to allow changes to be easily made in the algorithms. Because these chips will be repeatedly removed, reprogrammed, and installed on the memory board, special zero-insertion force sockets have been mounted on 28-pin header plugs. These headers plug into the sockets on the memory board and allow the memory chips to be inserted into the zero-insertion force sockets. This prevents the chip sockets on the memory board from being damaged by the many insertion and removal cycles that are anticipated.

The MVME-131 processor board has two serial ports which are converted to the RS-232 standard with the help of the Motorola MVME-707 board. This small auxiliary board fits into the same physical space as the other boards but does not connect to the VME bus. A jumper cable from the processor board makes all needed connections between the two. The 707 board converts the TTL level signals on the processor board to RS-232 levels for two full-duplex serial ports.

In order to issue commands to the outside world and to receive information from the external transducers, the processor board needs an interface device. The Xycom XVME-240 Digital I/O Module is a VME bus compatible unit that the processor can use as a multiple-port parallel interface. It allows for eight 8-bit parallel ports, which can be configured by the processor as either inputs or outputs. Pairs of 8-bit ports can be accessed simultaneously by the processor, permitting 16-bit wide data transfers on input or output. This parallel I/O board is the link between the CPU subsystem and the I/O subsystem in the profile computer. Data moves both directions through this board and external devices can cause the XVME-240 to issue interrupts to the processor board. The Xycom XVME-240 users manual will answer most questions that the reader might have (8).

A Motorola 921A backplane makes the interconnections between the boards required by the VME bus standard. It allows up to nine VME bus compatible boards to be installed in the CPU subsystem. Since only three boards are now in use, there is considerable room allowed for future expansion of the CPU. As part of the backplane, active bus terminators reduce noise and reflections on the lines, greatly increasing the reliability of the VME bus.

The backplane also distributes operating power to the boards in the CPU subsystem. Several amps of current must be made available to the VME bus for distribution. In addition, a secondary power plane is used by the CPU board and the parallel I/O board to reduce the amount of current in the VME bus connectors. A large block connector allows easy attachment of the CPU subsystem to the power supplies.

The CPU subsystem of the profile computer is installed in a special card-cage inside the computer case. Access is permitted through a door in the side of the profilometer computer to allow EPROM chips on the memory board to be changed. Entire boards can be inserted or removed from the card cage through an access plate in the top of the computer case.

Figure 3.2 shows a block diagram of the CPU subsystem of the profile computer. All communication between boards is over the VME bus except for the serial data between the processor board and the MVME-707 RS-232 converter.

The I/O subsystem

The purpose of the I/O subsystem is to allow the CPU to issue commands to all external devices and to permit the profilometer transducers to communicate their information to the CPU. A primary goal in the design of the I/O subsystem is the desire to eliminate as much work as possible for the CPU by transferring routine data gathering duties to the I/O subsystem hardware. By performing such mundane tasks in the I/O subsystem, the CPU is freed to perform more analysis on the data. Much of the data coming in from the transducers is stored in high-speed buffers and is available to the CPU in microseconds. It is the duty of the I/O subsystem to keep those registers updated as new information becomes available. In this way the CPU should never have to wait for data or stop the more important work of analysis to issue a time-consuming series of commands that could be done by the I/O hardware.

The I/O subsystem is itself made up of three parts.

(1) The analog-to-digital section accepts analog signals from up to eight transducers, converts them to digital form, and stores the resulting data in high-speed buffers that the CPU can read. This section drives itself without any intervention required from the CPU and can make a conversion and store the result every forty microseconds. At this conversion rate each and every transducer can be sampled three times an inch even when the van is going down the road at 55 miles per hour.

(2) The digital input section transfers digital data from the outside to the CPU. Up to 120 external devices can be accessed and each can have a data path up to 32 bits wide, although most are 16 bits wide or less. All inputs are fully buffered to reduce the load on the external devices and to protect the profile computer from damage due to voltage pulses on the data lines.

(3) The digital output section delivers buffered parallel data to external devices as well as to several points inside the profile computer. Examples of internal data distribution include setting the hardware filter characteristics and making DC offset adjustments in the

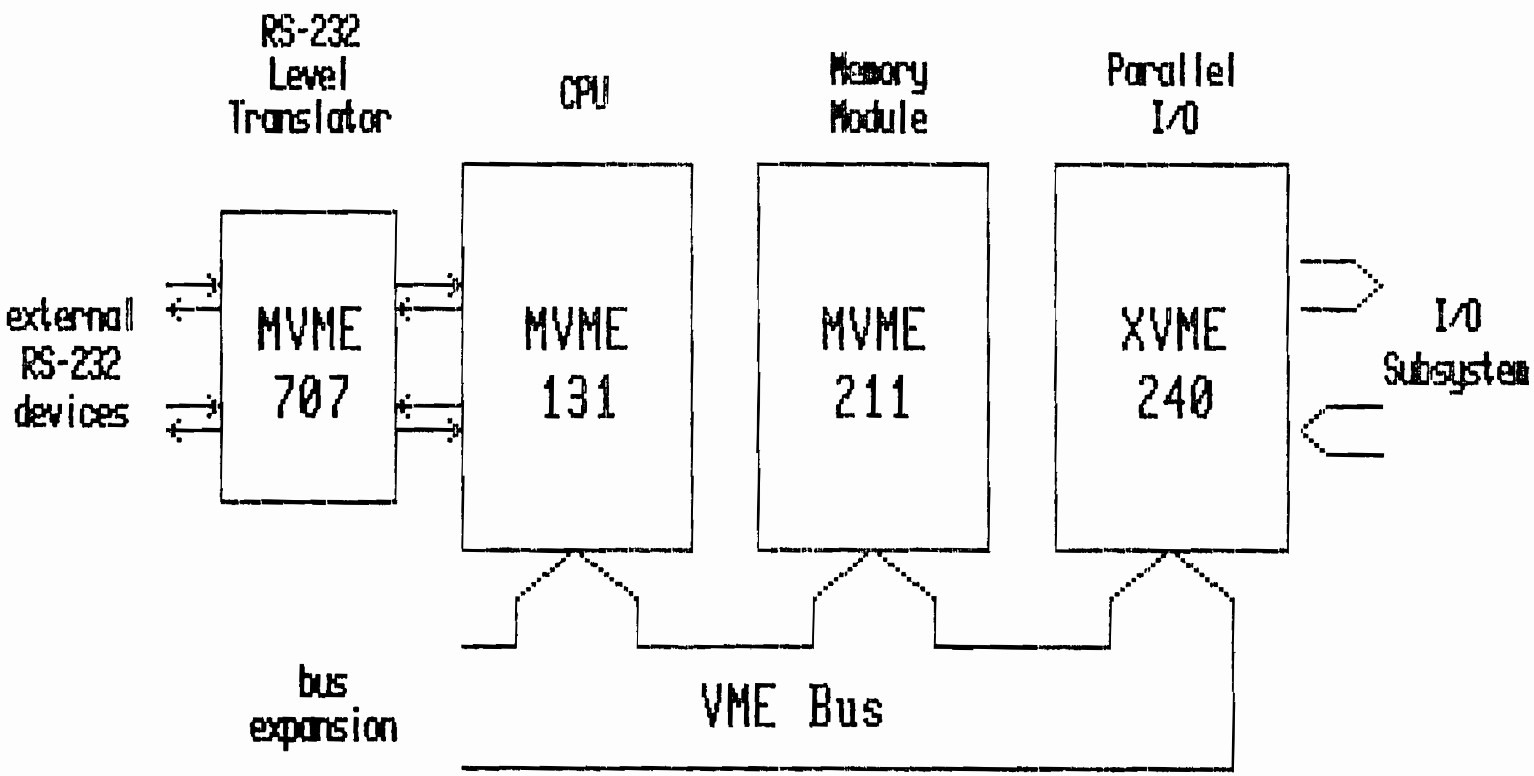

Figure 3.2. The CPU Subsystem.

analog-to-digital section. The data path can be up to 32 bits wide, although eight and sixteen bit paths are more common. The data bits are presented to all devices through a set of protective buffers. As many as 128 individual devices can be selectively strobed to notify them that the data being presented is theirs to latch.

