Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-91+1162-1F		

4. Title and Subtitle	5. Report Date
INFRARED SENSORS FOR COUNTING, CLASSIFYING, AND WEIGHING VEHICLES	December 1990
	6. Performing Organization Code
7. Author(s) Joseph E. Garner, Clyde E. Lee, and Liren Huang	8. Performing Organization Report No. Research Report 1162-1F
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Research Study 3-10-88/0-1162
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763-5051	13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Research Study Title: "Infrared Detectors for Counting, Classifying, and Weighing Vehicles"

16. Abstract

In this study, five field tests were conducted to determine the feasibility of using commercially-available infrared light-beam sensors for counting, classifying, and perhaps weighing vehicles. It was demonstrated that a single, reflex-type infrared sensor mounted just off the shoulder and working off a retro-reflective raised pavement marker in the center of the outside traffic lane can be used to count the tires on one end of each axle of a moving vehicle with accuracy comparable to human observers or to a flush-mounted piezo-strip sensor. Sensor installation involved no pavement cuts and only minimal interference to traffic. Tests were not conducted in snow or heavy rain. Arrays of two or more infrared light-beam sensors can be used to sense vehicle-body presence, to calculate vehicle speed, axle spacing, and tire-contact patch dimensions, to indicate single or dual tires, to detect direction of vehicle movement, and to sense over-height vehicles. Off-shoulder reflex-type infrared sensors with retro-reflective raised pavement markers operated for up to three months without cleaning. A two-sensor array tested in the Houston high-occupancy-vehicle (HOV) lane indicated promise as a replacement for loop-detector arrays. Infrared sensors can supplement weigh-in-motion systems by indicating off-transducer vehicle tires, but correlations between infrared light-beam sensor measurements and weight were not sufficient to make adequate weight estimates from such measurements practicable.

17. Key Words	18. Distribution Statement
infrared light-beam sensors, retro-reflective, pavement, vehicles, speed, axle spacing, weight, arrays, traffic, weigh-in-motion systems, estimate	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	80	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

INFRARED SENSORS FOR COUNTING, CLASSIFYING, AND WEIGHING VEHICLES

by

Joseph E. Garner
Clyde E. Lee
Liren Huang

Research Report Number 1162-1F

Research Project 3-10-88/0-1162

Infrared Detectors for Counting, Classifying, and Weighing Vehicles

conducted for

Texas State Department of Highways and Public Transportation

in cooperation with the

U.S. Department of Transportation Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH

Bureau of Engineering Research

THE UNIVERSITY OF TEXAS AT AUSTIN

December 1990

PREFACE

Throughout this research study, a number of agencies, companies, and individuals cooperated in providing information, helpful suggestions, materials, personnel, and other resources to support the work. The study contact individuals representing, respectively, the State Department of Highways and Public Transportation and the Federal Highway Administration were Jeff Seiler and Ted Miller. Their timely contributions of administrative and engineering support made the research possible. Personnel in D-10, Transportation Planning Division, cooperated generously in all phases of the effort, especially in scheduling and conducting the field studies at Seguin, Junction, San Marcos, and Jarrell, and by loaning hardware. Similarly, D-9, Materials and Tests Division, furnished sample retroreflectors and epoxy. Posts and retroreflectors were furnished by District 14, Austin. Department of Public Safety officers cooperated in the field measurements of tire-contact dimensions and weighing of trucks at San Marcos. The sensor tests in the high-occupancy-vehicle (HOV) lane in Houston were made possible by the efforts of Dick McCasland and Gene Ritch with the Texas Transportation Institute, and those of Lynn McLean and his associates with Houston Metro. Chet Freda, representing Motorola Inc.'s University Support Program in Austin, furnished, at no cost, numerous microprocessor devices and electronic components and also supported the research through Motorola's facilities in Phoenix. Southwestern Materials provided retroreflectors of various types for experimentation. All these contributions, and others not mentioned specifically, are sincerely appreciated.

ABSTRACT

In this study, five field tests were conducted to determine the feasibility of using commercially-available infrared-light-beam sensors for counting, classifying, and perhaps weighing vehicles. It was demonstrated that a single, reflex-type infrared sensor, mounted just off the shoulder and working off a retroreflective raised pavement marker in the center of the outside traffic lane, can be used to count the tires on one end of each axle of a moving vehicle with accuracy comparable to that of human observers or that of a flush-mounted piezo-strip sensor. Sensor installation involved no pavement cuts and only minimal interference to traffic. Tests were not conducted in snow or heavy rain. Arrays of two or more infrared-light-beam sensors can be used to sense vehicle-body presence; to calculate vehicle speed, axle spacing, and tire-contact patch dimensions; to indicate single or dual tires; to detect direction of vehicle movement; and to sense over-height vehicles. Off-shoulder, reflex-type infrared sensors, with retroreflective raised pavement markers, operated for up to three months without cleaning. A two-sensor array tested in the Houston high-occupancy-vehicle (HOV) lane indicated promise as a replacement for loop-detector arrays. Infrared sensors can supplement weigh-in-motion systems by indicating off-transducer vehicle tires, but correlations between infrared-light-beam-sensor measurements and weight were not sufficient to make adequate weight estimates from such measurements practicable.

SUMMARY

Infrared sensors can be used in three sensing modes: direct, reflex, or diffuse. The reflex mode, which requires a retroreflector, can be used in all applications discussed in this report. For a few applications such as vehicle-height detection, the direct-sensing mode, which requires the transmitter and receiver to be in separate locations, can also be used. The diffuse-sensing mode is not recommended for traffic applications.

Overhead, roadside, and pavement level are the three different arrangements of infrared sensors which can be used. In the overhead and roadside arrangements, vehicle bodies are sensed, and vehicle speed, length, and headway can be calculated. In the pavement-level arrangement, tires are sensed, and speed, axle spacing, tire-contact-patch dimensions, and lateral position of tires can be calculated. Also with this sensor arrangement, single and dual tires can be identified.

In the first two field studies, it was determined that the in-motion tire-contact patch constantly changes and is sometimes considerably different after the vehicle travels only a few inches. Attempts were made to correlate the in-motion dimensions of tire-contact patches with wheel weights of 149 semi-trailer trucks which were measured simultaneously with weigh-in-motion force transducers. Only a rough correlation was found for the dual tires on tandem axles, and virtually no correlation was found for the single tires of the front axles. These correlations between infrared-light-beam-sensor measurements and weight were not judged to be sufficient to make adequate weight estimates practicable. WIM system measurements can be aided by using infrared-light-beam sensors to make lateral-position calculations which identify off-transducer tires.

In a field test in a high-occupancy-vehicle (HOV) lane in Houston, an array of two infrared sensors was the basis for calculating vehicle speed, length, and headway, and for indicating direction. The current array of three loop detectors can possibly be replaced with infrared-light-beam sensors after only minor modifications of the infrared-sensor housing and the currently-implemented computer software.

In an extended performance test, it was determined that off-shoulder infrared sensors and in-lane retroreflectors can be operated for three months or longer without cleaning or adjustment. These tests were conducted in the summer and fall months in Texas.

In another field test, an array of two pavement-level infrared sensors was used to count axles per vehicle and indicate single and dual tires as the basis for classification. The two-sensor infrared array, combined with a loop detector, had a 95 percent success rate during periodic evaluation over a thirty-day period at a site where vehicles were traveling between about 50 and 65 miles per hour. Experienced human observers were the basis for the accuracy comparison.

IMPLEMENTATION STATEMENT

Arrays of infrared sensors and retro-reflectors in both the overhead and roadside arrangements can indicate vehicle presence and direction and thus provide information for counting vehicle bodies and for calculating vehicle speed, headway, and length. In the overhead arrangement, vehicles can be counted by lane. In the roadside arrangement, the height of vehicles can be determined. Arrays of infrared sensors and retroreflectors can be used in the pavement-level arrangement to calculate axle speed, axle spacing, tire-contact-area dimension, and lateral position of tires. They can also be used to indicate single or dual tires. Another sensor, either an infrared sensor placed to detect vehicle bodies or an inductance-loop detector, is required to match tires to the correct vehicle for classification. For longer-term performance, off-shoulder mounting of the reflex-type infrared sensors with retroreflective raised pavement markers in the center of the outside lane is recommended. Sensors on the edge line work only a few days without cleaning of the lenses and retroreflectors. Some infrared sensors are battery-powered and have a built-in counter with LCD display. These units cost about $130 each and are recommended for non-recording counter applications, perhaps at remote locations, where total counts can be recorded by a human observer at appropriate intervals. Output signals from infrared sensors can be connected to a counter or classifier which normally accepts road-tube, loop-detector, or piezo-cable input signals. These output signals can also be processed by a software program stored on a single-chip microprocessor board. Data can be stored on the board or sent to a computer to be displayed and stored. In-motion tire-contact dimensions measured with infrared-light-beam sensors were not found in this study to be an adequate basis for estimating vehicle weight and tire loads of static vehicles and are, therefore, not suggested for implementation. The reliability of weigh-in-motion measurements can be enhanced with infrared-sensor information which detects off-transducer positions of the tires of vehicles being weighed. The cost of an infrared reflex sensor and reflector is about $100, while a piezoelectric cable costs over $300 and requires traffic control and pavement cutting to install it.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

Transportation engineers require information about traffic and traffic loadings in order to design pavements and other structures that will endure and function adequately throughout their design life. Pneumatic road tubes, piezoelectric cables, and inductance-loop detectors are some of the sensing devices commonly used to count and classify traffic. Weighing is done both statically and dynamically. Static weighing uses special scales to measure the tire forces of a standing vehicle. Static vehicle weights can also be closely approximated by measuring the dynamic tire forces of a moving vehicle with weigh-in-motion transducers and by processing the force signals with electronic instruments. Most of the sensors currently in use for counting, classifying, and weighing moving vehicles require mounting in the pavement or on the pavement surface in the traveled lane.

The purpose of the research described herein was to determine the feasibility of using commercially-available infrared-light-beam sensors for some, or all, of these purposes. A primary objective was to sense the presence of a vehicle or a tire traveling in a highway lane without cutting into the pavement surface or having hardware on the surface where it would be impacted by the tires of every vehicle. It was felt that commercially-available infrared sensors have potential for use in counting, classifying, and weighing vehicles. The considerations in selecting candidate photoelectric sensors, designing the needed hardware and software, installing the systems at selected field sites, and evaluating their performance, are presented in this report.

The tests of infrared sensors for counting and classifying vehicles described herein began in 1988. In a test near San Marcos, Texas, in-motion infrared-sensor measurements of tire-contact area and axle spacing were compared with manual measurements taken after the vehicles were stopped by Department of Public Safety personnel. In another test near Seguin, Texas, infrared and WIM measurements were taken concurrently and compared. Overhead mounting was tried in a series of tests in Austin. In 1989, a test was performed on a high-occupancy-vehicle (HOV) lane in Houston to determine the feasibility of a two-sensor system to calculate speed, headway, length, and direction and to possibly replace loop detectors at locations where pavement cuts were not feasible. A test similar to the one at Seguin was performed at Junction, Texas, with improved infrared equipment. In 1990 a test was made near Jarrell, Texas, to determine long-term performance and durability. Comparisons were also made of vehicle classification systems using loop detectors and a piezo-cable sensor. Another test was made on the Turner Turnpike in Oklahoma City to determine the possibility of using infrared sensors for auditing toll collection based upon eight vehicle classes. Other tests were performed on several streets in Austin.

A self-contained data-collection and storage unit to be mounted on the pavement surface at the lane line was designed and constructed, but field testing was considered unwarranted after observing disabling amounts of road film accumulating on sensor lenses and retroreflectors after only two or three days of traffic.

This report will first describe how infrared sensors operate. Next, it will list a few of the vehicle classification schemes currently in use. It will then discuss different ways in which sensors and retroreflectors can be arranged. Finally, it will discuss various applications and field experiments using infrared sensors.

CHAPTER 2. PHOTOELECTRIC FUNDAMENTALS

A basic knowledge of photoelectric fundamentals is essential to understanding the arrangements, applications, and limitations of infrared sensors as they are used to count and classify vehicles in motion. This chapter gives a brief history of photoelectric sensors and introduces concepts and terminology.

DEVELOPMENT

ELECTRIC EYES

Photoelectric sensors have been around since the 1950's when incandescent lamps were used with cadmium sulfide photocells in systems commonly called electric eyes. When sufficient light hits the surface of the photocell, it conducts current to an output device. When the light is blocked, the cell stops conducting current and the output device directs an electric circuit to open a door or perform some other action. Several drawbacks of this system are that the incandescent bulb burns out rather quickly and is susceptible to vibration and temperature; both the bulb and the photocell are covered by lenses which must be carefully focused; and the photocell can be activated by other light sources such as the sun. Beginning in the 1940's, unmodulated visible light beams were used for traffic sensing, but with only limited success.

LIGHT-EMITTING DIODES

Light-emitting diodes (LEDs) were developed in the 1960's and became available in the 1970's. They are now widely used in calculator displays, watches, and optical sensors. LEDs are semiconductors made from materials such as gallium arsenide which emit light in a single wavelength when current flows through them in the forward direction. They have life spans much longer than those of incandescent bulbs and are not sensitive to shock, vibration, or extreme temperatures. LEDs are much smaller, which makes it possible for the packaging to be more rugged and weather-resistant.

Probably the biggest advantage of LEDs is their ability to be modulated, or turned on and off, thousands of times per second. Photodetectors tuned to this same modulation frequency ignore all other light sources, though the source may be thousands of times brighter. This alleviates the problems of critical alignment, partial blocking, and extraneous light.

LEDs operate in several visible-light wavelengths as well as infrared. Infrared light has a wavelength greater than about 800 nanometers (nm). Gallium arsenide LEDs emit infrared light in a tight band around 940 nm. Infrared LEDs are often preferred because they emit more light intensity than visible-light LEDs and because most photodetectors are more sensitive in the infrared range. In some applications, LEDs operating in the less efficient, visible-light wavelengths are preferred for ease of alignment.

SENSING MODES

As shown in Fig 2.1, photoelectric sensors are used in three main types of sensing modes or configurations, each having distinct properties and applications. The first sensing mode is called direct, opposed, or through-beam. The source and detector are in separate, opposing locations and the object to be sensed passes between them and breaks the light beam. The second mode, called retroreflective or reflex, has the source and detector side-by-side, usually in the same housing. A retroreflector receives the beam from the source and reflects it back to the detector. The object to be sensed passes between the source-detector and the retroreflector. The third mode, called diffuse or proximity, has the source and detector side-by-side with both aimed at a

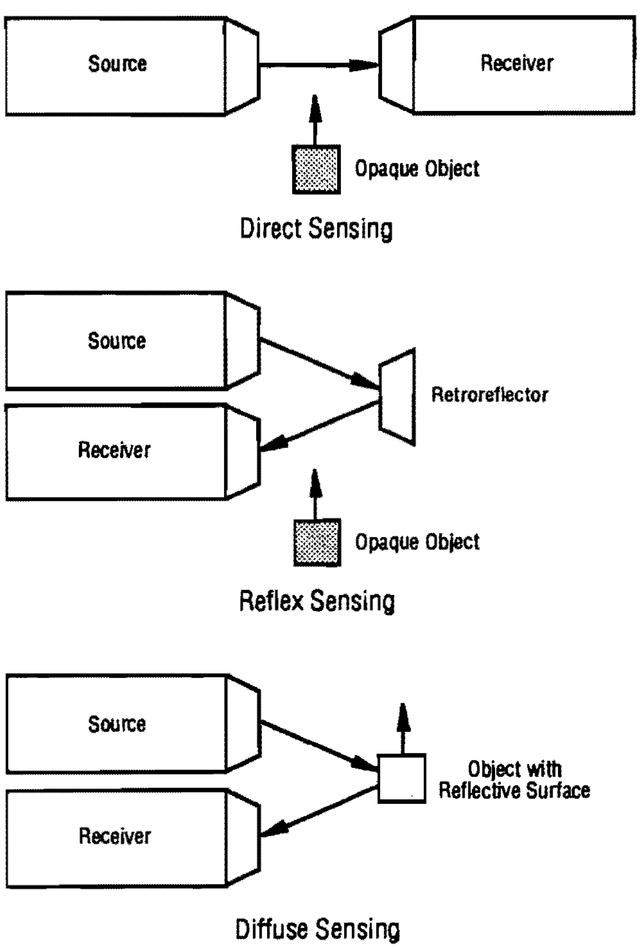


Fig 2.1. Sensing modes.

point in space. An object is sensed when it is at this point and reflects light from the source back to the detector.

Direct sensing has the longest range, since the light beam travels the distance between source and detector only once and energy is not lost by reflection. Reflex sensing has a shorter range, since the light beam crosses the distance between sensor and retroreflector twice and energy is lost by reflection. An object with high reflectivity might not be detected in the reflex mode if it reflects sufficient light back to the detector. To alleviate this effect, polarizing filters may be used to filter out specular reflections, but the resulting sensing range will be reduced. The range of the diffuse sensing mode depends on the amount of light reflected by the object to be detected.

EFFECTIVE BEAM

The effective beam is the energy that an object must block for detection. For direct and diffuse sensing, the effective beam is determined by the overlap of the radiation pattern from the source and the field of view of the detector. For the reflex mode, the effective beam is defined by the edge rays traced from the sensor lenses to the edges of the retroreflector (Ref 1). For reliable detection, the object to be detected must shadow the entire retroreflector at one time. Larger retroreflectors may be used to increase the sensing range, but the effective beam size is also increased and, therefore, so is the necessary size of the object to be detected.

EXCESS GAIN

Excess gain is the ratio of the light energy received by the detector to the minimum energy required for detection under ideal conditions. Ideal conditions are clean air and clean lenses; i.e., the beam is not attenuated. Each sensor has an excess gain curve which shows excess gain versus range. For reflex sensing, excess gain also depends on the type and size of the retroreflector. Excess gain is greatest at close range and falls to one at the maximum range. Guidelines for choosing sensors on the basis of excess gain are given in Table 2.1. The operating environment includes a cleaning schedule for lenses. An excess gain of 1.5X for a clean environment includes a safety factor. An excess gain of 50X will penetrate see-through paper or thin cardboard. In this study, the environmental effects of concern were dust, dirt, oil, moisture, and shock and vibration from cars and heavy trucks.

CONTRAST

Contrast is defined as the ratio between light received by the detector in the light condition and in the dark condition. The dark condition occurs when the light beam is blocked. When the beam is completely blocked, light received is zero and contrast is infinite. Contrast should be as high as possible for optimum reliability. This is important when the light beam is partially blocked, or when a specular reflection is returned to the detector. Contrast can be controlled by adjusting the sensitivity, or excess gain, of the detector.

RETROREFLECTORS

There are two basic types of retroreflectors used for the reflex-sensing mode: corner-cube and spherical-bead. Corner-cube retroreflectors consist of tiny plastic prisms embossed in thin films. Spherical-bead retroreflectors consist of glass beads embedded in a diffuse reflecting binder (Ref 3). Both types have the property of returning incident light beams straight back to the source as long as the angle of light incidence is less than about 15 degrees. The corner-cube type is more efficient than the spherical-bead type. If a polarizing filter is used on the sensor, the corner-cube retroreflector will reflect polarized light. The corner-cube type is commonly used on streets and highways in raised pavement markers and in guide signs. Both types are also available as reflective sheeting. For best efficiency, provision must be made to protect retroreflectors from accumulations of dust and moisture. This is usually accomplished with a clear plastic or glass cover. The size and efficiency of retroreflectors determine the excess gain as described above and also the sensing range. Larger retroreflectors, or an array of retroreflectors, will reflect more light energy, thus increasing the range, excess gain, and effective beam size.

SUMMARY

Photoelectric sensors have been used for many years. In the past decade, it has become feasible to use infrared sensors for traffic engineering applications. The three

TABLE 2.1. EXCESS GAIN GUIDELINES

Source: Ref 2

Minimum Excess Gain Required	Operating Environment
1.5X	Clean air: no dirt build-up on lenses or reflectors
5X	Slightly dirty: slight build-up of dust, dirt, oil, moisture, etc. on lenses or reflectors; lenses are cleaned on a regular schedule
10X	Moderately dirty: obvious contamination of lenses or reflectors, but not obscured; lenses cleaned occasionally or when necessary
50X	Very dirty: heavy contamination of lenses; heavy fog, mist,

sensing modes commonly used are direct, reflex, and diffuse. Each mode has different operating characteristics; these include effective beam and excess gain. Retroreflectors, integral components of the reflex-sensing mode, are either corner-cube or spherical-bead types. The next chapter discusses vehicle classification schemes used by several transportation organizations.

CHAPTER 3. VEHICLE CLASSIFICATION SCHEMES

Different criteria for classifying vehicles are used by organizations concerned with various aspects of transportation. The criteria commonly used include the number of axles per vehicle, axle spacing, number of tires per axle, number and type of units in a vehicle combination, and weight. Before designing and testing infrared sensor classification systems, it is important to know which classification criteria are to be used. This chapter describes the vehicle classification schemes used by four different organizations.

FEDERAL HIGHWAY ADMINISTRATION

The Federal Highway Administration's Traffic Monitoring Guide (Ref 4), as shown in Table 3.1, divides vehicles into passenger and non-passenger vehicles. The number of axles per vehicle, number of tires per axle, and number of trailer units are used to classify the non-passenger types. Passenger cars are not distinguished from passenger cars with trailers. Buses constitute a separate category.

OKLAHOMA TURNPIKE AUTHORITY

The classification schedule used by the Oklahoma Turnpike Authority, shown in Table 3.2 (Ref 5), distinguishes between passenger cars with and without trailers but does not include trucks with more than six axles, nor does it distinguish between single and multi-trailer trucks. Buses are classed with two-axle and three-axle trucks. Four-tire trucks are in the same class as passenger cars.

