PROPRIETARY

OFF ROAD AXLE DETECTION SENSOR (ORADS)

FINAL TECHNICAL REPORT

April, 2001

Sponsored by:

The Ohio Department of Transportation (ODOT)

AUTHORS: Gordon R. Little, Ph.D.
Michael R. Johnson

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Principal Investigator: Paul D. Zidek
Phone Number: (937) 299-5999
Fax Number: (937) 299-7773
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Prepared in cooperation with the Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

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Spectra * Research

3085 Woodman Drive, Suite 200 • Dayton, Ohio • 45420-1173
Tel ☎: (937) 299-5999 • Fax: (937) 299-7773
E-mail: sstarr@spectra-research.com

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16. Abstract

Spectra Research has developed a non-intrusive lane monitoring sensor which can be used to measure and classify vehicular traffic over multiple lane roadways. This sensor employs a dual beam laser radar (LADAR) that accurately measures location and passage of vehicle tires to determine axle count, velocity, volume, and classification over multiple lanes. The non-intrusive nature permits portable or permanent set-up on the road shoulder without creating costly traffic disruptions, construction, maintenance, or hazardous situations to highway personnel.

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Laser Radar (LADAR), Sensor, Portable, Non-intrusive, Axle count, Classification

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Ohio Department of Transportation (ODOT)
State Job No: 14710(0)
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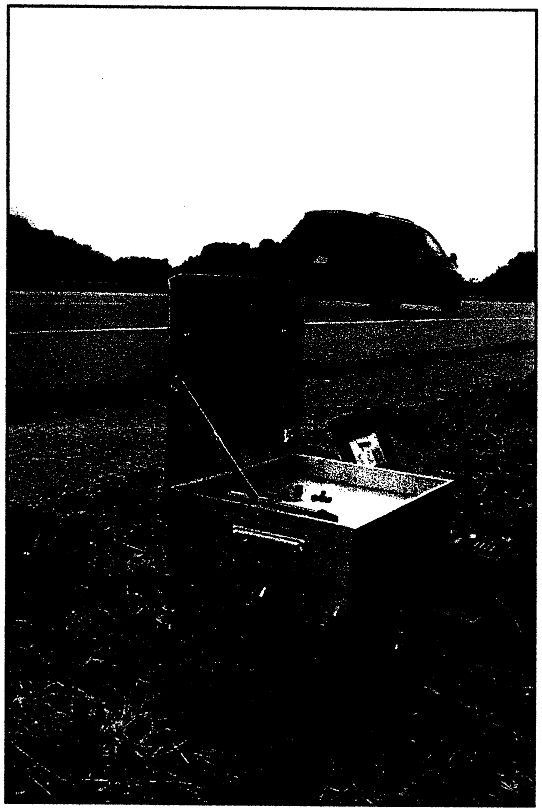
Innovative Technology

(937) 299-5999 • (937) 299-7773 • sstarr@spectra-research.com • www.spectra-research.com

Non-Intrusive Traffic Monitoring System (NTMS)

Spectra Research, Inc. (S*R) of Dayton, Ohio has developed a family of low-cost, non-intrusive, lane monitoring systems to measure and classify vehicular traffic over multiple lane roadways (*patent pending*). These systems employ a dual-beam laser radar that accurately measures location and passage of vehicle tires to determine axle count, velocity, volume, and classification over multiple lanes. The non-intrusive nature permits portable or permanent set-up on the road shoulder without creating costly traffic disruptions, construction, maintenance, or hazardous situations to highway personnel. Several models that facilitate data storage, remote monitoring, and GPS tagging are scheduled for initial delivery in 2000.



• FEATURES

- Non-intrusive
- Rapid setup
- Autonomous operation
- Accurate measurements
- Portable
- Rugged

• BACKGROUND

Spectra Research, Inc. has performed extensive research and development in this area under multiple contracts with the U.S. Air Force. The Ohio Department of Transportation (ODOT) has also sponsored further investigation to determine if errors are introduced due to occlusion of vehicle tires in the outer lanes.

S*R has also been awarded design contracts with the Ohio Department of Transportation and the Federal Highway Administration to further develop this technology. Safety to technicians and motorists is the primary consideration for these efforts. These programs result in a fully functional NTMS that can be easily integrated into the Intelligent Transportation System (ITS) network.

• PAYOFF

The remote traffic monitoring system is installed safely on the side of the road without disturbing traffic. This system can also collect data and monitor traffic at remote locations, as well as provide for growth to meet advanced requirements for both the Federal Highway Administration and state DOTs.

• EXISTING SYSTEMS

Current traffic monitoring systems consist of inductive loops, piezo switches and road tube sensors to monitor traffic flow. These systems are installed to collect and record traffic count, classify vehicle type, and gather speed data. Installations are both permanent and portable. When major road repairs are made at a permanent installation site, the monitoring sensors must also be replaced at additional costs. There is an expressed need for a non-intrusive traffic monitoring system that is safe to install. The key requirements include the capability to (1) classify by lane the vehicle type, (2) monitor 1-4 lanes of traffic simultaneously, and (3) accurately measure vehicle velocity. Additional requirements include packaging each system as a self-contained portable unit that can be set-up in less than 30 minutes, operate autonomously, and exhibit the capability to communicate electronically from remote sites.

Spectra * Research

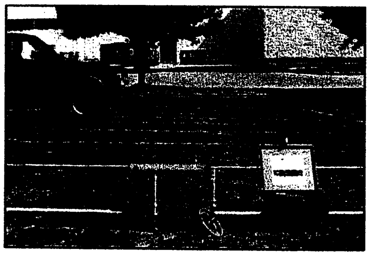
3085 Woodman Drive • Suite 200 • Dayton, Ohio • 45420-1173
(937) 299-5999 • 📠 (937) 299-7773 • sstarr@spectra-research.com • www.spectra-research.com

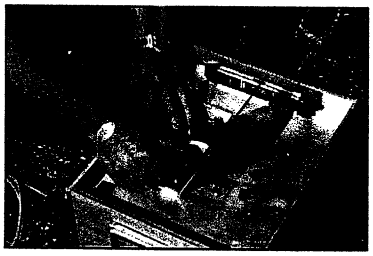
- **NTMS PERFORMANCE**

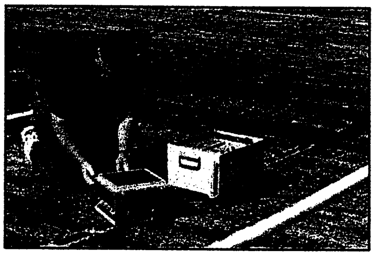
Current designs utilize dual-beam laser tripwires, resident processing algorithms, a self-contained power supply with solar augmentation, a user programmable control interface, and an interface port for use with existing recorder units. The NTMS units meet the following performance specifications:

Parameter	**Requirement**
Sensor Location	Off-road, non-intrusive to traffic (10-15')
Setup Time	< 30 minutes
Interface	Commercial recorders, I/O interface port
Vehicle Classification	14 classes, Scheme F, recorder specific
Lane Coverage	Multiple 1 to 4
Power	Solar augmented battery
Mobility	Portable, self-contained
Operation	24 hours autonomous w/augmentation
Safety	No hazard to technicians, eye-safe

The S*R Non-Intrusive Traffic Monitoring System (NTMS) represents a major achievement in traffic engineering through portability, high accuracy, easy setup, and reduced hazards to motorists and highway traffic engineering personnel.







- **SPECTRA RESEARCH EXPERTISE**

S*R expertise in the field of optics and electromagnetics originated in 1991 with the development of a laser identification systems. This technology was transitioned into application for traffic monitoring in 1994 through a Phase I Small Business Technology Transfer (STTR) contract with the U.S. Air Force. A successful demonstration of a breadboard traffic monitoring device was successfully conducted in October 1995. Subsequent product design enhancements were demonstrated to the Federal Highway Administration (FHWA) in September 1998.

- **PARTNERING OPPORTUNITIES**

Spectra Research, Inc. is actively seeking partnerships with companies, government agencies, universities, and individuals with interest in producing the S*R NTMS technology. For further information, please visit our website at www.spectra-research.com or contact:

Mr. Paul D. Zidek
President
Spectra Research, Inc.
3085 Woodman Drive, Suite 200
Dayton, OH 45420-1173 USA

(937) 299-5999 ext. 12
zidek@spectra-research.com

Mr. Jerry V. Capozzi
Senior Design Engineer
Spectra Research, Inc.
3085 Woodman Drive, Suite 200
Dayton, OH 45420-1173 USA

(937) 299-5999 ext. 23
capozzij@spectra-research.com

Mr. Michael R. Johnson
Senior Systems Engineer
Spectra Research Inc.
3085 Woodman Drive, Suite 200
Dayton, OH 45420-1173 USA

(937) 299-5999 ext. 19
mjohnson@spectra-research.com

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Off-Road Axle Detection Sensor (ORADS)
State Job No: 14710(0)
Contract No: 9001
Final Technical Report

1.0 INTRODUCTION

1.1 Purpose of ORADS Research Program

Under sponsorship of the Ohio Department of Transportation (ODOT), Spectra Research, Inc. developed a portable sensor utilizing laser-radar (LADAR) technology for traffic monitoring. This 30 month research program (11 August 98 to 11 February 01) applied laser-based technology to develop a safe, non-intrusive off-road traffic sensor that could interface with existing commercial traffic data collection devices. Utilization of the ORADS sensor maximizes safety for ODOT traffic engineers by drastically reducing their exposure to traffic. Its portability and installation also eliminates traffic disruption.

1.1.1 Research Goal

The objective of this program was to develop a safe, non-intrusive, portable traffic monitor that would emulate or replace current intrusive traffic monitoring devices. The program included development of a two beam laser tripwire sensor designed to accommodate the specific requirements of the Ohio Department of Transportation. Three prototype units were developed, tested, and delivered to ODOT.

1.2 Program Overview

A multiple step approach was used to develop ORADS: (1) refine needs, (2) define sensor requirements, (3) develop a LADAR sensor, (4) interface with a commercial data collection device, (5) demonstrate proof-of-concept, (6) fabricate and deliver 3 prototype units, (7) support field testing and evaluation, and (8) provide a final report.

This program commenced in August 1998 with the first successful demonstration to ODOT in August 1999. Successful ORADS performance demonstrations were completed with ODOT in October of 2000. These demonstrations showed that the ORADS worked for three lanes of high speed, high volume traffic for vehicle classification when interfaced to a Diamond® Phoenix counter. The ORADS unit is capable of monitoring 3 lanes of traffic whereas a conventional unit requires numerous road tubes and tape switches in all lanes to monitor the same site. ORADS eliminates the need for a second traffic data device, and does not block traffic.

1.3 ORADS Performance Goals

Early in the program, S*R consulted with members of ODOT to define performance requirements for the sensor design. The focus for this effort was on the performance goals outlined in Table 1.

Table 1. ORADS Performance Goals.

Parameter	Goal
Sensor Location	Off-road, non-intrusive to traffic
Setup Time	<15 minutes
Interface	Commercial traffic data collection devices
Velocity Accuracy	±1mph
Vehicle Type/Length	14 classes by length (5-75')
Lane Coverage	Multiple (1 to 4), bi-directional
Power	Solar augmented battery
Mobility	Portable, self-contained
Operation	48 hours continuous
Safety	Minimum hazard to technicians, eye-safe
Operating Temp	-20° C to 85° C
Cost Goal	$1,200 to $2,000 (estimated)

(See Table 13, page 35 for Goals vs. Actual Achievement)

2.0 ORADS RESEARCH OBJECTIVES

2.1 Specific Objectives

Several specific objectives were identified for ORADS:

1. Design a portable LADAR sensor capable of accurately measuring the velocity of vehicular traffic, when interfaced to a commercial traffic data collection device.
2. Develop processing electronics and software to interface raw data signals to a commercial traffic data collection device (Diamond® Phoenix).
3. Demonstrate less than 30 minutes setup time and the capability to accurately measure vehicle type, and travel lane.
4. Demonstrate design compliant with eye-safe regulations for Class 1 lasers.
5. Provide a hardware demonstration, and final report.
6. Fabricate and deliver 3 prototype sensors for field evaluation.

All of these objectives were achieved.

3.0 ORADS DESIGN OVERVIEW

3.1 ORADS General Description

ORADS consists of dual LADAR sensors, optics, electronics, processing elements, sorting algorithms, and interface electronics. The enclosure is an 8" X 17.5" X 14.5" weatherproof, electronically shielded package with leveling adjustments, and weighs approximately 70 lbs. Internal optical mechanical components are black anodized to minimize reflectivity. Non painted components are finished in gold iridite. Internal enclosure walls are painted black over gold iridite. External walls are painted machine gray over gold iridite. A photo of the ORADS development unit is shown in Figure 1.

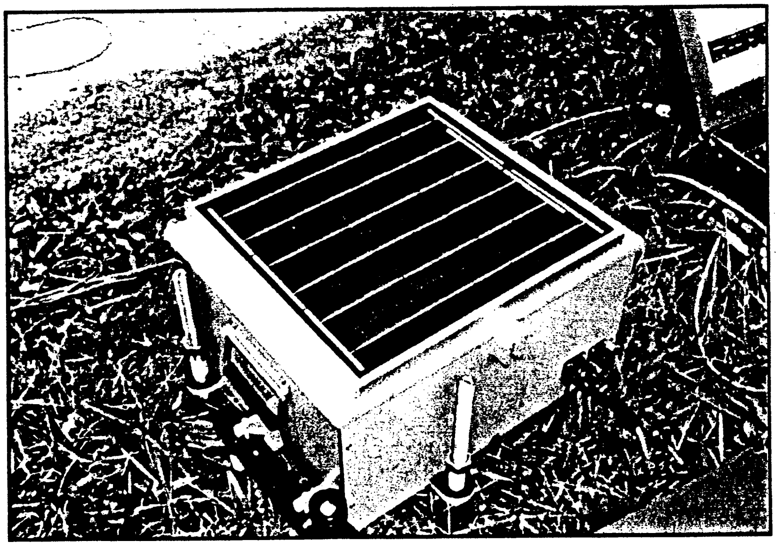


Figure 1. ORADS Development Unit

3.2 ORADS Theory of Operation

The ORADS sensor is based on a dual beam laser tripwire approach (see Figure 2.). There are two laser channels, each using a pulsed laser transmitter, detector and signal processor, to ascertain the presence and location of a vehicle axle on the roadway. The laser channels are alternately pulsed to eliminate adjacent channel interference. Each laser channel is pulsed at a frequency of 5 kHz to provide accurate range and velocity measurements. The time of travel of the laser pulse is determined by using an 8-bit counter operating at approximately 125 MHz. By counting the time the laser pulse takes to reflect off of a vehicle (tire/wheel) and return to the receiver, the distance of the vehicle from the sensor can be measured. The 125 MHz clock frequency provides 8 ns increments of timing for the laser pulse travel, and allows a lateral displacement resolution of approximately 4 ft. This configuration provides all of the information required by a commercial traffic data collection device to determine vehicle classification, lane, and velocity .

When a laser is pulsed, its 8-bit counter is started. The counter increments every 8 ns based on the 125 MHz clock reference supplied by the system clock. When the laser pulse reflects off of the vehicle tire and returns to the sensor, the laser receiver voltage raises to a level sufficient to indicate the detection of a laser pulse return. The laser receiver voltage level is sensed by a series of amplifiers and a comparator in the laser detector electronics, and a stop pulse is sent from the detector to the counter. The stop pulse indicates to the counter circuitry that a laser pulse return has been received and the 8 bit counter is stopped. The 8-bit counter stops counting and indicates the time, in 8 ns intervals, that has elapsed from the triggering of the laser to the detection of the laser return pulse. A signal is sent from the counter to the range processor indicating that the range count is available for processing. If the laser receiver and detector do not detect a laser pulse return, the counter is stopped when it overflows at a count of 256. The overflow bit is set so that the range & velocity processor knows that the range counter value is invalid and there was no vehicle axle present during this laser pulse cycle. This process occurs at a 5 kHz rate, alternating between laser channel 1 and laser channel 2.

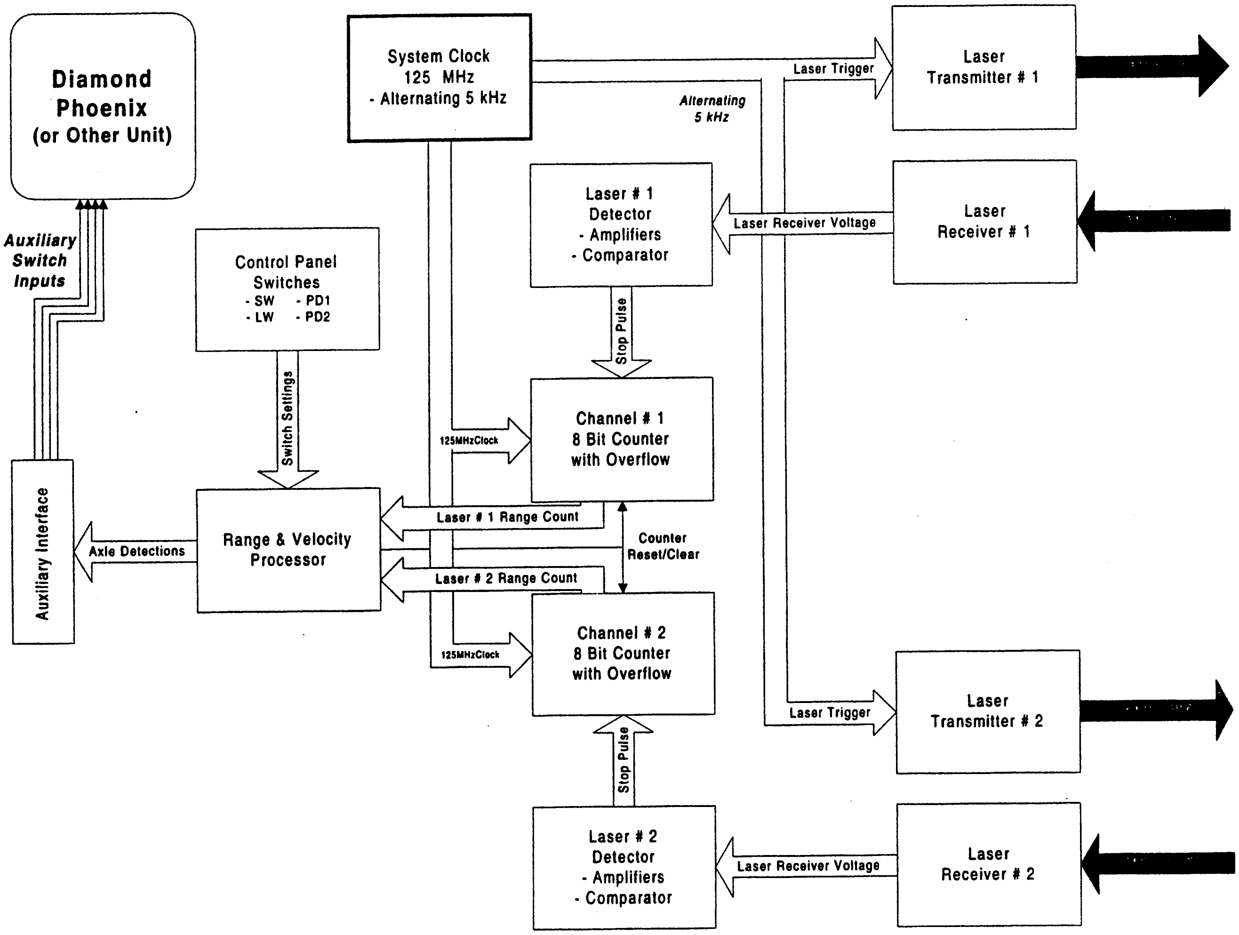


Figure 2. ORADS Functional Block Diagram.

The range & velocity processor reads the range count data from each laser channel and alternately resets the counters after each laser channel pulse. The range count data and overflow bit provided by the counters is used to accumulate all of the necessary information on each vehicle axle. The range count data requires some additional processing to determine the vehicle lane directly from the range information provided by the counters. The processor accomplishes this by periodically reading switches from the control panel that indicate the electronic delay in laser firing and detection, the ORADS sensor distance from the first lane, and the width of the lanes. The processor algorithms and switch settings are then used to determine the vehicle lane and velocity.

Once a vehicle axle has been detected and processed, the corresponding auxiliary switch input on the Diamond® Phoenix is triggered through the auxiliary interface. There are two auxiliary switch inputs corresponding to each laser channel for each lane of traffic. The Diamond® Phoenix will see the auxiliary switch input triggers as if they were tubes or switches configured on the roadway. This will enable Diamond® Phoenix data recorder to calculate and record all of the traffic statistics possible for its auxiliary switch input configurations.

3.3 ORADS Development Process

This section discusses the requirements for the laser subsystem, presents the preliminary design concept, and describes the development process leading to the demonstration unit.

3.3.1 ORADS Laser Sensor Development

The dual laser transmitters must generate infra-red pulses necessary for determining vehicle lane and velocity. This data must be sufficient for enabling vehicle classification using conventional traffic data collection devices.

Receivers tuned to the wavelength of the transmitted laser pulses must detect and amplify reflected pulses from vehicle tires to a level of sufficient amplitude to activate logic circuits.

The sensor, (transmitters, receivers, optics and processing electronics) must provide raw data from three lanes of traffic to a commercial traffic data collection device and must not present an eye hazard to motorists, highway personnel or pedestrians that may approach the sensor.

3.3.1.1 Laser Sensor Design Concept

The ORADS LADAR concept is based on the laser tripwire approach depicted in Figure 3. The tripwire sensor uses laser radar ranging techniques to generate lane-by-lane vehicle counting and classification data. The single-channel tripwire sensor is adapted to provide high accuracy vehicle speed measurement by adding a second channel spatially shifted with respect to the first, as indicated in Figure 4.

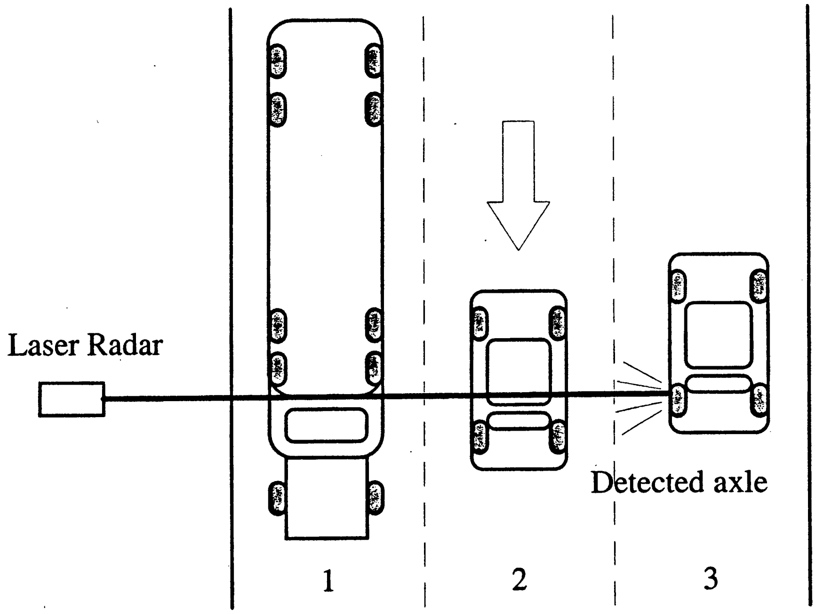


Figure 3. Laser Radar Tripwire Sensor.