A block diagram of the I/O subsection is shown in Figure 3.3 and the entire fourth chapter of this paper is devoted to descriptions of the circuitry.

The I/O subsystem is mounted in its own special card cage inside the profile computer. Boards can be installed or removed through an access door in the side of the computer. Up to fifteen boards can be held in the card cage, so there is room for future expansion of the I/O subsection should that become necessary at some later date.

The power supply subsystem

The power supply subsystem supplies operating voltages to the other sections of the profile computer. It also is responsible for protecting itself and the circuitry it is serving from fault conditions that might otherwise cause damage. Since the profile computer operates in an automotive environment, all operating power derives from a twelve-volt source in the van. This power source is shared with other electrical systems in the van. The power supply subsystem must guard against noise coming in on the power lines and interfering with the profile computer's operation. It must also protect against voltage pulses that are commonly found in automotive electrical systems.

There are five major power supplies in the power supply subsystem.

(1) The five-volt regulator supplying the CPU subsystem provides up to twenty amps of current.

(2) The five-volt regulator supplying the I/O subsystem provides up to five amps of current.

(3) An eight-volt regulator supplies up to ten amps of current to several small five-volt regulators distributed around the profile computer. In this way the smaller regulators are protected from noise and voltage pulses on the incoming power lines, and their power dissipation is greatly reduced over what it would be if they were supplied directly from the main twelve-volt input.

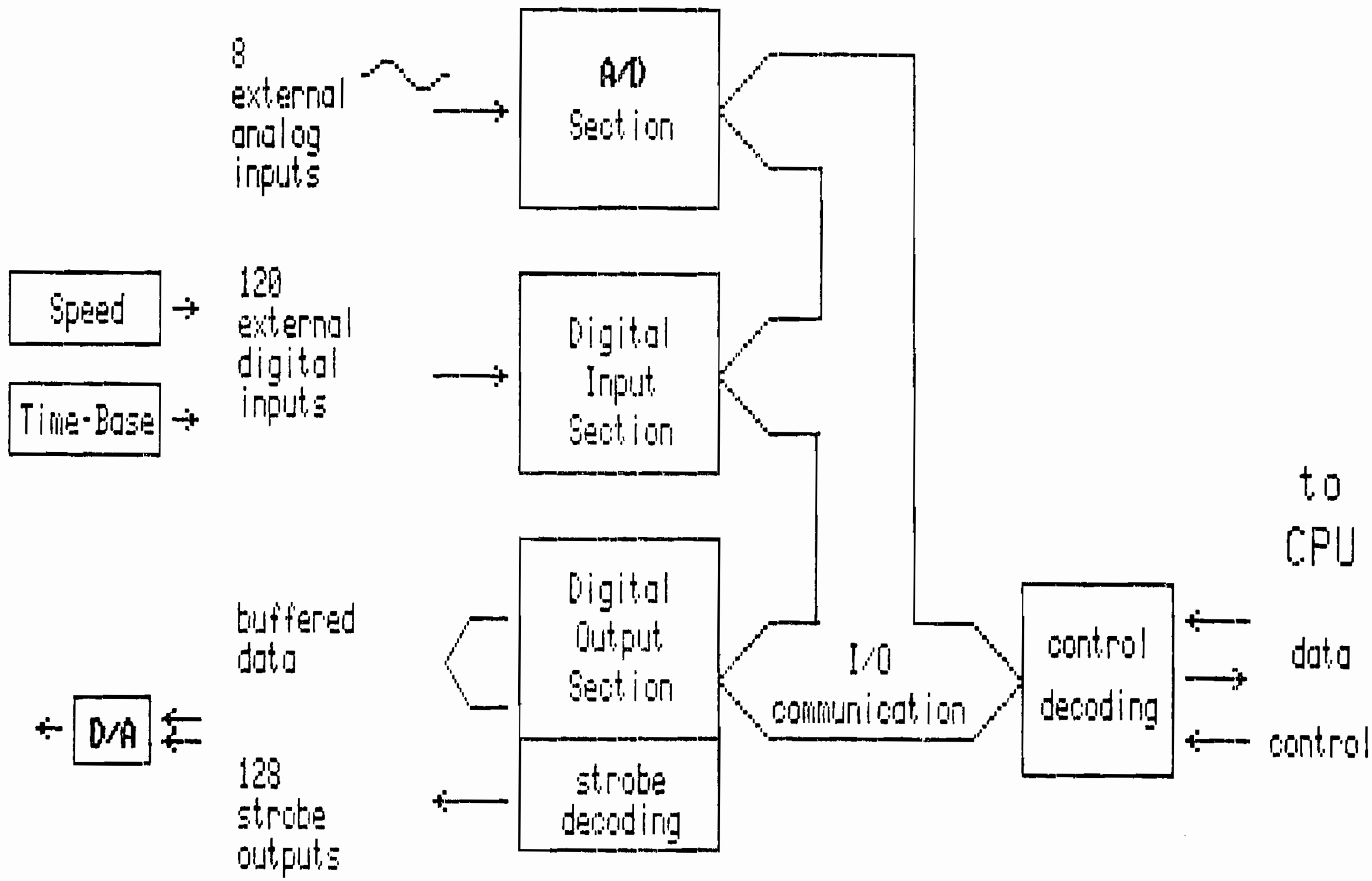

Figure 3.3. The I/O Subsystem.

(4) A positive fifteen-volt supply for the analog circuitry in the profile computer is generated by a DC to DC converter module. Up to 330 milliamps of current is available.

(5) A negative fifteen-volt supply for analog circuitry is generated in the same DC to DC converter. It also supplies up to 330 milliamps of current.

The MVME-707 board that converts voltage levels from TTL to RS-232 for the processor board requires positive and negative twelve-volt supplies. These voltages are derived from the plus and minus fifteen-volt supplies mentioned above.

The main twelve-volt power line coming into the profile computer is filtered to remove noise, current limited to reduce inrush peaks, and has voltage pulses clipped to safe levels. The cleaned-up twelve volts is made available to outside devices such as the electronics in the accelerometer assemblies. A limited amount of current is available but it is protected by the fuses of the profile computer and is switched on and off at the same time as the main unit.

Each of the five major power supplies is continuously measured by a monitor circuit to insure that all voltages are within acceptable limits. If any of the five fails or does not produce the minimum acceptable voltage, an internal beeper sounds to alert the operator to the problem. The offending power supply is identified by a green LED visible through a viewport in the side of the profile computer.