TABLE 3.2. OKLAHOMA TURNPIKE AUTHORITY VEHICLE CLASSIFICATION SCHEDULE

1. Automobile, Station Wagon, Motorcycle, Any Two-Axle, Four-Tire Truck
2. Class 1 Vehicle Towing One-Axle Trailer
3. Class 1 Vehicle Towing Two-Axle Trailer
4. Two-Axle Bus; Two-Axle, Six-Tire Truck
5. Three-Axle Bus; Three-Axle Truck, Single or Combination
6. Four-Axle Combination Truck
7. Five-Axle Combination Truck
8. Six-Axle Combination Truck

Only eight classes are used since toll operators must classify vehicles quickly and accurately by sight.

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

AASHTO Design Vehicles (Ref 6), as shown in Table 3.3, are defined by their dimensions, which include overall length, wheelbase, and overhangs. The numbers of axles are not considered, but axle spacings are. The chief purpose of AASHTO's design vehicles is that of designing streets and highways. Other purposes are planning, enforcing regulations, and collecting tolls or taxes.

TABLE 3.1. FHWA VEHICLE TYPES

Passenger Vehicles	
1	Motorcycles
2	Passenger Cars
3	Other Two-Axle, Four-Tire, Single-Unit Vehicles
4	Buses
Non-Passenger Vehicles	
5	Two-Axle, Six-Tire, Single-Unit Trucks
6	Three-Axle, Single-Unit Trucks
7	Four or More Axle Single-Unit Trucks
8	Four or Less Axle Single-Trailer Trucks
9	Five-Axle, Single-Trailer Trucks
10	Six or More Axle Single-Trailer Trucks
11	Five or Less Axle Multi-Trailer Trucks
12	Six-Axle, Multi-Trailer Trucks
13	Seven or More Axle Multi-Trailer Trucks

TABLE 3.3. AASHTO DESIGN VEHICLES

Vehicle	Symbol
Passenger Car	P
Single Unit Truck	SU
Single Unit Bus	BUS
Articulated Bus	A-BUS
Combination Trucks	
Intermediate Semitrailer	WB-40
Large Semitrailer	WB-50
Semitrailer — Full-Trailer	WB-60
Interstate Semitrailer	WB-62
Interstate Semitrailer	WB-67
Triple Semitrailer	WB-96
Turnpike Double Semitrailer	WB-114
Recreational Vehicles	
Motor Home	MH
Car and Camper Trailer	P/T
Car and Boat Trailer	P/B
Motor Home and Boat Trailer	MH/B

AMERICAN SOCIETY FOR TESTING AND MATERIALS

The ASTM Standard for Weigh-in-Motion Systems (Ref 7) has an optional vehicle classification scheme that may be used instead of the FHWA Vehicle Types. In the optional system, the number of axles and the axle spacing pattern are the classification criteria. The number of tires is not used. There is an overlap in the axle spacings between the three-axle, single-trailer truck and the passenger car with trailer. An ASTM task group is currently developing a standard vehicle classification scheme.

SUMMARY

Both FHWA and OTA use the number of axles per vehicle and the number of tires per axle for their vehicle classification schemes. In addition, FHWA uses the number of trailer units. AASHTO considers the number of units and axle spacings, but not the number of axles per vehicle or number of tires per axle. ASTM considers the number of axles per vehicle and axle spacing pattern, but not the number of trailer units or number of tires per axle. The next chapter considers the infrared sensor arrangements which can be used to count or measure the different classification criteria.

CHAPTER 4. SENSOR ARRANGEMENTS

Different arrangements of infrared sensors count or measure different criteria used to classify vehicles. Each type of arrangement has different properties and potential applications. These arrangements include overhead, roadside, and pavement-level, as shown in Fig 4.1. S1, S2, S3, S4, and S5 represent sensor positions, while R1, R2, and R3 represent retroreflectors or receivers. In the first two arrangements, vehicle bodies are detected; in the third arrangement, tires are detected. In the pavement-level arrangement, the infrared-light beams can be perpendicular or diagonal to the lane edge. The reflex-sensing mode may be used in all cases, but the direct-sensing mode requires mounting the transmitter in the roadside position and the receiver on or beyond the opposite lane edge or shoulder. The diffuse-sensing mode is not suitable for sensing vehicles.

OVERHEAD

Bridges or other overhead structures can be used to mount infrared sensors, S1 in Fig 4.1. The direct-sensing mode is not well-suited for this arrangement since the unit on the pavement surface, R1, must have either a power source or an external output connection, is difficult to protect, and must be very rugged. A suitable retroreflector array has been designed for this purpose. In the overhead arrangement, vehicles may be counted by lane, and their speed and overall length may be calculated. This is the only arrangement which can accurately sense vehicles in lanes other than the outside lane or the median lane. Only specially-designed and placed retroreflectors are durable enough to be used directly on the pavement for long periods of time.

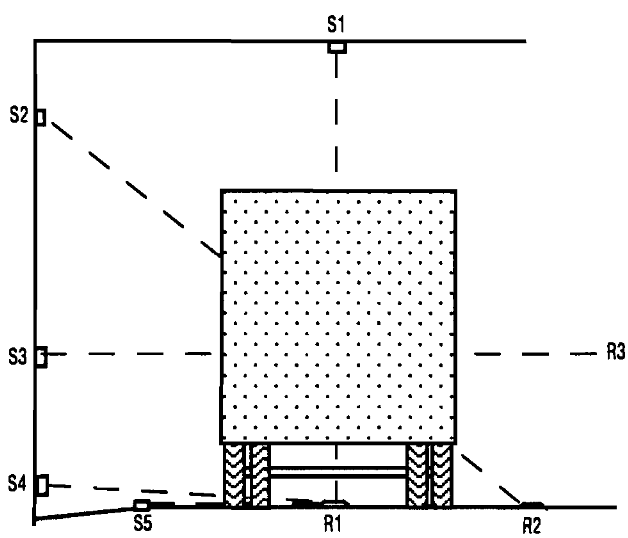


Fig 4.1. Sensor arrangements.

Some combination vehicles may interrupt a single light beam more than once and be counted as more than one vehicle. A sensor that extends the interruption time so that small gaps are not detected can be used in this case. The beam must be broken or unbroken for a longer time period before the sensor changes the output signal. The length of extension or delay depends on speed and length of gaps in the vehicle body. The shorter delay should be used for vehicles at higher speeds and the longer delay at lower speeds. This solution will not work well with highly-variable speeds or with short vehicle headways.

ROADSIDE

Either the direct or the reflex sensing mode may be used for the roadside mounting arrangement. If the direct mode is used, the transmitter and receiver must be placed on opposite sides of the lane or roadway. If the reflex mode is used, the sensor may be S2 or S3, and the retroreflector may be placed either on the pavement (R1 or R2) or on the opposite side (R3). With the units on opposite sides, there will be some mistakes if there is more than one lane of traffic and if vehicles interrupt the beam(s) simultaneously. This arrangement is recommended only if the traffic volume is low. It is, however, the required arrangement for measuring vehicle height. If two sensors are used in this arrangement, direction can be determined by knowing which beam is broken first.

When the reflector is on the pavement, the infrared beam is at an angle to the vertical. If only one beam is used, it will be difficult, if not impossible, to place the beam so that all passenger cars and all large trucks will break it. One beam would not be able to detect both a low car near the shoulder edge and a truck with high clearance near the lane line. Therefore, two or more sensors should be used at different levels with their output signals connected with a logical OR to give more coverage and accurately sense all vehicle types.

Some combination vehicles may interrupt the light beam more than once and be counted as more than one vehicle, as in a manner similar to the overhead arrangement previously described. A solution to this problem might be to use a sensor with a time delay as stated above.

If the sensor is close enough to the edge of the pavement, it is possible for specular reflections from highly polished cars to give a false signal. This problem was discovered while data were being collected on a high-occupancy-vehicle (HOV) lane in Houston, where some vehicles passed within about 4 feet of the reflex sensor-receiver unit. A possible solution might be to use a polarizing filter over the lens, but this approximately halves the sensing range. The manufacturer suggested offsetting the retroreflectors from the sensors, i.e., using diagonal light beams to cut the vehicle paths. Specular reflections are strongest along the angle of reflection which is equal to and opposite from the angle of incidence. Therefore, if the sensors are offset by 15 degrees or more, they will not receive strong specular reflection from flat reflecting surfaces parallel with the lane lines.

PAVEMENT-LEVEL

When tires are being sensed, both sensors and retroreflectors should be placed at the pavement level. The beams are broken by the tires just as they contact the ground and have their smallest cross-section. If the tires were measured closer to their vertical centers, the sensors might not have enough time to recover and count a closely-following tire separately. For this reason, only sensors with short response times should be used. The through-beam sensing mode is not generally recommended for sensing tires for the reasons discussed previously with respect to overhead sensor mounting. For the reflex-sensing mode, the retroreflectors should be placed in the center of the lane so that tires on the same axle straddle the retroreflector, and only the tires next to the shoulder break the beam.

A three-sensor, pavement-level array is shown in Fig 4.2. S1, S2, and S3 represent reflex sensors, while R1, R2, and R3 represent retroreflectors. D1, the distance between the two perpendicular beams, is used to measure speed. D2 is the distance between the center of the lane and the sensors, and θ is the angle used to determine the lateral position and the width of the tires. The retroreflectors are inside an inductance-loop detector in the center of the outside lane. The sensors are on the lane edge or off the shoulder.

The signals from a two-axle vehicle, with respect to time, are shown in Fig 4.3. S1, S2, and S3 are the signals received from the reflex sensors shown in Fig 4.2. A vehicle-presence signal is necessary for the tires to be matched to the correct vehicle. A presence signal may be generated by a separate infrared-beam array which senses the vehicle body, or by another presence sensor such as an inductance-loop detector. When a loop detector is used, the retroreflectors are normally placed on the pavement inside the loop, as shown in Fig 4.2, so that the presence signal begins before the first tire is sensed and ends after the last tire is sensed.

Speed is calculated by dividing the distance between the perpendicular infrared-light beams, D1, by the time taken for one tire to travel between beams, time tv, shown in Fig 4.3. If it is assumed that the vehicle and all tires are traveling at a constant speed, then speed may be determined in a similar manner with a second loop detector, two piezoelectric cables, or two WIM transducers. Axle spacing is calculated by multiplying the speed by the time between successive breaks of one beam, time ts.

Tire-contact length can be calculated by multiplying the speed by the time that a perpendicular beam remains broken by one tire, time tl. Tire-contact length is measured more accurately when the sensor is placed on the pavement at the edge of the lane so that the beam size is smaller and response is quicker. The retroreflector should be small in size to further reduce the effective beam size.

Other quantities may be measured with an infrared-light beam aimed diagonally across a vehicle path as shown in Fig 4.2. When the speed is known, the lateral distance of the tire from the center line or edge can be determined as a function of the time when a tire breaks the diagonal beam and the time when that tire breaks a perpendicular beam, time tp, or crosses some other threshold, e.g., a weigh-in-motion transducer.

The projected diagonal dimension of the tire-contact area is calculated similarly to the tire-contact length, except the interruption time of the diagonal beam, time td, is used. The diagonally-measured dimensions of tires of the same vehicle can be compared to give an indication of single or dual tires. The first tires of a vehicle are assumed to be single; following tires of the same vehicle

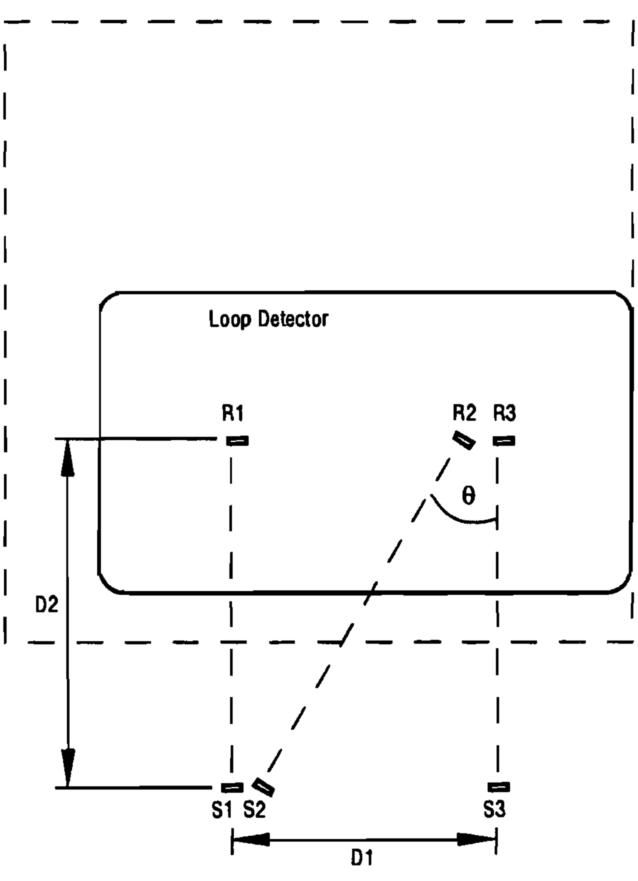


Fig 4.2. Pavement-level sensors.

having dimensions significantly longer are indicated as dual. The vehicle with the signal shown in Fig 4.3 has single tires on the front axle and dual tires on the rear axle. A factor of 1.2 has been found to be sufficient to distinguish between the diagonal dimensions of single and dual tires; i.e., diagonal dimensions of dual tires are at least 1.2 times longer than single tires on the same vehicle. This factor is a variable in the computer program which can be changed to account for different field conditions or observations. Output using the values of 1.1, 1.5, and 1.8 was compared with visual observations of approximately twenty vehicles with dual tires. The 1.1 factor was not acceptable; the larger factors were acceptable but not optimal.

A different method with diagonal beams has been used to distinguish between single and dual tires. Two beams at a 45-degree angle to the center line and 23 inches apart may be used to calculate speed and axle spacing in the manner previously described. Single tires interrupt only one beam at a time, while dual tires interrupt both beams simultaneously. In field tests performed on the Turner Turnpike outside Oklahoma City, the 23-inch distance was found to be critical. For closer spacings, some single tires broke both beams at once, and, for larger spacings, some dual tires broke the beams one at a time. At the 23-inch distance, only a few small dual tires, i.e., pickup-truck dual tires, were identified incorrectly. Approximately twenty large trucks and five pickup trucks with dual tires were visually observed and compared with the output for each distance tested. If this method were to be combined with the diagonal dimension method, then almost all vehicles should be classified correctly except motorcycles.

SUMMARY

Infrared sensors can be mounted in overhead, roadside, or pavement-level arrangements. In the overhead and roadside arrangements, vehicle bodies are detected, and vehicle speed, length, and headway can be measured. In the pavement-level arrangement, vehicle tires are detected, and vehicles can be classified according to the number of axles per vehicle, the axle spacings, and the sizes of the tire-contact areas. The infrared-light beams can be perpendicular or diagonal to the lane edge. Diagonal beams are used to measure tire-contact-area dimensions and the lateral position of tires. A presence sensor, usually an inductance-loop detector, is required to match tires with the correct vehicles. The next chapter discusses how infrared sensors in these arrangements can be applied for counting, classifying, and weighing vehicles.

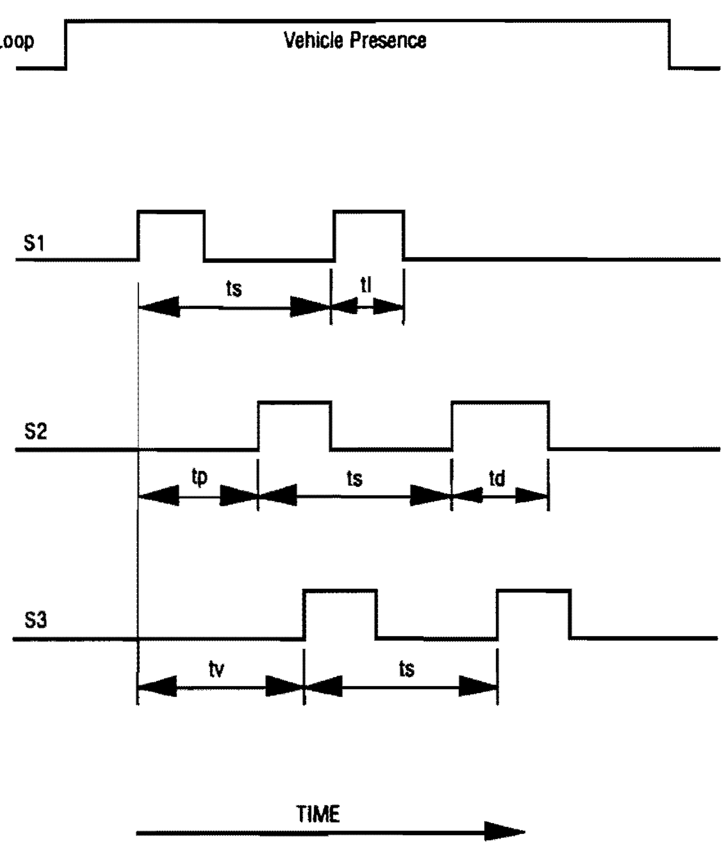


Fig 4.3. Signal relations.

CHAPTER 5. APPLICATIONS

Infrared sensors can be used for traffic counts, over-height detection, speed surveys, and vehicle classification. They can also aid weigh-in-motion measurements by giving the lateral position of tires with respect to tire-force transducers. The reflex-sensing mode can be used in all cases. In the direct-sensing mode, the sensor may be mounted in the roadside position if the receiver is mounted on the opposite side of the lane(s). The diffuse-sensing mode is not currently considered to be suitable for sensing vehicles. Infrared-light sensors have distinct advantages, but visible-light sensors can also be used.

VEHICLE PRESENCE

The presence signal required for matching tire signals to the correct vehicles can be given by a pair of infrared sensors mounted overhead or on the roadside. The first presence sensor should be located upstream from the tire sensors, and the second presence sensor should be downstream. The output signals of the two presence sensors should be connected with a logical AND. Infrared sensors mounted on the pavement surface at the lane edge have been used in a bridge research study to detect approaching vehicles and indicate the lane of operation in advance of the instrumented bridge (Ref 8). Tape switches had been used earlier but required closing lanes and re-taping after rain. The lenses of the infrared sensors and retroreflectors can be wiped clean without closing lanes.

COUNTING

Only one infrared sensor is necessary for counting vehicles or tires, though an array of sensors may be desirable. Overhead or roadside-mounted sensors may be used instead of inductance-loop detectors to count vehicle bodies. Infrared sensors mounted at the pavement level may be used instead of pneumatic road tubes or piezo cables to count tires or axles.

DIRECTION

The direction of a vehicle can be determined when two infrared sensors are used. Roadside or overhead mounting is recommended, but pavement-level mounting may also be used. When a vehicle breaks the beams in the wrong order, a warning of wrong-way travel may be given to the driver. This application may also be used for directional traffic counts on lightly-traveled, two-way roads.

VEHICLE HEIGHT

Infrared sensors mounted on the roadside may measure the height of vehicles or at least give the range of height. Two or more sensors should be mounted at different heights depending on the level of reliability desired. Infrared sensors can warn drivers of over-height vehicles that they are approaching a low-clearance bridge or tunnel. This system has been used in Mississippi and other states (Ref 9). The direct-sensing mode should be used because it has greater reliability than reflex sensing. An application that is being considered is detecting trucks on a ramp and warning the drivers if they are going too fast and might be at risk of overturning.

SPEED

Two infrared sensors are necessary for measuring speed. Speed is equal to the distance between sensors divided by the time between successive beam interruption. Sensors mounted overhead or on the roadside measure vehicle speed, while pavement-level sensors measure axle speeds which can be averaged for the vehicle speed.

CLASSIFICATION

Classification can be done in a number of ways depending on the desired classification scheme. One pavement-level infrared sensor and a presence sensor can be used to count the number of axles per vehicle. Two pavement-level sensors measure the axle spacing and indicate whether axles have single, tandem, or triple spacing. If an indication of dual or single tires is desired, the infrared beams can be aimed diagonally across the lane rather than perpendicularly. Alternatively, the first two beams may be perpendicular and a third beam diagonal. If overall vehicle length is desired, an additional sensor should be mounted on the roadside or overhead to detect the presence of the vehicle body. If vehicle height is desired, an array of sensors should be mounted at different heights along the roadside. Any of these arrangements can be used to distinguish between passenger cars and trucks.

WEIGHING

Tire-contact area multiplied by tire inflation pressure is an approximation of the downward force or weight of a tire if the pressure is uniformly distributed. Many other factors such as pavement roughness, speed, and suspension systems affect the dynamic tire force. Pavement-level infrared sensors can measure tire-contact lengths and calculate widths of tires on a moving vehicle. Field evaluations showed that tire-contact lengths measured by infrared sensors compared favorably with those measured statically, but widths did not (see Chapter 6). Tire-contact areas and, consequently, weight can be estimated only roughly by infrared sensor measurements.

Lateral position of tires from the edge of the pavement can be measured with infrared sensors. This information can be used to detect tires passing off the edge of WIM transducers. Lateral position measurements can also be used to estimate the percentage of loads running on or near the pavement edge.

SUMMARY

Infrared sensors can be used in several transportation engineering applications. Single sensors may be used to count vehicle bodies or axles. Other applications require an array of two or more sensors. Infrared sensors can detect wrong-direction or over-height vehicles. They can be used to classify vehicles according to number of axles per vehicle, axle-spacing pattern, and single or dual tire configuration. Infrared sensors can measure tire-contact-area dimensions and lateral position of tires in the traffic lane. These measurements can be used to supplement information from weigh-in-motion systems. The following chapter discusses field evaluations of several infrared-sensor arrangements and applications.

CHAPTER 6. FIELD EVALUATIONS

Five major field tests of infrared sensors were performed between 1988 and 1990. The objectives were (1) to determine the feasibility of improving or replacing current vehicle counting and classifying systems and (2) to explore the possibility of determining vehicle weight using infrared sensors. In San Marcos, Texas, in September 1988, tire-contact-area dimensions were measured manually and compared to infrared-sensor measurements of tires on moving vehicles. In December 1989, near Junction, Texas, tires were measured by infrared sensors and weighed simultaneously with WIM transducers. In May 1990, in Houston, a two-beam infrared-sensor array was field tested as a possible substitute for loop detectors. Sensors were installed at Jarrell, Texas, during the summer of 1990 to test their long-term performance. In August 1990, in Oklahoma City, the possibility of using two diagonal light-beam sensors to indicate single or dual tires and classify vehicles was tested. All field tests were performed on interstate highways. Except for the HOV lane in Houston, all tests were in rural or semi-rural areas.