Each channel of the laser radar tripwire sensor includes a pulsed laser diode transmitter and a high speed receiver. The laser beam is expanded to ensure eye safe operation and is directed horizontally across the pavement at a height of about six inches. The beam strikes the tires of passing vehicles. The tire then reflects a portion of the light (nominally 2%) back toward the sensor. The receiver detects the reflected pulses and determines the arrival times of each pulse. The arrival times are used by the sensor processor to assign a lane to each intercept.

Since the laser system detects axle crossings, the sensor system outputs may be designed to mimic contact switches or pneumatic tube sensors, enabling direct interface with conventional traffic data counting systems. When a detected pulse is assigned to a particular highway lane, a simulated, lane-specific contact switch closure signal is generated for relay to the host traffic counter system. The host system can then apply its algorithms to determine vehicle classification and velocity. Note that the tripwire sensor has the capability to provide more information than can be used by commercial counting systems. For example, the tripwire can accurately sense vehicle lateral position within a lane while contact switch, pneumatic tube, and induction loop sensors cannot.

Using a low-height laser beam to probe the highway allows accurate counting under high traffic density conditions because obscurations occur only as vehicle wheels pass through the beam (Figure). S*R developed a model (**OCCLUSION FEASIBILITY STUDY, State Job No. 14669(0),** 27 August 1997) that predicts a vehicle error rate of 2% for traffic density of 2200 vehicles per hour per lane with an average speed of 60 mph on a three-lane highway. As part of the study, S*R conducted highway field measurements for the Ohio Department of Transportation verifying these predictions.

Incorporation of narrow band filters and use of AC-coupling in the receiver channels provides effective suppression of the ambient background radiation to permit both day and night operation.

The configuration for a two-channel tripwire sensor is shown in Figure 4. The two laser transmitters, separated by distance Δx, direct laser pulses across the highway. Two receivers, each with its field of view matched to one of the transmitted beams, detects when a passing vehicle tire intercepts the viewed beam. Each receiver channel is processed separately to detect and time-stamp passing vehicle tires. This time stamp information is subsequently converted to a form simulating contact switch closings and passed to a conventional traffic counting unit for vehicle classification and velocity determination.

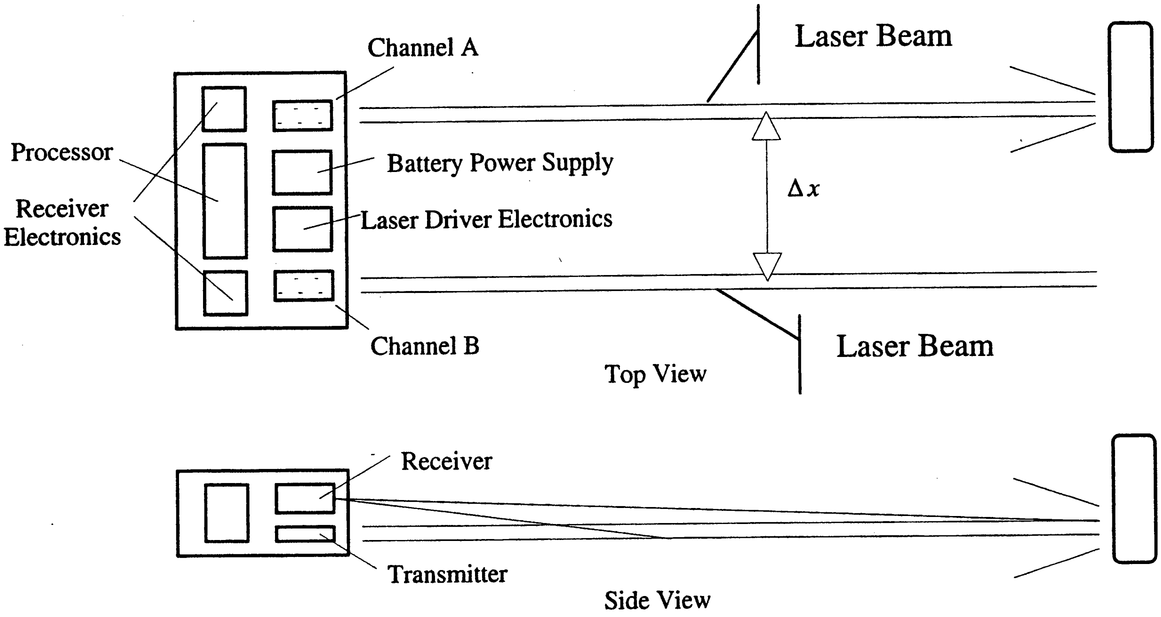


Figure 4. Two-Channel Sensor Configuration.

Figure 5. illustrates a single-channel, single-pulse return from a vehicle tire in Lane 2 of a four-lane highway with a 15-ft sensor-roadway offset and 12-ft traffic lanes. As indicated, the pulse is received at time $T_M + T_o + \sim 36$ns after the laser is triggered. Here, T_M is the delay between trigger application and laser firing and T_o is an additional delay that includes two way propagation over the sensor-roadway offset distance. Proper calibration of the delay and offset times and measurement of the arrival time is necessary to enable lane discrimination and determination of position within lane. Each channel is calibrated in the lab when the unit is assembled. Thereafter, the propagation delay switches should not be adjusted unless vehicles appear to be in the wrong lane as indicated by the control panel indicators. Only qualified personnel should adjust the propagation delays.

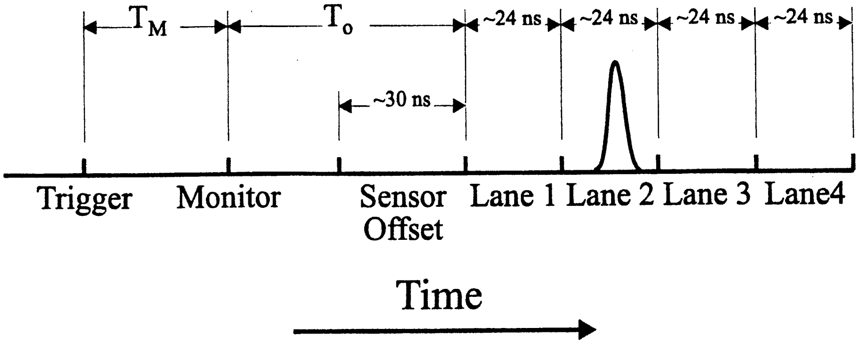


Figure 5. High resolution single-channel output from a vehicle tire in lane 2.

The time evolution of the dual-channel sensor outputs is represented in Figure 6. Here, a large number of pulse returns are indicated for each sensor channel as a vehicle tire passes through the two laser beams. At typical highway speeds (e.g., 80 ft/s) and pulse repetition frequencies (e.g., 5 kHz), over 60 pulses will be received from each tire. As indicated, the individual pulse returns will likely have differing amplitudes due to the varying reflectance of the tire and wheel surfaces intercepted by the beam. The simulated contact switch closure should be timed to represent the beginning of each detected pulse train. While there may be some fixed delay between receipt of the first tire-reflected pulse and the contact switch closure signal, the relative times between the two channels must be precise to within about 0.05 ms to permit 1% velocity accuracy.

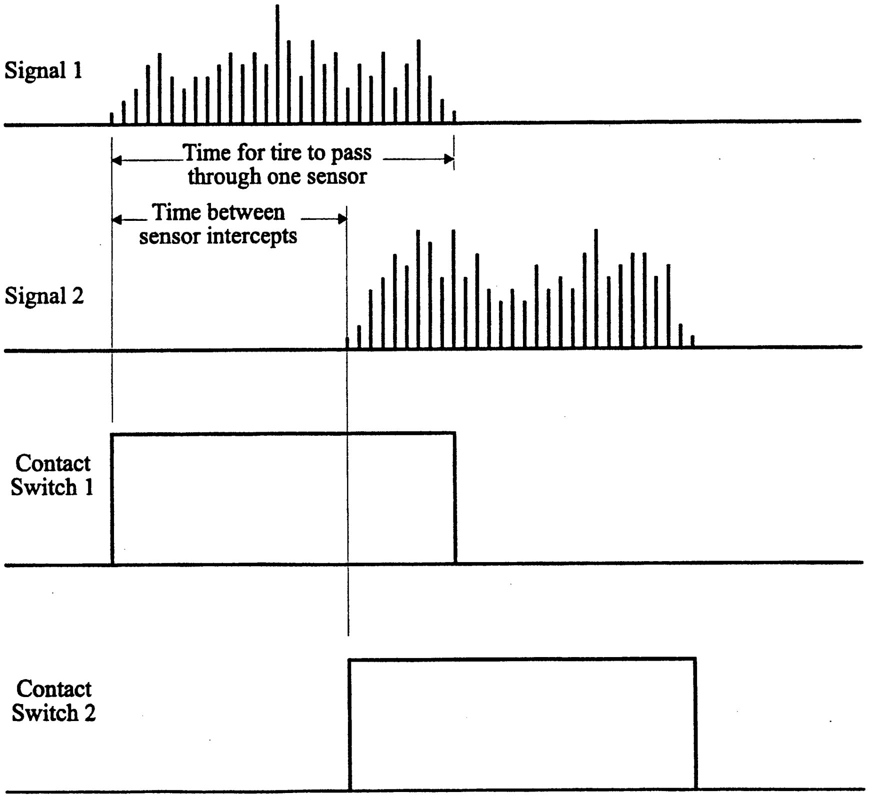


Figure 6. Detail of sensor output signals.

3.3.2 Laser Sensor Design Considerations

The ORADS sensor based on the design concept presented above has been developed, and is described below.

3.3.2.1 Radiometric Analysis

A radiometric analysis projects the performance anticipated in the sensor and permits tradeoff of candidate detailed designs. Table 2 defines important system and environmental parameters and gives representative values used in the computation.

Table 2. Definitions and Representative Values of Parameters Used to Analyze Sensor Performance.

Symbol	Parameter	Value
P_0	Laser peak power	20 W
λ	Laser wavelength	905 nm
A_r	Receiver area	20 cm^2 for 2" diameter aperture
R	Range from intercept to receiver	15-63 ft (four 12 ft lanes, 15 ft offset)
ρ_t	Tire reflectance	0.02
ρ_b	Background reflectance	0.9 (uncontrolled)
Ω	Receiver field of view	2×10^{-5} sr
$O(R)$	Field of view overlap factor	0.1 to 1.0
$\Delta\lambda$	Bandpass filter spectral bandwidth	70 nm
τ_f	Bandpass filter transmittance	0.5
τ_o	Optics transmittance	0.5
$\Re$	Detector responsivity	0.5 A/W (Si PIN photodiode) 25 A/W (Si avalanche photodiode)
NEP	Detector Noise Equivalent Power	0.2 $pW/Hz^{1/2}$ (Si PIN photodiode) 27 $fW/Hz^{1/2}$ (Si avalanche photodiode)
τ_a	Atmospheric transmittance	0.8
E_b	Spectral irradiance on background	100 mW/cm^2-µm (full sun);
Δf	Electronic bandwidth	250 MHz

Assuming a diffuse target and background, we compute the received signal power Ps as

$$P_s = \frac{P_0 \rho_t A_r \tau_a \tau_o \tau_f O(R)}{\pi R^2} \tag{1}$$

and the received background power P_b as

$$P_b = \frac{E_b \Delta\lambda \rho_b A_r \Omega \tau_o \tau_f}{\pi}. \tag{2}$$

We may describe the sensor's signal and background response in current form as

$$i_{s,b} = P_{s,b}\Re \qquad (3)$$

with rms noise current as

$$i_n = \sqrt{2q(i_s + i_b)\Delta f + \Re^2 NEP^2 \Delta f}\ . \qquad (4)$$

For detectors incorporating transimpedance preamplifiers having feedback impedance of R_F, the outputs may be expressed as

$$v_{s,b} = P_{s,b}\Re R_F \qquad (5)$$

and the rms noise can be expressed as the voltage

$$v_n = R_F i_n\ . \qquad (6)$$

The overlap factor *O*(*R*) listed in Table 2 and included in Equation (1) is applicable for sensor configurations having offset transmitter and receiver apertures. Such an offset is desirable to prevent reflections from optical surfaces of the transmitter from reaching (and saturating) the detector. To achieve acceptable performance with an offset system requires diverging the laser beam in one direction and tilting the receiver field of view with respect to the laser axis. Figure 8 shows values of the overlap factor for several candidate sensor geometries. While overlap factors of 0.7 are possible with small laser beam spreads, such configurations limit the ability to operate with modest (e.g., 15 ft) sensor-roadway offsets.

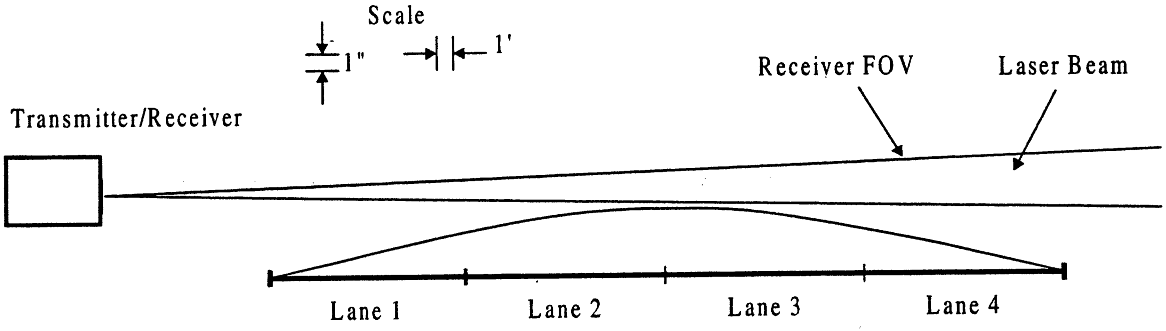


Figure 7. Representative sensor geometry for offset transmitter and receiver apertures.

The geometry illustrated in Figure 7 shows the laser divergence and receiver offset lying in the horizontal direction. Early breadboard sensors were configured with the laser divergence in the vertical direction but this produced occasional spurious returns from the bodies of vehicles in distant lanes especially when road crown was large. The ORADS sensor geometry was adapted to use a minimal vertical receiver offset (the transmitter aperture lies within the receive aperture) and to orient the laser with the larger divergence direction horizontal. This arrangement was found to achieve the required laser-receiver overlap and to substantially reduce spurious vehicle body returns.

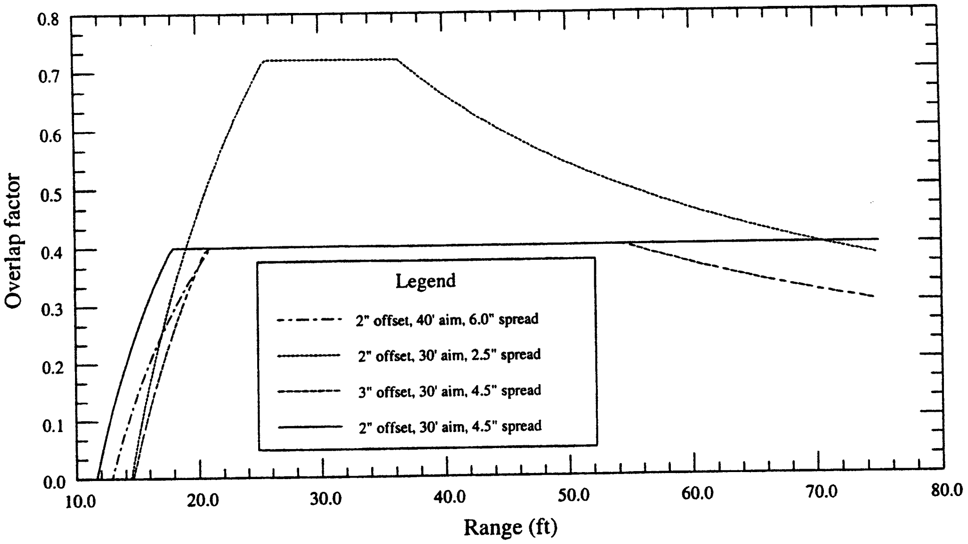


Figure 8. Overlap factor as a function of target range for four representative sensor configurations.

Table 3 gives predicted performance for a the ORADS design including an avalanche photodiode (APD) detector and transimpedance preamplifier. The results show good SNR for five-lane coverage but indicate the need for AC coupling to suppress the relatively strong background signal. Table 4 gives predicted performance for a similar design incorporating a PIN photodiode receiver. The predicted SNR values are marginal in this case. The better-performing APD system was chosen for the ORADS sensor.

Table 3. Predicted Performance For the ORADS APD-Based Sensor.

Lane	R (ft)	P_s (μW)	P_b (μW)	v_s (mV)	V_b (mV)	v_n(mV)	SNR
1	18	1.87	0.19	3401	352	46.2	73.6
2	30	0.67	0.19	1224	352	29.9	40.9
3	42	0.34	0.19	625	352	23.6	26.5
4	54	0.21	0.19	378	352	20.4	18.6
5	66	0.14	0.19	253	352	18.5	13.6

Table 4. Predicted Performance For A PIN-Based Sensor.

Lane	R (ft)	P_s (μW)	P_b (μW)	v_s (mV)	v_b (mV)	v_n(mV)	SNR
1	18	0.75	0.19	3.74	1.0	0.100	37.4
2	30	0.27	0.19	1.35	1.0	0.090	15.0
3	42	0.14	0.19	0.69	1.0	0.087	7.9
4	54	0.08	0.19	0.42	1.0	0.086	4.8
5	66	0.06	0.19	0.28	1.0	0.085	3.3

3.3.2.2 Laser Safety Analysis

The laser radar sensor must be eye safe. Meeting this requirement can be achieved through reducing laser power, expanding the laser beam, or using a laser whose wavelength is outside the primary ocular hazard region. This analysis examines the maximum permissible ocular exposure limits (OELs) and determines the beam sizes required to reduce exposures below these limits for several candidate laser wavelengths.

The maximum permissible ocular exposure limits for visible and infrared laser wavelengths, compiled from data in the Electro-Optics Handbook and the Laser Safety Guide published by the Laser Institute of America, are shown in Figure 9. As indicated, these limits are computed using a variety of expressions depending on the wavelength λ and exposure duration t.

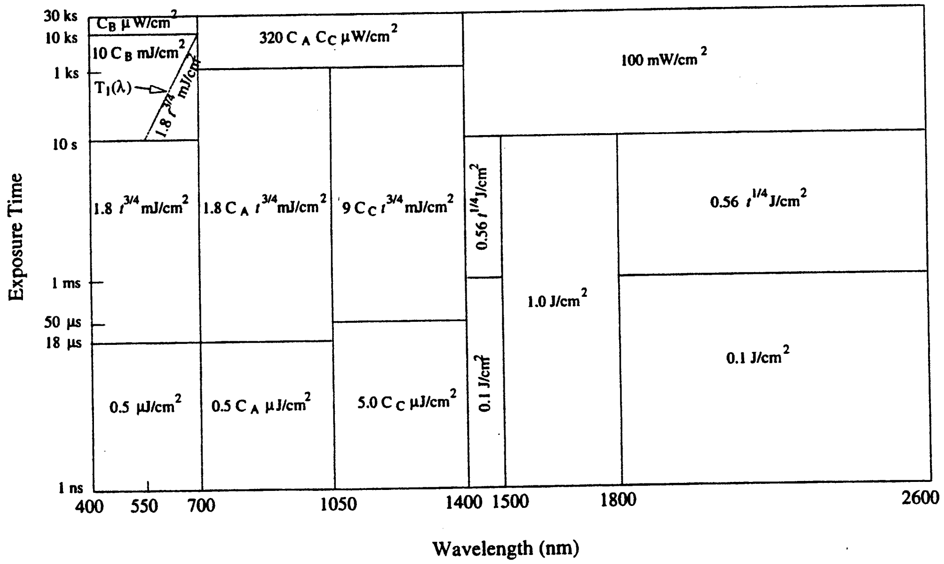


Figure 9. Ocular Exposure Limits for Visible and Infrared Lasers.

The various wavelength-dependent parameters used in Figure 7 are defined as follows:

$$C_A = \begin{cases} 10^{0.002(\lambda-700)} & 700\text{ nm} \le \lambda \le 1050\text{ nm} \\ 5 & 1050\text{ nm} \le \lambda \le 1400\text{ nm} \end{cases}, \tag{7}$$

$$C_B = \begin{cases} 1 & 400\text{ nm} \le \lambda \le 550\text{ nm} \\ 10^{0.015(\lambda-550)} & 550\text{ nm} \le \lambda \le 700\text{ nm} \end{cases}, \tag{8}$$

$$C_C = \begin{cases} 1 & 700\text{ nm} \le \lambda \le 1150\text{ nm} \\ 10^{0.018(\lambda-1150)} & 1150\text{ nm} \le \lambda \le 1200\text{ nm}, \\ 8 & 1200\text{ nm} \le \lambda \le 1400\text{ nm} \end{cases} \tag{9}$$

and

$$T_1(\lambda) = 10 \times 10^{0.002(\lambda-550)} \quad 550\text{ nm} \le \lambda \le 700\text{ nm}. \tag{10}$$

For the lasers under consideration for the ORADS sensor, wavelengths either in the 700 nm to 1050 nm band or the 1500 nm to 1800 nm band are anticipated. In addition, pulse widths of less than 20 ns and pulse repetition frequencies between 1 kHz and 10 kHz are expected. Under these conditions, the most stringent OELs occur for the longest exposure times. Table 5 lists OELs for candidate wavelengths of 850 nm, 905 nm and 1550 nm. We see that significantly higher beam irradiance can be tolerated with the longer wavelength that is not strongly transmitted through the eye.

Table 5. Maximum Permissible Exposures for Candidate ORADS Laser Wavelengths.

Laser Wavelength (nm)	Exposure Limit (mW/cm^2)
850	0.64
905	0.82
1550	100.

A target OEL for a given sensor design may be achieved by attenuating the laser beam, by reducing the PRF or pulse width, or by expanding the beam. Figures 10-12 provide tradeoff curves that may be used in optimizing the laser for achieving eye safe operation. Shown in each figure are plots of required beam diameter against laser peak power for several "duty factors," defined as the fraction of time (% duty cycle) that the laser is emitting and computed as the product of the pulse width and the pulse repetition frequency. A duty factor of 0.020% corresponds to a pulse width of 20 ns and a PRF of 10 kHz. Beam expansion to about one inch is indicated for the 850 nm and 905 nm wavelengths at the higher peak power and duty factor levels, while no expansion would be necessary for operation at 1550 nm.