If any of the five major power supplies produces a voltage output higher than a predefined limit, the monitor circuitry fires an SCR 'crowbar'. The crowbar draws a large current which blows the protection fuses in the profile computer, removing all circuit voltages very rapidly. Failed power supplies can be diagnosed through an access plate in the side of the computer. If the crowbar circuit has fired, removing all power from the computer, the technician can remove a large shorting plug from its socket in the power supply subsystem. This isolates all power supplies from their loads and allows the fuse to be replaced and the power supplies operated without endangering the circuitry of the profile computer. Any power supply delivering an overvoltage will be identified by a red LED. Once the failed power supply has been repaired the shorting plug can be reinserted to allow continued normal operation.

A simplified diagram of one section of the monitor circuitry is given in Figure 3.4. This illustrates how the minimum and maximum voltage levels for each power supply are

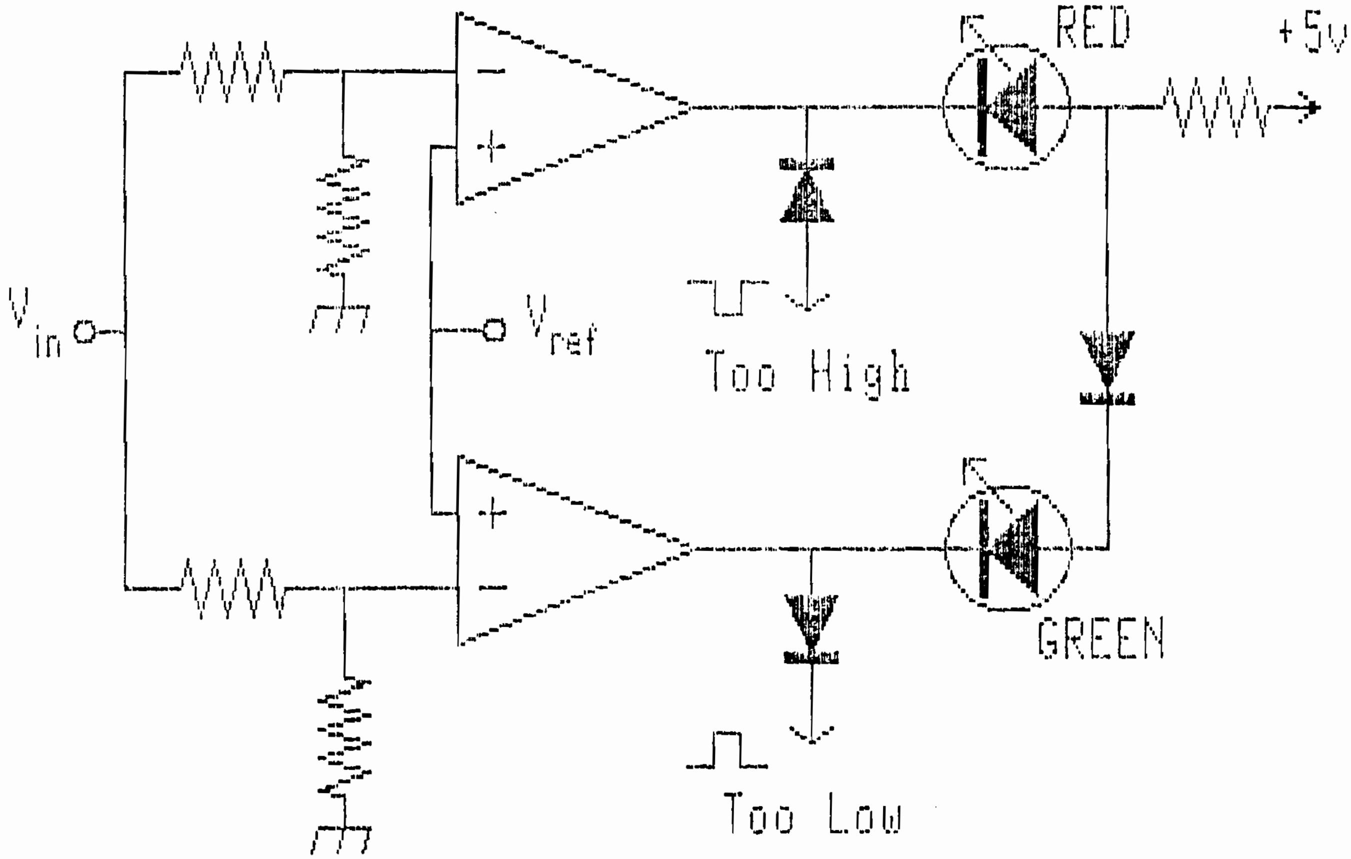

Figure 3.4. Simplified Diagram of Power Supply Monitor Section.

checked.

The threat of reverse polarity input voltages is eliminated by a high speed power diode that isolates the power supply subsystem from a negative voltage on the input. Another power diode will draw enough current from the reversed input to blow the protective fuses.

Mechanical Description

The profile computer is built into an aluminum frame box with dimensions twenty inches wide, eighteen inches tall, and fifteen inches deep. Cardcages for the CPU and I/O subsections were built independently and are mounted inside the main case in such a way as to allow easy access to important points in the circuitry. An entire cardcage could be removed, if necessary.

The profile computer will generate about 250 watts of heat during operation. A small DC cooling fan moves about 80 cubic feet of air per minute through the case to prevent heat from building up. The internal volume of the profile computer case is just more than three cubic feet. To further reduce heat build-up, the voltage regulator heat sinks are mounted on an external wall of the case so heat can be dissipated outside the computer.

All external connections to the profile computer are made on a single wall of the case. The connectors were chosen to be physically different from each other so that it is impossible to connect a device to the wrong point of the profile computer.

CHAPTER 4

DESCRIPTION OF THE I/O SUBSYSTEM

Overview

The enhanced profile computer has three main subsystems; the CPU, the I/O section, and the power supplies. The CPU is constructed of commercially available VME bus compatible boards. Detailed technical descriptions of the boards in the CPU can be found in their respective users manuals, previously discussed. The power supply subsystem is made up of conventional designs and has already been explained in some detail.

The I/O subsystem is designed to take a major load off the CPU by gathering data from external transducers and holding it in high-speed buffers for use at the convenience of the CPU. It also handles the details of communication between the CPU and external devices. Its general functions have already been detailed in the previous chapter. The purpose of this chapter is to give a full technical description of the circuits making up the I/O subsystem.

Analog-to-Digital Section

Signals from the analog transducers of the profilometer are processed and converted to digital form by the analog-to-digital section. Eight inputs can be accommodated and each is converted with twelve bits of resolution by a Hybrid Systems Corporation HS 9408 Data Acquisition System chip. Each analog input channel features a differential line receiver to give maximum rejection of noise that might be induced in the lines from the transducer to the profile computer. These line receivers also isolate and protect the relatively expensive converter chip from damaging static electricity.

The analog-to-digital section contains its own hardware driver and converts and stores data for each of the eight inputs in turn without intervention from the CPU. Digital data is stored in high-speed buffers that can be read by the CPU in microseconds. A conversion is made every 40 microseconds. At this rate every one of the eight input channels can be read three times per inch even when the van is moving at 55 miles per hour. With the hardware in the analog-to-digital section gathering the data, the CPU is free to devote more time to computation and analysis.