EQUIPMENT AND SOFTWARE

The two brands of sensors used in the research described herein were manufactured by Banner and Opcon (Refs 1 and 2). Some sensor housings were manufactured by Rainhart Co., 604 Williams Street, Austin, TX 78752, and others were fabricated at The University of Texas at Austin. The retroreflectors were manufactured by Stimsonite and 3M. In the field tests, a portable or convertible IBM computer was used. Motorola donated several evaluation boards and microprocessors that were used to collect the raw data, make time lists, and communicate with the computer. A research engineer on the staff of the Center for Transportation Research, The University of Texas at Austin, wrote all the software and developed support hardware for the microprocessor.

TIRE-CONTACT AREA

A field study of tire-contact areas was conducted on Interstate 35 near San Marcos, Texas, in September 1988. Infrared sensors measured speed, axle spacings, tire-contact lengths, and diagonal dimensions of tire-contact areas while vehicles were in motion. Vehicles were then stopped by Department of Public Safety personnel. The length and width of the tire-contact area was measured manually by calipers built on a meter stick, and axle spacings were tape measured. For the in-motion measurements, infrared sensors were set at the edge of the shoulder and aimed at retroreflectors in the middle of the adjacent lane. Two infrared beams perpendicular to the lane edge measured vehicle speed and tire-contact length, while a diagonal beam measured a projection of the diagonal dimension of the tire-contact area, as shown in Fig 6.1. Assuming a rectangular shape for the tire-contact area, the length and projected diagonal dimension were calculated by multiplying vehicle speed by the time of beam interruption for each tire. Width was computed by subtracting the length from the projected diagonal dimension, then dividing this remainder by the tangent of the angle between the diagonal and perpendicular beams. Static tire-contact lengths and widths were measured directly with the special calipers.

The axle spacings measured by infrared sensors and tape corresponded closely, which implied that speed calculations were accurate. The lengths and widths of the tire-contact areas are shown graphically in Figs 6.2 and 6.3 and are summarized in Table 6.1. If there were perfect agreement between the two sets of measurements shown in the figures, all data points would fall on the 45-degree line. The length values agree more closely than the width values. The widths measured manually are closely spaced around 21 inches, while the widths measured in motion are more widely dispersed around 19 inches. The tire-contact area for moving vehicle tires changes and is not the same as the static tire-contact area. Neither the dynamic nor the static tire-contact patch has a rectangular area, as is assumed for the in-motion width calculation. For dual tires, the width of the tire-contact area includes the gap between tires and is greater than the tire-contact length.

One reason for doing this test was to determine a correction factor for the gaps between dual tires, which could not be measured by infrared sensors. Gap size depends on tire size, construction, materials, and inflation pressure; vehicle design; and other factors. Because of

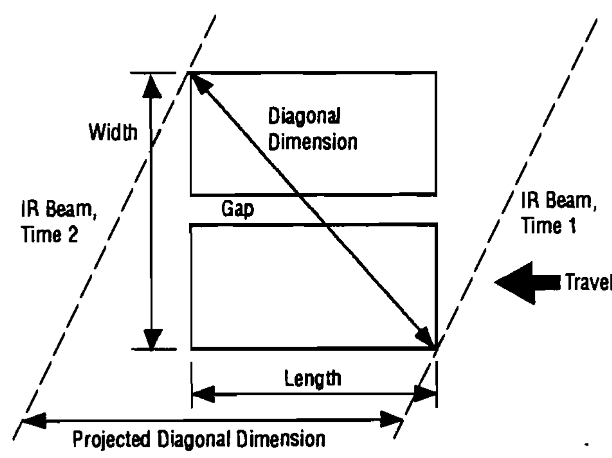


Fig 6.1. Tire-contact-area dimensions.

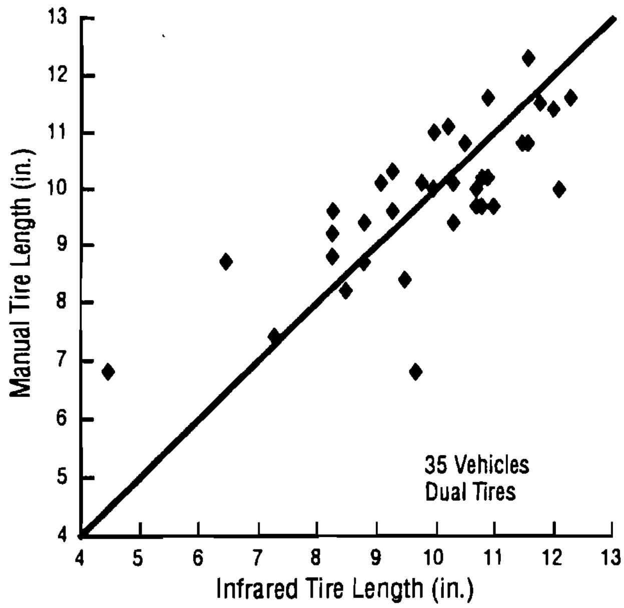


Fig 6.2. Comparison of tire-contact lengths.

TABLE 6.1. COMPARISON OF TIRE-CONTACT LENGTH AND WIDTH MEASURED MANUALLY BY TAPE AND BY INFRARED

	All Dual Tires Dimensions (in.)			
	Length IR	Length Manual	Width IR	Width Manual
Number	35 Tires		29 Tires	
Min	4.5	6.7	16.19	20.08
Max	12.3	12.2	21.97	22.13
Mean	9.9	9.7	19.37	21.18
Std Dev	1.7	1.3	1.63	0.42

Tire-contact width includes gap between dual tires.

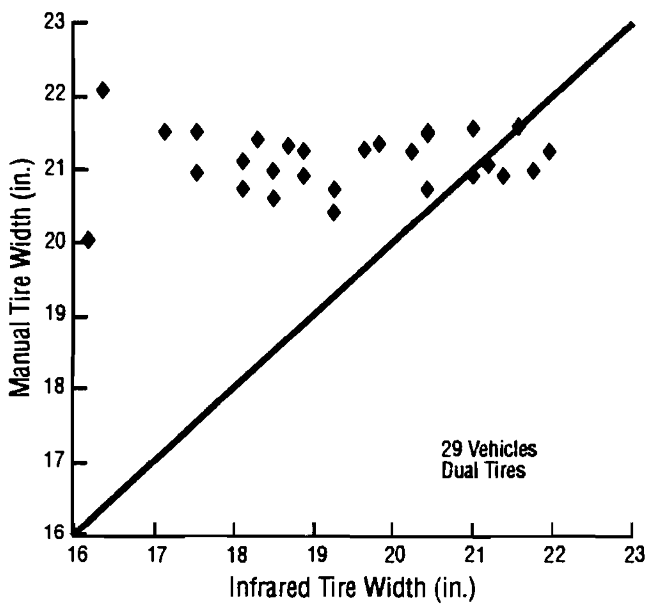


Fig 6.3. Comparison of tire-contact widths.

the rather large amount of scatter in the data, a suitable correction factor could not be determined from the available information.

WEIGHT

In December 1989, a three-sensor, pavement-level sensor array was field tested on Interstate 10 at Junction, Texas. The objective of this test was to determine the possibility of estimating weight from measurements of in-motion tire-contact-area dimensions. The sensors were installed on the edge of the lane, and the beams passed just above a flush-mounted Radian WIM transducer in the right-side wheel path so that tire-contact length and projected diagonal dimension could be measured as each right-side tire was being weighed. Both systems shared a loop detector to sense vehicle presence but computed vehicle speed and axle spacing independently. The infrared-light-beam system also calculated the tire-contact length, projected diagonal dimension of the tire-contact area, and the lateral position of the tire with respect to the edge of the pavement. All calculations were done on-site with a portable microcomputer. Both the infrared sensors and retroreflectors were smaller and closer together than those used in the test at San Marcos. The retroreflectors were 3/4-inch-diameter rather than 4-inch-long raised pavement markers as were used before. The infrared sensors were placed on the lane edge rather than off the shoulder. The new sensors had a range of about 20 feet rather than 50 feet. This arrangement reduced the size of the effective beam and thus enhanced the measurement accuracy of tire-contact dimensions.

SPEED, AXLE SPACING, AND LATERAL POSITION

Figures 6.4 and 6.5 compare the speed and axle spacing for infrared sensors and WIM, while Table 6.2 summarizes this information. In this test, speeds measured by infrared sensors were slightly higher than speeds measured by WIM, as shown by the data points above the 45-degree line in Fig 6.4. The speed measurements for the WIM system were made with two 6-foot-by-6-foot loop detectors separated by an 8-foot space. These two loops were not calibrated perfectly, and their response times were inherently affected by the different heights of the vehicles above the road surface. The axle spacings from the two measuring techniques show close agreement, but the effect of higher speed, computed from the infrared sensors, makes the corresponding axle spacings lie above the 45-degree line in Fig 6.5. The speeds calculated from the infrared-sensor measurements are probably more reliable than those from the loop detectors.

The lateral position of tires from the lane edge were measured by the diagonal infrared beam. This measurement determined whether vehicle tires were fully supported by the WIM transducer. Measurements resulting from all off-transducer vehicles were excluded from this analysis. A summary of field measurements is shown at the bottom of Table 6.2.

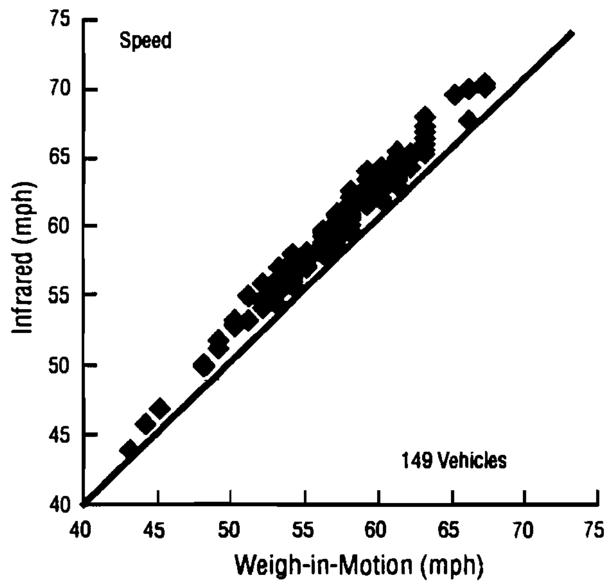


Fig 6.4. Comparison of speed.

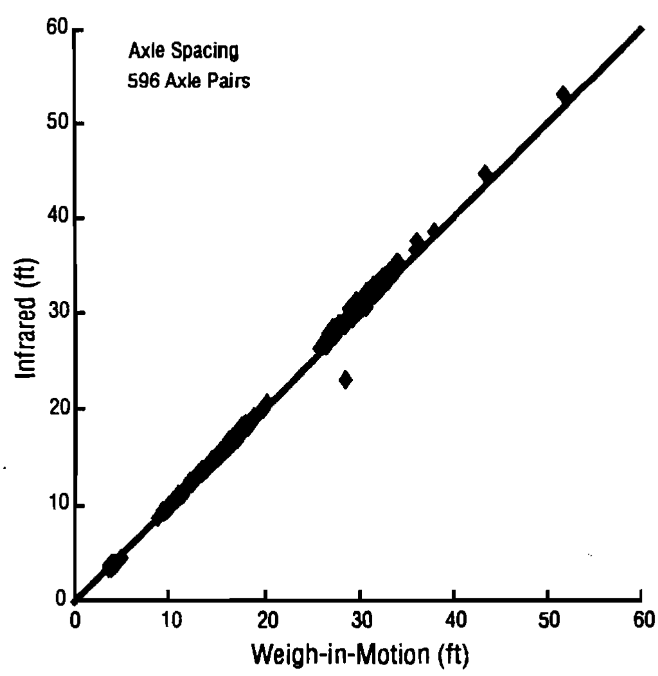


Fig 6.5. Comparison of axle spacing.

Figures 6.6 through 6.15 present tire-contact-area dimensions of various tires, or sets of tires, versus weight. All dimensions and weights are for the right-side tires. Tire-contact lengths, projected diagonal dimensions of tire-contact area, and weights are summarized in Table 6.3.

FRONT AXLE

Figure 6.6 presents tire-contact length versus weight for front axles. A least-squares regression line of these data points is shown, assuming that weight is the independent variable. Dynamic measurement of tire-contact length is probably accurate to within about ± 1 inch, slightly more than the standard deviation for the front axle, 0.8 inches. The regression line is valid only for observed tire-contact lengths from about 16 to 18 inches, while weights ranged from about 2,500 to 5,500 pounds. Therefore it is not feasible to estimate weight adequately from dynamic measurement of tire-contact length. The standard deviation of tire-contact length for the front axle is smaller than that for the other axles, but tire-contact length is a poor estimator of weight.

Projected diagonal dimension versus weight for front axles is shown in Fig 6.7. A least-squares regression line is shown, assuming that weight is the independent variable. The regression line is valid only for projected diagonal dimensions between 17and 20 inches, while weights ranged between 2,500 and 5,500 pounds. The standard deviation, 2.6 inches, is greater than the expected accuracy, about 1 inch; therefore, it is not appropriate to use the projected diagonal dimension of the tire-contact area to estimate weight. Evaluation of the data shown in these two figures indicates that wheel weights cannot be estimated from the tire-contact lengths nor projected from diagonal dimensions with acceptable accuracy.

The front-axle tires had longer contact lengths than the tandem-axle (dual) tires. As expected for single tires, the projected diagonal dimensions of the front-axle tires were considerably shorter than those of the tandem-axle tires, which were all dual. Some of the front-axle tires, in fact, had measured in-motion lengths longer than their projected diagonal dimensions. The technique described in the previous section for calculating tire-contact width yielded negative values for tire-contact widths in these cases. The dual tires all had measured in-motion lengths less than the corresponding projected diagonal dimensions. Analysis of the field data indicated that the calculated tire-contact width for tires on tandem axles was not correlated strongly enough with weight to serve as as an adequate weight-estimation basis.

TABLE 6.2. AXLE SPACING, SPEED, AND LATERAL POSITION

Measurements at Junction, Texas

Infrared Sensors vs Weigh-in-Motion

Axle Spacing Dimensions (ft)

	IR				WIM			
	IR12	IR23	IR34	IR45	WIM12	WIM23	WIM34	WIM45
Min	9.13	4.11	23.39	3.89	8.80	3.90	25.70	3.60
Max	21.03	4.90	53.39	4.17	20.20	4.90	51.70	4.10
Mean	15.10	4.31	31.35	4.02	14.57	4.18	30.31	3.90
Std Dev	2.94	0.07	3.25	0.06	2.83	0.11	3.11	0.09

IR12 and WIM12 represent the spacing between the first and second axle, etc.

Speed (mph)

	IR	WIM
Min	43.79	43.00
Max	70.24	67.00
Mean	60.18	57.38
Std Dev	4.70	4.39

Lateral Position (in.)

Min	26.12
Max	38.22
Mean	30.34
Std Dev	3.21

Theoretically, the diagonal dimension and projected diagonal dimension cannot be less than the tire-contact length or width. A circular tire-contact area, for which all these dimensions are equal, represents the limiting case. Some of the single tires on front axles were measured with lengths and projected diagonal dimensions close to the same value. Inconsistencies in the in-motion measurements are due in part to the dynamic behavior of the vehicle and the tires during the time of sensing. The location and cross-section of the rolling tire changes between the time the length is measured and the time when the projected diagonal dimension is measured. The elevation of the tire may also change slightly, i.e., the tire may ride into a depression or bounce off the pavement, causing a different cross-section to be measured. If the height above the pavement of the two infrared beams is slightly different at the two measuring locations, different tire cross-sections are sensed.

TANDEM AXLES

Plots of tire-contact area dimension versus weight for the front axle of the drive-tandem set are shown in Figs 6.8 through 6.12, along with least-squares regression lines. Figure 6.8 shows the tire-contact length versus weight, while Fig 6.9 shows the projected diagonal dimension versus weight. For the tire-contact length versus weight regression line, the correlation coefficient is 0.67, while for the projected diagonal dimension versus weight regression line, the correlation coefficient is 0.70. There is some linear correlation, but it is not sufficient to

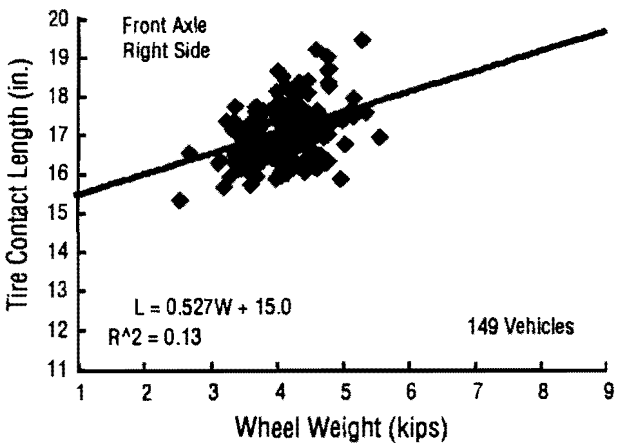


Fig 6.6. Tire-contact length versus weight for front axle.

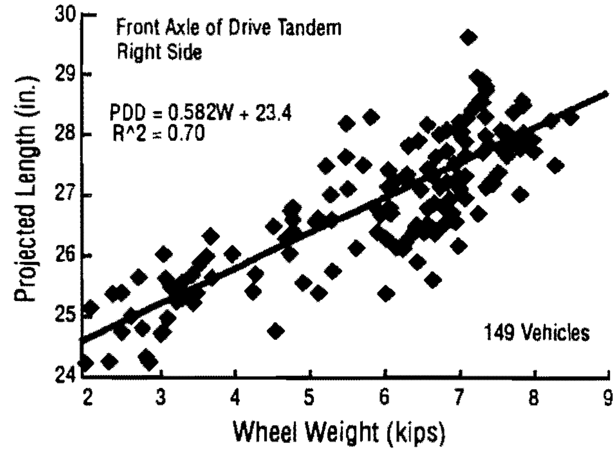


Fig 6.9. Projected diagonal dimension of tire-contact areas versus weight for front axle of drive tandem.

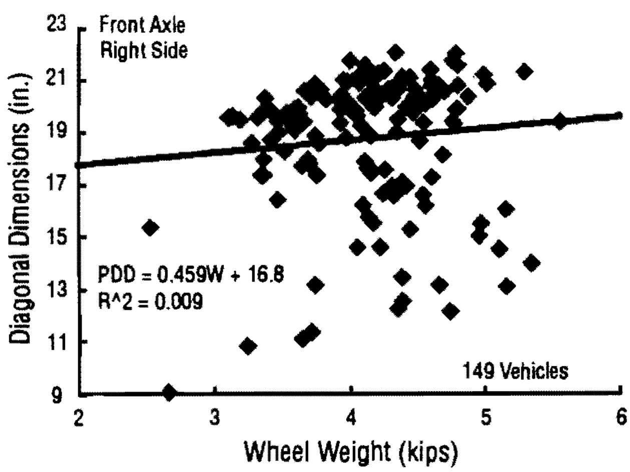


Fig 6.7. Projected diagonal dimension of tire-contact areas versus weight for front axle.

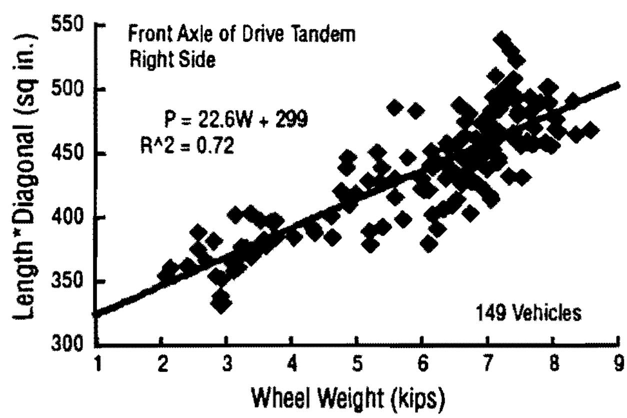


Fig 6.10. Product of tire-contact length and projected diagonal dimension versus weight for front axle of drive tandem.

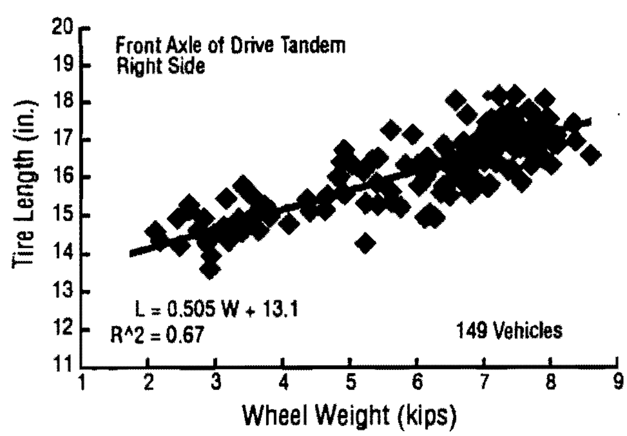


Fig 6.8. Tire-contact length versus weight for front axle of drive tandem.

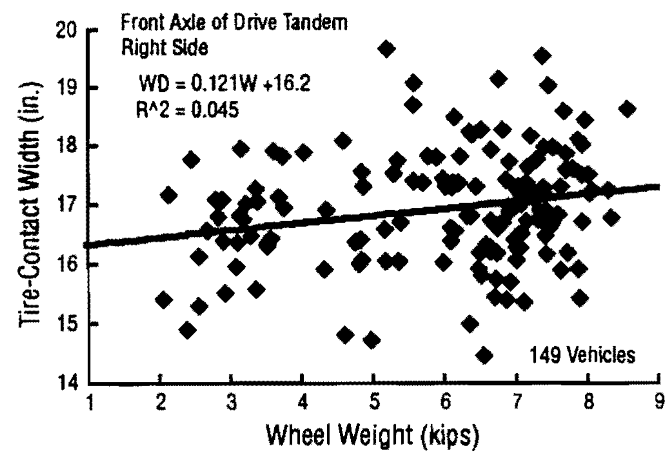


Fig 6.11. Tire-contact width versus weight for front axle of drive tandem.