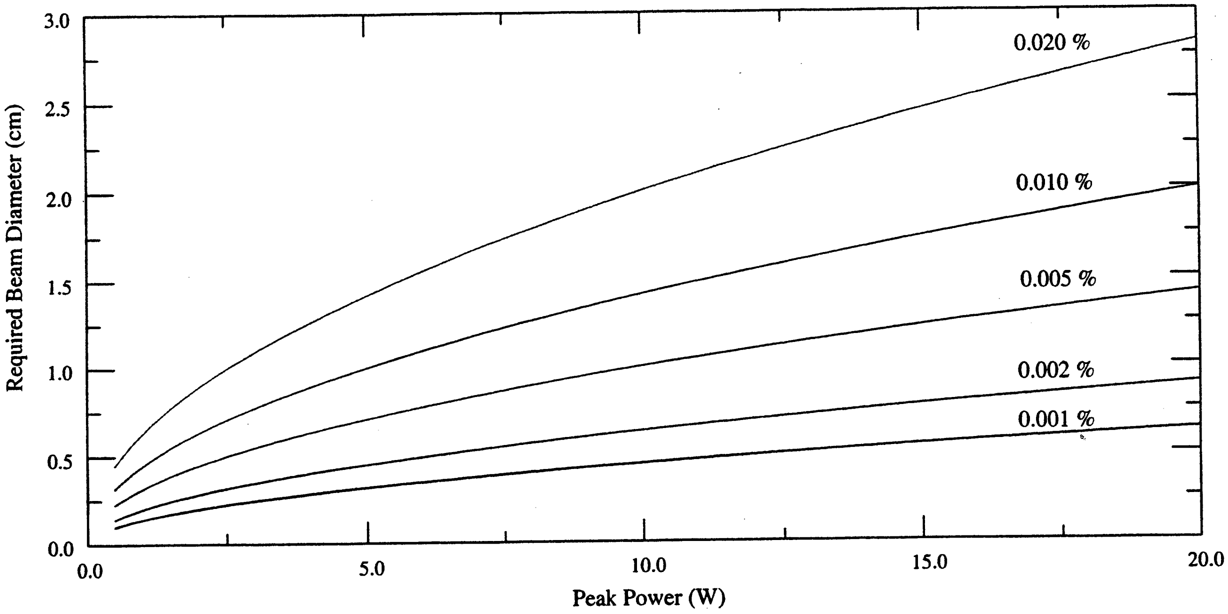


Figure 10. Required beam diameter as a function of laser peak power for a λ of 850 nm for eye-safe operation.

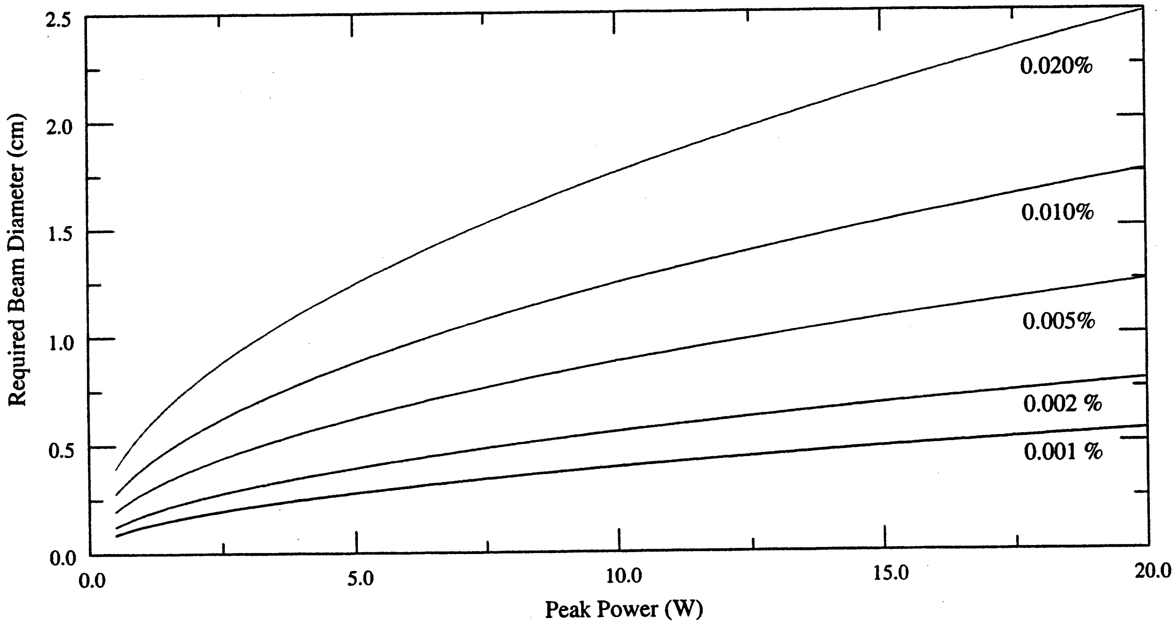


Figure 11. Required beam diameter as a function of laser peak power for a λ of 905 nm for eye-safe operation.

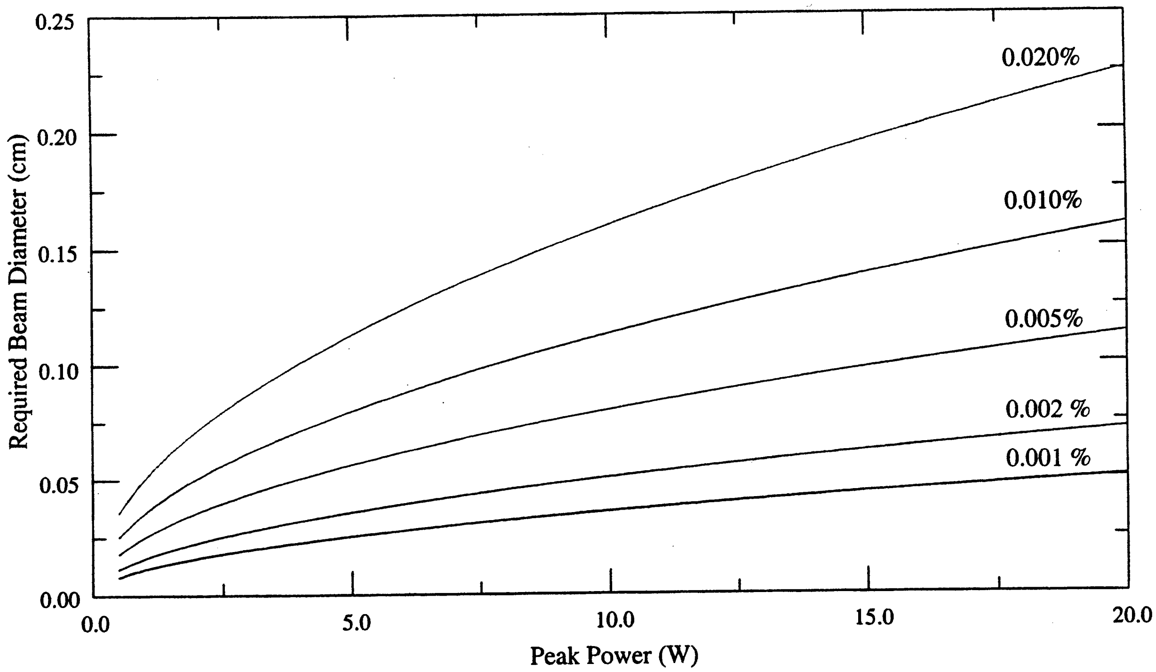


Figure 12. Required beam diameter as a function of laser peak power for a λ of 1550 nm for eye-safe operation.

3.3.2.3 Laser Pulse Requirements

Critical in designing the laser radar velocity sensor is the specification of laser pulse characteristics and receiver timing. To ensure that we do not detect laser pulses reflected from the background, the receiver gate must be set for a time of $2R_{max}/c$ where c is the speed of light and R_{max} is the maximum cross-highway range. For the five-lane example used above, we find a maximum timing gate width of 128 ns.

The laser pulse repetition frequency (*PRF*) must be high enough to provide the required speed determination accuracy. With a modest 12" channel separation, the spatial tire resolution requirement is ±0.12", well less than our projected transmitter beam size. Accordingly, the *PRF* must be large enough to provide multiple samples as the leading tire edge passes through the beam. If the channel separation is Δx and the maximum vehicle speed is v, we find that a one percent accuracy requires

$$PRF = \frac{100v}{\Delta x}. \tag{11}$$

For a 12" channel separation and 60 mph vehicle speed, a *PRF* of 8800 Hz is indicated. Under these conditions, we expect eight samples during the leading edge tire transit across the 1" beam. A *PRF* in the 10 to 20 kHz range would be needed to realize 1% accuracy in speed measurement. The ORADS system uses a *PRF* of 5000 Hz to achieve a speed resolution of 1.8%.

The allowed laser pulse width range is clearly bounded on the upper end by PRF^{-1} (e.g., 50 to 100 μs for the above scenario). Ideally, the pulses should be much shorter to minimize power consumption, reduce eye hazard and minimize possible interference from multipath effects. Commercially available pulsed laser diode systems have pulse widths in the 10 ns to 20 ns range with rise times of 5 ns to 10 ns, suitable for achieving good vehicle position measurement.

3.3.3 ORADS Laser Sensor Design

The major components selected for the ORADS laser sensor are described below.

3.3.3.1 Diode Laser

Pulsed laser diodes having peak powers in excess of one watt are commercially available from several sources. The PGAU1S12 laser diode made by EG&G Optoelectronics was chosen for use in the ORADS system. This laser can provide up to 24 W of peak power at 905 nm with a pulse width of up to 2 µs. The 905 nm wavelength was chosen over the more eye-safe 1550 nm wavelength to achieve higher laser power, increased detector sensitivity, and lower cost. Eye safe operation at 905 nm was achieved by operating the laser at reduced power and by expanding the laser beam.

A Model ETX-5 module made by E-O Devices was chosen to drive the laser. This driver was configured to operate the laser at approximately 17 W peak power with a pulse width of 20 ns and a pulse repetition frequency of 5 kHz. The driver circuit introduces a delay between trigger application and laser firing of 50 ns and pulse jitter of less than 1 ns. The 50 ns firing delay time (T_M in Figure 5) is accounted for in post detection processing.

3.3.3.2 Transmitter Optics

Diode lasers produce beams that are highly divergent (typically 20 to 30 degrees). Consequently, collimation optics are required to concentrate the beam so that the laser energy is efficiently directed onto passing tires. A 25-mm diameter, 50-mm focal length lens (Edmund Scientific H45353) was chosen for ORADS. With this lens, the beam is expanded to approximately 12-mm by 25-mm at the exit aperture. This expansion is sufficient to make the beam eye safe for direct viewing at the exit aperture. Since the laser beam continues to expand as it propagates away from the sensor, eye safe operation is ensured at all ranges.

3.3.3.3 Receiver Subsystem

The ORADS receiver channels use a 100-mm focal length, 50-mm diameter achromat lens from Edmund Scientific (Model 42629) to collect the returned laser radiation and an EG&G C30902E avalanche photodiode (APD) to detect the signals. Each of the ORADS sensor receiver channels also includes a spectral filter (Coherent Model 42-5843) to block background light, a preamplifier to boost the signals to a level sufficient for post detection processing, a temperature-compensated power supply to properly bias the APD, and a constant fraction discriminator (CFD) circuit to reduce range errors associated with varying return signal levels.

Specifications for the selected APD detector include a diameter of 0.5 mm, a noise equivalent power (NEP) of $4.\times10^{-15}$ W/Hz$^{1/2}$, a responsivity of 65 A/W and a gain of 135. With the 100-mm focal length receiver lens, the receiver solid angle field of view is 1.96×10^{-5} sr. This FOV subtends a 4" spot at a range of 63' (far edge of lane 4). The preamplifier uses a Phillips Semiconductor NE511 wide-bandwidth (180 MHz) transimpedance preamplifier that provides a transimpedance gain of 14 kΩ with rms noise current of 1.8 $pA/Hz^{1/2}$. The CFD circuit combines the detected signal pulse with a delayed, inverted replica to obtain a signal having a zero-crossing time that is largely independent of pulse amplitude.

The temperature characteristics of the breadboard detector/preamplifier were measured. Two test configurations were used. In the first, the APD bias voltage was held constant and the signal (S) was measured while the temperature (T) was varied from -30°F to 130°F. In the second test, the bias voltage (V_B) was adjusted to maintain constant signal as the temperature was again varied from -30°F to 130°F. Figure 11 shows the variation of signal with temperature to be highly nonlinear as expected for an avalanche device. However the constant signal bias vs. temperature curve shown in Figure 12 is linear, permitting a linear temperature sensor to be used to derive the bias control signal.

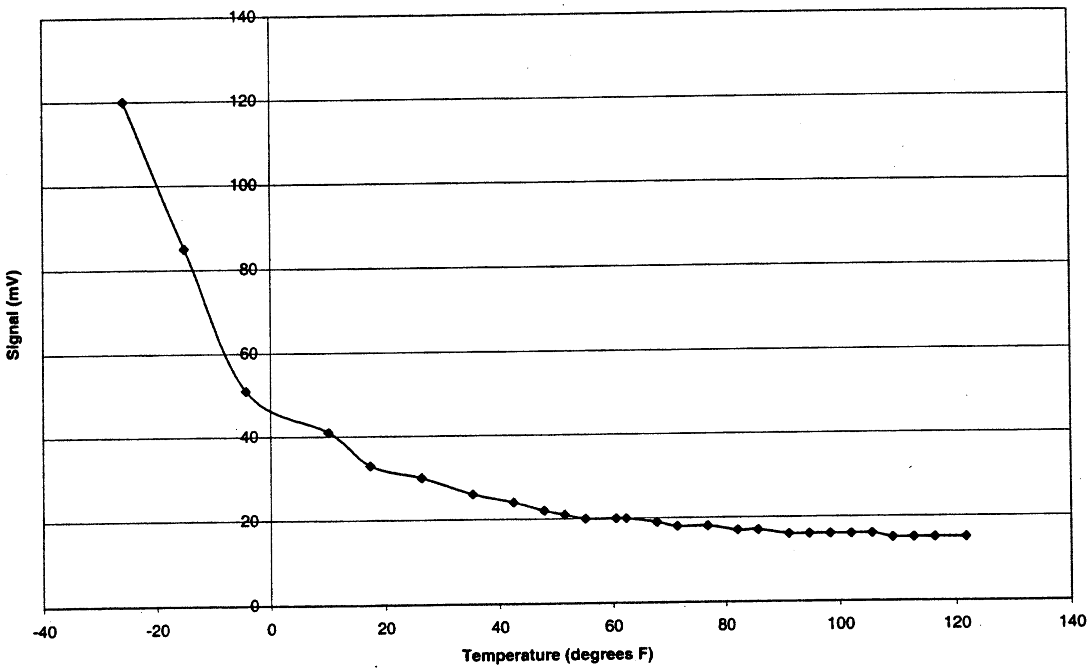


Figure 13. Temperature variation of signal with constant APD bias voltage.

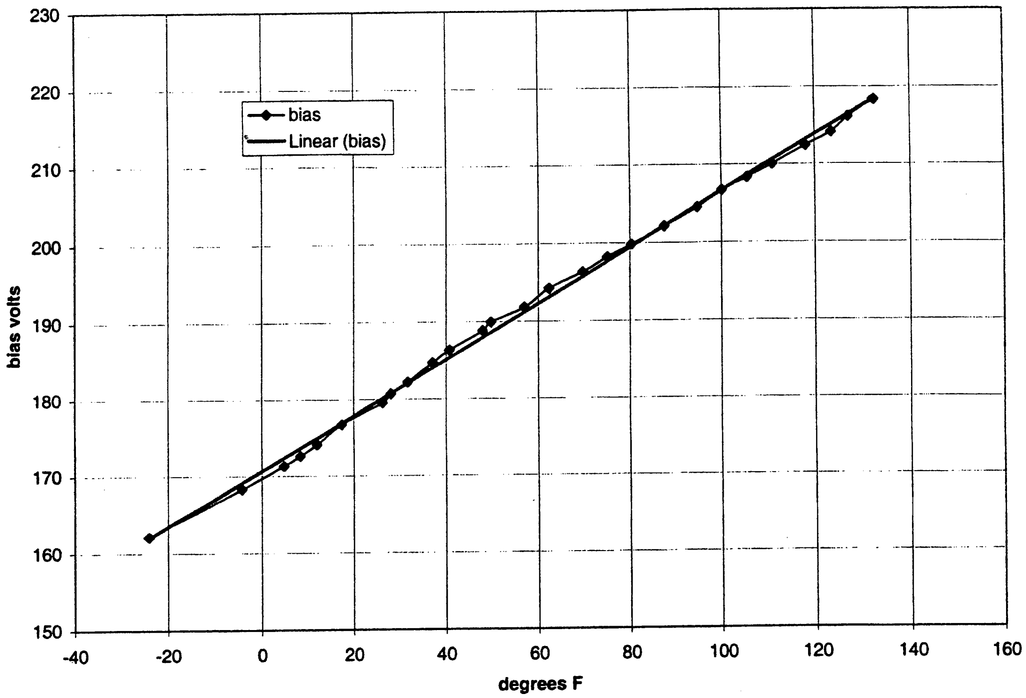


Figure 14. Variation of constant-signal bias voltage with temperature.

3.3.4 ORADS Laser Sensor Laboratory Testing

Prior to final integration into the ORADS system, the laser sensor was tested in the laboratory. These tests included measuring the received signal as a function of range and verifying the range discrimination of the system.

Figures 15-18 show oscilloscope traces of the detected analog signal (upper trace) and the receiver output TTL signal (lower trace) that indicates target detection. The time scale for all traces is 20 ns/div and the voltage scale for the TTL output trace is 1 V/div. These traces show reliable tire detection for over four lanes of traffic.

Figure 15 shows system outputs for a range of 70', well into the fifth lane for a 15' sensor offset. Here the analog output (upper trace) has two peaks, the first associated with detection of a small portion of the laser that was scattered from the transmitter optical elements and the second associated with detection of the target. The constant fraction discriminator circuit thresholds were set so that only the target pulse was recognized. The optical backscatter analog pulse provides a convenient marker for gauging approximate target range in this laboratory setup. Improved baffling eliminated this backscatter in the final ORADS system.

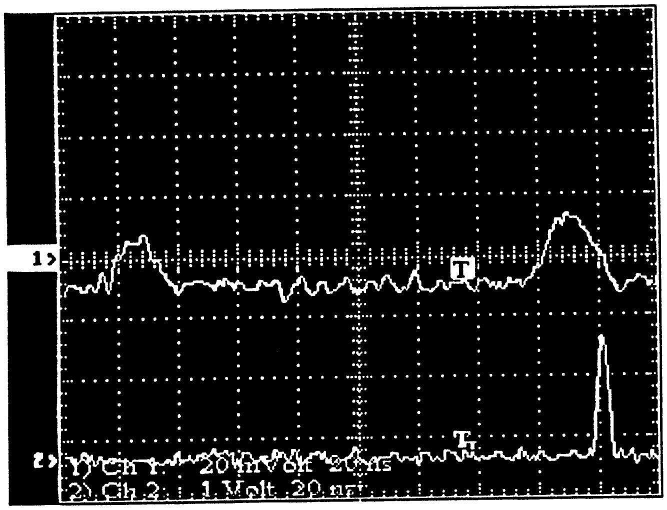


Figure 15. Analog and digital output signals for a tire target at 70 feet. The analog scale is 20 mV/div.

Figure 16 shows sensor outputs for a target range of 63 feet, corresponding to the far side of the fourth roadway lane (assuming 15-ft sensor offset and 12-ft lanes). The analog signal of 40 mV is twice that shown in Figure 13 due to residual parallax effects. The receiver/transmitter fields of view and the receiver focus were optimized for four-lane coverage.

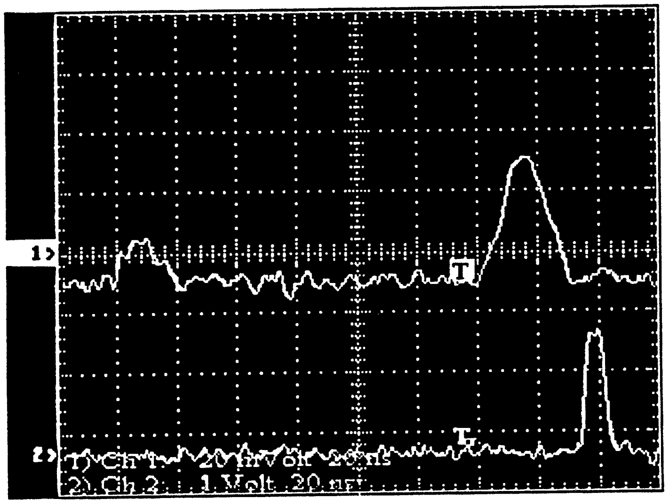


Figure 16. Analog and digital output signals for a tire target at 63 feet. The analog scale is 20 mV/div.

Figure 17 shows sensor outputs for a tire range of 30 feet. Here the analog signal has increased to approximately 150 mV. The signal associated with light scattered from the optics is barely visible at this scale. The 30-ft range corresponds to an automobile or truck traveling in the center of the second lane.

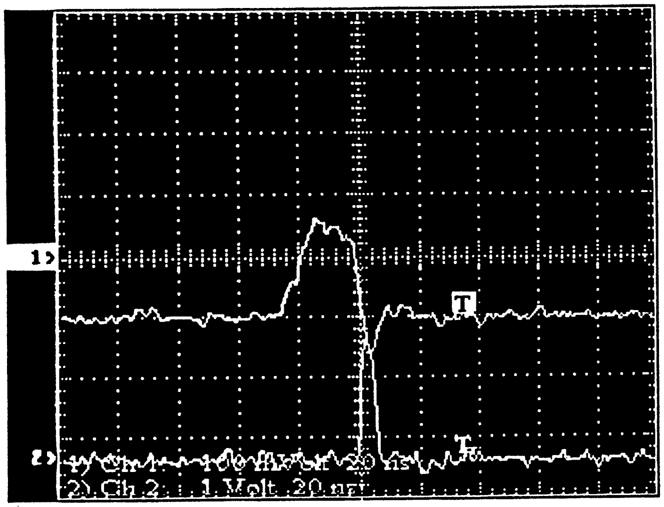


Figure 17. Analog and digital output signals for a tire target at 30 feet. The analog scale is 100 mV/div.

Figure 18 shows sensor outputs for a tire range of 15 ft, corresponding to the near side of the first lane. The analog signal level is approximately 150 mV.