Figure 4.1 shows a block diagram of the analog-to-digital section. The eight differential line receivers, one for each input channel, respond to the difference in voltage levels between their two input lines. Noise voltage induced into the lines between the transducer and the line receiver will affect each line equally, and so will be rejected. The signals delivered from the line receivers to the converter chip are single-ended and include a provision for adjusting the DC offset voltage with a precision trimmer pot to accommodate variations in components used.

The driver section is responsible for executing the correct sequence of actions in order to properly convert and store the signal being presented on each of the eight inputs. This is all to be done without help from the CPU in order to free it for more important work. The driver performs the following sequence for each conversion operation on an input.

(1) The HS 9408 converter chip is informed of the desired channel through three binary select lines. Channels are converted in order from zero to seven.
(2) The driver waits 12.5 microseconds to allow the converter chip to settle after the channel change.
(3) The converter is signaled to begin conversion. At this time it raises its status line high, indicating a conversion is in progress.
(4) When the conversion is completed the HS 9408 lowers the status line. A conversion typically requires 25 microseconds.
(5) The driver responds by strobing the sixteen-bit data buffer storing the converted data from the selected channel. Updated data is now available to the CPU for this input channel.
(6) The next channel is selected and the cycle is repeated for this input.

This entire cycle is repeated every 40 microseconds. The HS 9408 converter chip from Hybrid requires about 94% of the total cycle time; only the remaining 6% is driver overhead.

Digital data for each channel is stored as a twelve-bit binary number. The data buffers used are actually sixteen bits wide, allowing for future expansion if a converter chip with more resolution is selected. The converter chip and line receivers are on a small slave board that mounts on the larger

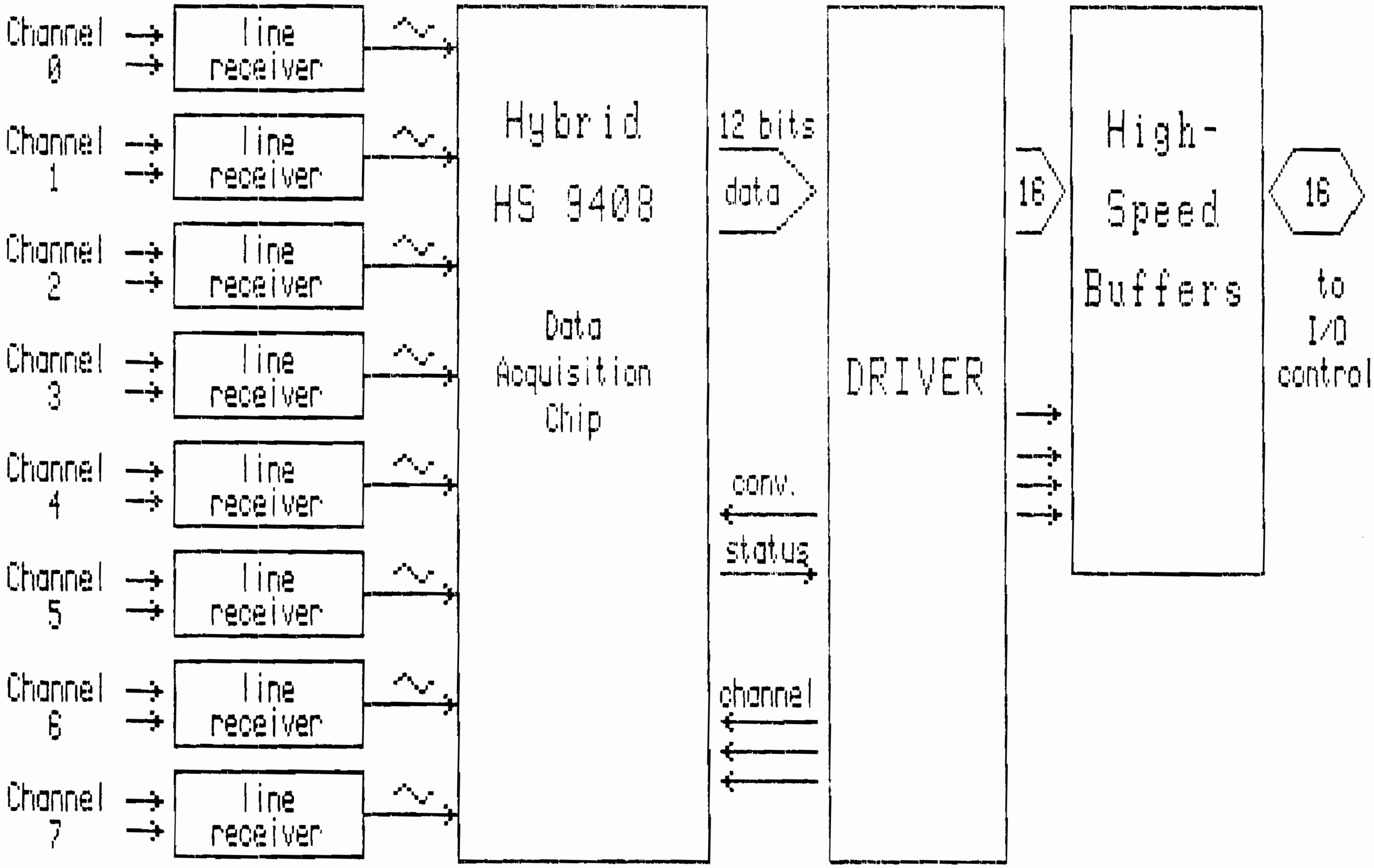

Figure 4.1. Block Diagram of Analog-to-Digital Section.

driver board. They are connected through a 36-pin contact assembly. This scheme allows for the converter to be upgraded in the future to more than twelve-bits of resolution by changing only the slave board. Converter chips of up to sixteen bits can be used by this driver board.

The high-speed buffers used to store the converted data for each channel are on separate printed circuit boards, four buffers per board. The driver communicates with them through a short jumper cable. Bus drivers send selected data to the CPU when it is requested.

Hardware Filters

The signals from the accelerometers pass through hardware filters to remove high frequency noise from the acceleration information. This noise represents common electrical system interference as well as engine vibration and other unwanted mechanically induced signals. The hardware filters include a filter module as well as other circuitry to allow the CPU to make necessary adjustments. The block diagram of a hardware filter is shown in Figure 4.2.

The filter module used is model 844P8B-2 from Frequency Devices, Incorporated. It is a Butterworth low-pass filter with the cut-off frequency digitally programmable in one Hertz steps from one to 256 Hertz. The proper setting depends on the speed at which measurements are being taken. The CPU can program the filter cut-off frequency through an eight-bit binary word and strobe sent through the I/O subsystem. Level translators on the filter board lift the TTL level programming signals to higher voltages required by the CMOS filter module.

The CPU can also set the DC offset voltage on the input to the filter module through another eight-bit digital word and strobe. A digital-to-analog converter lets the CPU precisely adjust the DC voltage to zero. This adjustment is necessary to eliminate the effect of gravity in the accelerometer signal. Vibration and temperature variations may cause the accelerometer zero-adjustment to drift, so the CPU is given the capability of trimming this critical adjustment.

