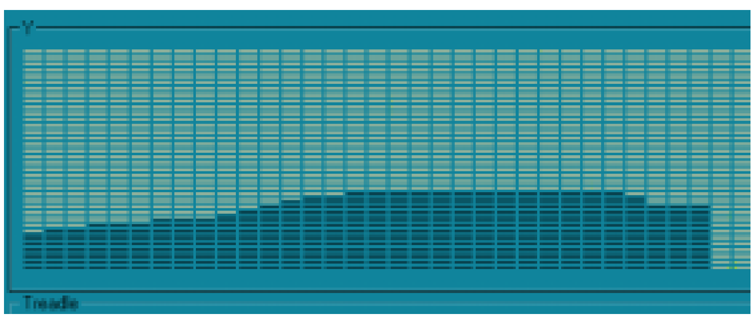
Technical Description

For

Model 320 Automatic Vehicle Classification System

Including

Laser Scanner, Doppler Radar, Weigh-In-Motion Sensors and AVC Processor



TRANSPORT DATA SYSTEMS

Table of Contents

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1.0 INTRODUCTION/SUMMARY

The purpose of this document is to define the design of the Model 320 AVC Classification Equipment. This system provides the capability of classifying vehicles into a complex class structure based on vehicle length, height profile, axle location and w eight.

2.0 CUSTOMER REQUIREMENTS

2.1 Vehicle Classes

The follow ing is a generalized list of vehicle classes. The final product w ill be customized to meet the customer class table.

i) Motorcycles (exceeding 50cc)

ii) Motor cars w ith and w ithout trailers w ithin given w eight ranges

iii) Buses or coaches w ithin given w eight ranges

iv) Light trucks – 2 axle w ith or w ithout trailers w ithin a given w eight range

v) Heavy trucks – 3 axles w ith or w ithout trailers w ithin a given w eight range

vi) Four Axle Trucks w ithin given w eight ranges

vii) Five Axle Trucks w ithin given w eight ranges

viii) Six Axle Trucks w ithin given w eight ranges

2.2 Accuracy

The AVC shall determine classes to an accuracy of at least 99%.

2.3 AVC Vehicle Separation Performance

The AVC system w ill differentiate betw een vehicles separated by a minimum of 1 meter at speeds of less than 60 kilometers per hour.

2.4 Interfaces

Sending vehicle's presence and class from the AVC to the host computer. Presence information can be used for vehicle separation.

3.0 SYSTEM DESIGN

The AVC system consists of the laser scanner, Doppler radar and tw in quartz sensors. This system is capable of providing the classification accuracy to meet the requirements defined in Section 3.

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The block diagram of the AVC is shown in Figure 3.0-1 below:

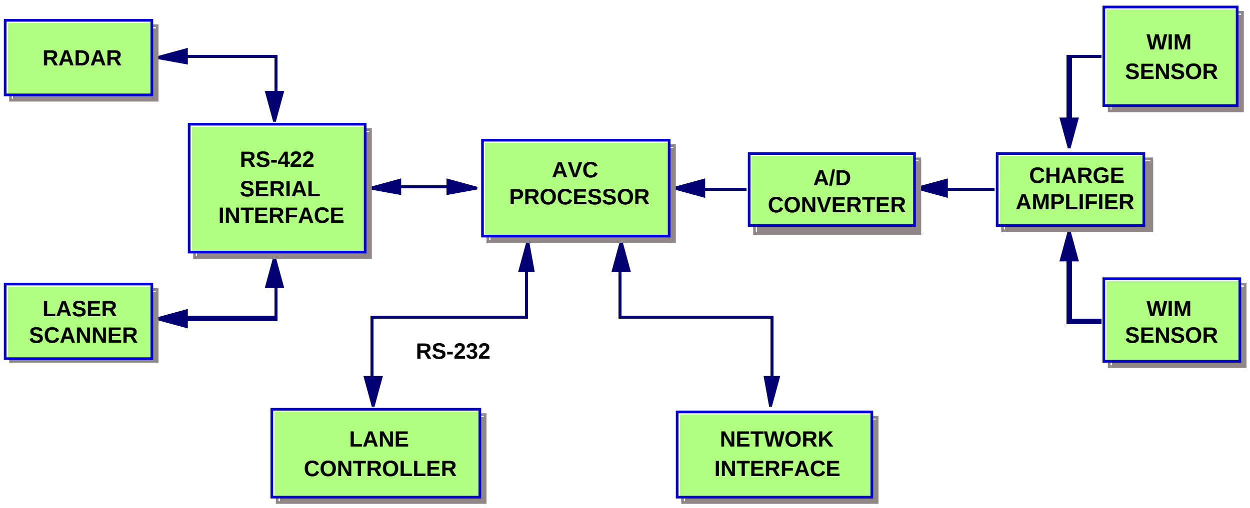


Figure 3.0-1; AVC Block Diagram

The lane layout for the AVC lane is shown in Figure 3.0-2 below:

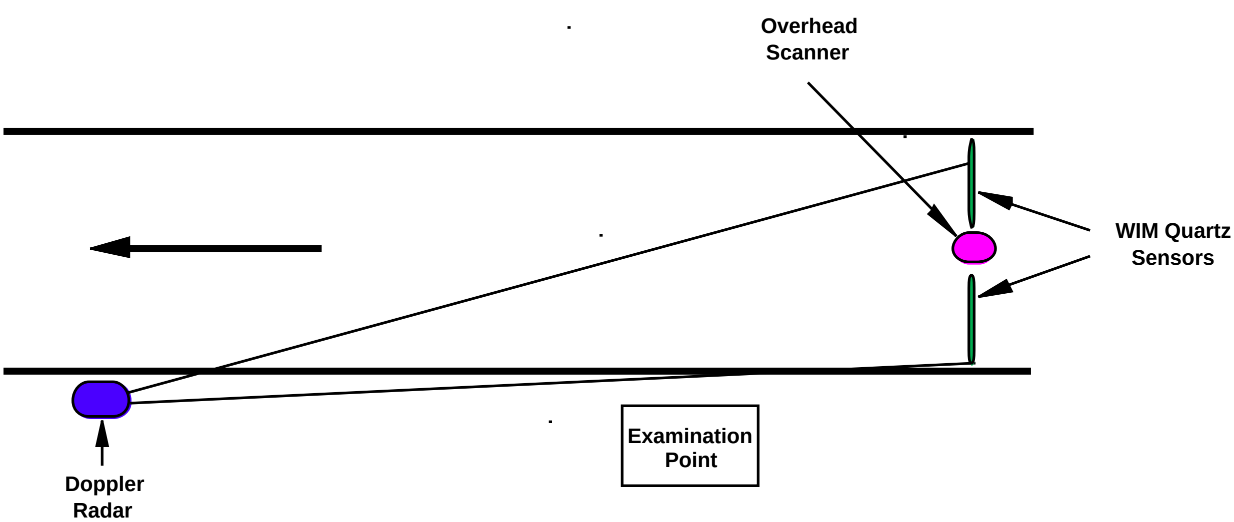


Figure 3.0-2; AVC Lane Sensor Layout

The vehicle class types will be detected according to a set of rules similar to those described below in Table 3.0-1.

Table 3.0-1 ; AVC Produced Classes - Sample

Vehicle Type	Toll Classification	Vehicle Characteristics
Motorbike	1	Length < 7 feet, Two or three axles (Sidecar)
Car	2	Length > 7 feet, < 20 feet Height < 6 feet Two axles Weight < 5000
2 Axle	3	Two axles, > 20ft without a van/bus profile (height < 6 feet) Weight < 5000
2 Axle Truck	4	Two axles, > 20ft without a van/bus profile (height > 6 feet) Weight > 5000 Dual Tires
Van	5	Two Axles Height > 6 feet Length > 7 feet Flat Roof, Weight > 5000
3 Axle Truck – Empty	6	Axle count, Length, Axle Location, Height Profile. Rear Wheel Weight < 5,000 Dual Tires
3 Axle Truck - Loaded	7	Axle count, Length, Axle Location, Height Profile. Rear Wheel Weight > 5,000 Dual Tires
3 Axle Bus	8	Axle Count, Length, Axle Location
4 or More Axle Trucks	9	Axle count, Height Profile Dual Tires