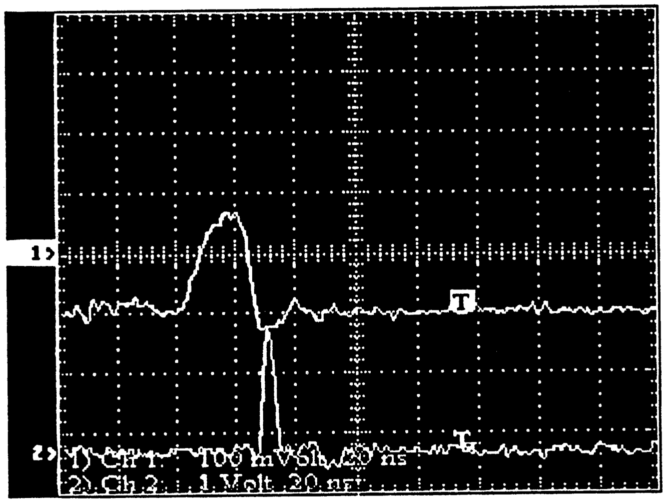


Figure 18. Analog and digital output signals for a tire target at 15 feet. The analog scale is 100 mV/div.

The range discrimination capability of the system is demonstrated in Figure 19 where the arrival time of the returned pulse is plotted against target range. As expected, we find linear behavior with a slope of about 2.1 ns/ft in reasonable agreement with the value of 2.03 ns/ft computed from the speed of light.

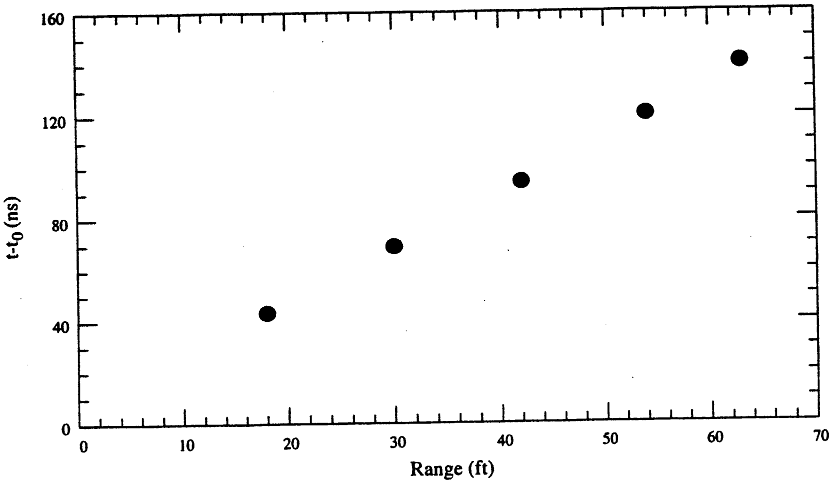


Figure 19. Variation of pulse arrival time with range to target.

3.3.5 Processor Subsystem Development

An Altera EFP 6016 Programmable Logic Device (PLD) performs as the processor in the ORADS sensor.

3.3.5.1 Processor Subsystem Requirements

The basic requirement of the processor subsystem is to process the data coming from the dual-beam LADAR sensor and translate it into signals that can be used to develop traffic data by switch inputs of the host recorder. This data includes the vehicle travel lane on the roadway surface and the vehicle velocity. All other classification data such as axle spacing, type of vehicle, headway, gap, etc. is determined by the host recorder.

3.3.5.2 Processor Subsystem Design

The processor subsystem is used as the central control of the ORADS interfaces. These interfaces include the dual-beam LADAR sensor interface electronics, the interface to the host recorder card, and the control switches. A basic block diagram of the processor subsystem and its interfaces is shown in Fig 20.

The operation of the processor is an ordered lock-step operation based upon the alternating pulses from the dual-beam LADAR. The processor reads data from the sensor each time a laser pulses. The pulsing of a laser and the availability of the corresponding range count data is indicated by the synchronization pulses. The data is processed to determine if there is a vehicle axle present by processing the range count using an algorithm based on LADAR techniques. The values from the control panel switches are read to determine the settings for the lane width, sensor distance from the roadway, and the propagation delays for each of the lasers. The data received from the switches is used by the processor to calculate the lane of the vehicle axle from the range count data provided by the laser sensor electronics.

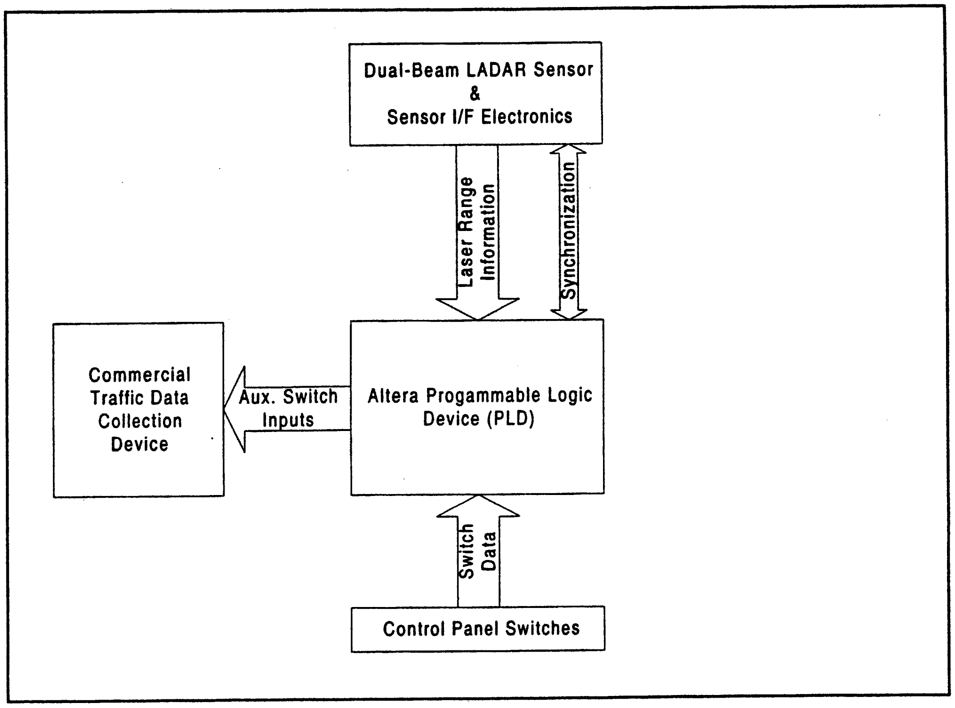


Figure 20. Processor Interfaces

Once the processor has determined the lane of the vehicle axle, a signal is sent to the host recorder, making it look as if a vehicle had closed an auxiliary contact switch laid in the appropriate lane. The processor waits for a corresponding range count on the second laser and sends a signal to the host recorder indicating the closure of second auxiliary contact switch that would be laid in the lane. The host processor then calculates the velocity of the vehicle by using the time between laser trips and the 12" distance between the lasers. Once the lane and velocity have been calculated, an internal counter for the applicable lane is incremented and this process is repeated for each vehicle axle in all of the lanes being monitored by the ORADS.

3.3.5.3 Software

The flowcharts shown in Figures 21 and 22 show the software control for axle detection, range determination and communication with the host recorder. Section I is the control for laser channel 1 and section 2 is for laser channel 2. For this application, all references to the user display and velocity counter may be disregarded.

As seen in the software flowchart, the first step is to initialize the variables and digital I/O. The program then enters a "never ending loop". The program waits for the laser #1 channel to indicate that the range count data is available to process.

Depending on the previous state of laser # 1, the program will use the range count data to look for the possible beginning of another vehicle axle (state 0), continue to process the first 10 range count values of a vehicle axle (state 1), or continue processing at the range count to determine when the vehicle leaves the field of view of the laser (state 2). The only state that contains significant processing algorithms is state 1. State 1 accumulates the first 10 range counts found on a vehicle axle and then determines which lane the vehicle was in. Once the lane has been determined, the digital I/O line associated with the host recorder auxiliary input switch is pulsed.

After laser #1 has been handled, the program waits for the laser # 2 channel to indicate that the range count data is available to process. Laser #2 is handled similar to laser #1 except that once the lane associated with a vehicle axle has been determined, additional actions occur. These additional actions are used to update the range and new axle count for the vehicle lane. After all the of the processing is completed for laser #2, the program loops back to the beginning and waits for the laser #1 channel to indicate that the range count data is available. This process continues in "lock-step" operation until the processor is reset or turned off.

3.3.5.4 Processor Interfaces

As illustrated in Figure 20, there are many interface signals being used and supplied by the processor subsystem. The PLD has 48 digital I/O lines that can be used t interface to other subsystems. The following paragraphs describe each of the interfaces and the uses of the 48 digital input/output lines.

There are several signals that will be received from the sensor and used to determine when a vehicle axle has passed in front of the laser. Table 6. Lists the processor subsystem input signals from the sensor. These signals provide the range data from both lasers along with an overflow bit to indicate when the range counters have overflowed. The processor uses these signals as raw data to determine the presence of a vehicle on the roadway surface and the corresponding lane and lateral displacement. The overflow bits signify when the counters have overflowed their maximum 8-bit count of 255. A range counter of > than 255 corresponds to a distance > 100 ft. from the ORADS and, therefore, more than four lanes away. Thus, when the counters overflow, it indicates there was no return signal from the lasers and , therefore, no vehicle axle present.

There is a synchronization pulse coming from each laser that tells the processor when the range counter data is ready. These two 1-bit lines act as triggers for the processor to indicate that the range counter data is valid and it is time to read the values. The laser electronics require a clear/reset pulse to be returned once the data has been read so that the counter values can be cleared and reset for the next laser pulses. The current method being used for clearing and resetting the range counters is delaying the data ready pulses provided by the laser electronics by approximately 18 µsec and sending it back as the clear/reset pulse. This is accomplished by using a counter reset circuit built with CD74HC221E Non-Retriggerable Monostable Multivibrators.

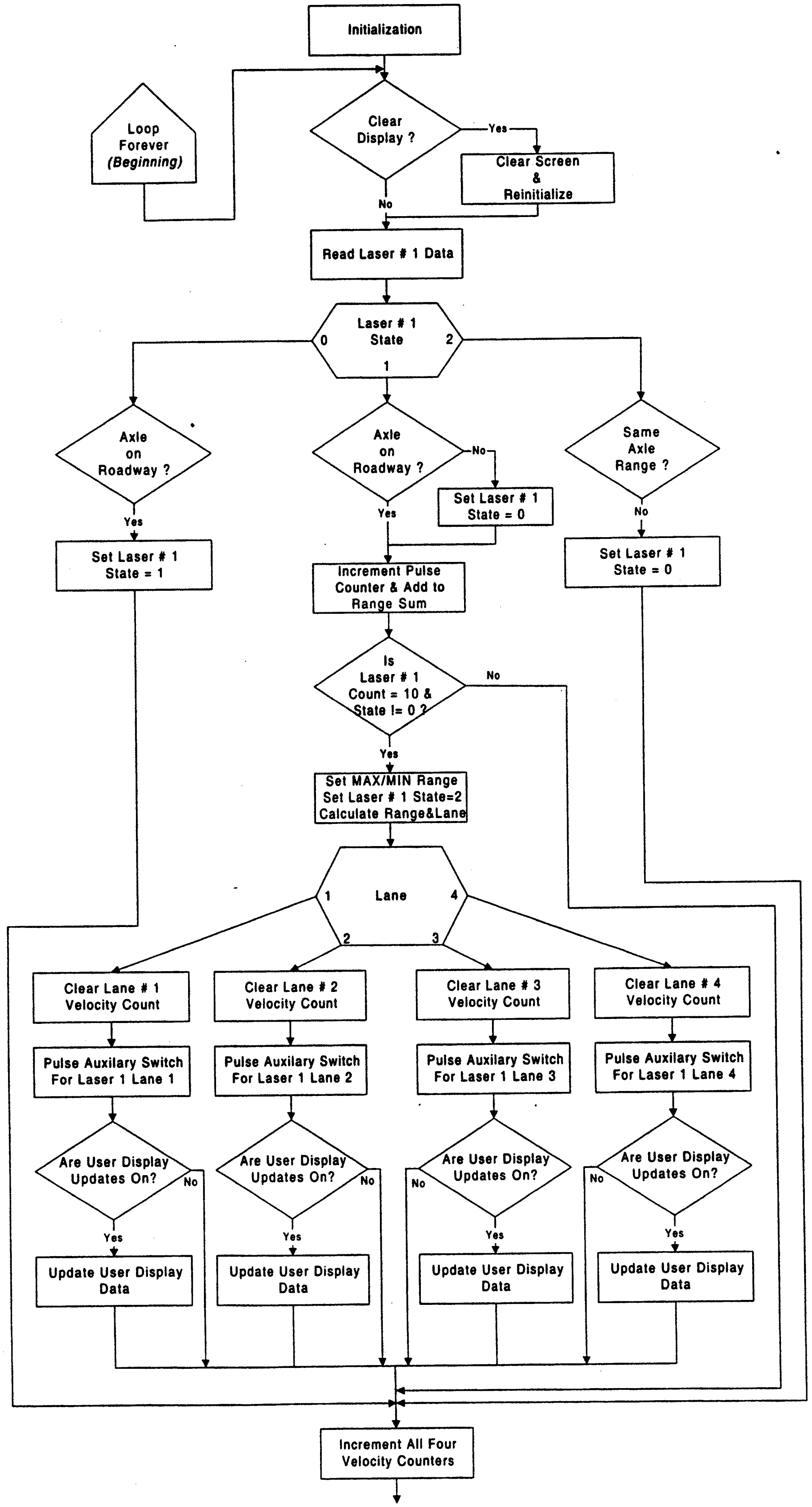


Figure 21. ORADS Software Flowchart (Section 1).

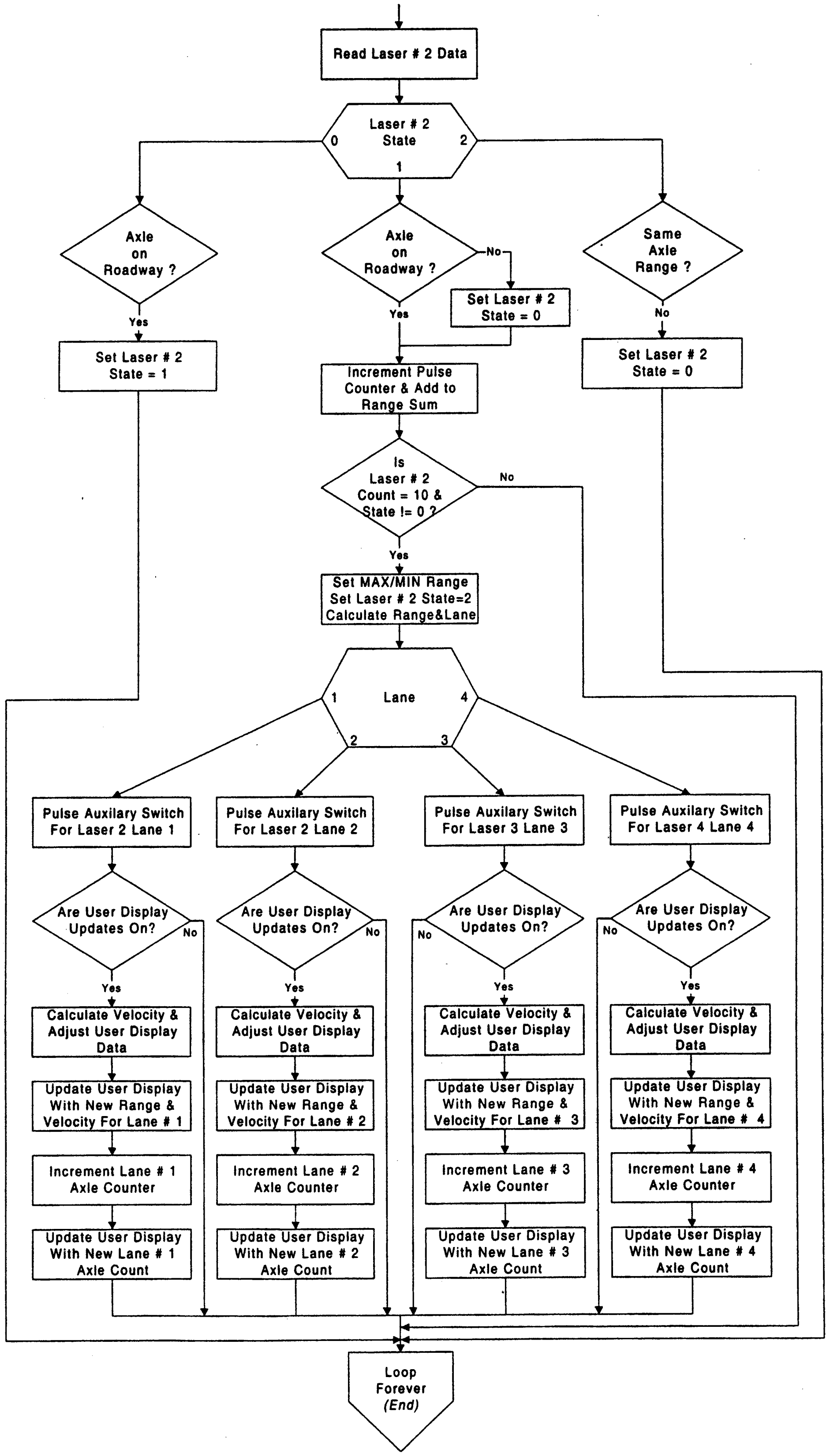


Figure 22. ORADS Software Flowchart (Section 2).

Table 6. Dual-Beam LADAR Sensor Interface Processor Inputs.

Signal Names	Signal Size
Laser 1 Range Counter Value	8 - Bits
Laser 1 Range Counter Overflow	1 - Bit
Laser 2 Range Counter Value	8 - Bits
Laser 2 Range Counter Overflow	1 - Bit

The range counter information from the dual-beam LADAR sensor electronics does not give the processor all of the information that it needs to calculate the vehicle axle lane. The range counters only provide a "raw" number that indicates the time between the initiation of the laser pulse and the detection of a return pulse. Information is needed on the propagation delays associated with the sensor electronics and the road surface dimensions. The control panel on the ORADS contains rotary switches to set the lane width, sensor distance from the roadway (shoulder width), and the propagation delays for each of the lasers. The control panel switch information interface with the processor is listed in Table 7. Each of these switches provide a 4-bit number indicating a value of $0 - 15_d$.

Table 7. Control Panel Switches Interface Processor Inputs.

Signal Names	Signal Size
Lane Width	4 - Bits
Shoulder Width	4 - Bits
Laser 1 Propagation Delay	4 – Bits
Laser 2 Propagation Delay	4 – Bits

The switch values are used along with the range counter values to calculate the lateral cross-highway position of the vehicle axle. The range counter values indicate the time between initiation of the laser pulse and the detection of the laser return in nanoseconds. This range counter value is directly related to the distance that the laser pulse has traveled through the knowledge that the travel time of the laser pulse is ~ 1 nsec/ft. Therefore, taking into account the propagation delay of the electronics, the formula for the final range is:

Final Range = (((Range Counter – Propagation Delay) / 2) - Shoulder Width)

And the lane of the vehicle axle is calculated using:

Vehicle Axle Lane = (*quotient* (Final Range / Lane Width) + 1)

{Note: A 1 is only added if there is a remainder from the division.}

Therefore, the range counter information and the switch settings, along with these two formulas, allow the ORADS processor to determine the lane and lateral cross-highway position of the vehicle axle to a resolution of ± 4ft.

The processor uses several of the laser pulses and averages the data to prevent a spurious return from indicating a vehicle axle. Once a vehicle axle has been detected and processed, the appropriate auxiliary switch input closure on the host recorder is simulated. This is done through the auxiliary switch input interface from the processor as indicated in Table 8. The Diamond® Phoenix recorder is setup so that it appears that there are two auxiliary switch inputs for each lane spatially separated by 12 inches to correspond with the separation between the two lasers in the ORADS. When the processor detects the presence of a vehicle axle at one of the lasers, the appropriate signal line is pulsed. The processor signal pulse is fed through a CD74HC221E Non-Retriggerable Monostable Multivibrator and an inverting buffer to provide the required interface protocol to the Diamond® Phoenix recorder.

Table 8. Diamond® Phoenix Auxiliary Switch Input Interface.

Signal Names	Signal Size
Laser 1 Lane 1 Aux. Switch Input	1 - Bit
Laser 1 Lane 2 Aux. Switch Input	1 - Bit
Laser 1 Lane 3 Aux. Switch Input	1 - Bit
Laser 1 Lane 4 Aux. Switch Input	1 - Bit
Laser 2 Lane 1 Aux. Switch Input	1 - Bit
Laser 2 Lane 2 Aux. Switch Input	1 - Bit
Laser 2 Lane 3 Aux. Switch Input	1 - Bit
Laser 2 Lane 4 Aux. Switch Input	1 - Bit

The lasers are alternating pulsing, each at a frequency of 5 kHz, effectively putting a 10 kHz update requirement on the processor. At a 10 kHz update rate, the processor must perform all of the data acquisition of the range count information from the laser electronics, and send auxiliary switch closures to the host recorder.

3.4 ORADS Design

This section describes the major subassemblies of the ORADS, a brief functional description of the subassembly and the physical location within the enclosure. Subassembly schematics are included in Appendix B.

3.4.1 Optical Bench

There are two identical optical benches within the ORADS enclosure. Each of these subassemblies contains a laser transmitter, receiver, and optical components for generating the laser pulses and receiving the returns reflected from the vehicle tires. The benches are situated within the enclosure so that the laser pulses emitted are exactly 1.0 ft. apart and generate parallel beams across the vehicle travel lanes perpendicular to traffic flow. The benches are fixed to the enclosure floor but have controls which permit azimuth and elevation adjustment of the beams.

3.4.1.1 Laser Driver

Each laser transmitter is pulsed by a laser driver circuit (ETX-5) manufactured by EO Devices. The laser diode (PGAU1S12) is mounted on the driver printed circuit board attached to the bench behind focusing lenses. The ETX-5 driver circuitry is proprietary to EO Devices and no schematic is available.

3.4.1.2 Laser Receiver

The laser receiver consists of an avalanche photodiode detector and two circuit cards contained within a shielded aluminum box attached to the optical bench. The bias card (SR-LMS-007-A-A) supplies bias voltage to the detector and regulates the bias amplitude according to the temperature of the detector mounting block. The receiver card (SR-LMS-006-A-A) amplifies the return signals from the vehicle wheels to a level sufficient to trigger logic circuits in the signal processor which determines the lane of the targeted vehicle.