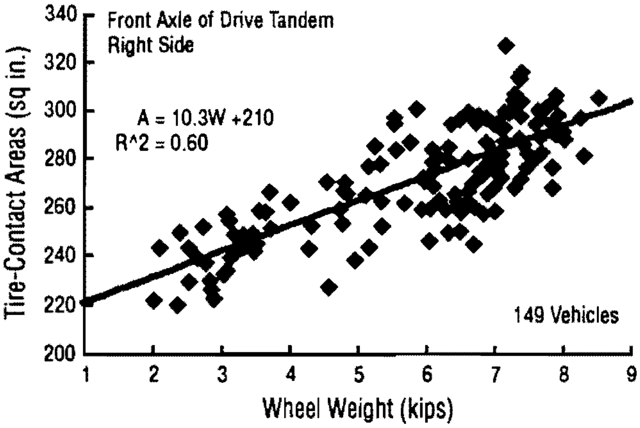


Fig 6.12. Tire-contact area versus weight for front axle of drive tandem.

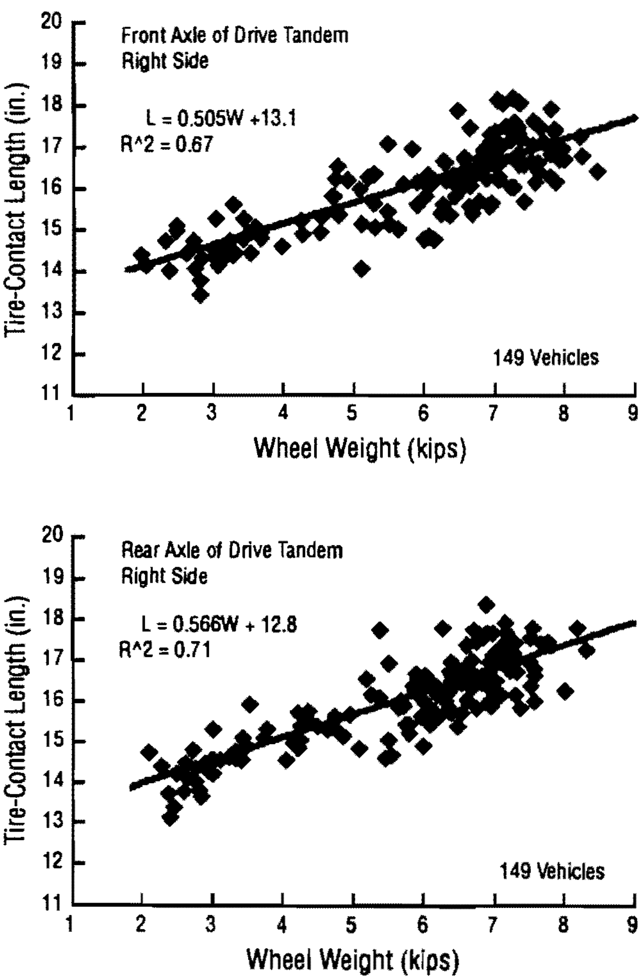


Fig 6.13. Tire-contact length versus weight for both axles of drive tandem.

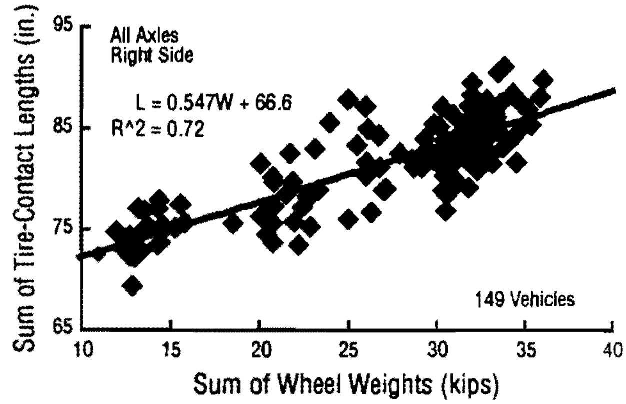


Fig 6.14. Sum of tire-contact lengths versus sum of weights for all axles.

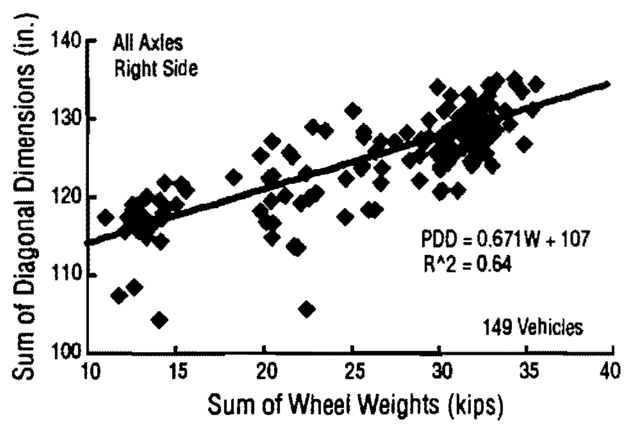


Fig 6.15. Sum of projected diagonal dimensions of tire-contact areas versus sum of weights for all axles.

TABLE 6.3. SUMMARY OF TIRE-CONTACT AREA AND WEIGHT

149 Five-Axle Semi-Trailer Trucks Right Side Only								
Tire Length (In.)	**Axle 1**	**Axle 2**	**Axle 3**	**Axle 4**	**Axle 5**	**Tan-dem 1**	**Tan-dem 1**	**All Axles**
Minimum	15.40	13.47	13.15	12.84	11.96	26.62	25.06	69.15
Maximum	19.48	18.20	18.39	18.46	19.26	36.00	37.26	90.88
Mean	17.15	16.07	15.96	15.82	15.99	32.03	31.81	80.99
Std Dev	0.76	1.05	1.10	1.30	1.29	2.10	2.51	4.79
Projected Diagonal Dimension (in.)								
Minimum	9.03	24.26	23.97	20.73	20.73	48.24	41.47	104.64
Maximum	22.03	29.65	29.33	29.13	28.90	57.51	56.99	135.08
Mean	18.73	26.88	26.81	26.23	26.23	53.68	52.46	124.88
Std Dev	2.63	1.18	1.12	1.63	1.61	2.23	3.18	6.21
Weight (lb)								
Minimum	2,528	2,008	2,128	1,288	1,296	4,136	2,680	10,984
Maximum	5,544	8,504	8,344	9,424	9,936	16,464	17,560	35,848
Mean	4,145	5,903	5,639	5,229	5,380	11,542	10,608	26,295
Std Dev	527	1,698	1,640	2,123	2,087	3,292	4,133	7,423

estimate weight from infrared-sensor measurements with reasonable accuracy.

In an attempt to explore other possible weight-estimation techniques from infrared-sensor measurements, the plots shown in Figs 6.10, 6.11, and 6.12 were generated. Figure 6.10 presents the *product* of tire-contact length and projected diagonal dimension versus weight. The correlation coefficient for the product is 0.72, only slightly higher than the values of 0.67 and 0.70 for the two factors taken individually. Figure 6.11 presents the tire-contact *width* versus weight. The tire-contact width was calculated by subtracting the tire-contact length from the diagonal dimension and dividing by the tangent of the angle between the perpendicular and the diagonal infrared beams. This calculation assumes a rectangular tire-contact patch. This assumption is perhaps more appropriate for dual tires than for single tires, since all the calculated widths were positive for dual tires. With the poor correlation obtained, calculated tire-contact width cannot be used to estimate weight satisfactorily. Figure 6.12 presents the calculated tire-contact *area*, i.e., the product of tire-contact length and width, versus weight. The linear correlation is again poor. None of the dependent variables described here can be used to estimate weight with reasonable accuracy.

The tandem axles were found to be similar to each other when tire-contact lengths and projected diagonal dimensions were compared, as can be seen from the values in Table 6.3. The tire-contact length for the drive tandem had standard deviation values of 1.05 and 1.10 inches, while the trailer tandem had standard deviation values of 1.30 and 1.29 inches. The projected diagonal dimension for the drive tandem had standard deviation values of 1.18 and 1.12 inches, while the trailer tandem had values of 1.63 and 1.61. The mean values of tire-contact length for both tandem axles were very close, between 15.82 and 16.07 inches. The mean values of projected diagonal dimension for each tandem were very close, 26.88 and 26.81 inches for the drive tandem, and 26.23 inches for both axles of the trailer tandem.

Figure 6.13 compares the regression lines of tire-contact length versus weight for the front and rear axles of the drive tandem. The lines are very similar, with slopes at 0.505 and 0.566 and the intercepts at 13.1 and 12.8. Since the axles have a common suspension point, it is expected that the weights will be similar. The data taken in this field test show that the tire-contact area dimensions are also similar.

ALL AXLES

In Figs 6.14 and 6.15, the dimensions of all the tires on each vehicle are summed. The least-squares regression lines and correlation coefficients are also shown. Figure 6.14 presents the sum of all the tire-contact lengths versus the sum of all the weights. Figure 6.15 presents the sum of the projected diagonal dimensions

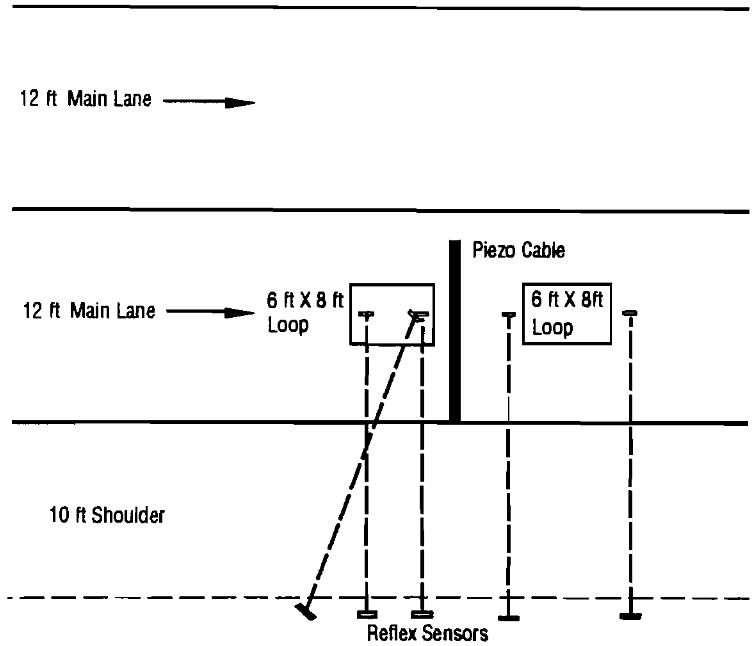


Fig 6.16. Sensor arrangement at Jarrell.

versus the sum of the weights. The correlation coefficients are 0.64 for tire-contact length versus weight and 0.72 for projected diagonal dimension versus weight. It might be possible to indicate whether trucks are empty or loaded, but the accuracy is insufficient to warrant any further study at this time. Accurate estimation of weight is not feasible.

SUMMARY

The tire-contact-area dimensions of the front axle are very poorly correlated with the weight. The tire-contact lengths and projected diagonal dimensions have similar values, indicating that the tire-contact patch for single tires is close to circular. Many of the front tires had lengths longer than the projected diagonal dimension, partially due to dynamic forces acting on the tire. A rectangular tire-contact patch is assumed for the tire-contact width calculation. This assumption is not valid, especially for the front tires. Values calculated for width are not correlated with weight.

On the plots for tire-contact length and projected diagonal dimension versus weight for the tandem axles, there are two definite clusters of data points representing the empty and loaded trucks. However, the accuracy is not adequate even for estimating weight to within 10,000 pounds. Closer estimates of weight do not seem to be possible at this time. More information is needed than can be sensed by infrared sensors, i.e., tire pressures and shapes of the tire-contact patches. If remote tire-pressure-sensing technology were developed, infrared sensors could be used to calculate the weight of vehicles quite accurately. For the present, infrared sensors are not recommended for calculating individual vehicle weights.

HOV LANES

A two-beam infrared-sensor array was field tested in a high-occupancy-vehicle (HOV) lane on Interstate 10 in Houston in May 1990. The two reflex-type infrared sensors were placed 2 feet apart in a special metal box on top of one concrete median barrier; the retroreflectors were placed on the nearly-vertical face of the other barrier 22 feet away. This system was tested as a possible substitute for an array of inductance-loop detectors that are currently used to determine vehicle speed, length, direction, and headway in the reverse-flow HOV lane. The system performed well for the first two weeks, until the lid on the metal box became ajar and road film accumulated on the lenses. It is felt that a sensor unit of this type will perform well over extended periods of time after a few minor modifications to the mounting hardware are made. Occasional cleaning of the lenses and retroreflectors may be necessary. Only minor modification of the currently-implemented computer software is required before a single pair of infrared sensors can be used to replace the existing array of three 6-foot-by-6-foot loop detectors.

ENDURANCE

Five infrared sensors were installed on Interstate 35 north of Jarrell, Texas, in June 1990 to test long-term performance. A piezo cable and two loop detectors were also installed, as shown in Fig 6.16. The infrared-sensor array consisted of a set of three sensors with the beams inside a loop and a set of two sensors placed upstream and downstream of another loop detector.

Prior to installing the sensors shown in the figure, a set of five low-profile sensors (not shown in the figure) was placed on the pavement surface at the edge of the lane. Cast-aluminum and epoxy housings were used to protect the miniature infrared sensors (approximately 1.5 X 2.0 X 0.5 inches). After about two weeks in summer temperatures, the sensors became nonfunctional because the beams were no longer high enough to crest the high point beside the wheel-path rut since they were depressed into the flexible pavement. Small, 1/2-inch-diameter retroreflectors, in a similar but smaller cast-aluminum housing, endured for about two months. A larger circular segment, sawn from a 1.5-inch-diameter retroreflector and housed in a special aluminum casting, was first used; but water migrated past the epoxy seal of the saw-cut and accumulated on the plastic reflecting surface, preventing retroreflection of the light beam.

A second set of five infrared sensors (approximately 2.0 X 2.0 X 4.0 inches) was placed on steel stakes driven into the ground a few inches off the shoulder edge. The locations of these sensors are shown in Fig 6.16. They performed well for over two months and could be easily aligned and adjusted without interrupting traffic. Metal cans over the plastic sensors kept off the rain and direct sunlight. After two or three days, the small retroreflectors in the center of the lane became covered with road film, and the system could not operate. After the retroreflectors were wiped clean during a traffic gap, the system resumed operation.

Larger retroreflectors, 4-inch-square reflectorized raised pavement markers, were used to replace the small circular retroreflectors, and under regular observation were found to perform reliably without cleaning for three weeks. Two "temporary" markers (placed with a liquid primer on the rubberized asphalt adhesive) were functional after more than three months, i.e., at the time of this writing. While the larger retroreflectors extended the endurance of the system, they also increased the effective size of the infrared-light beam and thereby reduced the accuracy of tire-contact-length measurements. Speed, counting, and classifying accuracy were not affected, however.

The infrared classification system was compared with a piezo-cable classification system. However, the two systems could not be directly compared, as the piezo

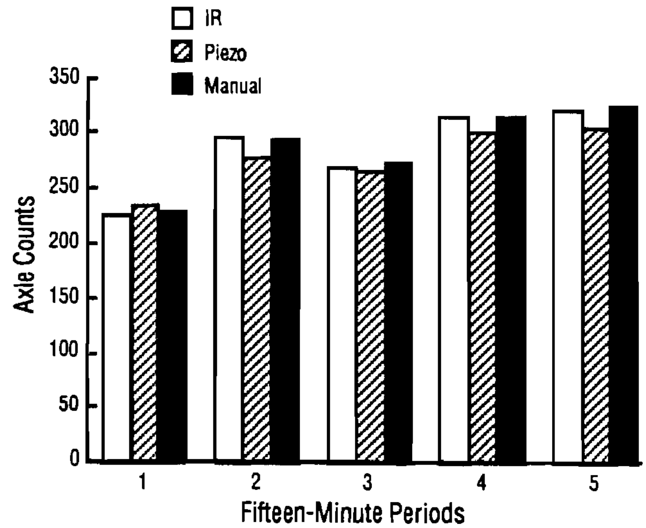


Fig 6.17. Comparison of infrared, piezo, and manual axle acounts.

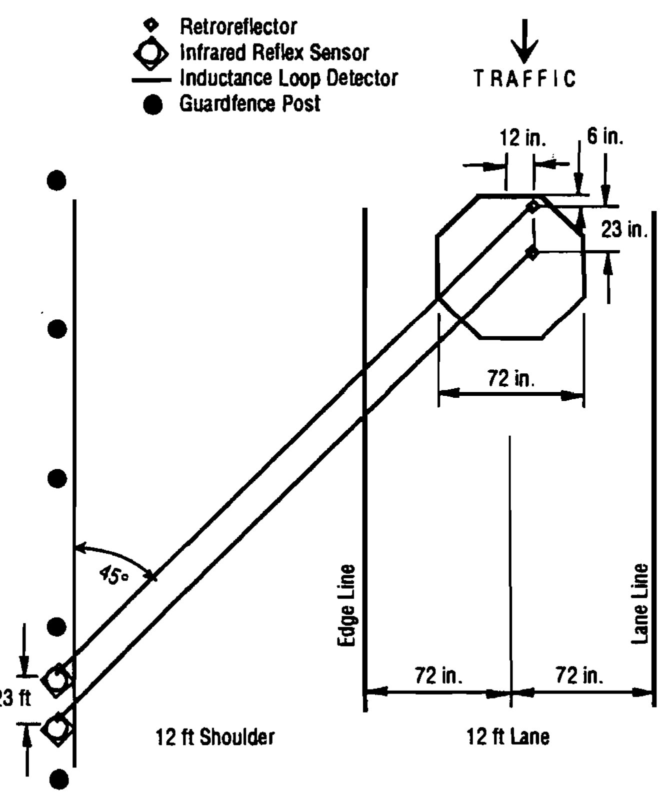


Fig 6.18. Sensor arrangement at Oklahoma City.

system required both loop detectors shown in Fig 6.16, and it was not possible for the loops to be used by both systems simultaneously. Figure 6.17 shows a comparison between axles counted by infrared sensors, piezo sensors, and by three human observers. The three human observers never agreed exactly, so an average count is shown in the figure. Except for period one, the infrared-sensor axle counts were greater than the piezo-sensor axle counts. Using the manual axle counts as a basis, the expected error for the piezo sensor was ten axles per 15 minutes, and for the infrared sensor, two axles per 15 minutes. This calculation is based on only five periods.

Infrared sensors can be used for long-term traffic surveys if proper precautions are taken to protect the sensors and retroreflectors from the environmental effects. Environmental effects include rain, road film, temperature extremes, and shock and vibration from vehicles.

SINGLE/DUAL TIRE IDENTIFICATION AND VEHICLE CLASSIFICATION

A system for classifying vehicles for auditing toll collection was tested on Interstate 44 (Turner Turnpike), in Oklahoma City, in August 1990. At the test site, about 500 yards downstream of a toll plaza, vehicles were traveling about 50 to 65 mph. The system included a loop detector and two diagonal beam sensors and retroreflectors, placed 23 inches apart, as shown in Fig 6.18.

Single tires interrupted the beams sequentially, while dual tires interrupted them simultaneously. It was found by field observation that a distance of 23 inches between infrared light beams was optimum. At a 22-inch distance, some large-diameter single tires were classified as dual; while at 24 inches, some small-diameter dual tires were classified as single. Generally, only the relatively small-diameter dual tires of pickup trucks were identified as single at the 23-inch distance. An initial value of 24 inches was established after measuring truck tires in a parking lot. In the field test, approximately twenty large trucks were observed visually and compared with the computer output based on 24 inches; several dual tires were misidentified. At the 22-inch distance, several single tires were misidentified. At the 23-inch distance, almost all vehicles were identified correctly for approximately one hundred observations.

This system, using two diagonal beams a fixed distance apart, was designed for use at toll gates where speed of vehicles would not be constant. The tire-contact length—diagonal dimension, three-beam system described in Chapter 4—could not be used since constant velocity is assumed. The system described here might be improved with a three-diagonal-beam array. Tires interrupting all three beams simultaneously would be classified as dual; tires interrupting the first two beams sequentially would be single; and vehicles interrupting the first two beams simultaneously would be single or dual depending on the classification of the other tires of that vehicle. This proposed system has not been tested. Under the Oklahoma Turnpike Authority Classification Schedule, axle spacing is not a criterion, so a classification system which does not assume constant velocity can possibly be used.

In the field tests, off-duty toll-booth operators recorded vehicle classifications based on visual observations. The operators were required to identify the vehicle class and press the appropriate computer key before the vehicles activated the loop detector. The operator and infrared-system classification errors are summarized in Table 6.4 (Ref 10). The operators were 94.7 percent successful, while the infrared system was 96.3 percent successful. Many of the operator errors were due to vehicles' following too closely, which made the time available for pressing the computer key too short. The system errors could be reduced by using a three-sensor array, as described above, which could classify small dual tires correctly.

TABLE 6.4. VEHICLE CLASSIFICATION ERRORS ON OKLAHOMA TURNPIKE

Date of Test	No. of Vehicles	Operator Errors		System Errors	
21 AUG 1990	120	6	5.0%	3	2.5%
1 SEP 1990	500	23	4.6%	11	2.2%
8 SEP 1990	502	37	7.4%	29	5.8%
14 SEP 1990	351	13	3.7%	10	2.8%
14 SEP 1990	260	12	4.6%	11	4.2%
Total	1733	91	5.3%	64	3.7%

SUMMARY

Five field tests of infrared sensors were performed. The objective of the first two tests was to determine the possibility of weighing vehicles with infrared sensors. The objective of the other three tests was to determine the feasibility of improving or replacing current vehicle classification systems with infrared-sensor systems. In the tire-contact-area study performed at San Marcos, Texas, it was determined that the tire-contact length but not the width could be calculated with reasonable accuracy from infrared measurements of vehicles moving at high speeds. In the test at Junction, Texas, it was determined that infrared sensors could estimate only roughly the dynamic weight of vehicles by measuring the tire-contact area. The lateral position of tires was also measured. In these two tests it was demonstrated that infrared sensors could accurately measure vehicle speed and axle-spacing patterns.