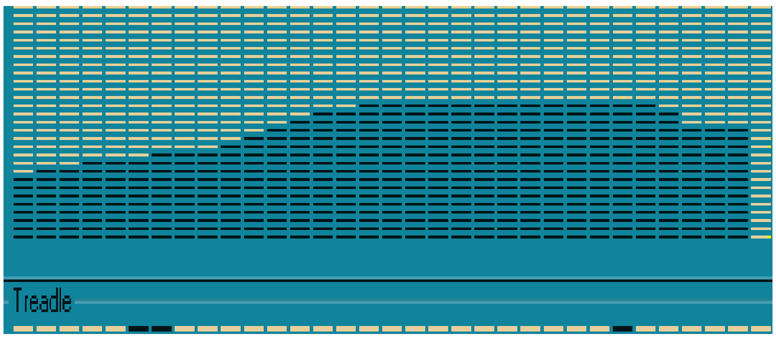
The TDS AVC Automatic Vehicle Classifier:

- Meets all of the individual classification requirements Section 3.1 fare classes based on axles, vehicle weight and length and the vertical profile of the vehicle.
- Allows easy modification of classification categories to readily accommodate future rate structure changes or additional classes.
- Provides accurate vehicle velocity (max and/or average) – accuracy = 1% +/- 0.2 mph.
- Maintains the position of the vehicle at all times while in the collection zone. This includes stop and go operation as well as reverse motion.

- Transmits entry and exit information to the host processor. This information is used by the host processor to augment the lane logic.
- Is composed of off-the-shelf technology from major suppliers.
- Has a system MTBF in excess of 20,000 hours.

3.1 AVC Operational Philosophy

The automatic vehicle classification system described herein is a pattern recognition system that relies on special pattern recognition algorithms to categorize vehicles into a number of distinct types. It uses the length of the vehicle, the number, weight and spacing of axles, and a height matrix depiction of the vehicle to form a complex pattern. This pattern is then fed to discrimination software that correlates with one of a predetermined set of vehicle types. A picture of an actual profile of an automobile is shown in **Figure 3.1-1; Vehicle Profile**.



3.1.1.1. Figure 3.1-1; Vehicle Profile

Vehicle detection and profiling are accomplished by processing the sensor data from the radar, laser scanner, dual tire detector and weigh-in-motion sensors. The AVC processor receives frequent sensor messages from the radar and laser scanner. Each radar message reports the distance and velocity of up to seven targets that the radar is currently sensing in its beam. Each laser scanner message provides a report of the beam status of each of the individual beams. The axle sensor inputs are sampled each time a laser scanner message is received. The vehicle detection process begins when the laser scanner reports sufficient penetration concurrent with a radar report of an object moving in the vicinity of the lane in the path of the laser scanner beams. A filter is implemented to eliminate false classifications from being reported due to penetration of the laser scanner by objects other than vehicles.

While the laser scanner is sufficiently penetrated, the processor creates a profile of the vehicle using the Doppler radar velocity information to determine which position in the vehicle profile to store each laser scanner and treadle sample. This process continues until the laser scanner no longer detects a presence in the path of the laser scanner beams. The vehicle profile is then sent to the correlation process where the classification will be determined.

The correlation process begins with the series of tests to determine the characteristics of the vehicle. These characteristics are the length of the primary vehicle, the presence/location of a hitch, the maximum height and height variance of the primary vehicle, the number of axles and their weights and locations, the existence of dual tires and certain other discrimination criteria. The test results are then correlated with a table of characteristic values that is configured for the user classification schedule. This table of characteristics is stored in a configuration file that is separate from the AVC application software. This provides an easy method for updating the class schedule should the user require modifications. After the classification has been determined the classification message is transmitted to the lane controller application. The classification message includes the maximum velocity of the vehicle measured during the period that it was within the laser scanner. The message also includes the vehicle height, weight and length as well as the total axle count.

After the vehicle has been classified the system continues to track the location of the vehicle in the lane.