A differential line receiver accepts the signal from the remotely located accelerometer but rejects most of the noise that may have been induced into the connecting lines. After passing through the filter module the signal leaves the board through two paths. A unity gain path and differential driver send the unamplified signal to the analog-to-digital section. A high-gain path is also provided which amplifies the signal

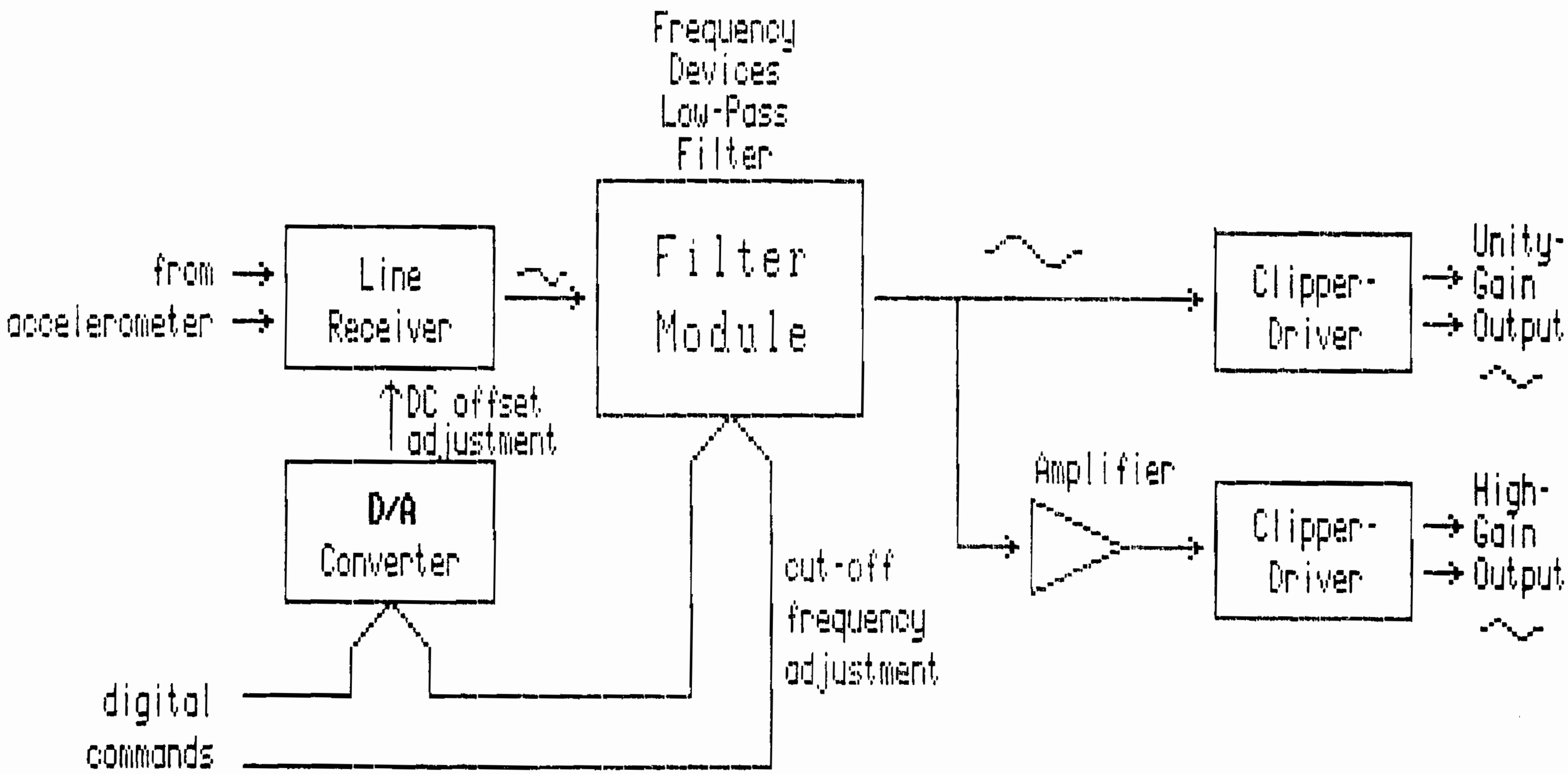

Figure 4.2. Block Diagram of Hardware Filter.

before it is passed to the differential driver. The high-gain signal is used unless large acceleration signals are being generated, in which case the CPU uses the unity-gain channel. In this way maximum information can be extracted from the accelerometer signal whether the vehicle is undergoing great or small acceleration while moving down the highway. Both output channels have clippers which prevent large voltage excursions from damaging the analog-to-digital section.

Reading from External Digital Devices

The I/O subsystem allows the CPU to read from many external digital sources of various data widths. For example, the Selcom laser Optocators provide twelve-bit parallel data on the distance from the vehicle body to the road surface. The design allows for up to 120 external devices to provide up to 32-bit wide data to the CPU. Each external input to the profile computer, including the eight analog inputs, is assigned a unique identification number. This port number allows the CPU to identify which input it needs to read so that the I/O subsystem can provide the data.

The CPU uses one of the eight-bit output ports on the parallel I/O board to identify which external device it would like to communicate with. The I/O subsystem reads this eight-bit identification and makes whatever arrangements are necessary to comply with the CPU request. The input channels are given the hex port numbers 00 to 7F.

Because the profile computer is interrupt driven, provision is made to latch the eight bits presented on the control port to identify the external device to be read. In this way an interrupted read can be continued without delay or further CPU attention. The I/O subsystem decodes the eight-bit identification to select the correct port. If the most-significant bit is low, the CPU is calling for an input. Further decoding uniquely identifies each port.

Standard digital inputs

Several external digital inputs are expected to be used and have been allotted space in the I/O subsystem. The Selcom lasers are an example, providing twelve parallel bits to the profile computer. Such standard digital inputs are accommodated with dual sixteen-bit input boards. Each board can pass either of two sixteen-bit inputs to the CPU when instructed to do so by the port selection decoding electronics. The inputs are fully buffered to prevent voltage pulses from passing into critical sections of the profile computer. Hysteresis on the inputs gives some measure of noise immunity, and pull-up resistors help reject undesired signal coupling.

Expansion digital inputs

In order to allow for easy expansion of the profile computer, eight completely decoded port selection lines are available to the outside through a connector on the side of the computer. This and buffered data lines allow eight external devices to be connected from the outside with minimal additional circuitry. Partially decoded port identification is also provided so that even more devices could be attached with only a little additional decoding of their identification port numbers. This allows external devices to be connected if it is not possible or convenient to include interface cards for them inside the profile computer case.

Writing to External Digital Devices

The same eight-bit control port used to identify input ports to be read is decoded to identify where output data is to be directed. When the most-significant bit of the port number is high, an output device is being selected by the CPU. Hex port numbers 80 to FF are reserved as output ports, allowing up to 128 devices to be written to by the profile computer.

There are several points inside to computer that the CPU writes to to make circuit adjustments. Buffered data is presented by the I/O subsection to all devices. The port identification number is decoded and the proper device is strobed to let it know that the data is available to latch. Data paths up to 32 bits wide can be used, although most devices use only eight or twelve bits.