In the HOV (high-occupancy-vehicle) lane test in Houston, it was shown that infrared sensors can replace inductance-loop detectors, which are currently used to measure vehicle speed, length, and headway. In the endurance test at Jarrell, Texas, it was shown that infrared sensors can function for several months with minimal or no maintenance. It was also demonstrated that axle counts by infrared sensors are at least as accurate as axle counts by piezo cables or human observers. In the turnpike test performed in Oklahoma City, it was demonstrated that infrared sensors can identify almost all single and dual tires. Vehicle classifications by the infrared-sensor system were as accurate as classifications by off-duty toll-booth operators.

The cost of a reflex-type infrared-sensor and retroreflector unit is approximately $100. A traffic lane closure is usually not required for installation of the unit. In comparison, a piezoelectric cable costs approximately $300, and installation requires closing a traffic lane and sawing a groove. The infrared sensors examined in this study were not tested to failure, so their life expectancy and long-term reliability are not known.

CHAPTER 7. CONCLUSIONS

Infrared sensors may be used in a variety of traffic studies. They can be installed to count and classify vehicles accurately without requiring pavement cuts or bumps as do loop detectors or road tubes. Classification criteria, which can be calculated with information obtained from infrared sensors, include number of axles per vehicle, axle-spacing pattern, and single or dual tires. Infrared sensor information can also be used to calculate overall length or height of the vehicle, speed, and headway. These data can supplement weigh-in-motion systems by identifying tires of vehicles not fully in contact with the force transducers.

The reflex-sensing mode is recommended for most traffic detection applications. The direct-sensing mode may be used for over-height detection and other applications where the transmitter and the receiver are mounted on opposite sides of the roadway. The diffuse-sensing mode is not recommended for traffic applications.

Either roadside or overhead arrangements may be used for sensing vehicle bodies, but the overhead arrangement must be used for sensing vehicles in lanes away from the roadside. To reduce miscounting resulting from gaps between vehicle units, sensors with a time delay may be used. For sensing vehicle height, an array of sensors at different heights should be used in the roadside arrangement. Pavement-level sensors should be used for sensing tires. The shoulder-edge location is recommended, especially for heavy traffic. The lane-edge location may be used for short-term applications of less than about three days' duration or when retroreflectors and lenses can be cleaned frequently.

Corner-cube retroreflectors are recommended for all applications. Spherical-bead retroreflectors should not be used if polarizing filters are used with the sensors.

Five major field tests were carried out to determine the feasibility of using infrared sensors for counting, classifying, and weighing vehicles. A tire-contact-area study was performed at San Marcos, Texas. In-motion tire-contact area was calculated from infrared-sensor measurements and compared with static measurements taken manually. Static and dynamic tire-contact lengths showed good agreement, but because the tire-contact patch is not rectangular and constantly changes, the in-motion tire-contact widths did not agree very well.

Another study was performed at Junction, Texas, to determine the feasibility of using infrared sensors to weigh vehicles. Infrared sensors measured tire-contact dimensions and WIM transducers measured wheel weights simultaneously. It is not feasible to estimate weight from tire-contact dimensions measured in motion. Infrared sensors can be used to determine the lateral position of tires with respect to the WIM transducer, thus improving the performance of WIM systems.

A third field test was performed on an HOV lane in Houston to determine the feasibility of replacing an array of three inductance-loop detectors used for calculating vehicle speed, length, direction, and headway with an array of two infrared reflex sensors. With minor modifications of the sensor housings and the current computer software, infrared sensors can replace the loop detectors.

Five infrared sensors were installed near Jarrell, Texas, to test long-term performance. For applications longer than about a week, it is necessary to mount pavement-level sensors off the shoulder to protect them from the shock of heavy vehicles and the accumulation of road film. Small retroreflectors used on the pavement surface for measuring tire-contact dimensions accumulate road film and must be cleaned every two or three days. Larger retroreflectors or reflectorized raised pavement markers may be used for measuring speed, counting, and classifying.

The fifth test was performed on the Turner Turnpike in Oklahoma City, with the objective of identifying single and dual tires and classifying vehicles for auditing toll collection. Ninety-six percent of the vehicles were identified correctly with the array of two infrared sensors and a loop detector. The accuracy can be improved with an additional infrared sensor.

The cost of a reflex-type infrared sensor and retroreflector unit is about $100, and installation can be accomplished without pavement cuts, usually without traffic barricades. Thus, infrared sensors are accurate and economical alternatives to sensing devices currently used to count and classify vehicles. Infrared sensors can also be used with weigh-in-motion systems to sense off-transducer vehicles.

REFERENCES

1. Opcon Catalog of Photoelectric Controls, OPCON, 720 80th Street S.W., Everett, WA 98203, p 13-8, 1984.

2. Banner Engineering Product Catalog, Banner Engineering Corporation, 9714 10th Ave. No., Minneapolis, MN 55441, 1987.

3. *Photoelectric Sensors and Controls: Selection and Application*, Juds, Scott M., Marcel Dekker, Inc., New York, 1988.

4. Traffic Monitoring Guide, Federal Highway Administration, Office of Highway Planning, 1985.

5. Classification Schedule, Oklahoma Turnpike Authority.

6. *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, Washington, D. C., 1990.

7. Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Method, E 1318-90, American Society for Testing and Materials, Philadelphia, 1990.

8. Schulz, Jeff, University of Colorado, personal correspondence.

9. "Overheight Vehicle Warning Systems in Mississippi," Hanchey, Craig M., and Slade F. Exley, *ITE Journal*, June 1990, pp 24-29.

10. *Test of a System to Classify Vehicles for Toll Collection*, Gattis, J. L., and Clyde E. Lee, Report to Traffic Engineering Consultants, Inc., October 1990.

APPENDIX

Photographs and descriptions of the equipment and circuit diagrams of the systems used in the field evaluations are included in this appendix. Figure A.1 shows the metal box housing two Opcon infrared sensors which was placed on top of a concrete median barrier on one side of the Houston HOV lane. Figure A.2 shows from left to right a loop detector, two Opcon reflex-type sensors mounted on a tripod, a Motorola evaluation board, and an IBM computer. The M68HC11EVBU universal evaluation board manufactured by Motorola can be used to process and store the output signals of infrared sensors. The board is a single-chip microcontroller unit which can operate programs down-loaded from an RS-232C-compatible host computer. Space is provided on the board for custom interfacing. The primary power requirement is + 5.0 Vdc @50 mA.

Figure A.3 shows a StreeterAmet traffic counter (normally connected to a road tube) connected to an Opcon sensor. A retroreflector is also shown. Figure A.4 shows a cast-aluminum housing which can be mounted on the lane edge; a Banner sensor is shown both inside and next to the housing.

Figure A.5 shows an Opcon sensor mounted off the shoulder edge on a metal stake. Figure A.6 shows three different Banner sensors used in the field tests. At the top left is a sensor with a built-in counter with liquid-crystal display. The sensor at the top right was used in some preliminary tests. The sensor at the bottom was used at Junction inside the cast-aluminum housing.

Detailed descriptions of the infrared sensors, shown in Figs A.1 through A.6, appear in the following pages. Descriptions of the Opcon reflex sensor, the DC/NPN control modules, and the three Banner sensors pictured in Fig A.6 are included.

The OR gate circuit diagram used on the HOV lane in Houston is shown in Fig A.7. Figure A.8 shows the system layout for the three-sensor vehicle classification system used in the field tests at San Marcos, Junction, and Jarrell. Figure A.9 shows the system layout of the two-sensor vehicle classification system used in the Oklahoma City field test.

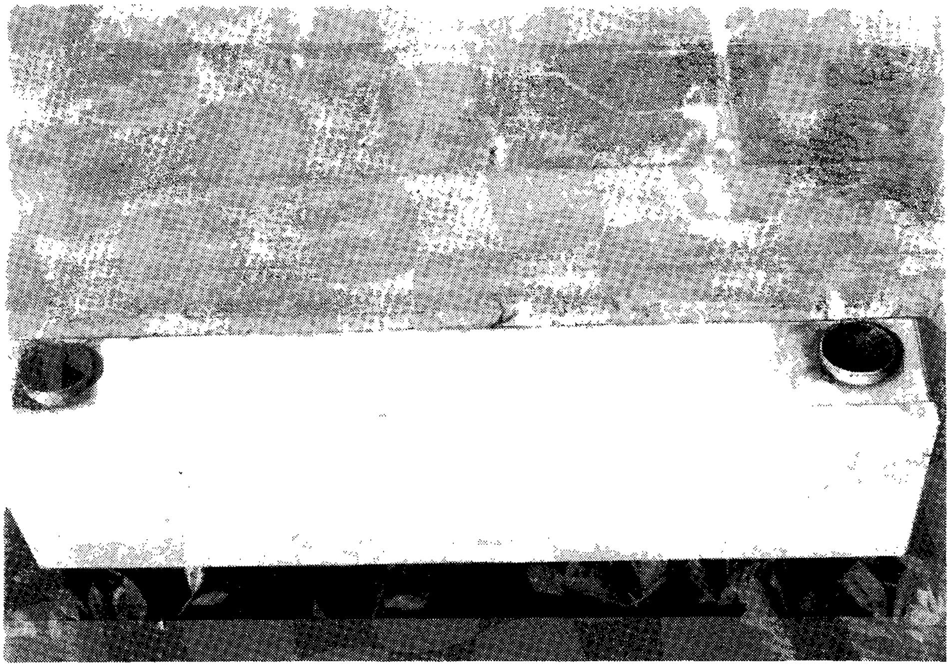


Fig A.1. Metal box housing two Opcon infrared sensors, HOV lane in Houston.

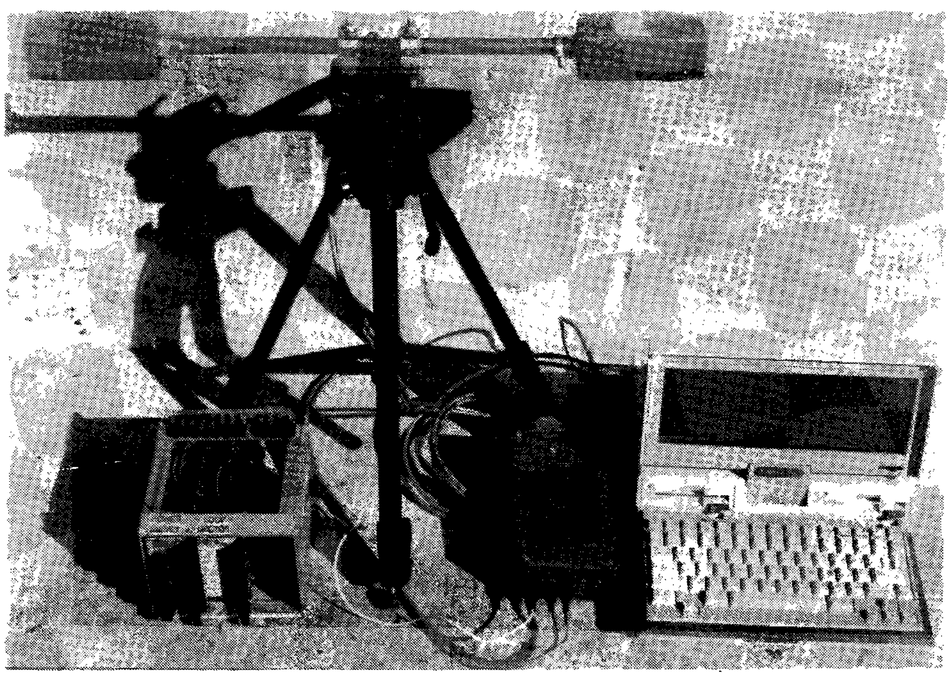


Fig A.2. Infrared sensors, loop detector, Motorola Evaluation Board, and IBM portable computer.

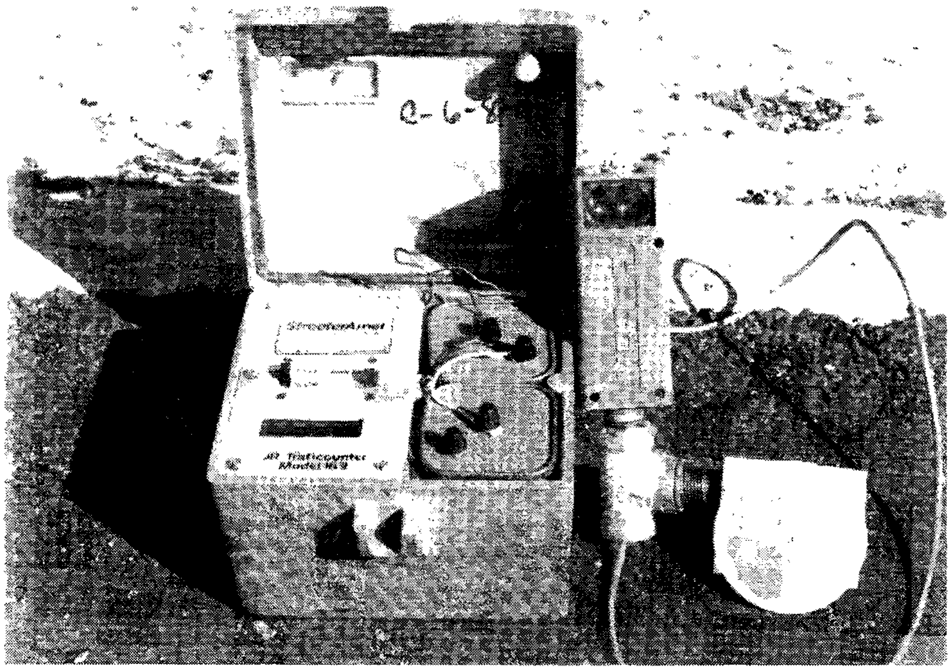


Fig A.3. Streeter Amet Counter using reflex infrared sensor.

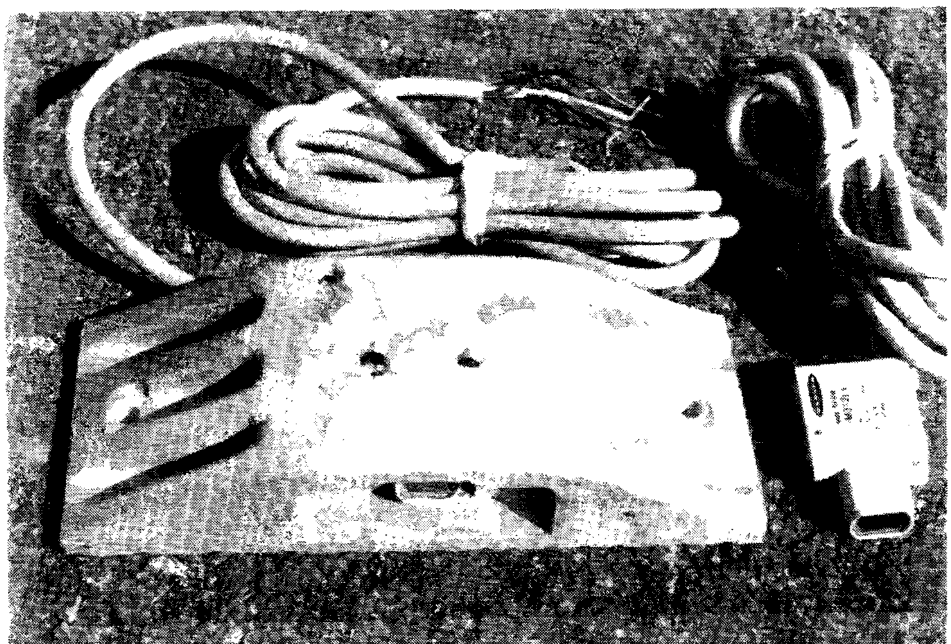


Fig A.4. Cast-aluminum housing for mounting miniature infrared sensor on lane line.

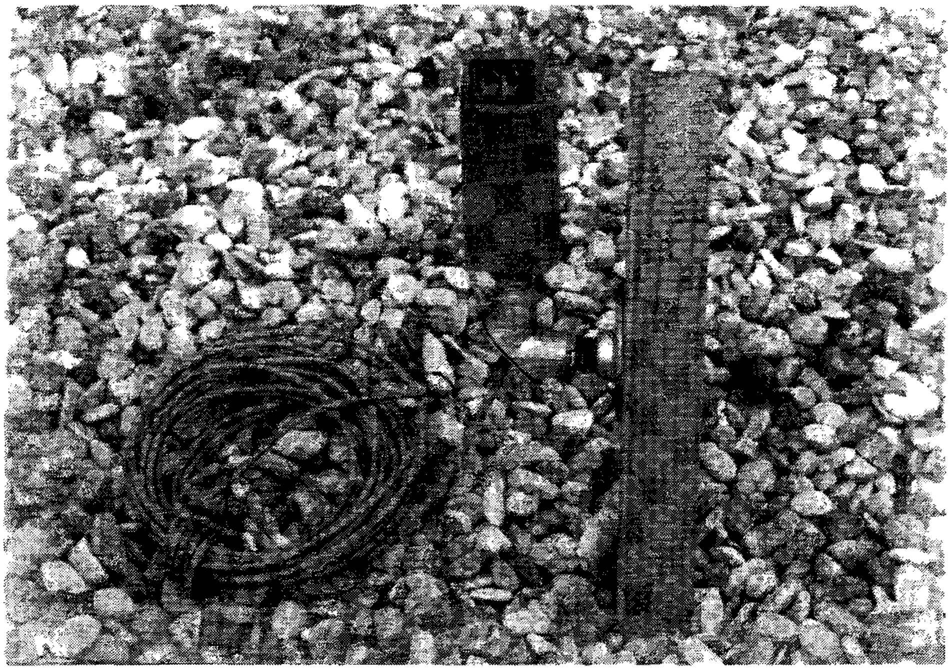


Fig A.5. Opcon reflex infrared sensor mounted on metal post off edge of shoulder.

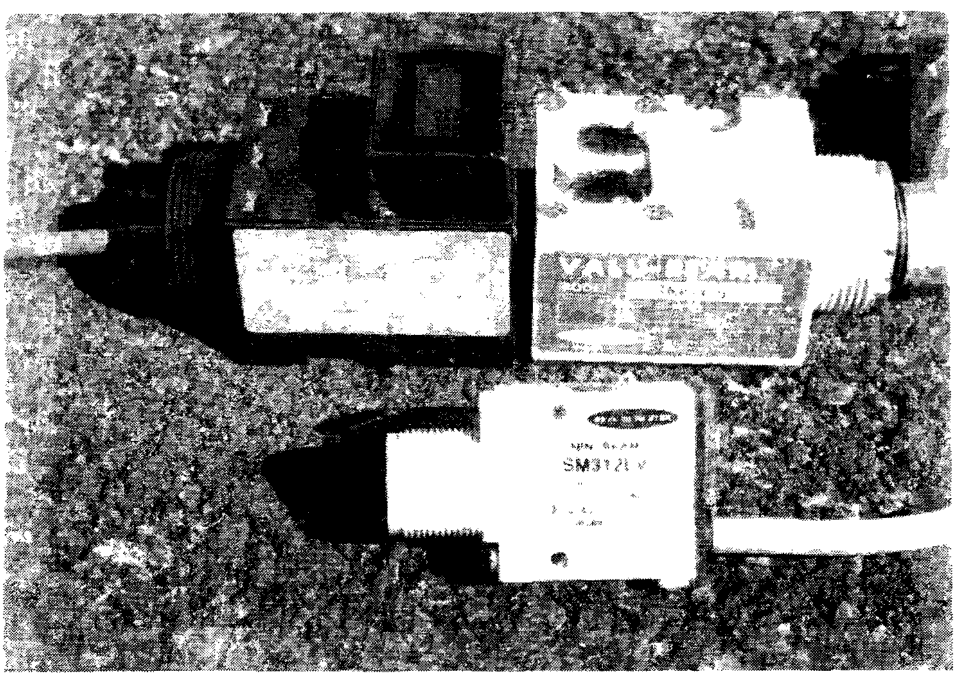


Fig A.6. Three types of Banner sensors used in study.

Reflex Sensor Module Installation Instruction

1480B

Introduction

Opcon's 1480B Reflex Sensor Module is designed to plug directly into the 80 Series "Blue Eyes" Control Modules. The power supply and output device are contained in the control module. The sensor head contains the infrared source and detector elements and all related circuitry. All required power and output wiring between the sensor head and control module is accomplished through the plug-in connection.

Reflex control systems operate by establishing a beam of infrared light between a control unit and a distant retroreflector. Retroreflectors, because of their special surface geometry, reverse the direction of incoming light rays, returning them to their source. Retroreflectors will tolerate a certain amount of misalignment with the light source at little or no loss in reflective efficiency. Since the reflector is a low cost component, it may be placed wherever there is a high probability of damage during normal operation. The more expensive control components can be placed in a sheltered location.

Specifications

Input Power:

Supplied only by Opcon Series 80 Control Modules; do not connect the head to external power.

Response Time:

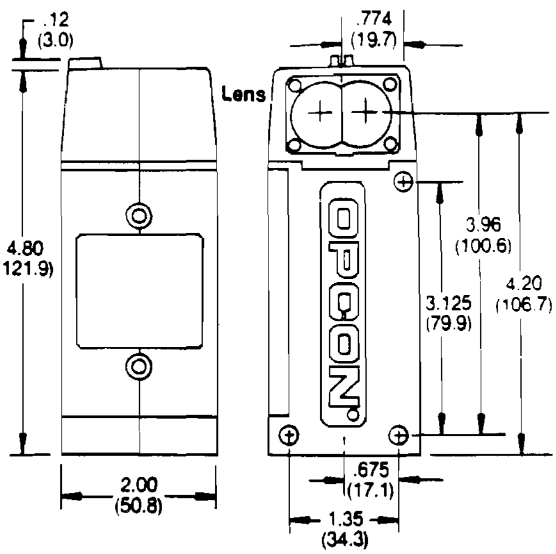
LT to DK Transition 5ms
DK to LT Transition 3ms
Note: For total response time, add the control module's response time.