3.4.2 Printed Circuit Card Functions

To expedite troubleshooting, assembly, and checkout, ORADS electronic circuits are divided into five removable modular PC circuit boards located in a shielded card cage. These cards have test points which are accessible without removing the card from the cage. Interconnection from these cards to other components is made via a printed circuit back plane attached to the card cage and via cables which plug into the cards. The following boards are located in the shielded card cage between the lasers:

1.	SR-LMS-001-A-A	Low Voltage Power Supply
2.	SR-LMS-002-A-A	Signal Processor
3.	SR-LMS-003-A-A	Counter/Trigger
4.	SR-LMS-004-A-A	Interface
5.	SR-LMS-008-A-A	High Voltage Power Supply

3.4.2.1 Low Voltage Power Supply (SR-LMS-001-A-A)

This card consists of 3 high efficiency DC-DC converters which develop ± 12, ± 9 and +5 V from the 12 VDC primary battery power. The voltages are distributed from the card cage via the back plane and cabling to the channel 1 and channel 2 transmitter and receiver electronics and control panel.

3.4.2.2 Signal Processor (SR-LMS-002-A-A)

This card contains an Altera EFP 6016 Programmable Logic Device (PLD) which receives logic inputs from the control panel and both sensor receiver channels and provides lane and vehicle time of arrival data to the interface card which communicates with the host traffic data collection device.

3.4.2.3 Counter/Trigger (SR-LMS-003-A-A)

The counter/trigger circuit uses a 1 MHz oscillator and a 12 stage binary counter to develop alternating 5 KHz TTL laser trigger pulses which are applied to the ETX-5 laser driver in each transmitter channel.

3.4.2.4 Interface (SR-LMS -004-A-A)

Logic data from the PLD on the processor board activates 74VHC221 one-shots on the interface board to simulate contact closures (for 1-4 lanes) to the auxiliary inputs of the host recorder.

3.4.2.5 High Voltage Power Supply (SR-LMS-008-A-A)

This card contains two high voltage power supplies which provide high voltage for the laser drivers in channel 1 and channel 2. These supplies are modular DC-DC converters with cables which connect to each laser driver. Spectra purchased the supplies from EO Devices and mounted the modules on a plug-in card which fits the card cage. The plug-in card is fabricated by Spectra Research.

3.4.2.6 Control Panel (SR-LMS-005-A-A)

Basic controls on the ORADS control panel are used for setup and testing of the sensors. The switches on this panel control power to the circuits, set lane width, set offset distance from lane 1 to the sensor and activate the test indicators. The control panel on the host recorder must be used to configure the system for the desired data and record intervals.

3.4.2.7 Battery

The ORADS 12 V, 33 Amp-hour battery is the primary power source for the ORADS sensor. When operating normally, the ORADS circuits require approximately 1.5 amps of current and, under laboratory conditions, will power the ORADS for approximately 20 hours without solar augmentation.

3.4.2.7.1 Solar Panel

The ORADS is equipped with a TGM-750-12V solar panel capable of delivering 12.75 Watts of power. The solar panel measures 17” x 14” x 1” and is mounted on the top of the ORADS enclosure. The top may be opened and supported in the open position during operation of the control panel.

4.0 RESEARCH RESULTS

4.1 ORADS Initial Findings and Results

The ORADS sensor interfaced to a Diamond® Phoenix recorder has undergone preliminary testing on various roadways in Dayton, Ohio and near Columbus, Ohio. The most significant testing occurred on October 19, 2000 near Columbus, Ohio on I-270 southbound near the Weigh-in-Motion (WIM) station south of Roberts Road. Figure 23 shows the test setup for the collection and comparison of data.

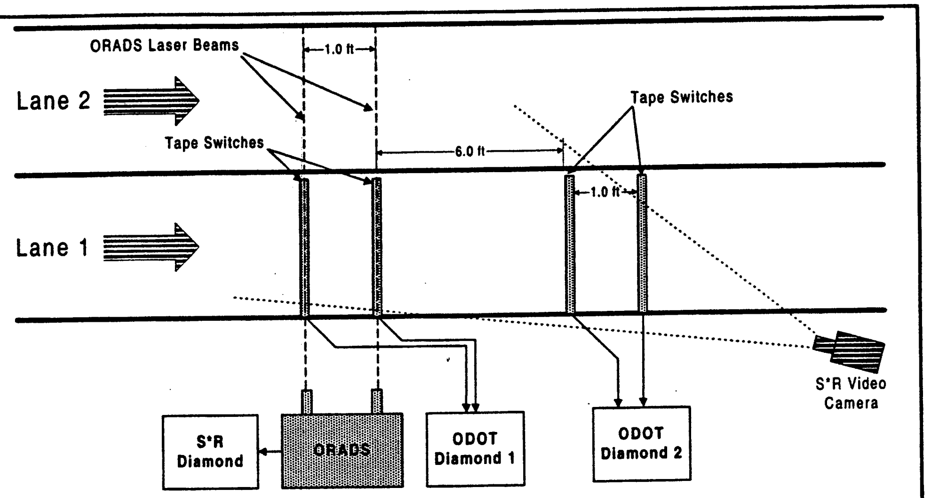


Figure 23 I-270 Test Setup

4.1.1 Test Setup I-270

The purpose of this test was to compare data collection between the ORADS and a Diamond data collection box under identical conditions. A single lane of high speed, high volume traffic was monitored for one hour with the ORADS laser beams spaced one foot apart positioned directly over ORADS Box 1 tape switch sensors with 1.0 ft spacing. A second ODOT Diamond box (ODOT Diamond 2) with sensors spaced at 1.0 ft collected data in the same lane approximately 6 ft from the ORADS and ODOT Diamond 1 box. All three Diamond boxes were set up identically and sensor misses were recorded. Except for rare occurrences such as vehicle lane changes between sensors and between sets of sensors, all three sets of data should agree. A video camera also recorded portions of the test as a means to resolve data conflicts.

Following the one hour of data collection, the ORADS was moved to the WIM site to collect one hour of 3 lane data to compare with the WIM data.

4.1.2 I-270 Secondary Test

During the data collection process for the test above, two ODOT vehicles (one with a calibrated odometer and speedometer) made a total of eleven preplanned passes over the sensors and speed and axle spacing measurements were made and time stamps were noted. The axle spacing measurement for each vehicle was made at the test site by ODOT and Spectra Research personnel and is shown in the data summary. Table 9 summarizes the data collected for the two vehicles. It should be noted that if the correct axle spacing is measured, then speed will be accurate within the capabilities of the Diamond box.

Table 9. Secondary Test Data

			Vehicle 1 ODOT van 9.3 ft axle spacing			
	ORADS				**Diamond**	**(ODOT 1)**
Pass	Time	Speed (mph)	Axle spacing (ft)		Speed (mph)	Axle spacing (ft)
1	10:17:29	59.2	9.3		61.7	9.7
2	10:24:57	59.2	9.2		61.2	9.5
3	10:33:06	62.7	9.5		65.0	9.8
4	10:42:12	58.2	9.1		61.2	9.6
5	10:49:38	59.7	9.4		60.7	9.6
6	10:56:38	59.2	9.3		59.7	9.4
			Vehicle 2 ODOT van 11.2 ft axle spacing			
1	11:06:01	48.6	11.2		49.2	11.4
2	11:15:47	47.9	11.1		49.5	11.5
3	11:35:51	57.4	11.1		59.7	11.6
4	11:43:54	58.7	11.4		60.2	11.7
5	11:53:39	57.4	11.1		57.4	11.6

Vehicle 1: ORADS Avg. axle meas. % error: 1.1 **ODOT Avg. axle meas. % error: 3.2**

Vehicle 2: ORADS Avg. axle meas. % error: 0.9 **ODOT Avg. axle meas. % error: 3.2**

These results show that the ORADS unit (with 1ft. sensor spacing) interfaced to a Diamond Phoenix measured speed and axle spacing more accurately than two other Diamond Phoenix units using tape switches spaced 1 ft. apart.

4.1.3 I-270 Test Results

At the end of one hour of data collection, the data from all three boxes was saved to a disk and printed out for review. Spectra Research and ODOT completed separate analyses of the data and the tables below best summarize the ORADS performance for this particular test but they are not indicative of the performance which can be achieved. Tables 10 and 11 prepared by ODOT and Spectra respectively, cover the same general time period, however, there may be a difference in exact starting and truncating times for the two analyses.

Table 10. ODOT Summary of Test Results. (10-19-00 Test)

ORADS DEMO

October 19, 2000
oradt2 c10/27/00

ODOT Data Summary

Hour 11-12 Vehicle Class	ORADS	Percent of total	ODOT#1	Percent of total	ODOT #2	Percent of total	WIM	Percent of total
1	5	0.5%	3	0.3%	1	0.1%		
2	613	57.8%	598	55.2%	611	57.5%		
3	174	16.4%	224	20.7%	197	18.5%		
4	0	0.0%	0	0.0%	0	0.0%		
5	26	2.5%	32	3.0%	42	4.0%		
6	27	2.5%	26	2.4%	25	2.4%		
7	6	0.6%	5	0.5%	5	0.5%		
8	45	4.2%	41	3.8%	38	3.6%		
9	120	11.3%	127	11.7%	112	10.5%		
10	24	2.3%	22	2.0%	18	1.7%		
11	7	0.7%	4	0.4%	4	0.4%		
12	1	0.1%	0	0.0%	0	0.0%		
13	13	1.2%	2	0.2%	9	0.8%		
Total	1061		1084		1062			
sensor miss	74		3		23			
grand total	1135		1087		1085			

Table 11. Summary of Vehicle Classification Results. (10-19-00 Test)

CLASS	ORADS	Percent of Total	ODOT 1	Percent of Total	ODOT 2	Percent of Total
1	2	0.2%	3	0.3%	1	0.1%
2	571	57.4%	545	54.8%	567	57.0%
3	160	16.1%	200	20.1%	182	18.3%
4	0	0.0%	0	0.0%	0	0.0%
5	25	2.5%	30	3.0%	40	4.0%
6	27	2.7%	24	2.4%	23	2.3%
7	6	0.6%	5	0.5%	5	0.5%
8	44	4.4%	38	3.8%	36	3.6%
9	116	11.7%	122	12.3%	109	11.0%
10	23	2.3%	21	2.1%	18	1.8%
11	7	0.7%	4	0.4%	4	0.4%
12	1	0.1%	0	0.0%	0	0.0%
13	12	1.2%	2	0.2%	9	0.9%
	994		994		994	

Table 12. S*R Summary of Statistical Analysis Results. (10-19-00 Test)

	ORADS	ODOT 1	ODOT 2
Speed precision	±0.88 mph	±1.51 mph	±1.34 mph
Length precision	±0.30 ft	±0.90 ft	±0.86 ft
Spurious sensor miss	44*	1	1
Missed detection	26	0	20
Missed detection or coverage mismatch	20	2	11
Coverage mismatch	25	1	0
Axle count errors	37	1	3
Axle bin/vehicle class errors	45	32	31
Vehicle length errors	18	4	3
Vehicle length bin errors	32	94	34
Vehicle speed errors	4	4	4

*Random noise in one channel of the ORADS laser caused sensor misses. This noise will be eliminated in subsequent units.

Table 12. was prepared by Spectra Research and is part of the complete statistical analysis included in Appendix A of this report.

These results are from a single test completed with an experimental ORADS unit and are not indicative of the potential which can be achieved with the improved units which have been delivered to ODOT. More testing and analysis is required.

5.0 SUMMARY AND CONCLUSIONS

5.1 Summary of Work Accomplished

During the first 12 months of the ORADS 30 month research program, S*R engineers:

1. Designed a portable LADAR sensor capable of accurately measuring the velocity of vehicular traffic.
2. Demonstrated a setup time less than 30 minutes and the capability to accurately measure vehicle type, travel lane, and lane position.
3. Developed processing electronics and software to interface raw data signals to a commercial traffic recorder (Diamond® Phoenix).
4. Developed design compliant with eye-safe regulations for Class 1 lasers.
5. Provided a successful hardware demonstration.

The S*R developmental unit field tests demonstrated the capability of applying laser radar technology to traffic monitoring. These tests determined that the ORADS technology offers the following specific advantages over existing sensor designs:

1. Non-intrusive set-up and operation – does not block traffic.
2. Precise measurement of travel lane, vehicle velocity, and axle wheelbase.
3. Minimizes hazardous exposure to field technicians and engineers.
4. Easily deployable with minimum setup time (< 30 minutes).
6. Compatible with existing traffic monitoring processing and instrumentation protocols.
7. Self contained system with a modular construction.
8. Cost effective compared to other multi-lane measurement schemes.

5.2 Hardware Delivered

Spectra completed fabrication of three operational ORADS units and delivered two of these units to ODOT for further evaluation. The third unit will be retained during the ODOT evaluation period by Spectra Research as an engineering tool to facilitate troubleshooting and problem solution during the evaluation period.

5.3 Performance Achieved

Table 13 shows the goals and parameters at the beginning of the research program compared to the actual performance achieved.

Table 13. ORADS Goals vs. Actual Achievement

Parameter	**Goal**	**Actual**
Sensor Location	Off-road, non-intrusive to traffic	Off-road, non-intrusive to traffic
Setup Time	<15 minutes	<30 minutes
Interface	Data collection devices	Data collection devices
Velocity Accuracy	±1mph	± 0.88mph
Vehicle Type/Length	14 classes by length (5-75')	14 classes by length (5-75')
Lane Coverage *	Multiple (1 to 4), 2 lane both directions	Multiple (1 to 3), 2 lane both directions
Power	Solar augmented battery	Solar augmented battery
Mobility	Portable, self-contained	Portable, self-contained (wt. 71 lbs)
Operation	48 hours	20 hours (without solar augmentation) **
Safety	Minimum hazard to technicians, eye-safe	Minimum hazard to technicians, eye-safe design
Cost Goal	$1,200 to $2,000 (estimated)	Approx. $ 12K

* Bi-directional mode not verified by ODOT.
** Tested by Spectra Research, not verified by ODOT.

6.0 IMPLEMENTATION

Two units initially delivered to ODOT are candidates for field evaluation by ODOT Tech Services. In past meetings, ODOT has identified several unique locations where the ORADS could be installed and evaluated. These locations are primarily unsuitable for portable units with tubes or tape switches because of hazardous conditions during installation.

The delivery of these units included operating instructions and a brief operator's manual. Spectra will be available on an "on call" basis for approximately one week of assistance during the evaluation period.

A third unit retained by Spectra Research for troubleshooting will be delivered at a future date.

APPENDIX A

ROAD TEST DATA

TABLE 1A ODOT SUMMARY OF 10-19-00 DATA

ORADS DEMO

October 19, 2000
oradt2 c10/27/00

ODOT DATA

Hour 11-12 Vehicle Class	ORADS	Percent of total	ODOT#1	Percent of total	ODOT #2	Percent of total	WIM	Percent of total
1	5	0.5%	3	0.3%	1	0.1%		
2	613	57.8%	598	55.2%	611	57.5%		
3	174	16.4%	224	20.7%	197	18.5%		
4	0	0.0%	0	0.0%	0	0.0%		
5	26	2.5%	32	3.0%	42	4.0%		
6	27	2.5%	26	2.4%	25	2.4%		
7	6	0.6%	5	0.5%	5	0.5%		
8	45	4.2%	41	3.8%	38	3.6%		
9	120	11.3%	127	11.7%	112	10.5%		
10	24	2.3%	22	2.0%	18	1.7%		
11	7	0.7%	4	0.4%	4	0.4%		
12	1	0.1%	0	0.0%	0	0.0%		
13	13	1.2%	2	0.2%	9	0.8%		
Total	1061		1084		1062			
sensor miss	74		3		23			
grand total	1135		1087		1085			

S*R Analysis of 10/19/00 ORADS Field Test Data

The three field test data files were loaded into a single Excel spreadsheet and the individual clocks and reported vehicle axle counts were used to prepare a single "event" list that included all vehicle assignments and all sensor misses for the one-hour period from 11:00 AM to 12:00 Noon. Of the 1150 total number of events, 994 were vehicle declarations on all three sensors. The remaining 156 events included those where one or more sensor misses was reported, or where only one or two of the sensors declared a vehicle.

The speed and vehicle length values for the 994 simultaneous vehicle declaration points were analyzed by examining the differences between all three sensor pairs (i.e., ORADS vs. ODOT 1, ORADS vs. ODOT 2, and ODOT 2 vs. ODOT 1). We found a handful of these events in which a clearly erroneous value was reported by one or more of the sensors. We excluded these "outlier" points and did a statistical analysis of the rest. These results are listed in Table 9 for vehicle speed and Table 10 for vehicle length.

Table 9. Statistical Analysis of Reported Vehicle Speed Differences.

	ORADS – ODOT 1	ORADS – ODOT 2	ODOT 2 – ODOT 1
Minimum	-13.1 mph	-6.9 mph	-14.6 mph
Maximum	12.2 mph	14.6 mph	5.9 mph
Mean	-2.01 mph	-0.56 mph	-1.45 mph
Variance (σ^2)	3.05 mph^2	2.56 mph^2	4.07 mph^2
Standard Deviation (σ)	1.75 mph	1.60 mph	2.02 mph

Table 10. Statistical Analysis of Reported Vehicle Length Differences.

	ORADS – ODOT 1	ORADS – ODOT 2	ODOT 2 – ODOT 1
Minimum	-10.7 ft	-8.7 ft	-7.3 ft
Maximum	4.8 ft	8.0 ft	8.3 ft
Mean	-0.63 ft	0.09 ft	-0.72 ft
Variance (σ^2)	0.89 ft^2	0.84 ft^2	1.55 ft^2
Standard Deviation (σ)	0.94 ft	0.92 ft	1.25 ft

Several conclusions are evident from the tabulated results:

- The ORADS sensor reports speeds that are (on the average) 2 mph less than ODOT 1 and 0.6 mph less than ODOT 2.
- The speed differences between the sensors are within the 1-σ error bars (standard deviation).

- The variances of both ORADS-ODOT pairs are less than the variance for the ODOT 1-ODOT 2 pair, implying that the ORADS sensor has a better precision in speed measurement.
- The ORADS sensor reports lengths that are (on the average) 0.6 ft less than ODOT 1 and 0.1 ft more than ODOT 2.
- The length differences between the sensors are within the 1-σ error bars (standard deviation).
- The variances of both ORADS-ODOT pairs are less than the variance for the ODOT 1-ODOT 2 pair, implying that the ORADS sensor has a better precision in length measurement.
- The ORADS sensor is in better agreement with the ODOT 2 sensor than with the ODOT 1 sensor.

Under the assumption that errors in individual sensors are uncorrelated, the variances from the difference statistics can be used to estimate individual sensor precisions. In particular, this assumption implies that the variance in the difference measurement of a pair of sensors is equal to the sum of the variances of the individual sensors:

$$\sigma^2_{\text{ORADS-ODOT1}} = \sigma^2_{\text{ORADS}} + \sigma^2_{\text{ODOT1}}$$

$$\sigma^2_{\text{ORADS-ODOT2}} = \sigma^2_{\text{ORADS}} + \sigma^2_{\text{ODOT2}}$$

and

$$\sigma^2_{\text{ODOT2-ODOT1}} = \sigma^2_{\text{ODOT2}} + \sigma^2_{\text{ODOT1}}.$$

Using the variances listed in Tables 9 and 10, we compute the individual sensor precisions listed in Table 11. Note that the listed values describe the repeatability of the measurements. Other factors such as misalignment or improper spacing would lead to systematic errors impacting accuracy. However, the data indicate that the ORADS sensor is more precise than Tape-Switch sensors operating with one-foot spacing.

Table 11. Estimated Precision in Reported Vehicle Speed and Length.

	Vehicle Speed	Vehicle Length
ORADS	±0.88 mph	±0.30 ft
ODOT 1	±1.51 mph	±0.90 ft
ODOT 2	±1.34 mph	±0.86 ft

We examined the 156 events for which either sensor misses or non-unanimous vehicle declarations occurred. These included 97 events in which one or more of the sensors reported a sensor miss and 59 events in which no miss was reported but only one or two of the sensors made a vehicle declaration.

A breakdown of the 97 sensor-miss events is given in Table 12. We see that the ORADS sensor had a high number of sensor misses (44) when neither ODOT sensor detected a vehicle. These misses may have been caused by electronic noise in one of the ORADS channels or by a sensor response to blowing debris in the road. In any event, these 44 sensor misses do not represent a vehicle counting error. The ORADS sensor also reported 26 misses when both ODOT sensors made a vehicle declaration. These events represent a vehicle counting error (a missed detection) for ORADS. The ODOT 2 sensor had 20 such missed detections. Twelve of these occurred in a "burst" and likely represent some transient mechanical problem with one of the tape switches. The other 7 sensor miss events are judged to reflect noise on an ODOT sensor (2 instances) or are labeled inconclusive because: (1) two sensors reported misses or (3 instances) or (2) only one of the two non-miss sensors reported a vehicle declaration (2 instances).

Table 12. Breakdown of the 97 Sensor Miss Events.

Sensor Misses	Description	Interpretation
44	ORADS miss with no vehicle declaration	Noisy sensor – does not represent an error
2	ORADS miss with one ODOT vehicle declaration	Inconclusive
26	ORADS miss with two ODOT vehicle declarations	Missed detection for ORADS sensor
1	ODOT 1 miss with no vehicle declaration	Noisy sensor – does not represent an error
1	ODOT 2 miss with no vehicle declarations	Noisy sensor – does not represent an error
20	ODOT 2 miss with ORADS and ODOT 1 vehicle declarations	Missed detection for ODOT 2 sensor
2	ORADS miss and one ODOT miss	Inconclusive
1	ODOT 1 miss and ODOT 2 miss	Inconclusive
Total: 97		

Table 13 presents a breakdown of the 59 events in which only one or two of the sensors made a vehicle declaration. We assumed that a missed detection occurred when only one sensor did not make a declaration. With this criterion, we identify 20 missed detections by ORADS, 11 missed detections by ODOT 2, and 1 missed detection by ODOT 1. The remaining cases where only one sensor declared a vehicle may be due to roadway coverage mismatch. For example, the 25 such instances where only ORADS declared a vehicle could be due to sensing a vehicle at the edge of a neighboring lane, just a few inches beyond the end of the tape switch.

Table 13. Breakdown of the 59 Non-unanimous Declaration Events.

Disagreements	Description	Interpretation
25	ORADS declaration with no ODOT declaration	Probable coverage mismatch (i.e., a real vehicle at edge of neighboring lane)
11	ORADS and ODOT 1 declaration	Probable missed detection by ODOT 2
1	ORADS and ODOT 2 declaration	Probable missed detection by ODOT 1
2	ODOT 1 declaration with no ODOT 2 or ORADS declaration	Probable coverage mismatch
20	ODOT 1 and ODOT 2 declaration with no ORADS declaration	Probable missed detection by ORADS
Total: 59		

A comparison of classification data for the 994 three-sensor-declaration events is given in Table 14. We see that the ORADS sensor reported a different axle count 37 times (about 3.7%) while the ODOT sensors had only 4 instances of a different axle count. Generally, when the ORADS sensor disagreed, it yielded a larger axle count. Such events could be due to detection of mud flaps or other vehicle structures. Interestingly, the three sensors seemed to have similar rates of disagreement in the Axle Bin category (41 for ORADS, 32 for ODOT 1, and 31 for ODOT 2). The ORADS sensor reported vehicle length differing from the three-sensor median by more than 20% on 18 events (a 1.8% rate). The sensors agreed on Length Bin 830 times with ORADS differing from the others 32 times, ODOT 1 from the others 94 times, and ODOT 2 from the others 34 times. The sensors showed only small differences in reported speeds. The comparison numbers listed in the Speed Bin category count the number of times that a sensor's speed bin differed from the median of the three bins by more than one. There were only four such instances for each sensor.