One board in the I/O subsection decodes the port numbers and delivers strobe signals to up to thirty-two points within the profile computer case. Either totem-pole or open-collector outputs can be implemented by plugging in the desired type of chips to the board. To write data to devices outside the profile computer case, buffered data is available on the connector on the side of the computer. Eight output ports have been completely decoded so that many external devices could be signaled with no other circuitry required. To strobe additional external devices, partially decoded port identification signals are provided which require a minimum of circuitry to be added.

Speed Transducer Interface

A shaft encoder in the power train of the vehicle delivers information to the profile computer about longitudinal distances being traveled by the van. When taken in combination with time signals, vehicle speed can be calculated. Figure 4.3 shows a block diagram of the transducer interface board.

The shaft encoder delivers TTL level signals on two output lines which are ninety degrees out of phase with each other. It would be possible to determine the direction of movement but this feature is not taken advantage of since it is reasonable to assume that profile measurements will be taken with the van driving forward. The two quadrature phase signals do give a considerable noise immunity to the system.

Twenty pulses per foot of motion are delivered by the shaft encoder on each of the two output lines. The speed interface board accepts these signals, processes them, and delivers twenty pulses per foot to the input of a digital counter. The CPU can load an eight-bit number into a buffer. When the counter has seen the selected number of pulses come in, an interrupt is issued to the CPU. For example, if the CPU has loaded the decimal number twenty into the buffer, then interrupts will be issued once per foot of motion. In this way the CPU can set itself to take a measurement every time the van has moved the desired distance down the road. If the divider was not used, the CPU would be distracted by twenty interrupts per foot even though nothing was to be done. This illustrates the design philosophy of relieving the CPU of as much mundane work as possible to free it for more important duties.

Time-Base Generator

Figure 4.4 shows the block diagram of a time-base generator that allows timing information to be delivered to the CPU by the I/O subsystem. This allows the CPU to have an accurate measurement of the passage of time. A 10 mHz crystal oscillator and a series of decade dividers provide output frequencies all the way down to one Hertz. A bus driver chip makes all eight outputs available for selection of the desired time-base period. The CPU will be interrupted at the selected rate by the I/O subsystem.

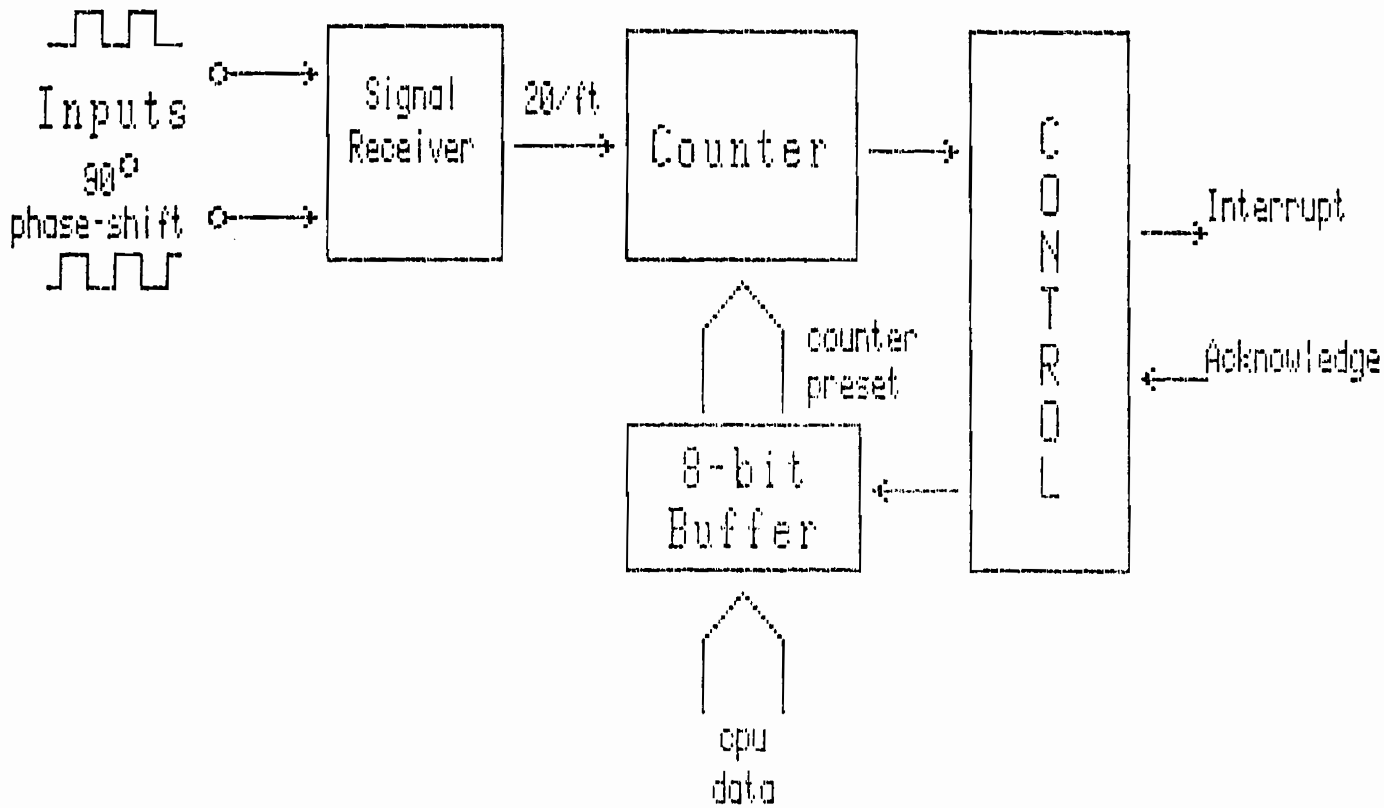

Figure 4.3. Block Diagram of Speed Interface Board.