A key element in this design is the use of the CW Doppler radar. When vehicles are traveling at higher speeds, the problem of resolving two vehicles in close proximity is particularly vexing. However one characteristic that these two vehicles have in common is that their velocities are obviously very nearly the same. Therefore the Doppler return from each of the vehicles is also nearly the same. The laser scanner acts to provide excellent vehicle separation. The current design allows for separating two vehicles that are within 4 foot of each other at a velocity of 100 miles per hour. At more reasonable speeds (60 mph), the vehicles may be within two feet of each other and at manual lane speeds, the vehicles may be within 8 inches of each other. The processor uses the velocity provided by the Doppler radar to determine the positioning of the various samples in the vehicle profile. Since in this particular case the velocities of the two adjacent vehicles and the corresponding Doppler radar outputs are nearly identical, errors in the sampling distance that are due to returns from the adjacent vehicle are negligible.

The output from the Doppler radar provides an excellent measure of the vehicle velocity. This data is used to calculate the weight of each wheel set as the wheel crosses the quartz sensor. This data will be transmitted to the lane controller as part of the primary AVC message.

The AVC software can provide any/all of the following functions:

- Receipt of data from the radar
- Receipt of data from the laser scanner
- Receipt of data from the axle detection and weighing equipment
- Vehicle presence detection
- Vehicle position tracking through the collection zone
- Determination of the vehicle classification
- Vehicle speed
- Lane entry and exit messages
- Vehicle At ACM message for associating coins with a vehicle
- AVC system diagnostics (remote or local)
- Error reporting to the host processor

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The processor will be able to handle all types of vehicle motion including negative speeds. It will identify back-outs and terminate the transaction.

4.0 DETAILED DESCRIPTION – EQUIPMENT

4.1 Laser Profiler

The laser profiler is a model LMS211 produced by Sick Optic-Electronic. It is a non-contact measuring system that scans its surroundings two dimensionally. The scanner does not require any reflectors or positional markers to function as a scanning system.

The LMS 211 operates by measuring the time of flight of laser light pulses. The time between emission and reception of a light pulse, after it has been reflected from a surface, is directly proportional to the distance between the light source and the object. The laser can scan a large area by using a pulsed laser beam deflected by a rotating internal mirror. The LMS can produce the contour of an object using a rapid sequence of distance measurements. The serial data itself is sent to the lane controller in real time via the RS-422 link.

The unit operates at a scanning rate of 75 scans per second. The scan angle that is reported is programmable. For this application it will be set to 68 degrees. The beam width of the laser beam is approximately 1 degree. The reported angular scanning resolution is programmable. For this application it will be set to 4 degrees, resulting in 17 segments being reported per scan. The range resolution of this configuration is approximately 50 millimeters.

The unit includes internal heaters for environmental control. A built-in thermostatically controlled heater and a front screen heater enable the LMS to be used at temperatures to minus -30 degrees Centigrade. The heaters are activated at 10 degrees Centigrade to prevent any thawing from occurring within the unit.

The unit is delivered with an optional dust prevention shield. This shield prevents direct exposure of the front screen to precipitation or sources of dirt.

The scanner unit weighs approximately 9 kilograms. The unit is delivered with a separate mounting bracket that provides adjustment of the device in both of the relative axes.

The electronic part of the sensor is powered directly from a regulated 24 VDC 1 amp power supply. The scanner heater is also powered from 24 VDC at 6 amps. The heater supply does not require regulation. Both the electronics and the heaters can be powered from the same primary power supply if desired.

TDS provides a maintenance screen in the AVC software package that allows a technician to easily align the scanner and configure the height and lane width settings during installation.

4.2 Eaton Vorad Doppler Radar

The Doppler Radar consists of the following components:

- Radar Antenna assembly
- Power Supply (220/240 VAC)
- Radar Mounting
- Power and communication cables
- RS422 interface to AVC Processor

The Doppler CW radar is a Ku band (24.725 Ghz) radar produced by Eaton Safety Systems. It is designed to provide coarse position and very accurate velocity data on moving vehicles. Coarse position is provided by a 50 kilohertz frequency shift keying applied to the transmitted signal. Velocity data is provided by the Doppler offset of the received signal. The received signal is mixed with a coherent transmitter signal to produce in-phase and quadrature Doppler signals, which are then sampled and fed to a digital signal processor, implemented as a Fast Fourier Transform (FFT). The outputs of the FFT are correlated with the coarse range data to provide data on up to seven separate targets.