Table 14. Comparison of Vehicle Classifications for ORADS, ODOT 1, and ODOT 2 Sensors.

Axle Count				Axle Bin				Vehicle Length			Length Bin				Vehicle Speed			Speed Bin		
All Same	ORADS Different	ODOT 1 Different	ODOT 2 Different	All Same	ORADS Different	ODOT 1 Different	ODOT 2 Different	ORADS > 20% Different	ODOT 1 > 20% Different	ODOT 2 > 20% Different	All Same	ORADS Different	ODOT 1 Different	ODOT 2 Different	ORADS > 10% Different	ODOT 1 > 10% Different	ODOT 2 > 10% Different	ORADS: 2 Different	ODOT 1: 2 Different	ODOT 2: 2 Different
953	37	1	3	883	45	32	31	18	4	3	830	32	94	34	4	4	4	4	4	4

The Axle Bin assignment gives the assigned vehicle class. A summary of the class assignments for the 994 events where all sensors made a classification is given in Table 15. These results do not differ significantly from those presented by ODOT.

Table 15. Summary of Vehicle Classification Results.

CLASS	ORADS	Percent of Total	ODOT 1	Percent of Total	ODOT 2	Percent of Total
1	2	0.2%	3	0.3%	1	0.1%
2	571	57.4%	545	54.8%	567	57.0%
3	160	16.1%	200	20.1%	182	18.3%
4	0	0.0%	0	0.0%	0	0.0%
5	25	2.5%	30	3.0%	40	4.0%
6	27	2.7%	24	2.4%	23	2.3%
7	6	0.6%	5	0.5%	5	0.5%
8	44	4.4%	38	3.8%	36	3.6%
9	116	11.7%	122	12.3%	109	11.0%
10	23	2.3%	21	2.1%	18	1.8%
11	7	0.7%	4	0.4%	4	0.4%
12	1	0.1%	0	0.0%	0	0.0%
13	12	1.2%	2	0.2%	9	0.9%
	994		994		994	

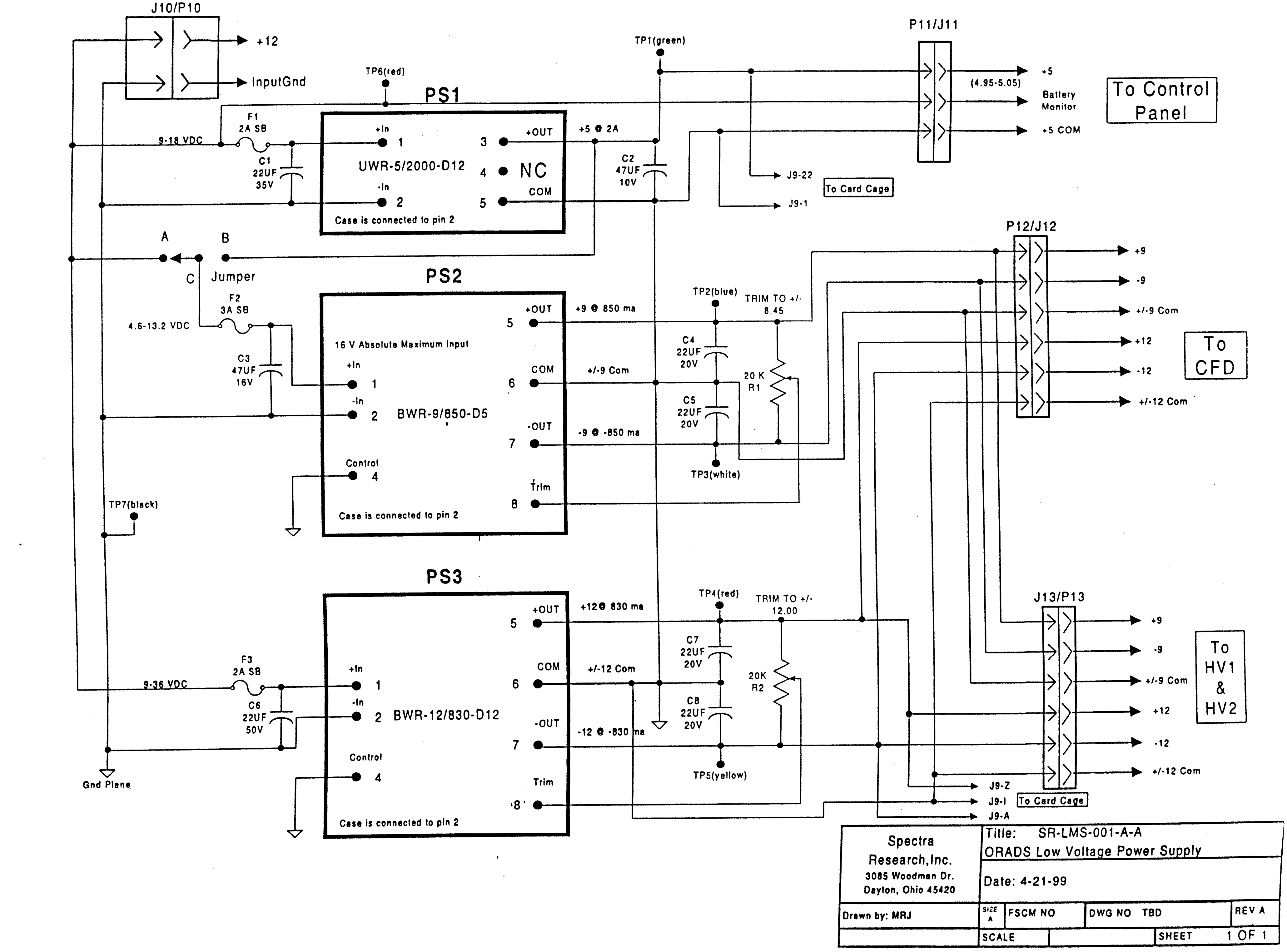
Table 16 summarizes the above analysis.

Table 16. Summary of Statistical Analysis Results.

	ORADS	ODOT 1	ODOT 2
Speed precision	±0.88 mph	±1.51 mph	±1.34 mph
Length precision	±0.30 ft	±0.90 ft	±0.86 ft
Spurious sensor miss	44	1	1
Missed detection	26	0	20
Missed detection or coverage mismatch	20	2	11
Coverage mismatch	25	1	0
Axle count errors	37	1	3
Axle bin/vehicle class errors	45	32	31
Vehicle length errors	18	4	3
Vehicle length bin errors	32	94	34
Vehicle speed errors	4	4	4

APPENDIX B

ORADS SCHEMATICS

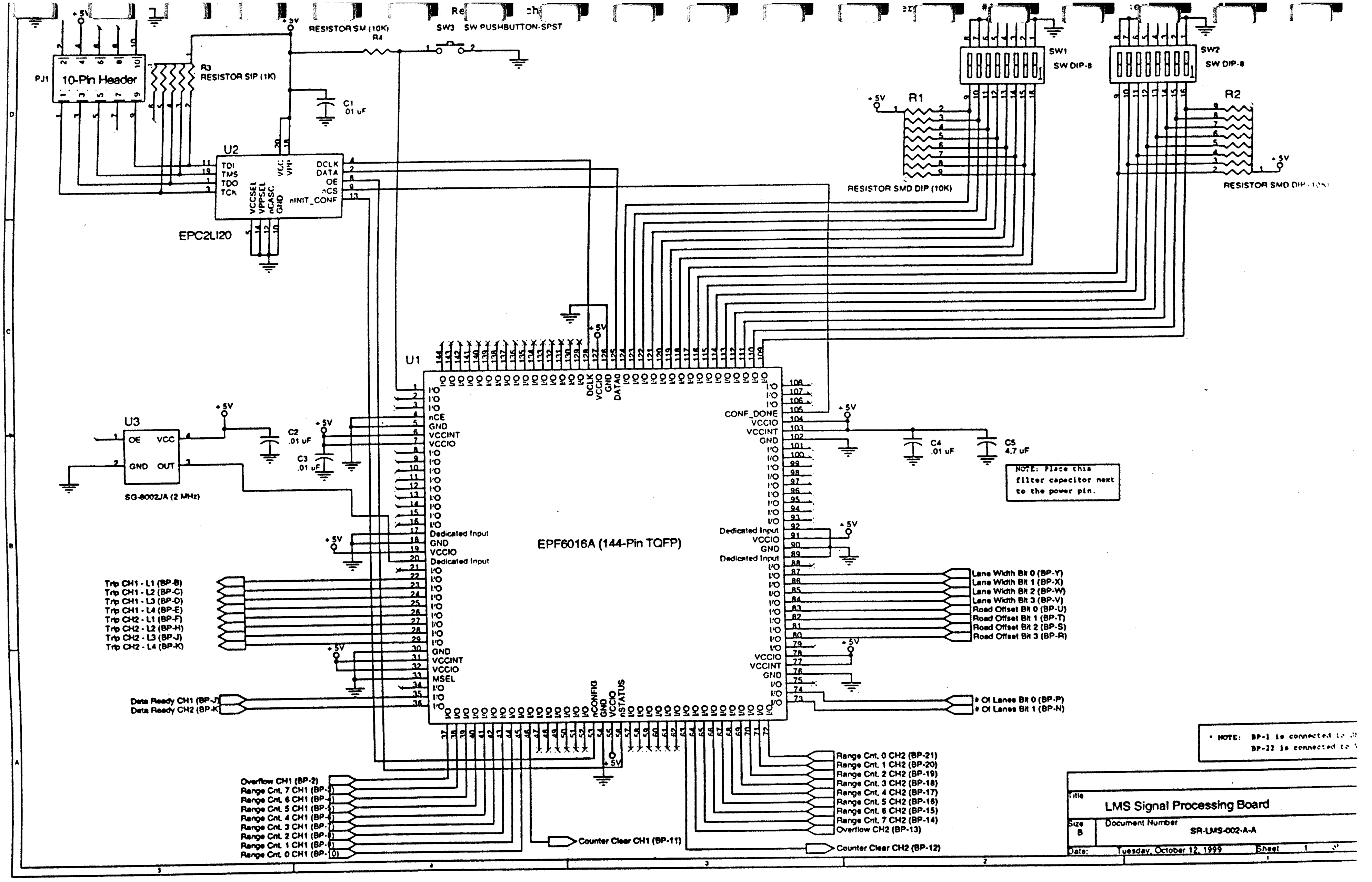


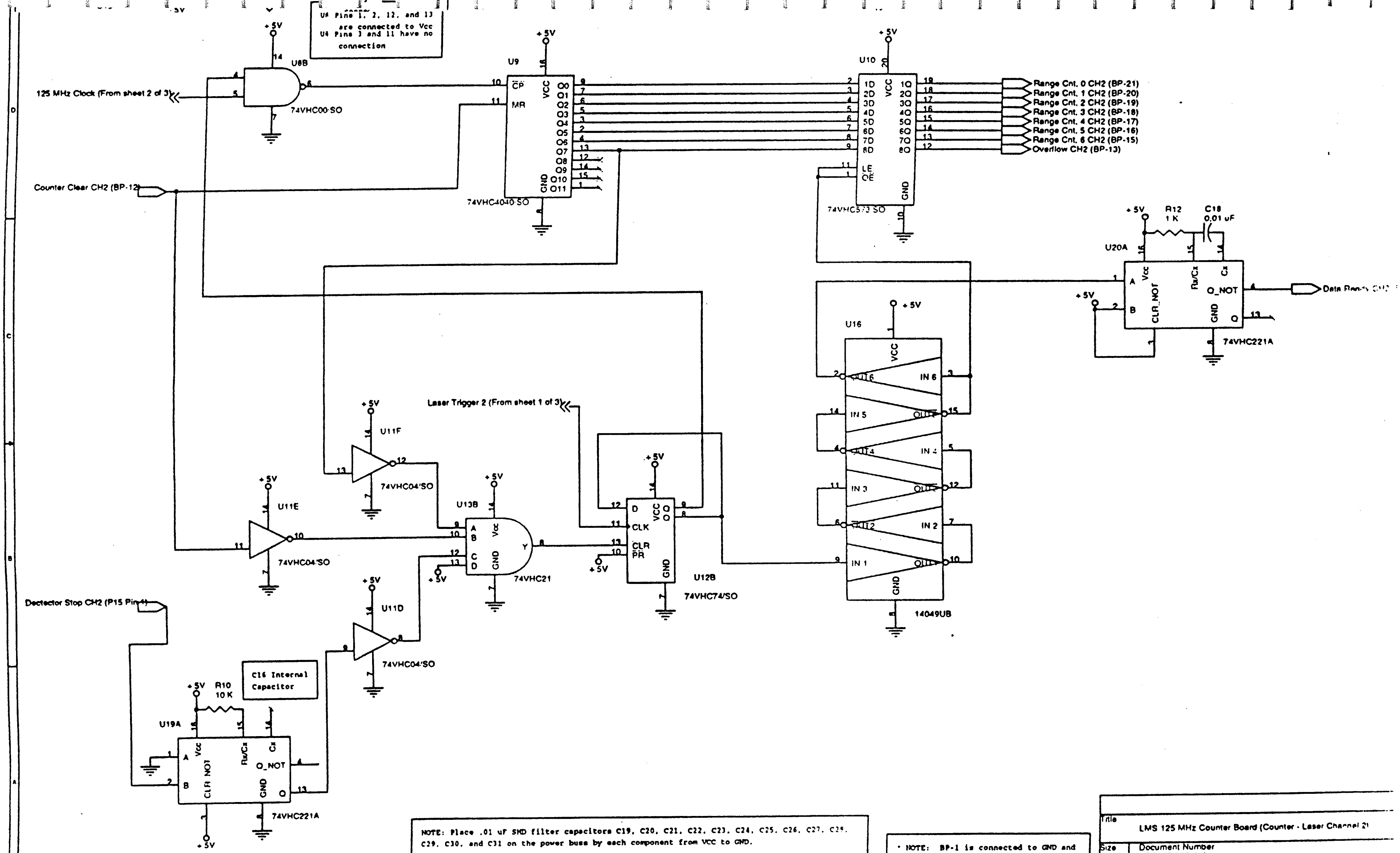
Spectra
Research,Inc.
3085 Woodman Dr.
Dayton, Ohio 45420

Title: SR-LMS-001-A-A
ORADS Low Voltage Power Supply

Date: 4-21-99

Drawn by: MRJ	SIZE A	FSCM NO	DWG NO TBD	REV A
	SCALE		SHEET	1 OF 1

PJ1
10-Pin Header
+5V
R3
RESISTOR SIP (1K)
RESISTOR SM (10K)
R4
SW3
SW PUSHBUTTON-SPST
C1
.01 uF
U2
TDI
TMS
TDO
TCK
VCC
VPP
VCCSEL
VPPSEL
nCASC
GND
DCLK
DATA
OE
nCS
nINIT_CONF
EPC2LI20
SW1
SW DIP-8
SW2
SW DIP-8
R1
RESISTOR SMD DIP (10K)
R2
RESISTOR SMD DIP
U1
EPF6016A (144-Pin TQFP)
I/O
nCE
GND
VCCINT
VCCIO
Dedicated Input
MSEL
nCONFIG
nSTATUS
DCLK
DATA0
CONF_DONE
U3
OE
VCC
GND
OUT
SG-8002JA (2 MHz)
C2
.01 uF
C3
.01 uF
C4
.01 uF
C5
4.7 uF
NOTE: Place this filter capacitor next to the power pin.
Trip CH1 - L1 (BP-B)
Trip CH1 - L2 (BP-C)
Trip CH1 - L3 (BP-D)
Trip CH1 - L4 (BP-E)
Trip CH2 - L1 (BP-F)
Trip CH2 - L2 (BP-H)
Trip CH2 - L3 (BP-J)
Trip CH2 - L4 (BP-K)
Data Ready CH1 (BP-J)
Data Ready CH2 (BP-K)
Overflow CH1 (BP-2)
Range Cnt. 7 CH1 (BP-3)
Range Cnt. 6 CH1 (BP-4)
Range Cnt. 5 CH1 (BP-5)
Range Cnt. 4 CH1 (BP-6)
Range Cnt. 3 CH1 (BP-7)
Range Cnt. 2 CH1 (BP-8)
Range Cnt. 1 CH1 (BP-9)
Range Cnt. 0 CH1 (BP-10)
Counter Clear CH1 (BP-11)
Range Cnt. 0 CH2 (BP-21)
Range Cnt. 1 CH2 (BP-20)
Range Cnt. 2 CH2 (BP-19)
Range Cnt. 3 CH2 (BP-18)
Range Cnt. 4 CH2 (BP-17)
Range Cnt. 5 CH2 (BP-16)
Range Cnt. 6 CH2 (BP-15)
Range Cnt. 7 CH2 (BP-14)
Overflow CH2 (BP-13)
Counter Clear CH2 (BP-12)
Lane Width Bit 0 (BP-Y)
Lane Width Bit 1 (BP-X)
Lane Width Bit 2 (BP-W)
Lane Width Bit 3 (BP-V)
Road Offset Bit 0 (BP-U)
Road Offset Bit 1 (BP-T)
Road Offset Bit 2 (BP-S)
Road Offset Bit 3 (BP-R)
Of Lanes Bit 0 (BP-P)
Of Lanes Bit 1 (BP-N)
* NOTE: BP-1 is connected to
BP-22 is connected to
Title
LMS Signal Processing Board
Size
B
Document Number
SR-LMS-002-A-A
Date:
Tuesday, October 12, 1999
Sheet
1
A
B
C
D
1
2
3
4
5

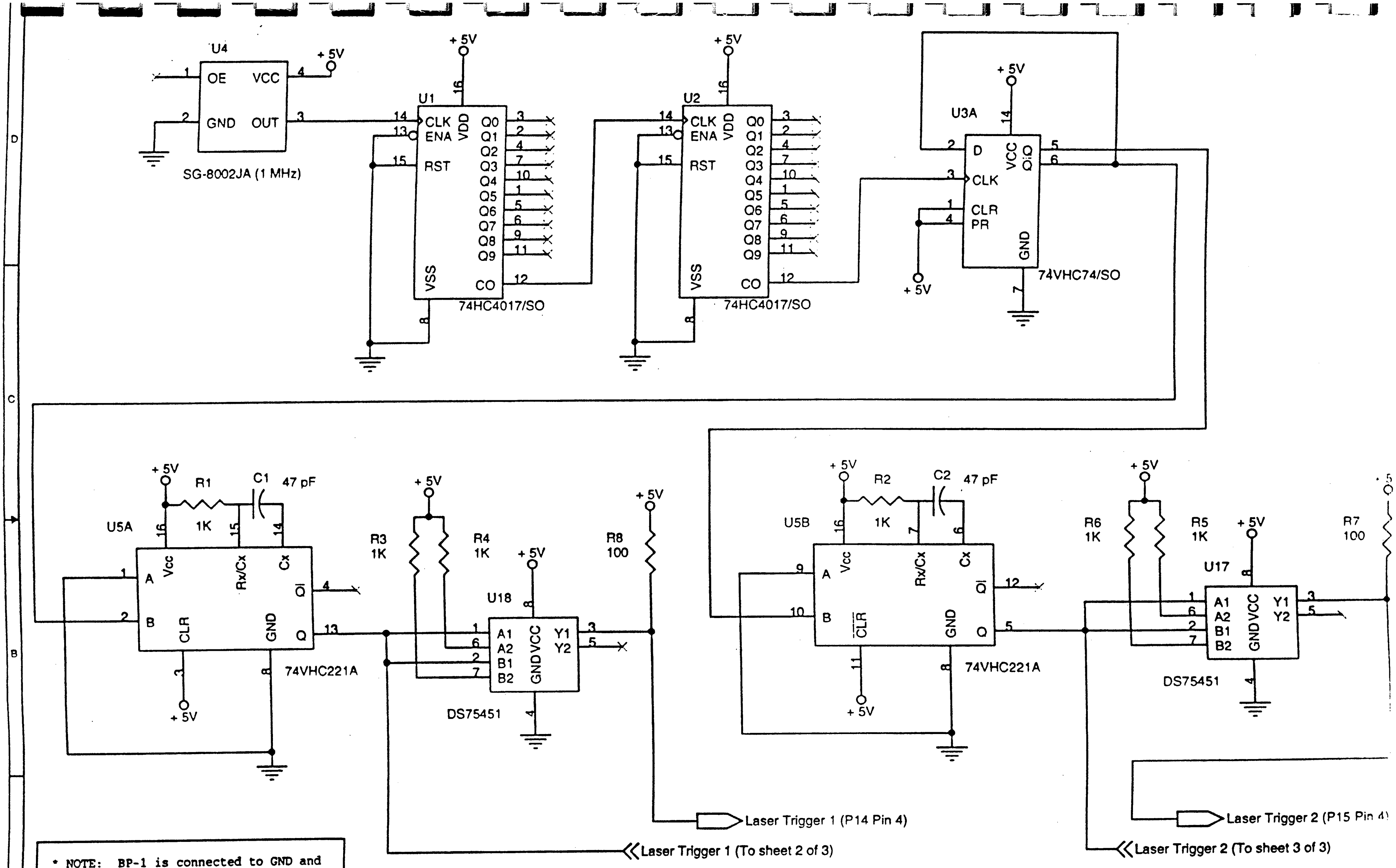


NOTE: Place .01 uF SMD filter capacitors C19, C20, C21, C22, C23, C24, C25, C26, C27, C28, C29, C30, and C31 on the power buss by each component from VCC to GND.

NOTE: Place 4.7 uF SMD filter capacitor C14 on the power buss from VCC to GND.