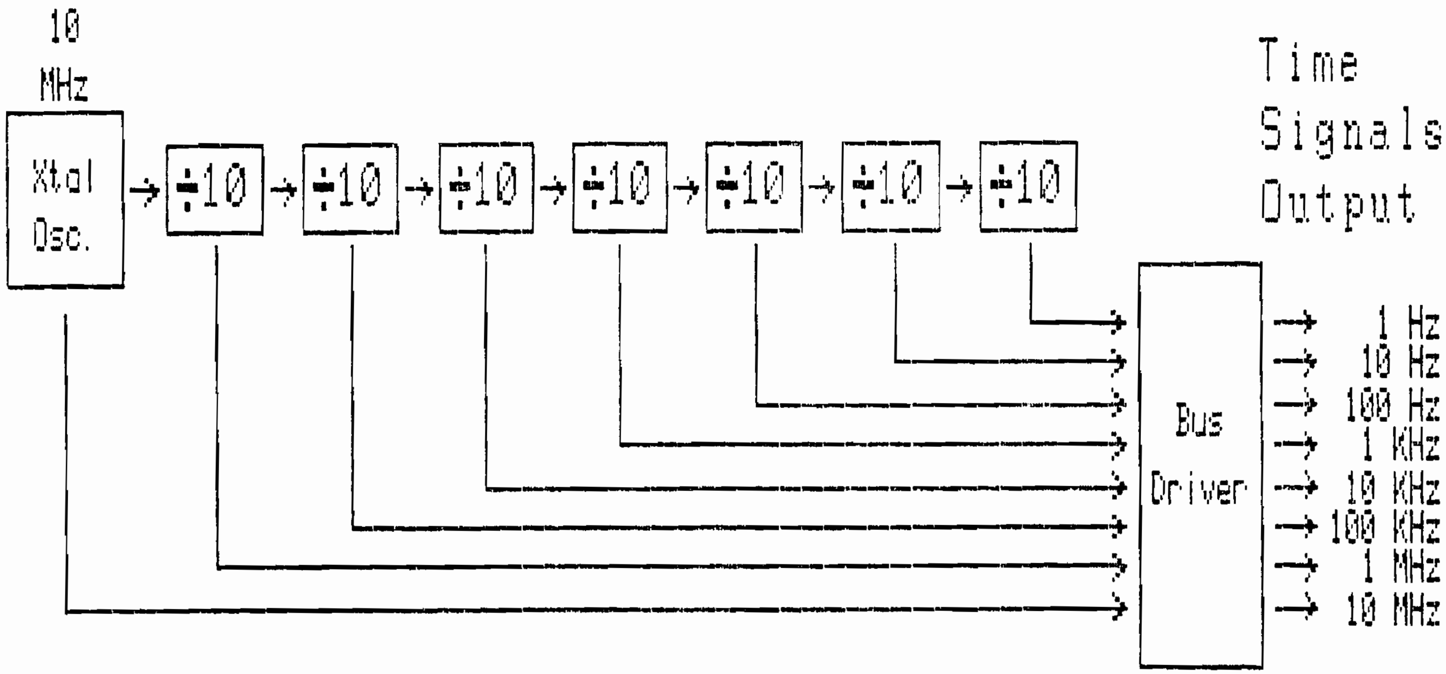

Figure 4.4. Block Diagram of the Time-Base Generator.

Digital-to-Analog Section

Since a chart recorder is to be driven to leave a paper record of the road profiles along the left and right sides of the vehicle, an analog output for each is necessary. The digital-to-analog section uses two twelve-bit D/A converter chips to develop these signals. The CPU sends data to them through the digital output scheme detailed previously.

The output voltage to the chart recorder ranges from zero to five volts and a differential driver is used to reduce the effect of noise on the lines going to the chart recorder. The CPU also issues digital commands to the chart recorder to control mechanical aspects of its operation. These signals have been previously explained.

CHAPTER 5

COMPAQ 286 ON-BOARD COMPUTER SYSTEM

Measuring Process

The measuring process for the SDP was illustrated in Figure 1.1, of Chapter 1. This process included integrating the digitized vehicle body acceleration data twice to obtain the vertical body displacement Z. This value is then added to the displacement, W-Z (or difference between the road profile and car body) to obtain the road profile value, W. Finally, the road profile value is filtered to remove the long wave lengths. The process is identical for both sides or each wheel path.

As noted earlier, the initial plans called for using the data acquisition system described in Chapters 2, 3, and 4 for collecting the data and computing the road profile. However, because of the equipment problems described in Chapter 1, an intermediate system was devised using a COMPAQ 286 computer. This on-board computer (COMPAQ 286) performs both the data acquisition functions and the road profile computations.

In order to use the COMPAQ computer, a Data Translation DT2821 Data Acquisition board was obtained and placed in the COMPAQ. This board provides Analog-to-digital capability for up to eight channels. Only four channels are needed, two for the accelerometers and two for the probes. Jumpers are used so either the road following system or the non-contact probe system can be selected in the measuring process.

Figure 5.1 provides a comparison of data runs using the laser probes and the road following wheels for several of the Austin Test Sections. As discussed earlier, more extensive runs were not possible because of the problems in adding the COMPAQ system. More extensive data runs are currently underway and will be reported later in the project report on the implementation of profiling equipment.

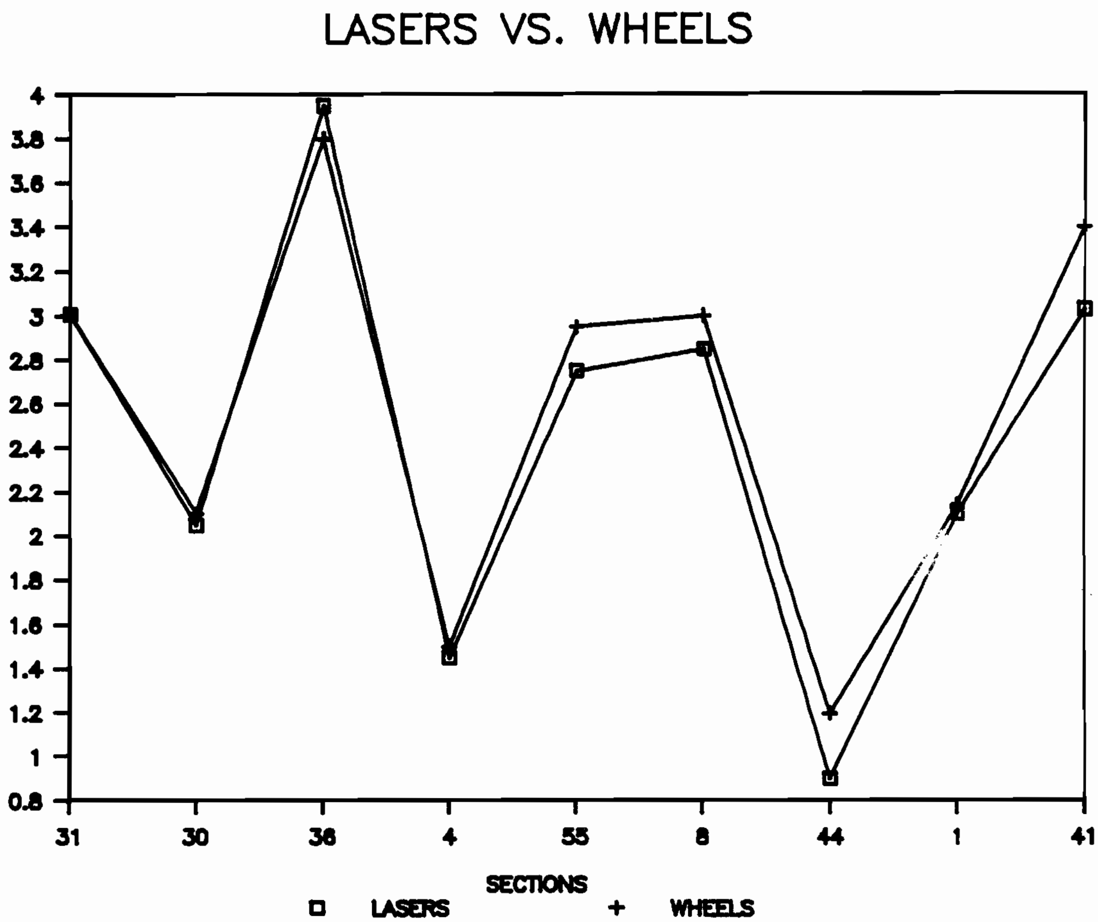

Figure 5.1. Laser vs Wheels Data Runs.