The radar was originally designed to be part of a vehicle mounted collision avoidance system that is now being sold in production quantities by Eaton. The radar is a weatherproof unit, packaged to withstand extremes in temperature and humidity. As sold by Eaton, the unit is mounted above the front bumper on a vehicle and provides target information about vehicles directly ahead of the instrumented vehicle. .

The radar is a very low power device (< 5 milliwatts CW). It has complete FCC approval (FCC ID I3L3JC) for operation on the open road and is not an RF hazard to humans under any conditions.

The antenna unit is a planar array. The horizontal beam width is 12 degrees and the vertical beam width is 4 degrees.

The radar processor provides a variable length message containing range and range rate on up to seven targets to the processor. This message is transmitted to the processor every 65 milliseconds. The interface is a 19200 bps RS-422 interface. The resolution of the range is 1 foot and of the range rate is 0.1 foot per second. The accuracy of the range reading has limited value as the phase center tends to move about the vehicle as it passes through the radar beam. On the other hand the accuracy of the range rate is 1% +/- 0.2 miles per hour. The unit will handle velocities up to a maximum of 120 miles per hour and ranges up to 350 feet.

The unit is capable of operating in a temperature range of - 40 degrees to + 85 degrees Centigrade.

The radar requires a maximum of 10 watts of power from a regulated 7.5 VDC source.

As shown below, the Doppler Radar is mounted approximately 35-40 feet "downstream" of the Laser scanner, with the top of the antenna positioned 2-3 feet above the road surface. The unit should be located a maximum of 2 feet from the edge of the lane. The radar antenna should have an unobstructed view of the lane to the laser scanner. The power supply must be located within 6 feet of the radar unit.

4.3 Axle Detector

The axle detector will consist of two 1 meter quartz sensors connected to a charge amplifier.

4.3.1. Quartz Sensor

Kistler's LINEAS WIM Type 9195C is a force sensor with quartz elements. The sensor is a modular element that is installed into a slot that is saw-cut across an asphalt or concrete road. When a force is applied to the sensor surface, the quartz disks yield an electric charge proportional to the applied force through the piezoelectric effect. The electric charge is converted by a charge amplifier into a proportional voltage which can then be processed as required. Key characteristics include:

- Excellent long term stability.
- Measures very accurately at both walking and freeway speeds.
- Insensitive to temperature changes.
- Frost-resistant and protective against ingress of water.
- Quasistatic and dynamic calibration is possible.
- Wide measuring range.

The sensor is not dislodged from the road and can be reground by up to 10 mm in the event of road deformations.

The sensors are available in 0.75 and 1.0 meter lengths. Two or more sensors can be connected together to make a longer single sensor strip. Several sensors that are installed adjacent to one another can be connected electrically in parallel and operated with a single charge amplifier. The output signal then corresponds to the sum of the forces acting simultaneously on all sensors connected.

4.3.2. Charge Amplifier

The industrial charge amplifier (Type 5038A2Y43) is a 2 channel amplifier. Each channel converts the charge output of the Lineas sensor to a proportional voltage. The adjusting potentiometers are designed as plug in units to avoid the need for recalibration when an amplifier is replaced. The unit requires an unregulated 15 to 20 volt DC supply. Its key features include:

- Robust aluminum diecast housing
- Vibration proof
- No adjustments required

4.3.3. Lane Controller Interface

The outputs of the sensor amplifier are brought to the lane controller over special cables capable of extending the distance from the sensor amplifier to over 80 feet. The signals are fed into a digital processing card that contains a 12 bit analog to digital converter.

4.4 AVC Processor

The AVC software module will be installed on an AVC Processor. TDS offers a choice of two different AVC processors. One is for installation inside a controlled environment like the plaza and the other is for external installations.

For the inside installation, the processor is a Dell Series 600 server or equivalent. It uses a Celeron processor. It includes 128 megabytes of RAM and a 20 Gb hard drive. It will contain an Ethernet port for LAN connection. The unit will run the Linux operating system.

For an external installation, the processor is a hardened PC designed to be installed in tunnels and open air booths. It uses a Celeron processor. It includes 128 megabytes of RAM and a 20 Gb hard drive. It will contain an Ethernet port for LAN connection. The unit will run the Linux operating system. The unit is equipped with a heat exchanger to allow for completely sealed operation.