* NOTE: BP-1 is connected to GND and BP-22 is connected to VCC +5V

Title	LMS 125 MHz Counter Board (Counter - Laser Channel 2)
Size B	Document Number SR-LMS-003-A-A
Date:	Tuesday, October 12, 1999
Sheet	3

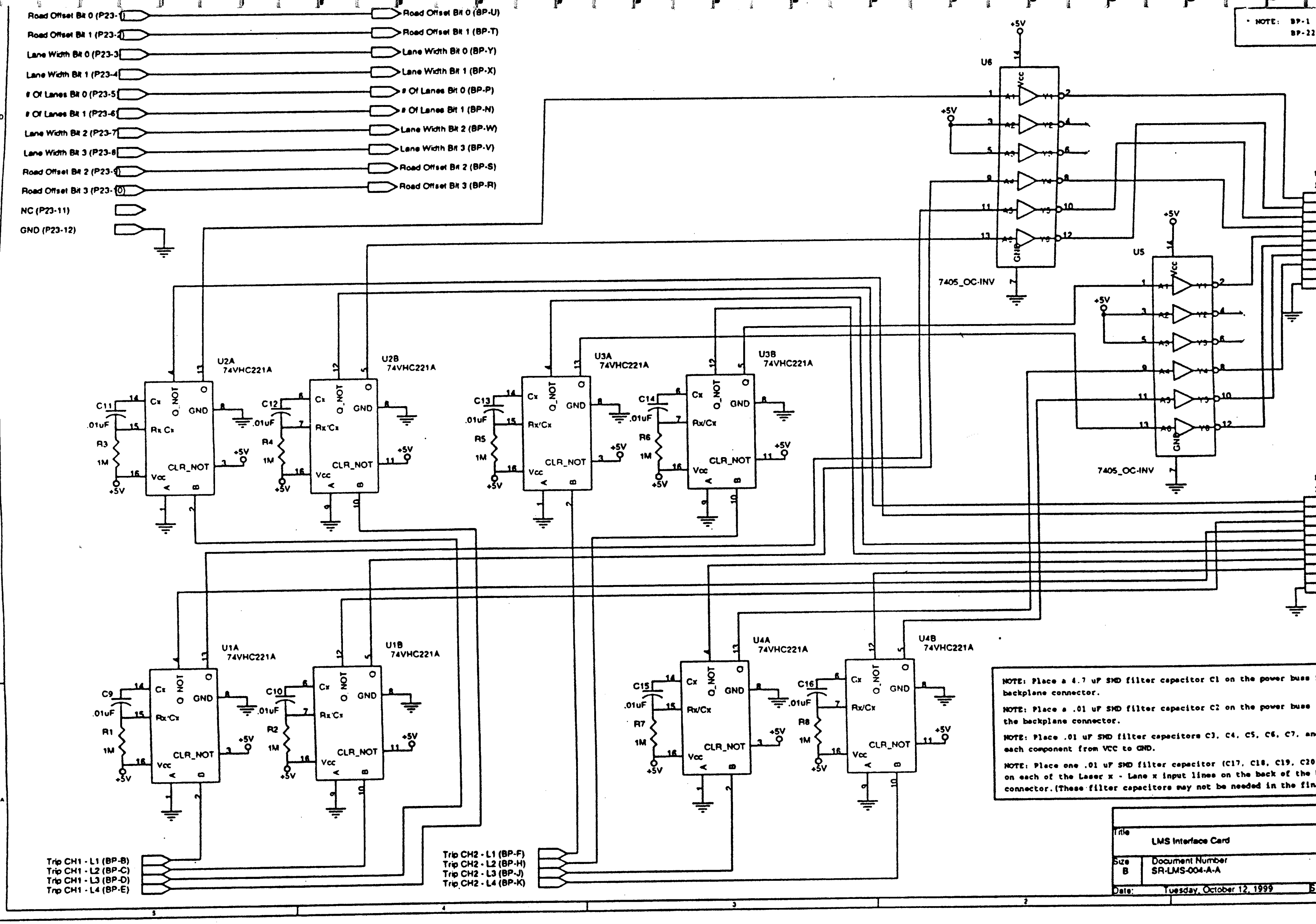


* NOTE: BP-1 is connected to GND and
BP-22 is connected to VCC +5V

NOTE: Place .01 uF SMD filter capacitors C3, C4, C5, C6, C7, C8, and C9 on the power buss by each component from VCC to GND.

NOTE: Place 4.7 uF SMD filter capacitors C10, C11, C12, and C13 on the power buss from VCC to GND.

Title	LMS 125 MHz Counter Board (Laser Triggers)
Size A	Document Number SR-LMS-003-A-A
Date: Thursday, October 14, 1999	Sheet 1 of 3



* NOTE: BP-1 is connected to GND and BP-22 is connected to VCC +5V

NOTE: Place a 4.7 uF SMD filter capacitor C1 on the power buss from VCC to GND next to the backplane connector.

NOTE: Place a .01 uF SMD filter capacitor C2 on the power buss from VCC to GND next to the backplane connector.

NOTE: Place .01 uF SMD filter capacitors C3, C4, C5, C6, C7, and C8 on the power buss by each component from VCC to GND.

NOTE: Place one .01 uF SMD filter capacitor (C17, C18, C19, C20, C21, C22, C23, and C24) on each of the Laser x - Lane x input lines on the back of the board next to the backplane connector. (These filter capacitors may not be needed in the final implementation.)

Title
LMS Interface Card

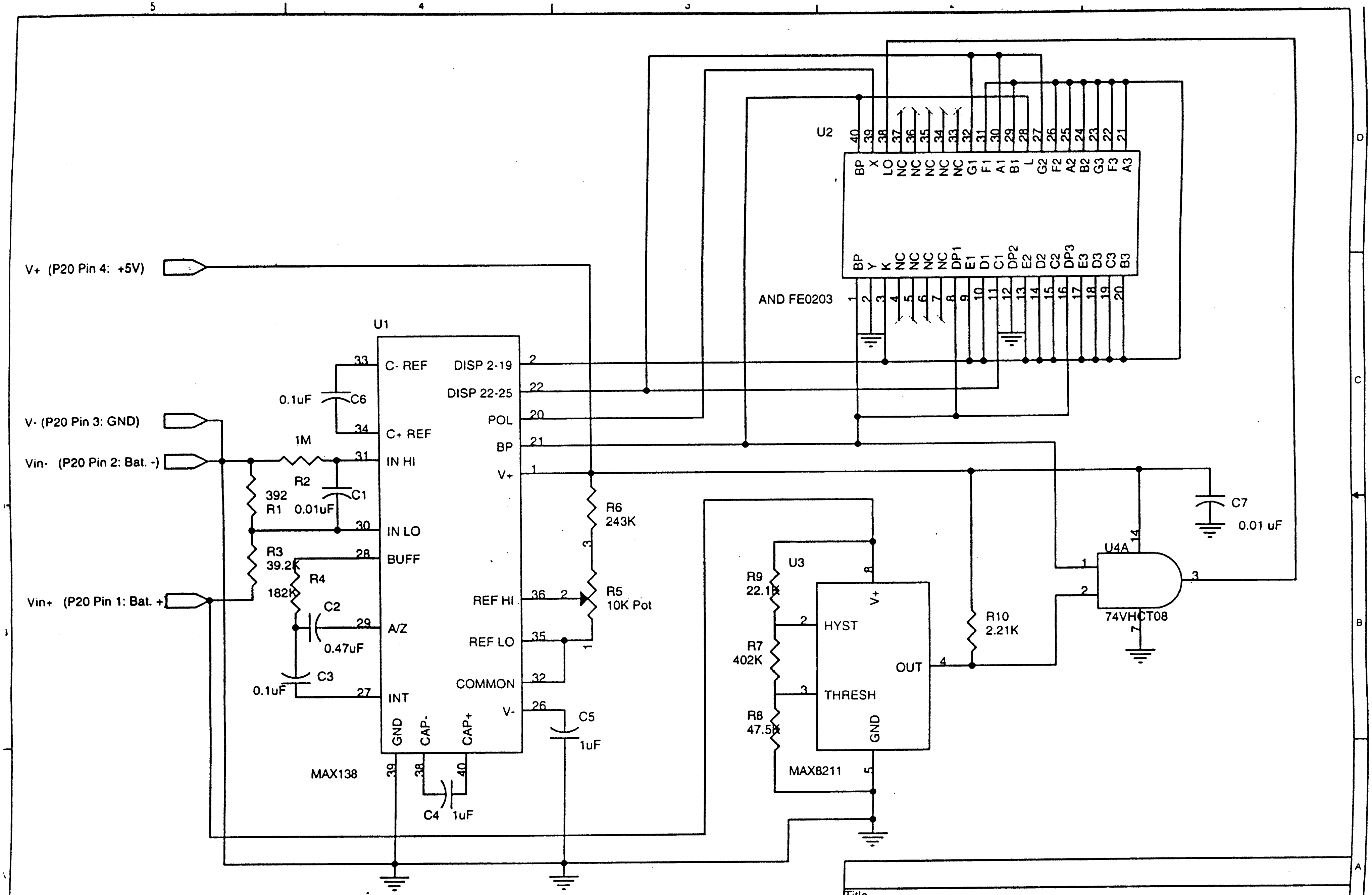
Size
B

Document Number
SR-LMS-004-A-A

Rev
A

Date: Tuesday, October 12, 1999

Sheet 1 of 1

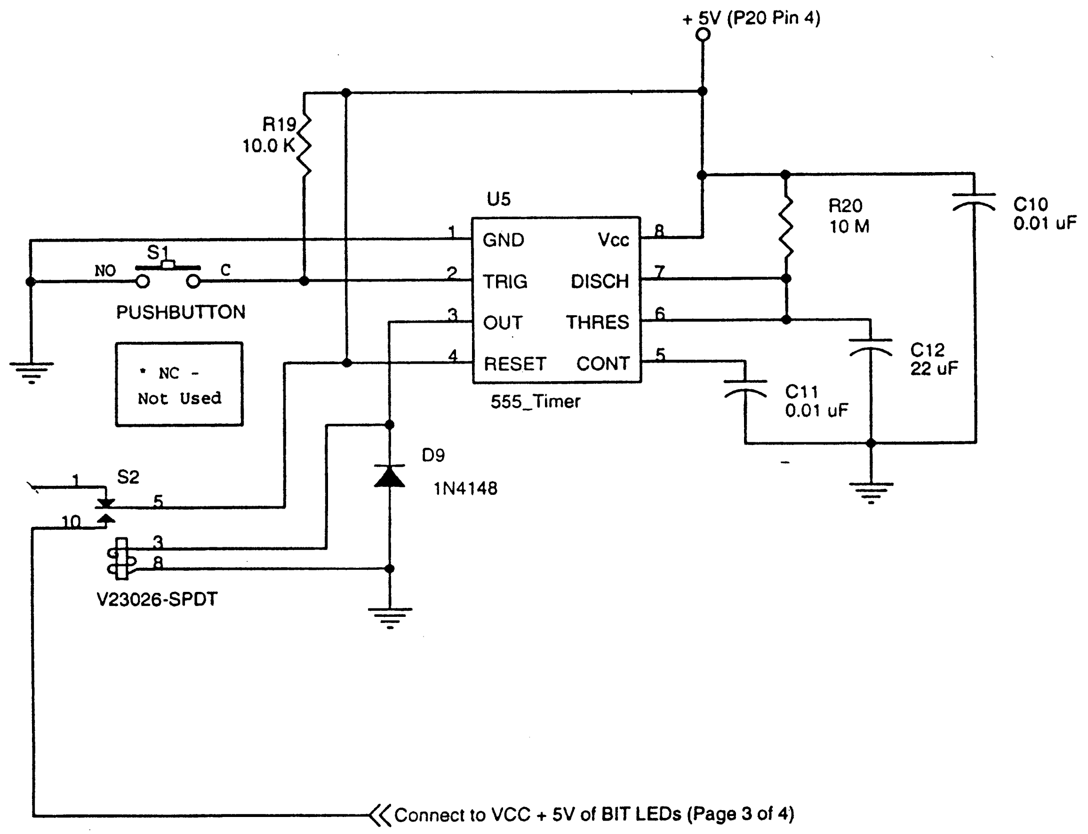


Title

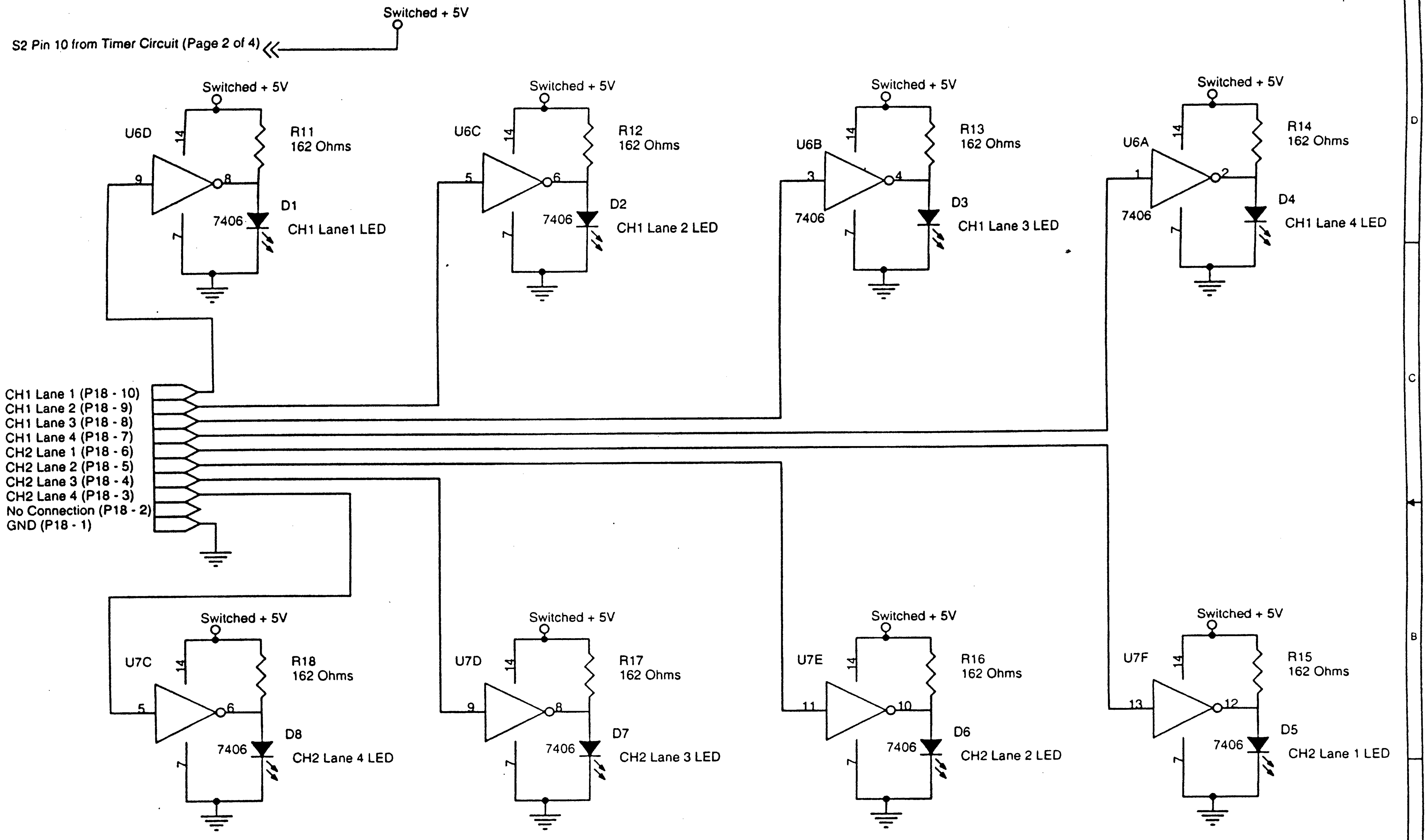
LMS Control Panel - Battery Power Display Circuit

Size	Document Number	Rev
A	SR-LMS-005-A-A	A

Date: Tuesday, November 02, 1999 Sheet 1 of 4



Title	LMS Control Panel - Timer Circuit		
Size A	Document Number SR-LMS-005-A-A		Rev A
Date:	Tuesday, November 02, 1999	Sheet	2 of 4

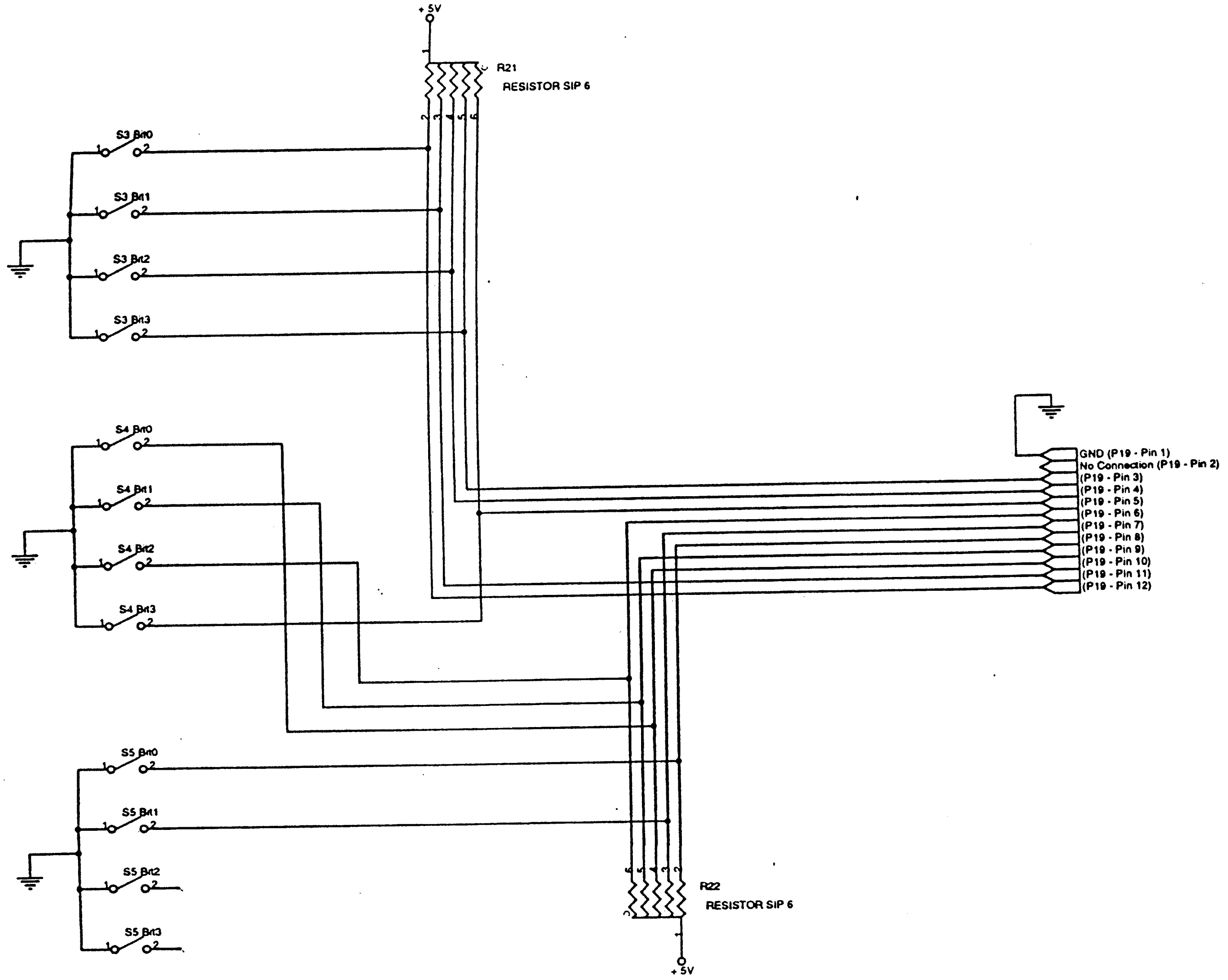


NOTE: Place .01 uF SMD filter capacitors C8 next to the power bus by U6 from VCC to GND.
NOTE: Place .01 uF SMD filter capacitors C9 next to the power bus by U7 from VCC to GND.
NOTE: Connect pins 11 and 13 of U6 to VCC and leave no connection on pins 10 and 12.
NOTE: Connect pins 1 and 3 of U7 to VCC and leave no connection on pins 2 and 4.
NOTE: Connect Switched + 5V to Pin 10 of S2 on the Timer Circuit Schematic. (Page 2 of 4)
NOTE: Connect P18 Pin # 1 to GND plane of board.

Title
LMS Control Panel - BIT LEDs

Size	Document Number	Rev
A	SR-LMS-005-A-A	A

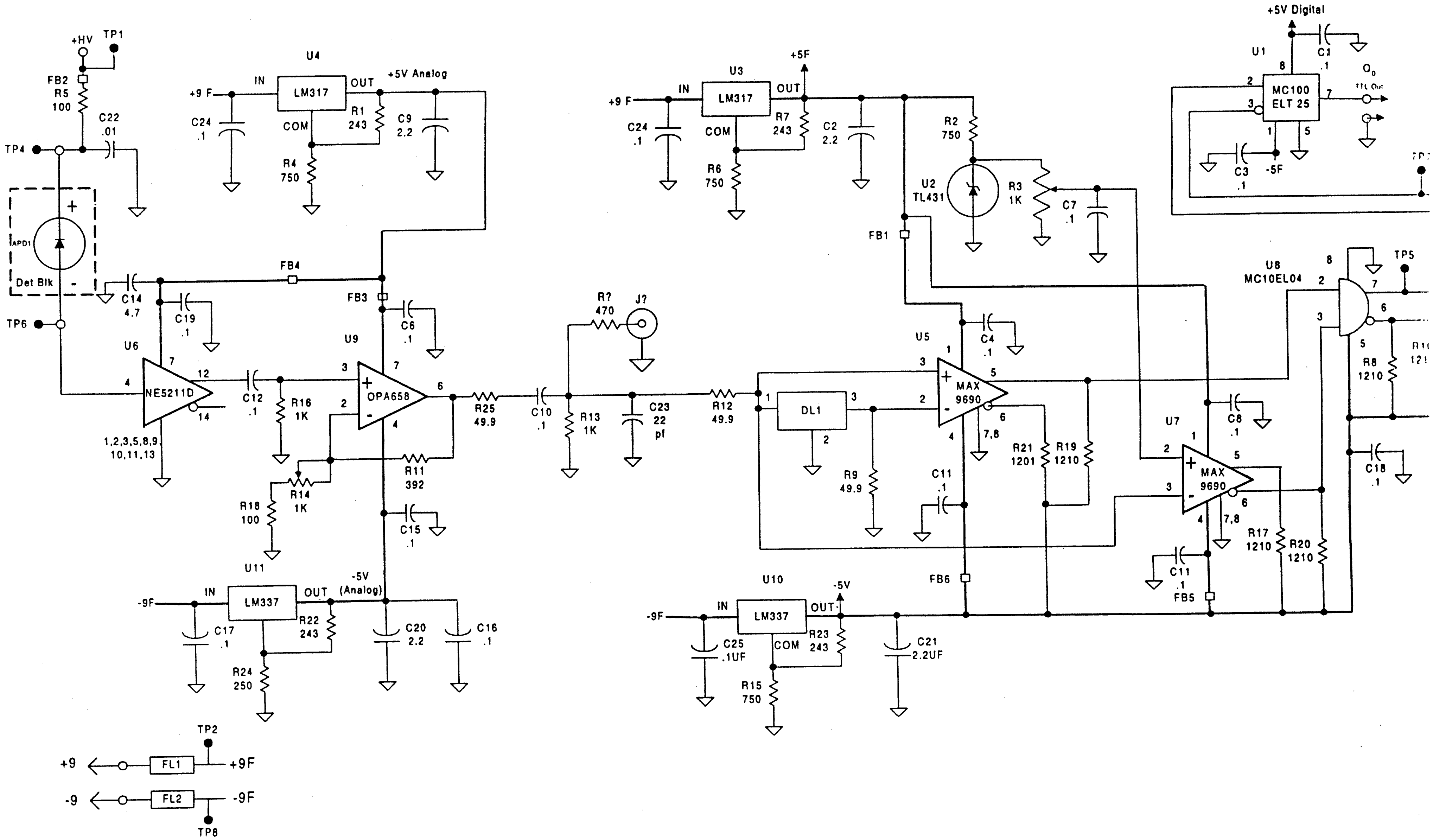
Date: Tuesday, November 02, 1999 Sheet 3 of 4



Title LMS Control Panel - Switches

Size B Document Number SR-LMS-005-A-A Rev A

Date: Monday, November 15, 1999 Sheet 4 of 4



Notes
1. All capacitanes are UF unless otherwise noted.
2. All resistances are Ohms unless otherwise noted.