Software

Four programs were written for the data collection process. The first program, COLLECT, is used for collecting and storing the raw acceleration and probe data. This data is stored on hard disk which can then be transferred to floppy. The second program, VERT, uses this raw data to compute the road profile. The third program, PROFILE, performs the data collection and road profile computations in real-time. The road profile data is once again stored on hard disk or floppy. The fourth program performs the PSI computations or duplicates the VERTAC program functions described in Reference 9. This program reads the road profile data generated from either VERT or PROFILE and writes the results to the CRT, disk, or printer, or all three. A more detailed description of this program appears in the Appendix.

Normally, only PROFILE and VERTAC is used for a measuring process. COLLECT and VERT are useful for debugging and are also useful to examine accelerometer or probe data directly for other studies. One such study is the usage of the laser probes for crack identification.

Computation Algorithms

The basic computation algorithm for the SDP is well known. The computation is performed in FORTRAN in VERT, and Assembler in PROFILE. (Assembler was required in PROFILE in order to meet the real-time requirements.)

The double integration in both programs is performed using the Trapezoidal rule. The high pass filtering operation is performed using an Infinite Impulse Response Discrete-Time Filter (IIR). The integration and filtering had to be done together in the real-time version to prevent errors in measurements for the longer sections. The general Fortran computations can be summarized in the following statements:

```
C
C INPUT VARIABLES
C
C       AR: ACCELEROMETER RIGHT (BODY READING)
C       AL: ACCELEROMETER LEFT (BODY READING)
C       PR: PROFILE RIGHT (READING)
C       PL: PROFILE LEFT (READING)
C
```

```
C RELATION AMONG VARIABLES:
C
C       RPROF = AR (INTEGRATED TWICE) + PR
C       LPROF = AL (INTEGRATED TWICE) + PL
C
C INTEGRATION RULE: TRAPEZOIDAL APPLIED TWICE
C                   (INTEGER EXTENSIONS TO VARIABLES DENOTE DELAYS)
C

C INTERMEDIATE VARIABLES:
C
C       BR = AR (INTEGRATED TWICE)
C       BL = AL (INTEGRATED TWICE)
C
C CORRECTED AND FILTERED PROFILE:
C
C                               ____________
C                              |            |
C       RPROF=BR+PR ------->| HIGH PASS |---> FRPROF
C       LPROF=BL+PL ------->|  FILTER   |---> FLPROF
C                              |____________|
C
C==============================================================
C
C     5 Volts => 32 FT/(SEC*SEC)
C X2 IN VOLTS => 12*32/5  IN/(SEC*SEC) (=76.8)
C SPD = SPEED IN MILES/HR => FT/SEC
C X3 = TIME INTERVAL BETWEEN TWO  SAMPLES
C X3 SQUARED FOR DOUBLE INTEGRATION
C-----------------------------------------------------
C                 RIGHT PROFILE
C-----------------------------------------------------
C
C INTEGRATION
            BR = 2.*BR1-BR2+0.25*X3*(AR+2.*AR1+AR2)
            AR2 = AR1
            AR1 = AR
            BR2 = BR1
            BR1 = BR
            RPROF = BR + PR
       IRT=FRPROF*1000
C
C---------------------------------------------------
C                 LEFT PROFILE
C---------------------------------------------------
C
C INTEGRATION
            BL = 2.*BL1-BL2+0.25*X3*(AL+2.*AL1+AL2)
            AL2 = AL1
            AL1 = AL
            BL2 = BL1
            BL1 = BL
```

```
      LPROF = BL + PL
C
C RECURSIVE HIGH PASS FILTER TO FILTER OUT WAVE LENGTHS
C ABOVE X FT  AT S FT/SEC SAMPLING RATE (TIME DOMAIN FORMULA):
C
C F(R/L)PROF = A*F(R/L)PROF + B*[(R/L)PROF(N)-(R/L)PROF(N-1)]
C
C                C = TAN(PI/S*X)
C                A = (1-C)/(1+C)
C                B = 1/(1+C)
```

CHAPTER 6

SUMMARY AND RECOMMENDATIONS

Summary

This project report presents results of Research Project 8-10-85-494, Upgrade Profilometer for Non-Contact Measurements. In this project the 690D Surface Dynamics Profilometer, is updated so that profile measurements can be obtained using non-contact probes in addition to the road following wheels.

The laser probes make the Profilometer more useful for data collection by reducing maintenance problems occurring with the mechanical road-following wheels. The use of non-contact probes in the profilometer is also safer for data collection personnel as greater highway speeds can be used in the measuring process. Appropriate Selcom laser probes were obtained and installed. A Motorola 68020 based data acquisition system was developed during the project.

A second major problem using the profilometer has been the length of time required to process the profile data to obtain various roughness statistics, such as Present Serviceability Index (PSI). A COMPAQ 286 computer system was obtained and programs written so that PSI could be computed in the SDP soon after road profile data was collected.

During the testing phases of the lasers, a major hardware problem occurred in the PDP computer. Because of the costs and time to fix the system it was decided to use the Compaq 286 for an intermediate solution to all computing.

Recommendations

Because of the SDP computer and accelerometer problems, extensive usage of the laser and new computer system was not completed. (Such extensive usage is currently underway.) Such usage is needed to correct any problems overlooked in the upgrade process. The Motorola 68020 system should be completed and a decision made to either use this system or to continue with the current COMPAQ 286 based system.

The system is currently operational with the Compaq 286 unit. It can be used in its present condition improving previous procedures for road profile and roughness measurements.

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APPENDIX

VERTAC

This appendix describes the user interface of VERTAC, the implementation of the mathematical model used by the Surface Dynamics Profilometer (SDP). The program accepts as input the road profile, computes the Root-Mean-Square Vertical Acceleration (RMSVA) over a section, and produces the serviceability index for that section.

The input file contains profile values (in thousandths of an inch), alternately specified for the right and left wheel paths. Two profile data points per foot of pavement are computed for each path.

Besides the PSI value VERTAC also optionally shows the RMS values for various base lengths.

Other inputs to the program include:

. OUTPUT MEDIUM. The results can be sent to the printer, displayed on the screen, or saved onto a file.

. PAVEMENT TYPE. Flexible or rigid.

. SKIPPED DISTANCE. Distance to be skipped before the section begins.

. SECTION LENGTH. The minimum length is required by the model, and the maximum length is set by the program.

. DISPLAY RMS, NEW PSI, GRAPHICS. Various options can be specified. New PSI refers to model VERTAC6 (implemented program is based on version 3.1). Graphics option allows interactive plot of the road profile.

These input parameters can be set to default values for user's convenience. For example, the results are displayed on the screen, the skipped distance is zero, the section length is 1056 feet, etc.

During the execution of the program, the output appears on two virtual screens (graphic and text), only one of which can be displayed at a time. Hitting the space bar switches between the two screens. In the graphic screen the plot of the road profile is displayed. The user can graph any portion of the profile within the section, or print out the plot. The text screen shows the PSI and miscelaneous results for the same section. The user can continue processing with the next section or terminate the program (and save the output file, if any).

The program takes thirty to ninety seconds to finish (a weakness of the SDP: time-consuming analysis of road profile data). Performance of the program mainly depends on:

. section length

. type of computer

. availability of co-processor on the computer

VERTAC is written in Turbo Pascal on the IBM-PC. Running the program with the Intel 8087 math co-processor reduces the overall run time. Running the program using BCD (Binary-Coded Decimal) computation increases the precision of the results. A new version attempts to implement VERTAC in Motorola 68020 assembly language so that the program can be executed in real-time.