Environmental:

Operating Temperature . . -40 °C(-40 °F) to +55 °C(+131 °F)
Storage Temperature . . . . -40 °C(-40 °F) to +75 °C(+167 °F)
Operating Humidity ....95% Relative Humidity
Storage Humidity ....95% Relative Humidity, Max.
NEMA Ratings 3, 4, 12, 13
NOTE: The 1480B meets NEMA 4 specification (wash down proof) when used with the following control modules: 8880C,81C,84C-6501, 8880C,81C,84C-6502 and 8882B-6501.
Sunlight Immunity ....10,000 Foot Candles
Note: 10,000 Foot Candles is equivalent to direct sunlight reflecting off a diffuse white surface.

Mechanical:

Case - Noryl* Plastic
Lens - Clear polycarbonate
Note: Avoid exposing the lens or case to chlorinated, halogenated, or aromatic hydrocarbons.
Vibration - 5G or .06 inch displacement, whichever is less, over a frequency range of 10Hz to 2000Hz
Alignment Aid - Gunsight groove on the case top



Reference Dimensions for Center of Lens.
Dimensions in inches (millimeters)

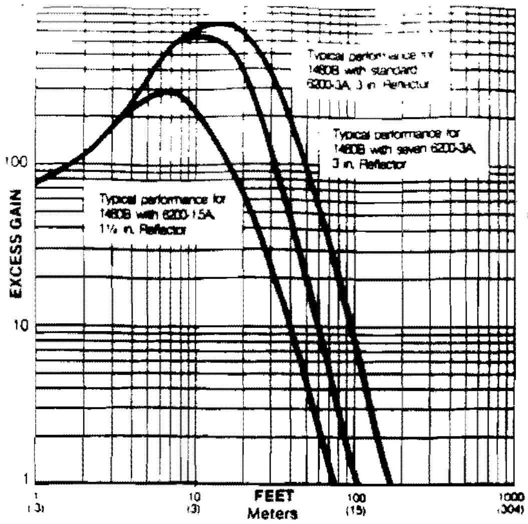
Optical:

Optical performance is measured in units of excess gain (Gx). Excess gain is the ratio of received infrared signal strength to the minimum signal (threshold) required to operate the system.

$$Gx = \frac{\text{Signal Received}}{\text{Threshold Signal}}$$

High excess gain values for a given range indicate that a system has reserve signal strength to overcome the effects of dirt and contamination. The accompanying graphs are performance estimates calculated for clean air, clean lens, and optimum alignment. Conditions in the working environment will vary considerably. The plotted values are based on the signal returned from a clear plastic retroreflector. Curves for 3in. and 1 ¼in. diameter reflectors are given. A curve for a seven reflector array is also shown. The graphs are useful tools for achieving the highest excess gain consistent with mounting requirements.

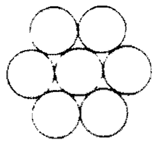
opcon®
sensing your needs

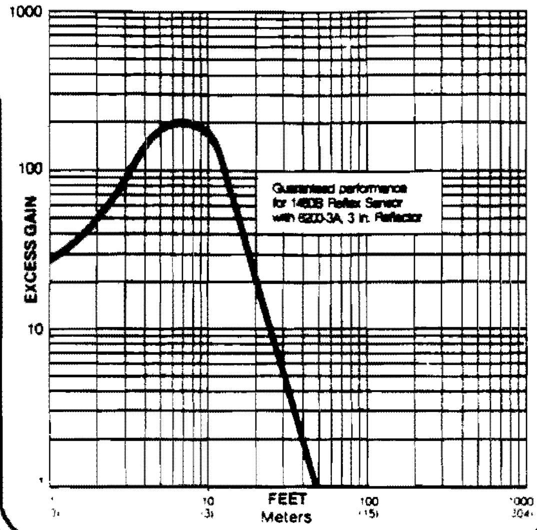


Reflector Arrays

Larger diameter reflectors can increase performance at extreme range. Effectively, this can be achieved by arranging several retroreflectors in a circular array. Of course there is no advantage in increasing the reflector's diameter beyond the boundary of the sensor field-of-view. Note also that since the effective beam diameter of a reflex unit is related to reflector diameter, a larger object will be required to block a larger diameter beam. The accompanying excess gain curve shows the typical performance of the 1480B sensor when used with an array of seven 6200A-3 reflectors. Performance in the working environment may vary.

Seven reflector array



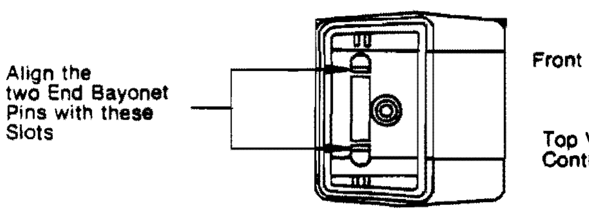


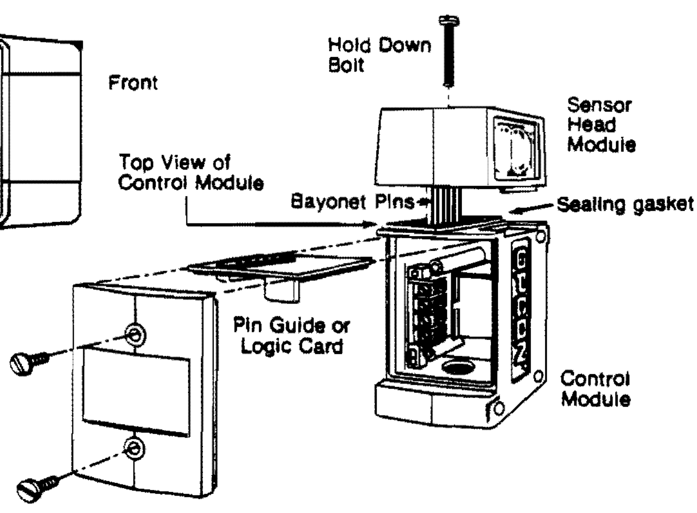
Installation 1480B

For parts identification and orientation during installation, refer to the accompanying exploded view. Before plugging the sensor head into the control module check that the bayonet pins are straight and that there is a sealing gasket on the control module. Also check that there is a gasket on the hold down bolt.

Insert a pin guide or logic card, if used, into the control module. Line up the bayonet pins as shown and seat the head on the gasket. The bayonet pins are a snug friction fit, but excessive fource should not be necessary. Tightening the hold down bolt will compress the gasket and complete the seal.

To remove the sensor head from the control module, unscrew the hold down bolt, be sure that it is completely free. Pull up while carfully rocking the sensor head from side to side. The head may release suddenly when the pins clear the receptacles.

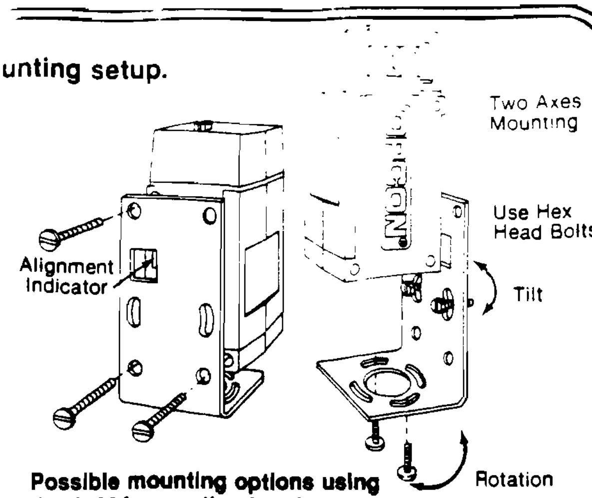




Proximity Mount

1 Provide some flexibility in the mounting setup.

Whenever possible, position the sensor looking down or at a slight downward angle to avoid dirt build up on the lens. Since the retroflector is a low cost component, it should be mounted on the side of the detection region most subject to damage during normal operation. Allow some room to move the reflector from side to side as well as up and down for alignment purposes. To prevent misalignment due to large amplitude vibrations both the sensor and reflector should be mounted rigidly with respect to each other. Provide some means to aim the sensor for alignment. For most installations, Opcon recomends the use of its 6180A Universal Mounting Bracket. For special applications or if difficulties are encountered contact Opcon's Applications Engineering Staff, 1-800-426-9184. Opcon will also supply, on request, a user's manual: Industrial Photoelectic Controls, PN 102264.



Possible mounting options using the 6180A mounting bracket.

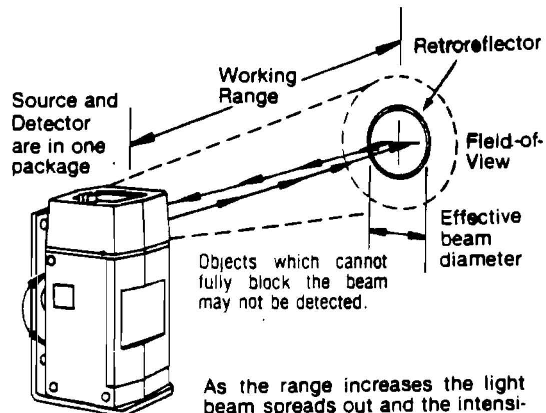
2 Select the mounting site carefully.

Reflex sensors operate by establishing a beam of infrared light between the sensor and a distant retroreflector. The infrared light beam defines a detection region having two important characteristics:

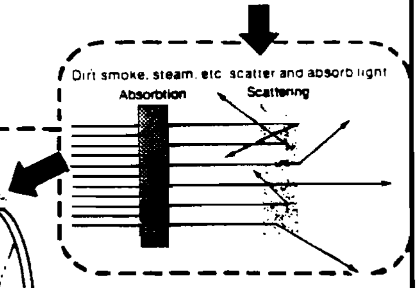
1. Effective Beam Diameter
2. Maximum Working Range

The effective beam diameter is equal to the reflector's diameter except at very short ranges where the actual beam diameter may be less than that of the refletor. It will be difficult, if not impossible, to detect objects smaller than the effective beam diameter. In general, the beam must be completely blocked at some point for detection to occur.

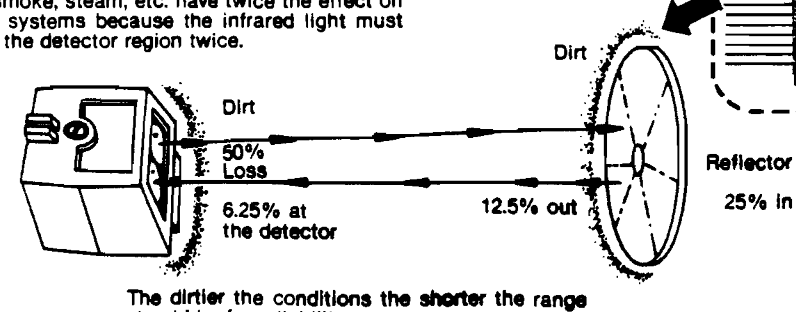
The maximum working range varies with the diameter of the retroreflector. Within limits, increasing the size of the reflector will extend the sensor's working range, however, it will then require a larger object to block the beam. Other factors which affect working range are contaminants such as dust and steam in the air and/or dirt collecting on the sensor's lens and the surface of the reflector. Optimum range information can be obtained from the excess gain curves given in this manual. If possible, choose a working range which corresponds to the sensor's peak excess gain point.



As the range increases the light beam spreads out and the intensity per unit area is reduced because the same amount of light must cover a much greater area.



Dirt, smoke, steam, etc. have twice the effect on reflex systems because the infrared light must cross the detector region twice.

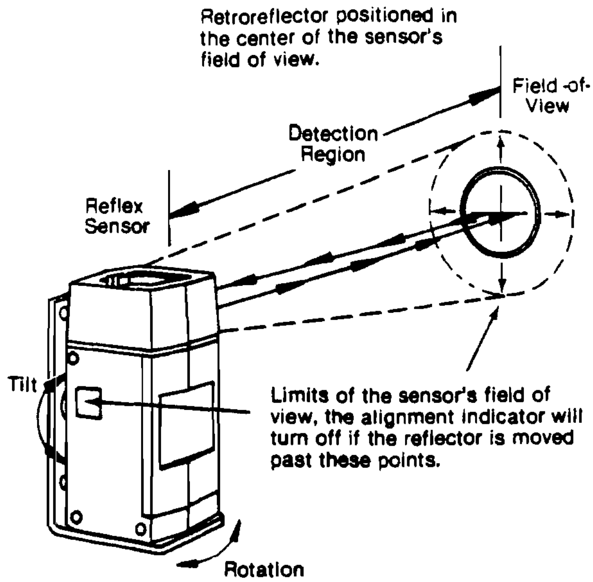


The dirtier the conditions the shorter the range should be for reliability.

3 Basic Reflex Alignment

Reflex alignment consists basically of aiming the sensor at the reflector, to establish the infrared light beam, and adjusting the reflector's position so that it is on the sensor's optical centerline:

1. Adjust the control module's sensitivity to maximum (fully clockwise).
2. Aim the reflex sensor at the retroreflector. The control module's indicator light will glow red when the infrared light beam is established.
3. Move the reflector from side to side as well as up and down, mark the points where the reflector moves out of the sensor's field of view (the alignment indicator will go off at that point).
4. Position the reflector in the center of the sensor's field of view as shown.
5. Secure both the sensor and reflector. Be sure that the reflector and sensor are rigidly mounted with respect to each other. Severe vibration or impact shock could shift the relative positions of the sensor and reflector. A false detection event could occur if the position shift was large enough to move the reflector out of the sensors field-of-view.
6. Alignment is complete.



6180A
Mounting Bracket

106899 (1185) Printed in U.S.A.

Guarantee/Service

Opcon guarantees all standard products, except output devices, for three years against electrical and mechanical defects in material and workmanship. Repair or replacement will be made free of charge during this period. This guarantee does not cover damage caused by misuse, negligence, or use on current or voltage other than that specified; nor does this guarantee cover damage or liability for improper application of Opcon products. This guarantee is in lieu of any other warranty either expressed or implied.

If service is required, package the unit carefully since damage in transit is not covered by the guarantee. Include a letter describing the problem and designating a contact person in case Opcon has a question concerning the repair. Send the unit, prepaid, along with a purchase order to an athorized Opcon repair center. Contact Opcon for the repair center nearest you.

Information furnished by Opcon, Inc., is believed to be accurate and reliable. However, no responsibility is assumed by Opcon, Inc., for its use; nor for any infringements of patents or other rights of third parties which may result from its use. No license is granted by implication or otherwise under any patent or patent rights of Opcon, Inc.

opcon®
sensing your needs

720 80th St. S.W., EVERETT, WA 98203-6299
Toll Free [800] 426-9184 or [206] 353-0900, or TLX 152-963

DC/NPN Control Module Installation Instructions

8882B-6501

Introduction

Opcon's 8882B Control Module is the DC power and output base for Opcon's 80 Series "Blue Eyes" Sensors. The 8882B provides high and low logic levels through a pair of open collector transistor outputs. An open collector output functions as an electronic switch between the load cicuit and DC common. At any given time, one output is conducting to DC common while the other is not. The outputs may be applied to relay coils, DC switching controls, TTL, or CMOS inputs (with pull-up resistor).

The 8882B will accept Thru-Beam, Proximity, and Reflex Sensor Heads. In addition, Time-Delay and One-Shot Logic Modules are available. A complete DC control package consists of:

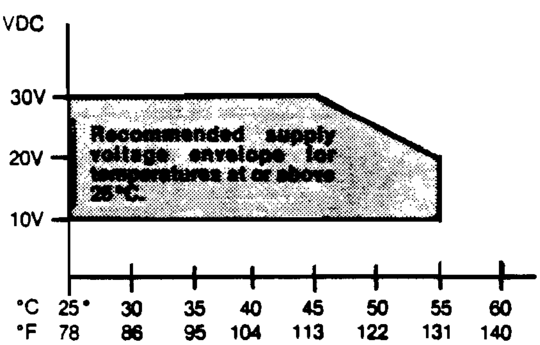
- One (1) 8882B DC/NPN Control Module. Note: A Thru-Beam control package requires two (2) control modules.
- 80 Series Sensor Head(s):
  - 1180B,80R/1280B . Thru-Beam Source/Detector pair
  - 1380,81,82,83B,83R .... Proximity Sensors
  - 1480B,80R .... Reflex Sensor
  - 1580B .... Fiber Optics
- Optional Logic Modules:
  - 8280A .... Dual Time-Delay
  - 8281A .... Non-Retriggerable One-Shot
  - 8282A .... Retriggerable One-Shot
- Miscellaneous:
  - 6180A .... Universal Mounting Bracket
  - 6200A-3 .... 3 Inch Reflector
  - 6200A-1.5 .... 1.5 Inch Reflector
  - Note: Reflectors are for reflex control pkgs. only.

Specifications

Input Power:

Voltage · 10 to 30VDC, unregulated

Current · less than 90ma



Note: Operation outside the recommended supply voltage envelope will result in erratic performance at high temperature.

Output Characteristics:

Output Active, "On" · Less than 500mv at 200ma

Output Inactive, "Off" · Output will shut off up to 30VDC at less than 20ua leakage

Transient Protection · Outputs are protected from inductive load switching for energy signals of less than 0.18 Joule (Watt/Sec) and power signals of less than 200mw.

Power On Delay · Outputs are inactive for 100 to 300 ms after power up regardless of the beam's status.

Response Time · Instantaneous ON and OFF.

Controls, Switches, and Indicators:

Alignment Indicator Light · An alignment indicator light is visible through a lens located on the back of the module. The indicator glows red whenever the detector element "sees" infrared light from the source (beam complete). On Thru-Beam systems, only the detector module's indicator light functions as an alignment aid; the source module's light serves as a power on indicator.

LT/DRK Mode · An active output on beam complete (LT) or beam blocked (DRK) can be obtained by selecting the appropriate wiring configuration.

Sensitivity Adjustment · A potentiometer varies the control module's responsiveness to the level of incoming infrared light detected by the sensor head. The sensitivity adjustment range is 20 to 1. At minimum sensitivity, a proportionally greater amount of infrared light is required to turn the output "ON". Normally the control module is set at maximum sensitivity (fully clockwise) which insures reliable operation even through dust in the air and dirt build-up on the sensor's lens.

Environmental:

Operating Temperature ... -40°C(-40°F) to +55°C(+131°F)

Storage Temperature ..... -40°C(-40°F) to +75°C(+167°F)

Operating Humidity .... 95% Relative Humidity

Storage Humidity .... 95% Relative Humidity, Max.

NEMA Ratings 3, 4, 12, 13

NOTE: NEMA 4 (wash down proof) specification is met when these control modules are used with the following sensor heads: 1180R, 1180B, 1280B, 1380B, 1381B, 1382B, 1383B, 1383R, 1480B, 1480R, 1481R, or 1580B.

Mechanical:

Case · Noryl® Plastic

Terminals · No. 6 slotted screws in barrier strip

Weight · 173g(6.0oz), Sensor Head included

Vibration · 5G or .06 inch displacement, whichever is less, over a frequency range of 10Hz to 2000Hz

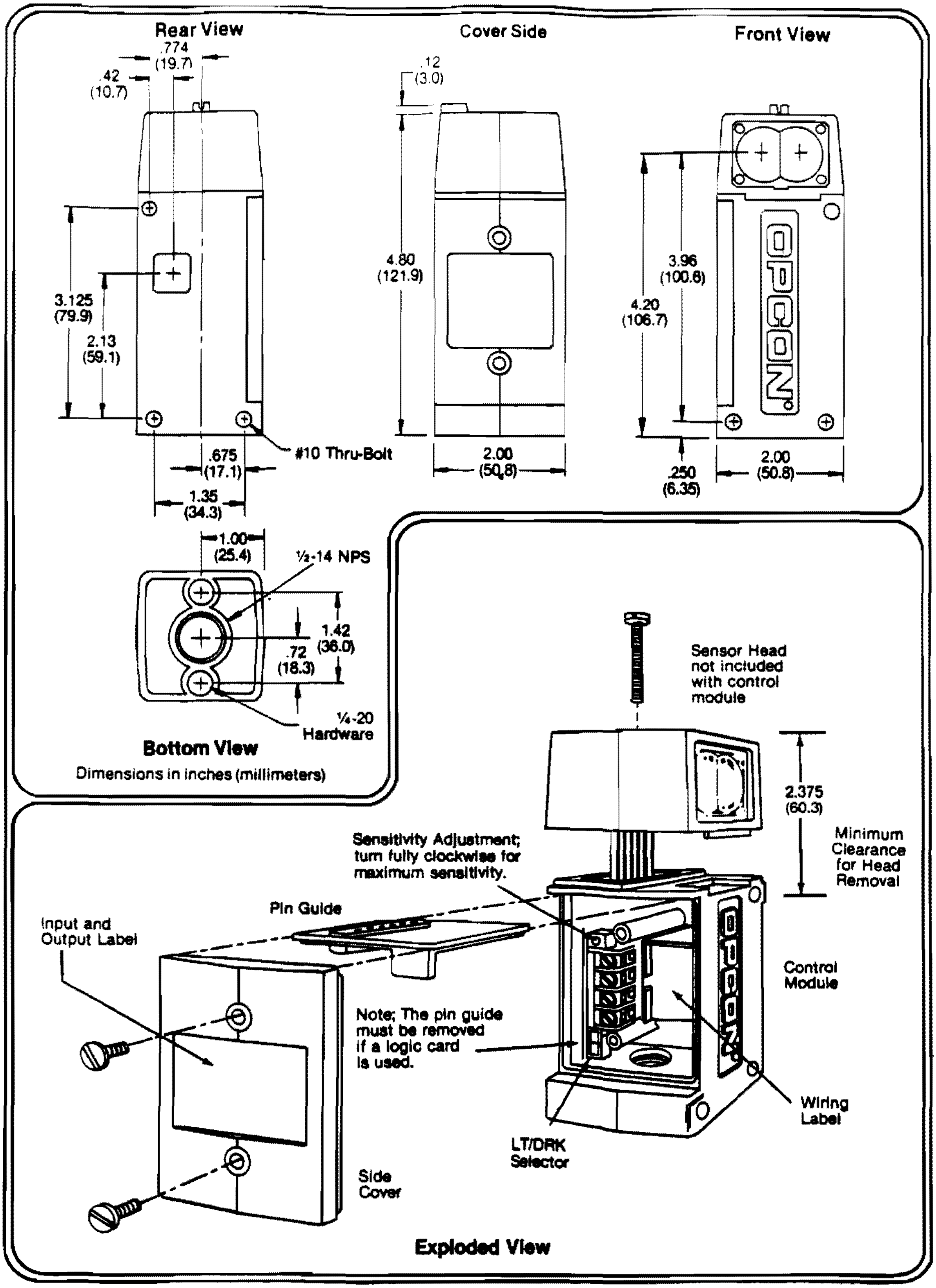
Mounting · Module can be mounted from the bottom with two ¼-20bolts or from the side with three 10-32 × 2 ½ bolts.