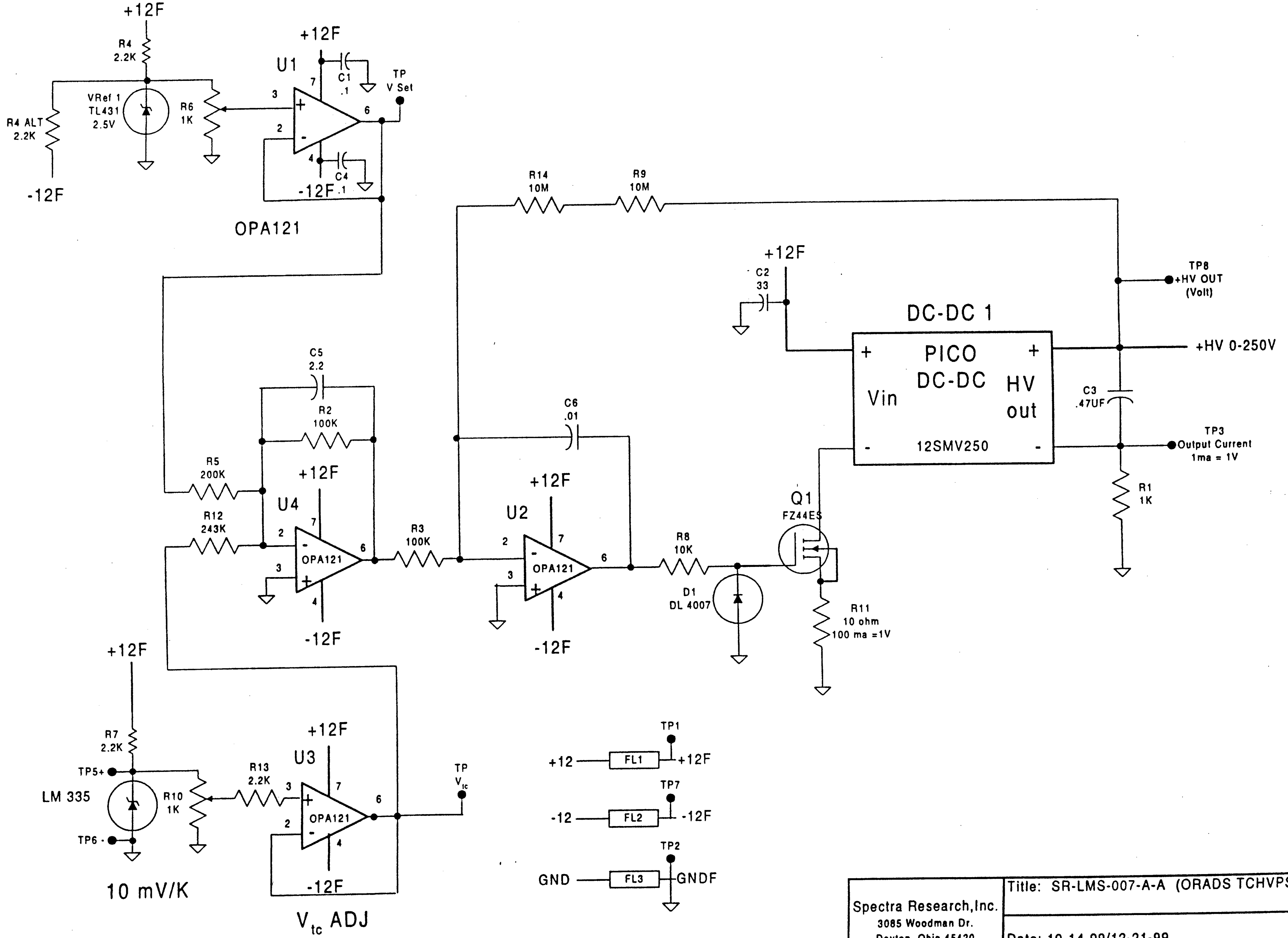
PROPRIETARY
Spectra Research

Spectra Research,Inc.
3085 Woodman Dr.
Dayton, Ohio 45420

Title: SR-LMS-006-A-A (ORADS CFD)

Date: 10-14-99

Drawn by: MRJ
SIZE A
FSCM NO
DWG NO TBD
REV
SCALE
SHEET 1 OF



Spectra Research,Inc. 3085 Woodman Dr. Dayton, Ohio 45420	Title: SR-LMS-007-A-A (ORADS TCHVPS) Date: 10-14-99/12-21-99		
Drawn by: MRJ	SIZE A FSCM NO	DWG NO TBD	REV A
	SCALE		SHEET 1 OF 1

Proprietary
Spectra Research

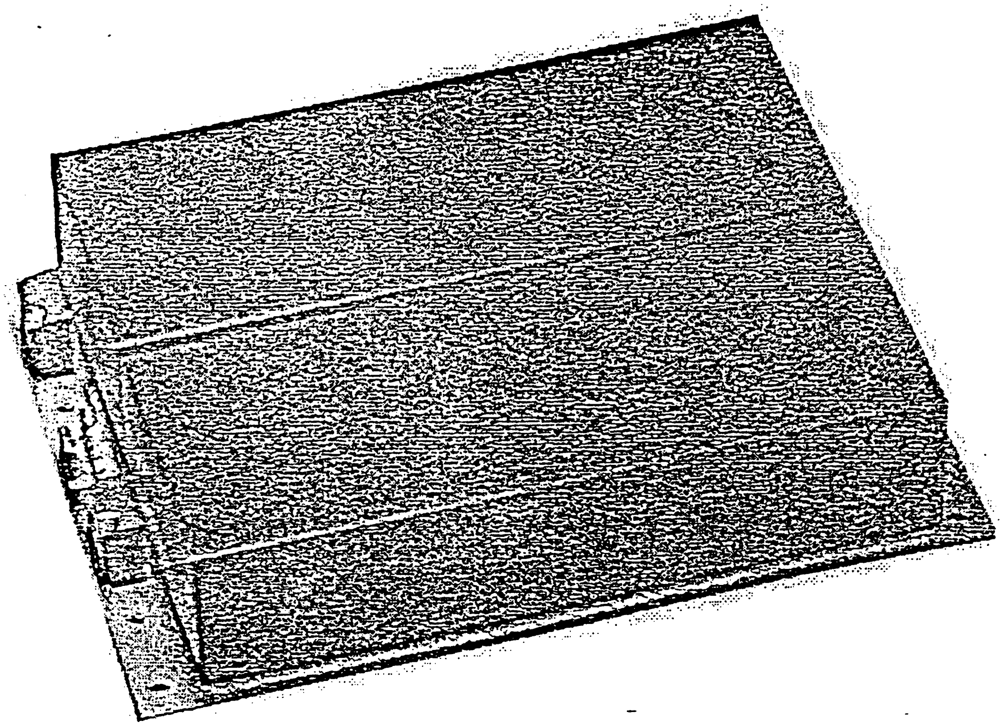
Specialists in Electro Optic Product Development

EHV-4

8 Watt Power Supply for ETX Series Laser Diode Drivers

FEATURES:

- Dual 0-500Vdc outputs for compatibility with all ETX Series Drivers.
- Input voltage 11 - 15 Vdc (12 V nominal) @ 200mA (typ. load).
- TTL/CMOS Compatible Shutdown Input.
- Standard 0.1" center Molex style locking connectors.
- Compact Circuit Board 3.2 x 4.4 inches, max height 0.9 in., weight < 11 oz.

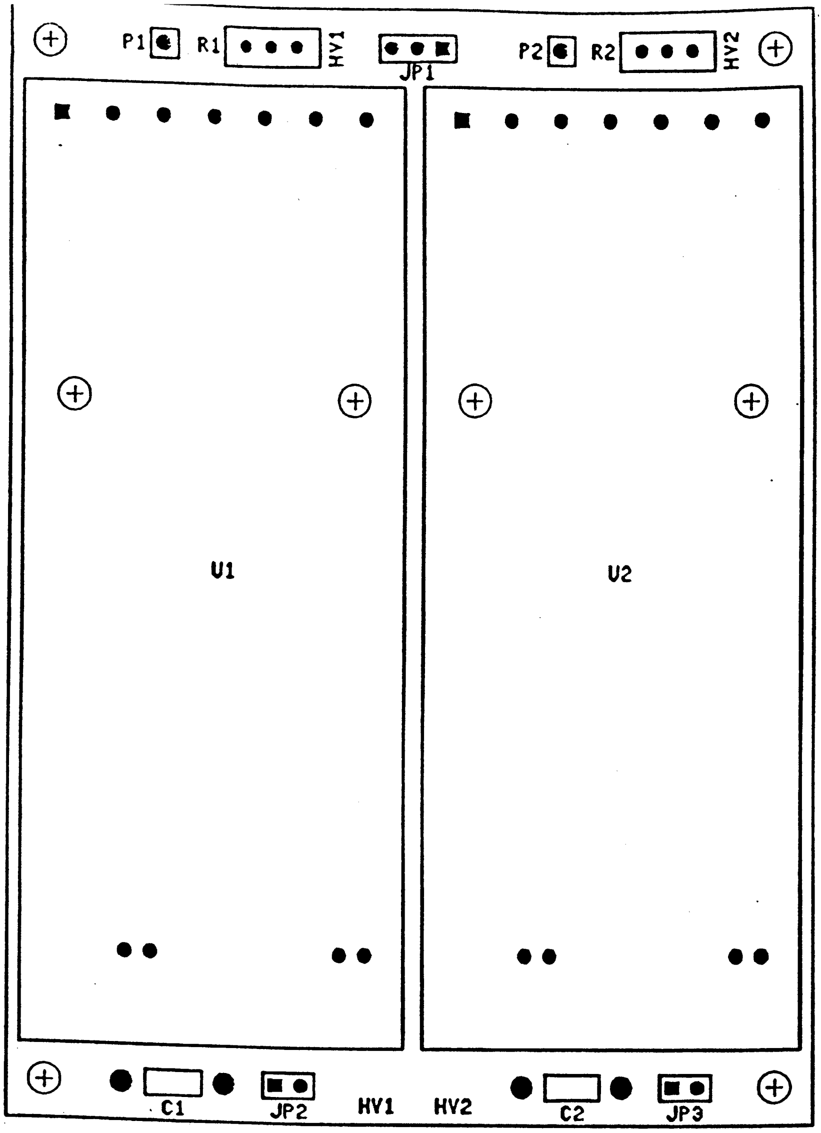


OPERATING SPECIFICATIONS:

PARAMETER	MIN.	TYP.	MAX.	UNIT
Supply Voltage (Vin)	11.0	12.0	15.0	Vdc
Supply Current (no load, Vin = 12Vdc)		100		mA
Supply Current (100K load)[1]		200		mA
Maximum Output Current (per output, 500Vdc)		8		mA
Output Ripple Voltage (100K load)[1]		10		mV(rms)
Switching Frequency			100	kHz

NOTES:

1. Vin = 12.0Vdc, Vout = 250Vdc



INTERFACE :

Input (JP1)
① Vin (12 Vdc nom.)
② Common Ground
③ Shutdown (when grounded or driven below 0.7 Vdc)

Output 1 (JP2)
① +HV1 – Output 1 (adjustable via R1)
② Common Ground

Output 2 (JP3)
① +HV2 – Output 2 (adjustable via R2)
② Common Ground

Mechanical Information:

EHV-4 Dimensions are: 3.20" (W) x 4.35" (L) x 0.90" (H).
Corner mounting holes are 0.125" diameter and separated 2.875" (W) x 4.050" (L).

CAUTION! Exercise extreme care when working with this or any other High Voltage Power Supply.

Spectra Research

3085 Woodman Drive • Suite 200 • Dayton, Ohio • 45420-1173

APPENDIX C

ORADS Mechanical

Innovative Technology

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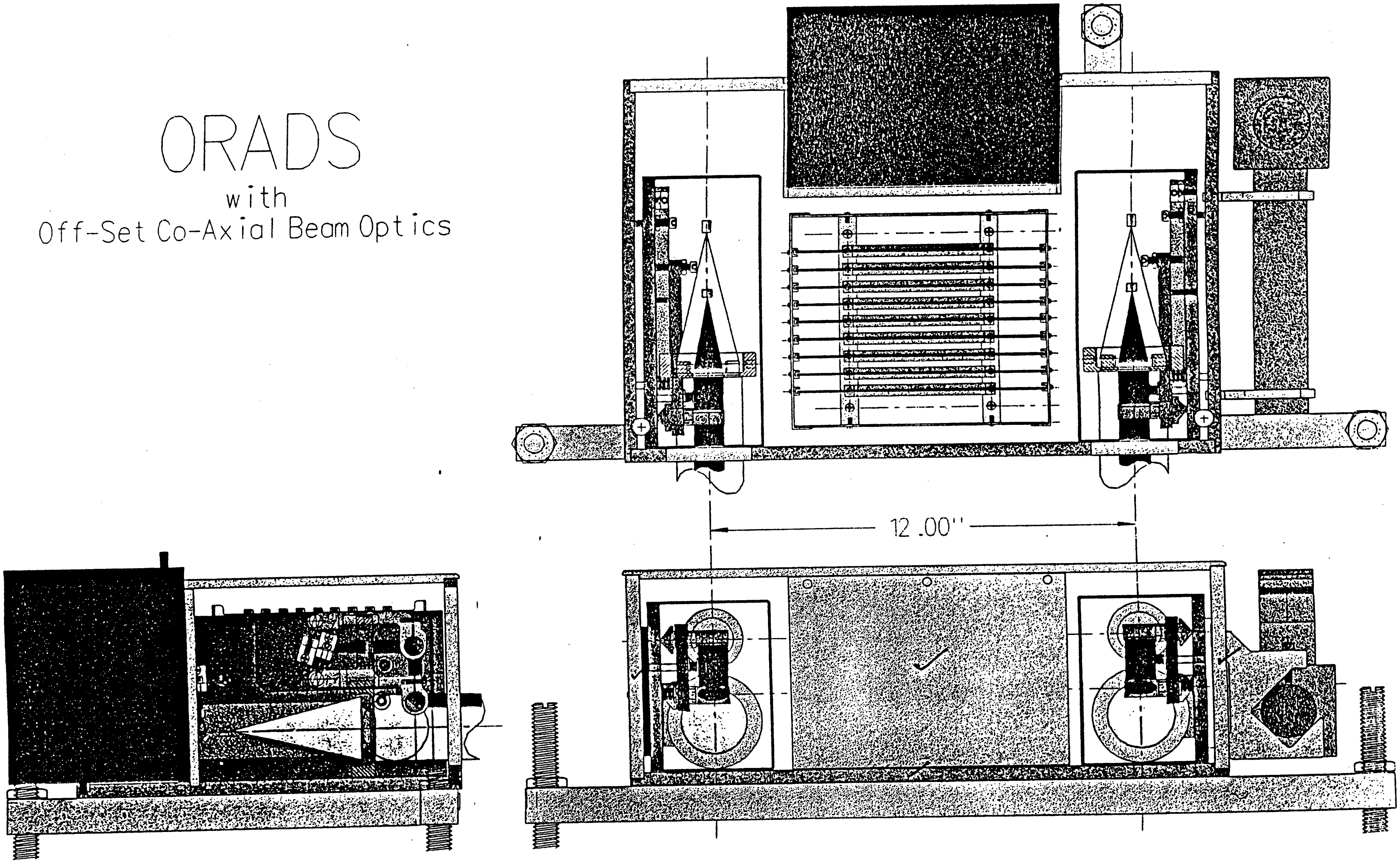
ORADS
with
Off-Set Co-Axial Beam Optics



SCALE = 25%. All edges deburred.
Tolerence: x.xx = +/- 0.01'', x.xxx = +/- 0.002'', Angle +/- 0.5deg.
Finish: Iridite, Color - Gold

PREPARED DATE S E Tate 9 Nov 98	APPROVED DATE	THIS DOCUMENT CONTAINS INFORMATION PROPRIETARY TO S*R, INC. AND USE BY OTHERS IS PROHIBITED EXCEPT AS PROVIDED BY CONTRACT. THE INFORMATION IN THIS DOCUMENT MAY NOT BE DUPLICATED IN ANY WAY WITHOUT THE WRITTEN CONSENT OF S*R, INC. © 1998 S*R, INC.		
FILE 0 140 10 AA .CAD	CAGE: 0GTZ6			

S·p·e·c·t·r·a * R·e·s·e·a·r·c·h
INCORPORATED
DAYTON, OHIO 45459 USA

TITLE	OFF ROAD AXLE DETECTION SENSOR [ORADS] TOP LEVEL SYSTEM		
DATE 9 Nov 98	SHEET 1 OF 1	DWG. NO. 0 14-0 10	VER. REV.

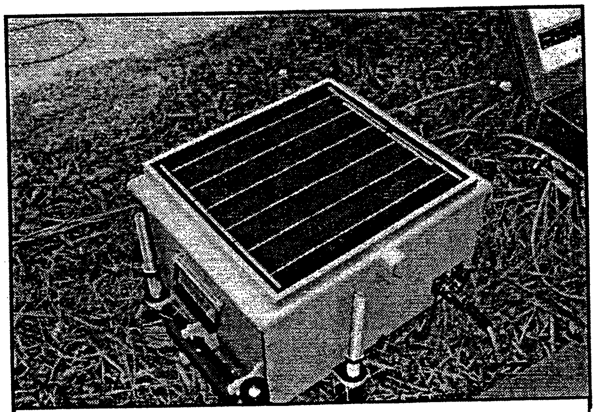


Figure 1 ORADS (Rear View)

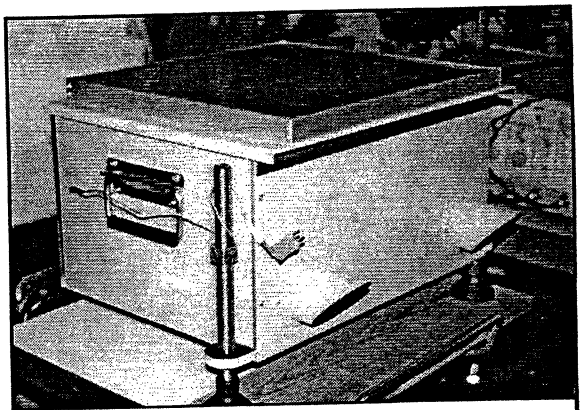


Figure 2 ORADS (Front View)

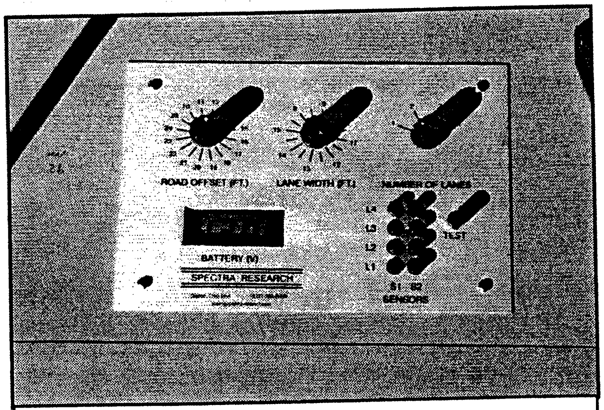


Figure 3. ORADS Control Panel

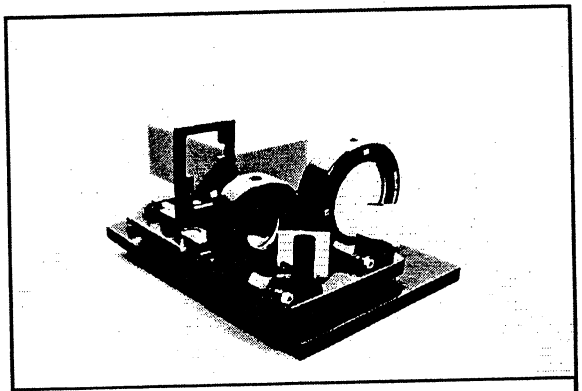


Figure 4. ORADS Optical Bench

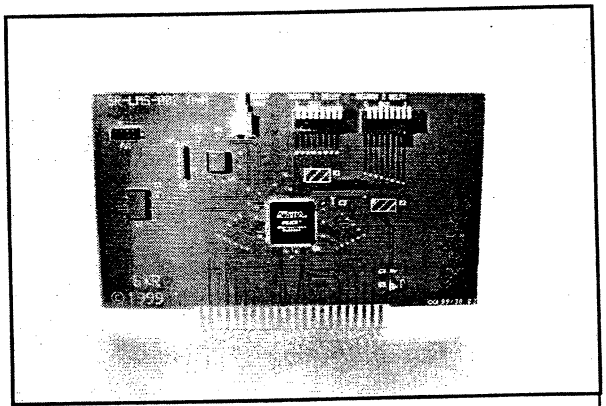


Figure 5. ORADS Signal Processor

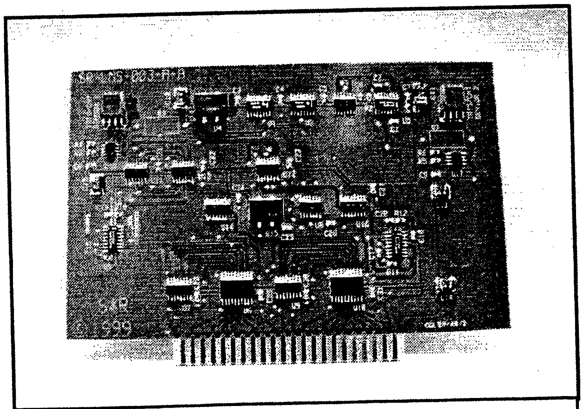


Figure 6. ORADS Counter Trigger