The AVC unit will be equipped with a two channel RS-422 serial channel board and an analog to digital convertor board for interfacing to the sensors. The AVC unit will include an RS-232 port for interfacing with the host computer. One processor is required for each lane.

In the event the user system design incorporates a lane controller running Linux or Windows XP/2000, the AVC software can be integrated into the lane controller. This does require a development effort by the system integrator.

5.0 INSTALLATION

5.1 Laser Scanner Installation

The laser installation consists of:

- Mounting the laser mount on the overhead structure.
- Mounting the laser power supply near the scanner. The laser power supply will need to be put into an enclosure for external mounting.
- Installing a single cable between the power supply and the scanner.
- Installing a single cable between the scanner and the AVC processor.

The laser scanners must be installed overhead at a height of approximately 18 feet from the road surface.

5.1.1. Scanner Installation

The scanner is supplied with a mounting bracket for attachment to the structure. The mount is adjustable to allow for alignment of the scanner.

5.1.2. Scanner Power Supply Installation

The scanner requires a special 24 volt DC power supply. TDS will supply this power supply in a separate rugged container for installation near the scanner installation. The power supply for the scanner must be mounted either on the gantry or at the base of the gantry

5.1.3. Scanner Cabling Installation

The scanner is connected to the AVC processor via an RS-422 link. A single cable connects the scanner to the AVC processor and the scanner power supply. The cable will be supplied with the scanner connector installed and the AVC processor connections left un-terminated. This cable should be run inside of a conduit to the AVC processor location.

5.2 Radar Installation

The radar installation consists of:

- Mounting the radar mount on the island.
- Mounting the radar pow er supply near the radar antenna. The radar pow er supply w ill need to be put into an enclosure for external mounting.
- Installing a single cable betw een the pow er supply and the antenna.
- Installing a single cable betw een the radar and the AVC processor in the plaza.

5.2.1. Radar Antenna Installation

TDS has designed and built a small pedestal mount for the Doppler radar. The mount is adjustable in both azimuth and elevation. The mount is attached to the island w ith four bolts. The mount is adjustable in both azimuth and elevation to allow for beam alignment of the radar.

5.2.2. Radar Pow er Supply Installation

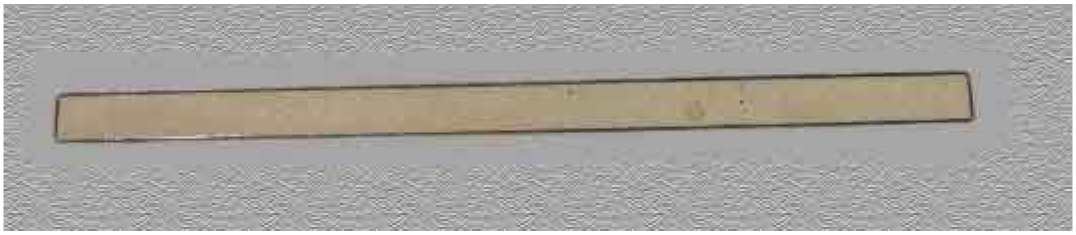
The radar requires a special 7.5 volt DC pow er supply. TDS w ill supply this pow er supply in a separate rugged container for installation near the radar installation. This unit must be installed w ithin 3 meters of the radar.

5.2.3. Radar Cabling Installation

A single cable connects the radar antenna/processor to the AVC processor and the radar pow er supply. The cable w ill be supplied w ith the radar connector installed and the pow er supply/AVC processor connections left un-terminated.

5.3 Quartz Sensor Installation

Special sand/epoxy grout secures the sensor strips into the pavement slots. After curing, the hardened grout and the exposed top surfaces of the sensor modules are ground flush w ith the surrounding pavement using a belt sander. After grinding, the sensors may be immediately exposed to traffic. An overnight post cure is recommended before calibration and acceptance tests are performed.



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Installation instructions for the installation of the sensors will be provided by TDS. The potting compound used to install the sensors will be supplied by TDS.

5.4 AVC Processor Installation

The AVC processor can be located anywhere within 500 feet of the lane.