Wiring Port · A ½ inch NPS conduit port is molded into the case bottom.

Adjustment Access · Provided by a removable panel in the module's side. Adjustment access is possible without disturbing mounting or alignment.

8882 Control Module

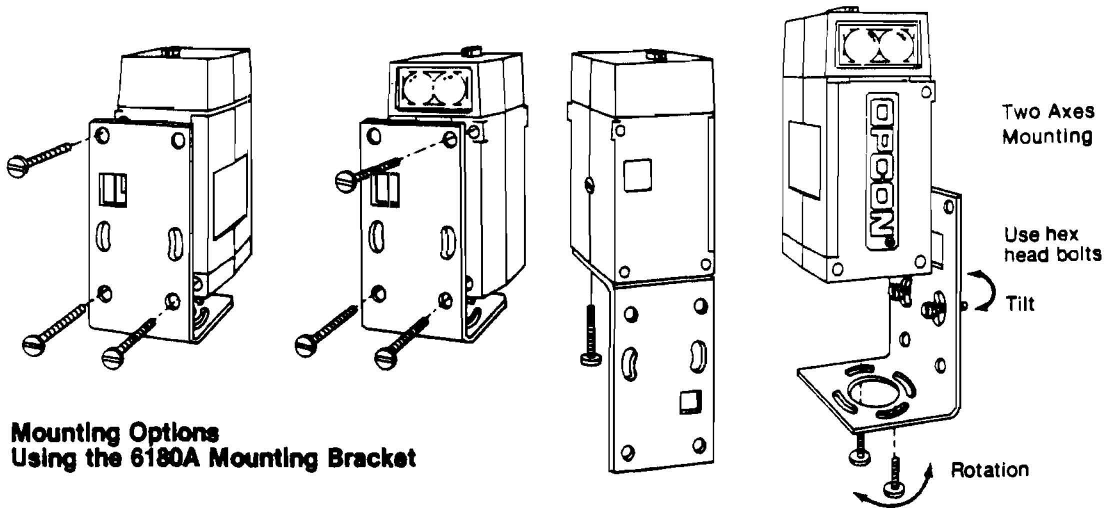
opcon® sensing your needs


Rear View
.774
(19.7)
.42
(10.7)
3.125
(79.9)
2.13
(59.1)
.675
(17.1)
#10 Thru-Bolt
1.35
(34.3)
Cover Side
.12
(3.0)
4.80
(121.9)
2.00
(50.8)
Front View
3.96
(100.6)
4.20
(106.7)
.250
(6.35)
2.00
(50.8)
OPCON
1.00
(25.4)
½-14 NPS
1.42
(36.0)
.72
(18.3)
¼-20
Hardware
Bottom View
Dimensions in inches (millimeters)
Sensor Head
not included
with control
module
2.375
(60.3)
Minimum
Clearance
for Head
Removal
Sensitivity Adjustment;
turn fully clockwise for
maximum sensitivity.
Pin Guide
Input and
Output Label
Control
Module
Note; The pin guide
must be removed
if a logic card
is used.
Wiring
Label
LT/DRK
Selector
Side
Cover
Exploded View

Mounting:

The control module's mounting site is largely determined by the job to be done. Whenever possible, however, avoid mounting sites that will subject the control module to severe vibration or impact shocks; protect the lens from abrasive materials or exposure to chlorinated, halogenated, or aromatic hydrocarbons. Exercise special care if you must open the control module's case around fluid spray or heavy dirt contamination.

Before deciding on the mounting site and method, review the installation and operating information contained in the sensor head instruction manual. Regardless of the sensing mode used, thru-beam, reflex, or proximity, you should provide some flexibility in the mounting setup for alignment purposes. For most installations, Opcon recommends the use of its 6180A Universal Mounting Bracket with the 8882B Control Module. For special applications or if difficulties are encountered, contact Opcon's Applications Engineering staff, 1-800-426-9184. Opcon will also supply, on request, a user's manual: Industrial Photoelectric Controls, PN 102264.



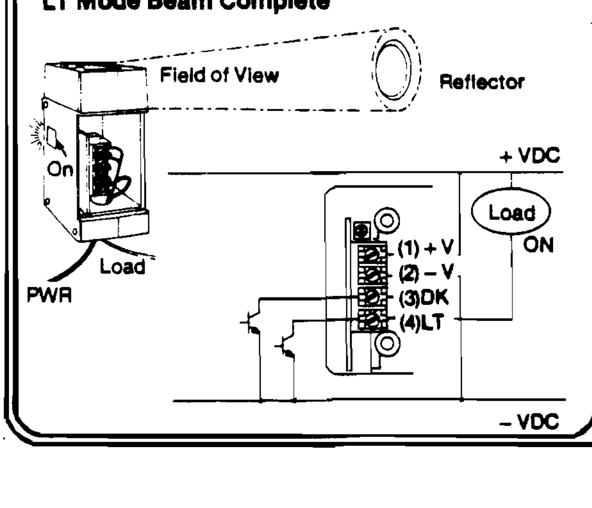
Mounting Options
Using the 6180A Mounting Bracket

Wiring

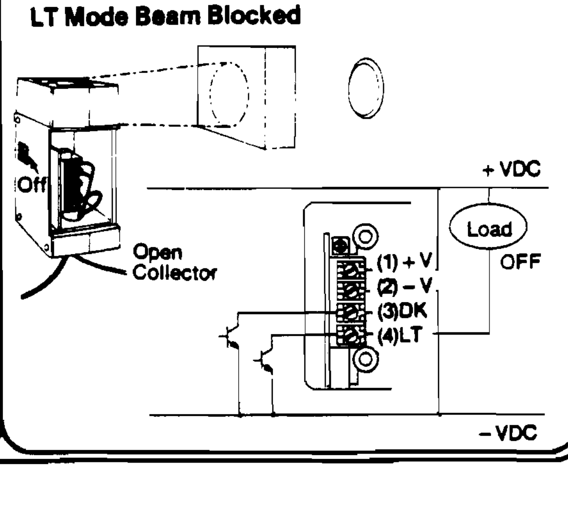
All input and output wiring connections are made on a barrier strip inside the control module's case. There are two labels that you should find prior to making any connections. The first label is located on the case cover and gives the model number, input and output ratings, control and terminal designations. The second label is located on the inside of the case and graphically identifies input and output terminals.

The 8882B provides high and low logic levels through a pair of open collector transistor outputs. An open collector output functions as an electronic switch between the load circuit and DC common. While one output is conducting to DC common the other is not. The accompanying wiring diagrams illustrate a simple DC hookup for the light (LT) mode, output turned "on" when the light beam is complete, and the dark (DRK) mode, output turned "on" when the beam is blocked. A reflex system is shown for illustration purposes. Additional diagrams illustrate a parallel (wired-or) hookup and how the complementary outputs of a single control module can be used to drive two independent loads.

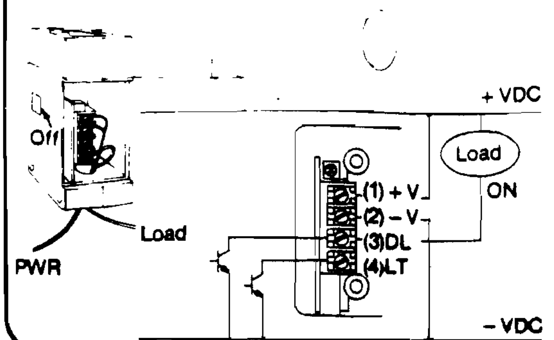
LT Mode Beam Complete



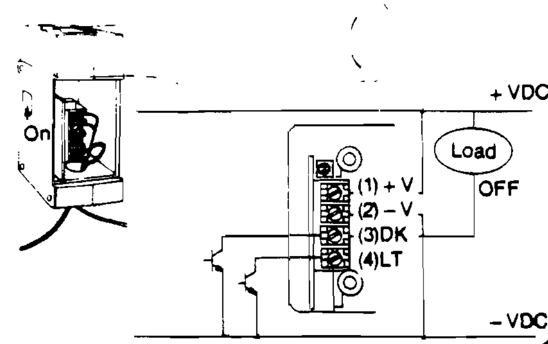
LT Mode Beam Blocked

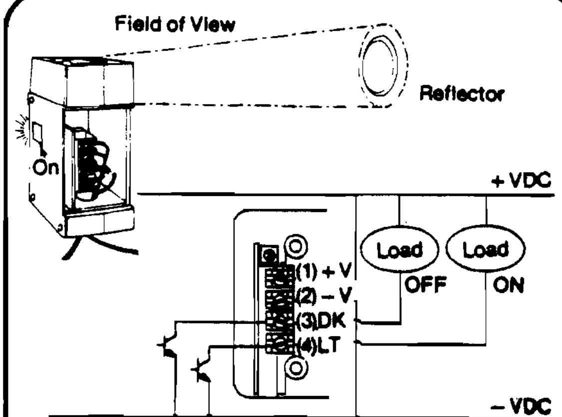


DRK Mode Beam Blocked

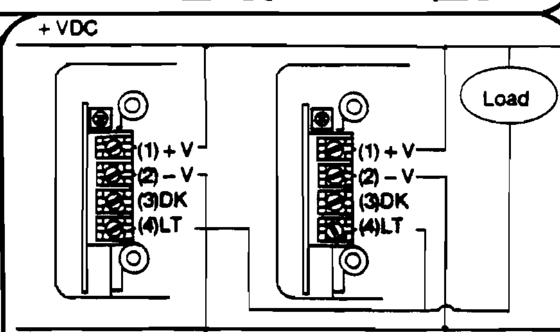


DRK Beam Complete





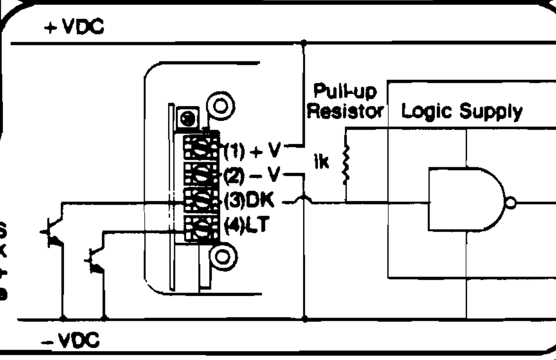
Two independent loads driven by a single control module.



Parallel (Wired-or) Hookup

TTL, CMOS Hookup

If the control module will be used to drive a TTL or CMOS load, then a pull-up resistor is required. Opcon suggests a 1K ohm resistor. The illustration shows the general wiring requirements for LT mode, TTL or CMOS operation; DRK mode operation is similar.



106832 (885) Printed in U.S.A.

Guarantee/Service

Opcon guarantees all standard products, except output devices, for three years against electrical and mechanical defects in material and workmanship. Repair or replacement will be made free of charge during this period. This guarantee does not cover damage caused by misuse, negligence, or use on current or voltage other than that specified; nor does this guarantee cover damage or liability for improper application of Opcon products. This guarantee is in lieu of any other warranty either expressed or implied.

If service is required, package the unit carefully since damage in transit is not covered by the guarantee. Include a letter describing the problem and designating a contact person in case Opcon has a question concerning the repair. Send the unit, prepaid, along with a purchase order to an authorized Opcon repair center. Contact Opcon for the repair center nearest you.

Information furnished by Opcon, Inc., is believed to be accurate and reliable. However, no responsibility is assumed by Opcon, Inc., for its use; nor for any infringements of patents or other rights of third parties which may result from its use. No license is granted by implication or otherwise under any patent or patent rights of Opcon, Inc.

opcon®
sensing your needs

720 80th St. S.W., EVERETT, WA 98203-6299
Toll Free [800] 426-9184 or [206] 353-0900, or TLX 152-963

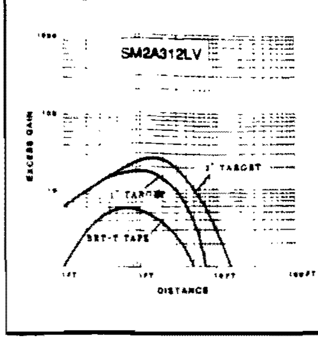
MINI-BEAM™ SM2A312LV 2-WIRE AC RETROREFLECTIVE SENSOR

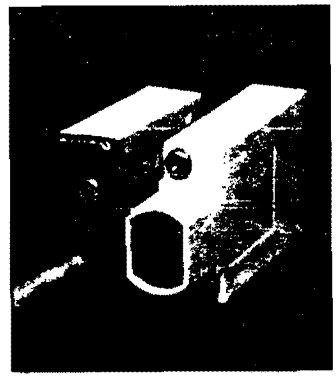
BANNER
the photoelectric specialist

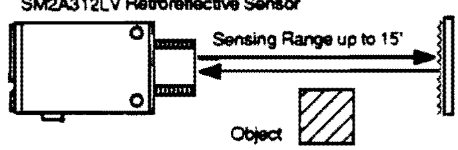
FEATURES

- Retroreflective sensor with range to 15' (used with 3" retroreflector)
- Physically and electrically interchangeable with inductive proximity switches and 18-mm photoelectric switches
- Small effective beam (1/2" dia. at 1' distance from lens)
- Modulated visible red light beam for immunity to ambient light and ease of alignment
- Switch-selectable for light or dark operate
- Solid-state output switches up to 300 ma.
- Easy interfacing to programmable controllers: low leakage current; low saturation voltage
- LED indicator lights when load is energized
- 24-250V ac (50-60 Hz) operation*
- No false pulse on power-up

Excess gain curve, SM2A312LV







- 15-turn sensitivity adjustment
- Compact size: only 2.6" long x 1.2" high x .5" wide
- Rugged and epoxy-encapsulated: meets NEMA standards 1, 2, 3, 3S, 4, 4X, 12, and 13

DESCRIPTION

The Banner MINI-BEAM series SM2A312LV is a self contained visible-light retroreflective sensor having a sensing range of 15 feet. Its small effective beam (1/2 inch dia. at 1 foot from the lens) makes it a good choice for sensing relatively small objects, and its visible red light beam makes it extremely easy to align.

SM2A312LV retroreflective sensors consist of an LED light source, a sensitive phototransistor, an alignment indicator, and a custom designed state-of-the-art CMOS integrated modulator/demodulator/amplifier circuit. Digital modulation/demodulation makes the SM2A312LV nearly immune to interference from ambient light. A red LED indicator on the rear of the sensor makes alignment and system monitoring easier by lighting whenever the load is energized. The SM2-A312LV's solid-state output is capable of switching up to 300 ma. (at 50 degrees C ambient; 100 ma. at 70 degrees C), and its low output leakage and low saturation voltage make it ideal for interfacing to programmable controllers and other solid-state circuitry. SM2A312LVs are electrically interchangeable with many existing photoelectrics and inductive proximity switches. They are fully protected against false pulse on power-up and inductive load transients. The SM2A312LV operates on 24 to 250V ac, 50-60 Hz*. ***(NOTE: use on low voltages requires careful analysis of the load to determine if the leakage current or on-state voltage of the sensor will interfere with proper operation of the load.)***

A convenient control on the back of the SM2A312LV allows a choice of *either* light or dark operate sensing mode. A rugged 15-turn slotted brass screw clutched GAIN control enables very precise adjustment of system sensitivity. The maximum sensing range of 15 feet will be attained when using the model BRT-3 3" corner-cube retroreflective target.

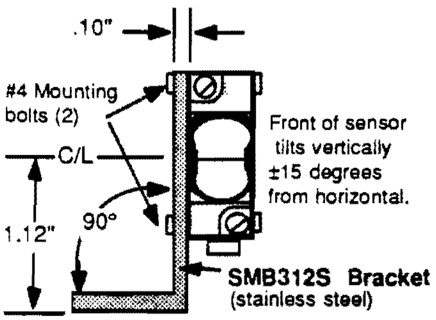
The SM2A312LV is fully encapsulated and gasketed against moisture and other contaminants and conforms to NEMA standards 1, 2, 3, 3S, 4, 4X, 12, and 13. It is supplied with 6 feet of rugged, PVC-covered 2-conductor

***Early models are rated for use only up to 120V ac, and are so marked on their labels.**

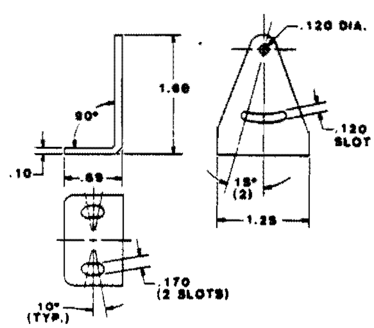
The SM2A312LV's wide array of mounting options is designed to simplify mounting and alignment in any industrial environment. Its 18-mm threaded barrel allows it to be physically interchanged with existing 18-mm barrel sensors and proximity switches. It may also be mounted using an adjustable, stainless steel side-mounting or bottom-mounting bracket (models SMB312S and SMB312B, respectively) which allows two axes of sensor movement and thus greatly simplifies alignment. Alternatively, the SM2A-312LV can be custom-mounted via its built-in mounting peg and a special accessory mounting foot (model SMB312F) with brass-threaded screw insert.

MOUNTING OPTIONS

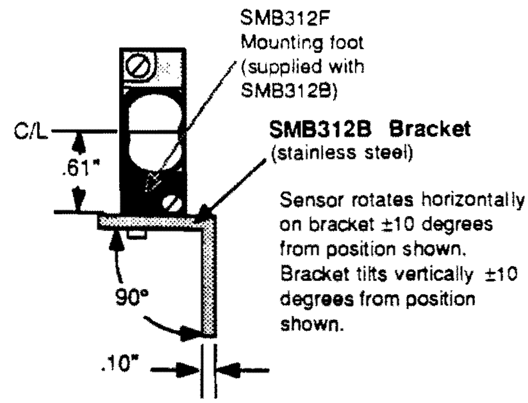
SMB312S Side Mounting Bracket

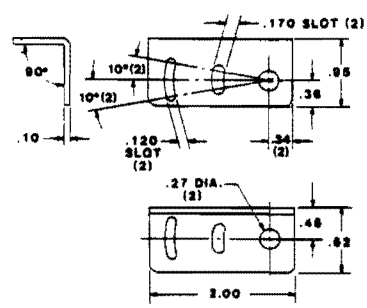


Bracket rotates horizontally ±10 degrees from position shown.

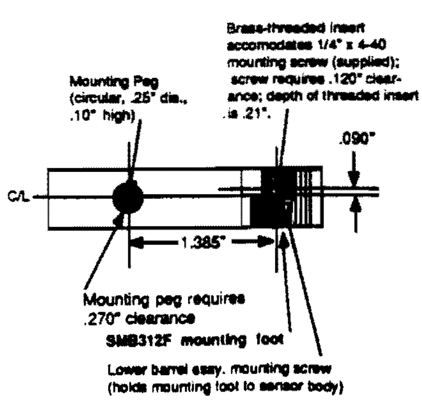


SMB312B Bottom Mounting Bracket

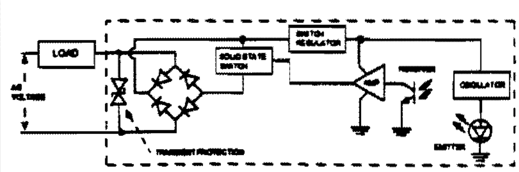




SMB312F Mounting Foot (bottom view)

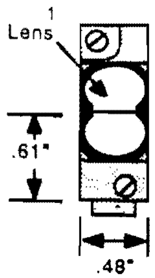


FUNCTIONAL DIAGRAM, SM2A312LV

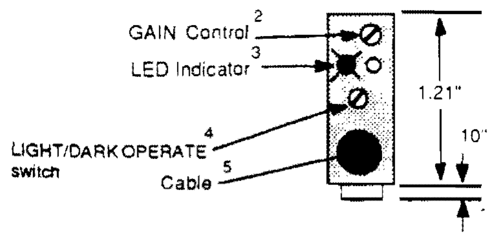


DIMENSION DRAWINGS

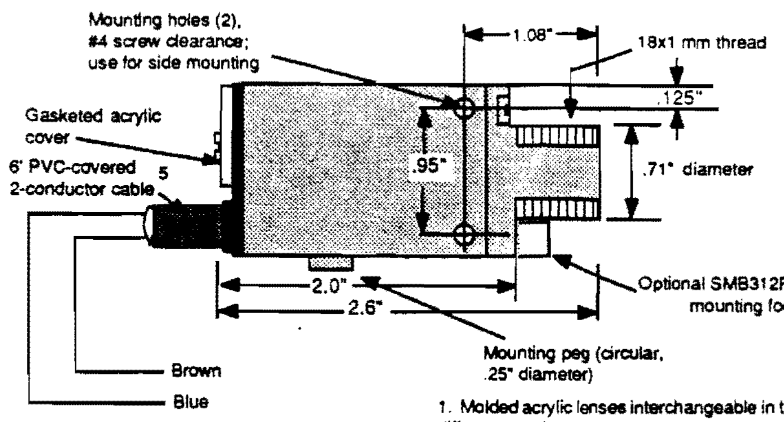
FRONT VIEW

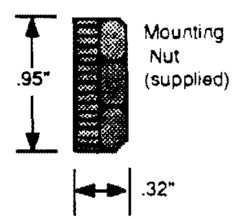


REAR VIEW



SIDE VIEW

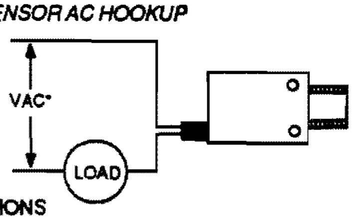




1. Molded acrylic lenses interchangeable in the field for replacement repair or for different sensing ranges.
2. GAIN (sensitivity) control: rotate clockwise to increase gain.
3. LED indicator lights when output is energized.
4. LIGHT/DARK OPERATE SELECT control: DARK OPERATE=fully counterclockwise; LIGHT OPERATE=fully clockwise
5. 6' PVC-jacketed 2-wire cable supplied.
6. Optional SMB312F mounting foot used for bottom mounting of sensor with or without SMB312B Bottom Mounting Bracket. Mounts at front of sensor body beneath barrel. Supplied with SMB312B bracket order, or order separately.

HOOKUP INFORMATION

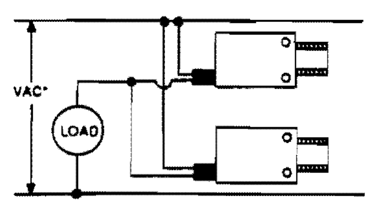
BASIC SINGLE-SENSOR AC HOOKUP



*see SPECIFICATIONS

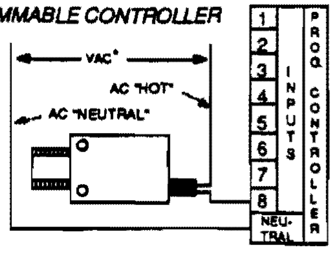
PARALLEL HOOKUP

NOTE: in a parallel hookup, the load leakage increases with the number of sensors, i.e., 2 sensors together have two times the leakage of one sensor alone, etc.



*see SPECIFICATIONS

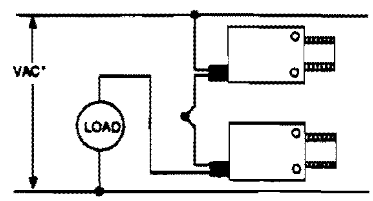
HOOKUP TO PROGRAMMABLE CONTROLLER



*see SPECIFICATIONS

SERIES HOOKUP

NOTE: in a series hookup, the total saturation voltage across the sensors increases with the number of sensors, i.e., 2 sensors together have 2 times the saturation voltage of one sensor alone, etc.



*see SPECIFICATIONS

INSTALLATION AND ALIGNMENT

Proper operation of the SM2A312LV requires that it be mounted securely and aligned properly. Excessive movement or vibration can result in intermittent or false operation caused by loss of alignment to the retro target. For best results, the SM2A312LV should be mounted using one of the four methods described on page 2.

Alignment of the SM2A312LV is quite simple, and is accomplished as follows:

1) With power applied to the SM2A312LV, direct its visible red light beam at its retro target while observing the red LED indicator on the back of the sensor. Temporarily reducing the ambient light level in the room will make the red sensing beam easier to see and align. With the GAIN control set at the clockwise end of rotation (maximum gain), center the sensing beam on the target.

2) Place the object to be sensed in sensing position (between sensor and target). Best retroreflective sensing results are usually obtained when the sensor is operating at the maximum excess gain possible without "burning through" the object or reacting to light reflected from the object ("proxing"). If the red LED indicator remains "on" with the object in sensing position (an indication of "burn-through" or "proxing"), reduce the GAIN control until the LED goes out, then reduce the gain by two more full turns. Remove the object from the sensing position while observing the LED. If the LED goes "on" with the object removed from the sensing position, alignment is complete.

ALIGNMENT NOTE: "Proxing" occurs when a retroreflective sensor reacts to light reflected from the object being sensed instead of only to light reflected from the retro target. Proxing may often be a problem when sensing shiny objects such as bottles, metal cans, or objects wrapped in cellophane or shrink-wrap. Proxing can be reduced or eliminated by directing the sensor beam at an angle of 10 to 15 degrees off of the line perpendicular to the object's reflecting surface. *Both a horizontal and a vertical displacement may be necessary.* The sensing beam may be angled as far as 15 degrees away from "straight-on" to the reflector without compromising efficiency. It is not usually necessary to do away with *all* reflections. The goal is rather to reduce the strength of the *unwanted* signals while maintaining or increasing the strength of the signal from the retro target. For more information, refer to Section 7 of the Banner Catalog (Reference Manual portion) for an in-depth discussion of sensor alignment and adjustment.

ELECTRICAL AND MECHANICAL SPECIFICATIONS, SM2A312LV SENSOR

SUPPLY VOLTAGE: 24 to 250V ac, 50/60 Hz. Use on low voltages requires careful analysis of the load with respect to the leakage current and on-state voltage of the sensor. See note, page 1.

OFF-STATE LEAKAGE CURRENT: less than 1.7 milliamps rms.

ON-STATE VOLTAGE: ≤5V at 300ma, ≤10V at 15 ma. load.

MINIMUM LOAD CURRENT: 5 milliamps.

INRUSH CAPABILITY: 3 amps for 1 second (non-repetitive); 10 amps for 1 cycle (non-repetitive).

RESPONSE TIME: 10 milliseconds ON and OFF (plus response time of load).

STEADY-STATE LOAD CAPABILITY: 300 milliamps up to 50 degrees C ambient (122 degrees F); 100 milliamps up to 70 degrees C ambient (158 degrees F).

INDICATOR LED: Red indicator on rear of unit is "ON" when load is energized.

TEMPERATURE RANGE: -20 to +70 degrees C (-4 to +158 degrees F).

POWER-UP INHIBIT: less than 300 milliseconds (switch is non-conducting during this time).

CONSTRUCTION: reinforced Valox ™ housing, totally encapsulated, acrylic lenses, o-ring sealing, stainless steel screws. Meets NEMA standards 1, 2, 3, 4, 4X, 12, and 13.

CABLE LENGTH AND MATERIAL: PVC-jacketed 2 conductor cable, 6' long.

MOUNTING: *front mounting* via 18-mm nut (supplied) through 18-mm clearance hole. *Side mounting* via two no. 4 clearance holes on .95" centers; use with or without optional model SMB312S stainless steel two-axis mounting bracket. *Bottom mounting* via sensor's mounting peg and optional model SMB312F mounting foot, or via SMB312B stainless steel two-axis mounting bracket (supplied complete with mounting foot).

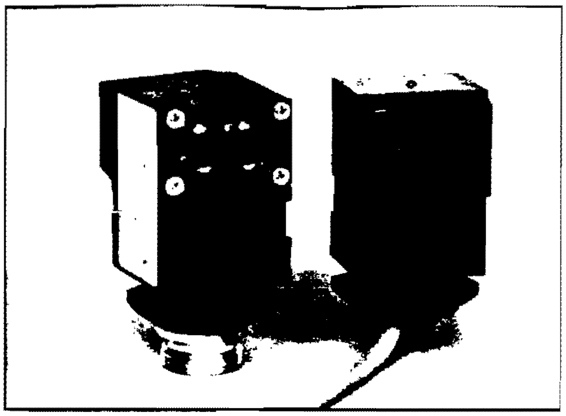
WARRANTY: Banner Engineering Corporation warrants its products to be free from defects for a period of one year. Banner Engineering Corporation will repair or replace, free of charge, any product of its manufacture found to be defective at the time it is returned to the factory during the warranty period. This warranty does not cover damage or liability for the improper application of Banner products. This warranty is in lieu of any other warranty either expressed or implied.

VALU-BEAM™ "990" Series

Sensors with Built-in Totalizing Counter

BANNER
the photoelectric specialist

VALU-BEAM 990 series sensors boast the same high optical performance offered by the front-line 912-series, and also contain a built-in 6-digit totalizing counter. Sensor models are available for opposed, retroreflective, and convergent beam sensing modes. In addition, there are models for use with both glass and plastic fiberoptics.



A special infrared retroreflective version is available, which is designed for counting people passing through entry ways. It has built-in on/off time delays to minimize the chance of multiple counts.

The "990" series VALU-BEAM's 6-digit LCD counter is reset simply by touching the area of the housing shown with the permanent magnet supplied with the sensor (see dimension drawing, below). Standard models automatically reset to zero upon power-up.

Memory backup option: SMA990 series sensors with internal memory backup for maintaining "count memory" while power is removed are available by special order. These models will "hold" a count for over 100 hours, and are indicated by the model number suffix "MB" (i.e., "SMA990LVMB" is the memory backup version of sensor model SMA990LV). Contact the factory for availablility and pricing of these models.

SMA990-series sensors wire directly to either 10 to 250V ac (50/60Hz) or 12 to 115V dc.

SPECIFICATIONS, SMA990 SERIES VALU-BEAM SENSORS

SUPPLY VOLTAGE: 10 to 250V ac, 50/60Hz or 12 to 115V dc at less than 20 milliamps.

SENSOR RESPONSE: 15 milliseconds LIGHT, 15 milliseconds DARK. 100 millisecond delay on power up (no counts are entered during this time). Models with memory backup have no power-up delay. *Note: Some models with memory backup may increment 1 count upon reapplication of power.*

COUNT ENTRY: counts are entered on DARK-to-LIGHT transition.

COUNT RESET: in *standard* models, counter is reset to zero automatically upon applying power to the sensor. All models may be reset by touching the housing on top of the sensor (see below) with a permanent magnet (supplied with sensor).

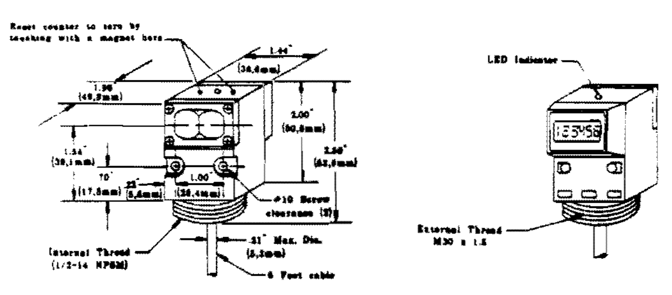
CONSTRUCTION: reinforced black Valox™ housing, totally encapsulated circuitry, molded o-ring sealed lenses or fiber fittings, stainless steel hardware. Meets NEMA standards 1, 2, 3, 3S, 4, 4X, 12, and 13.

CABLE: 6 feet (2m) of PVC-jacketed 2-conductor cable is standard. Three-pin quick-disconnect ("QD") models are available optionally (one conductor goes unused); see page 4.

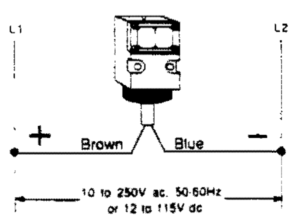
INDICATOR LED: top-mounted red LED indicator lights whenever the sensor "sees" its modulated light source.

OPERATING TEMPERATURE RANGE: 0 to 50 degrees C (32 to 122 degrees F).

DIMENSIONS, SMA990-SERIES VALU-BEAMs



HOOKUP DIAGRAM



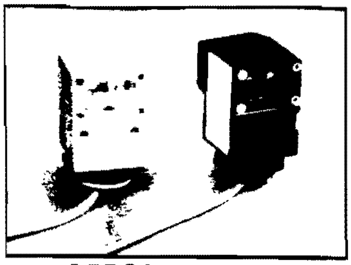
Observe proper polarity for DC hookups.

AC hookups have no polarity.

WARRANTY: Banner Engineering Corporation warrants its products to be free from defects for a period of one year. Banner Engineering Corporation will repair or replace, free of charge, any item of its manufacture found to be defective at the time it is returned to the factory during the warranty period. This warranty does not cover damage or liability for the improper application of Banner products. This warranty is in lieu of any other warranty either expressed or implied.

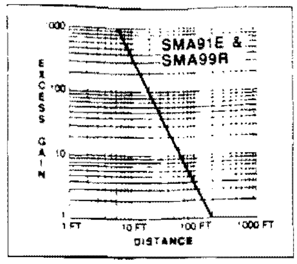
VALU-BEAM "990" Series Sensors

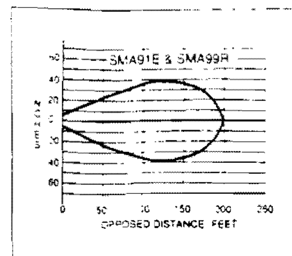
Sensing Mode | *Models* | *Excess Gain* | *Beam Pattern*



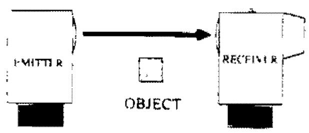
SMA91E & SMA99R

Voltage: 10 to 250V ac or 12 to 115V dc; ("E": 10-250V ac/dc)
Range: 200 feet (60m)
Beam: infrared, 880nm; visible red tracer beam
Effective beam: 0.5" dia.

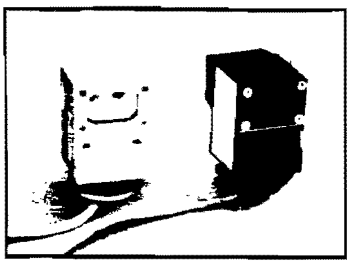




OPPOSED MODE

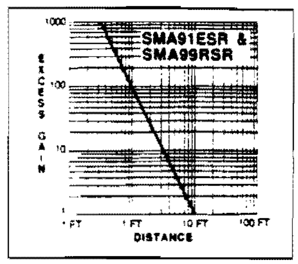


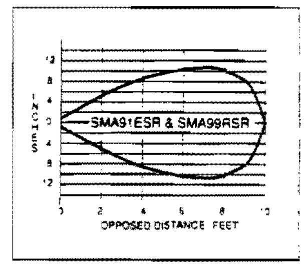
Opposed mode sensors have higher excess gain than other models, and therefore should be used whenever possible. Opposed mode is the most reliable sensing mode for counting opaque materials. The small size of these sensors makes them ideal for many conveyor applications, and their small effective beam size (particularly of the ESR/RSR models) enables them to reliably count relatively small objects. ESR and RSR models also have a wide beam angle for very forgiving alignment within the 10-foot range. VALU-BEAM opposed mode sensors have a visible red "tracer beam" which greatly simplifies sensor alignment.

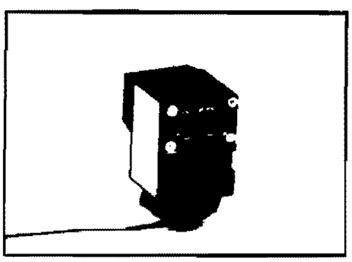


SMA91ESR & SMA99RSR

Voltage: 10 to 250V ac or 12 to 115V dc; ("ESR": 10-250V ac/dc)
Range: 10 feet (3m)
Beam: infrared, 880nm; visible red tracer beam
Effective beam: .12" dia.

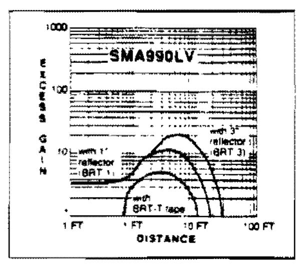


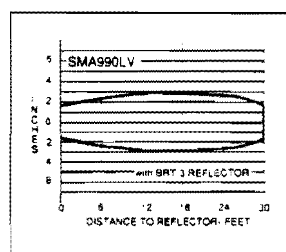




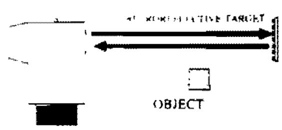
SMA990LV

Voltage: 10 to 250V ac or 12 to 115V dc
Range: 30 feet (9m)
Beam: visible red, 650nm

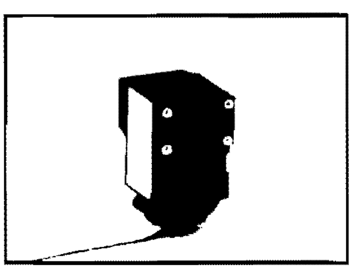




RETROREFLECTIVE MODE

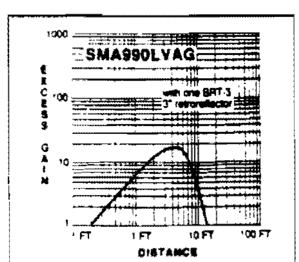


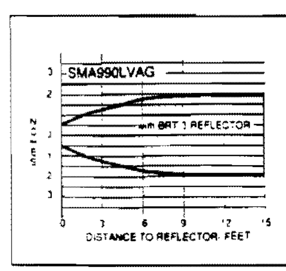
A visible-red light beam reduces the potential for false signals from highly reflective objects ("proxing") and simplifies alignment. *The AG (anti-glare) model polarizes the emitted light and filters out unwanted reflections,* making its use possible in applications otherwise unsuited to retroreflective sensing (and where reduced excess gain is acceptable). Maximum range with all units is attained when using the model BRT-3 3" corner cube retroreflector. See the Banner catalog for details about available retroreflective materials.



SMA990LVAG

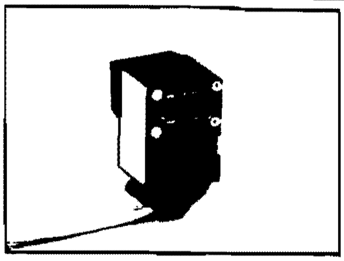
("AG"= anti-glare filter)
Voltage: 10 to 250V ac or 12 to 115V dc
Range: 15 feet (4.5m)
Beam: visible red, 650nm (with polarizing filter)





VALU-BEAM "990" Series Sensors

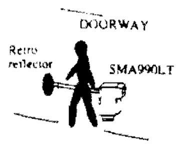
Sensing Mode	*Models*	*Excess Gain*	*Beam Pattern*

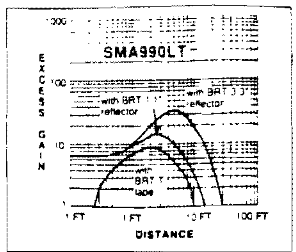


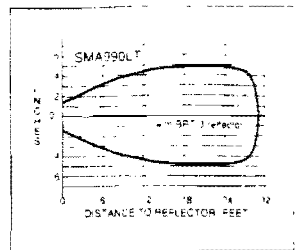
RETROREFLECTIVE MODE (continued)

SMA990LT

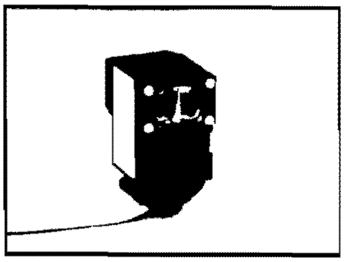
Voltage: 10 to 250V ac
or 12 to 115V dc
Range: 30 feet (9m)
Beam: infrared, 880nm



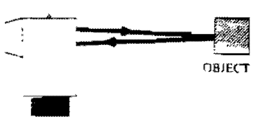




VALU-BEAM model SMA990LT is designed specifically for "people counting". Its strong (30 foot range) infrared beam is invisible to the eye, and a built-in one-tenth second on/off delay helps prevent multiple counts. Maximum retroreflective signal strength is attained when using the model BRT-3 corner-cube retroreflector. Other retroreflective materials may also be used (see the Banner catalog for descriptive information).

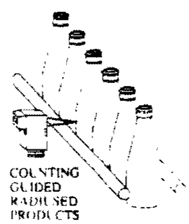


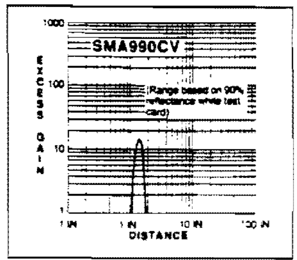
CONVERGENT MODE

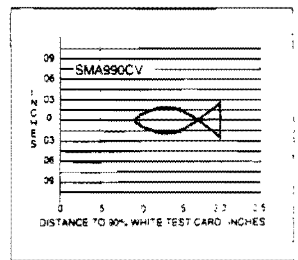


SMA990CV

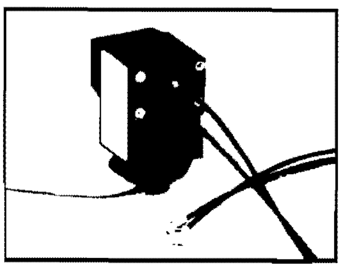
Voltage: 10 to 250V ac
or 12 to 115V dc
Focus at 1.5" (38mm)
Beam: visible red, 650nm





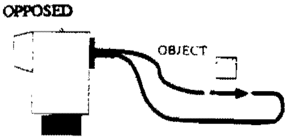


VALU-BEAM convergent sensors produce a precise .06" diameter visible red sensing spot at a focus point 1.5" in front of the sensor lens. Due to its very narrow depth of field, this model excels at counting small objects only a fraction of an inch away from backgrounds. This convergent sensor may be used for reliable counting of some radiused products which flow past at a *fixed distance* from the sensor lens.

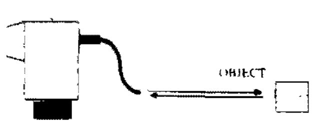


FIBEROPTIC MODE (*plastic* fiberoptics)

OPPOSED



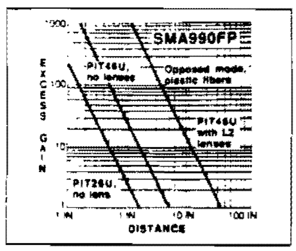
DIFFUSE

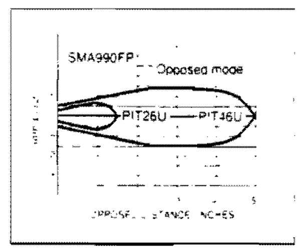


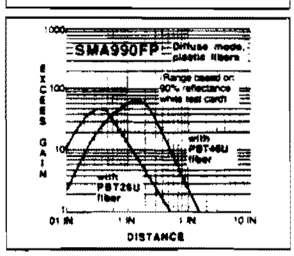
SMA990FP

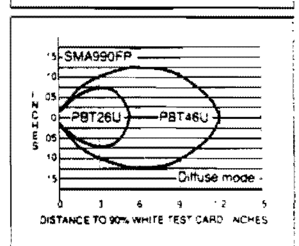
Voltage: 10 to 250V ac
or 12 to 115V dc
Range: see E.G. curves
Beam: visible red, 650nm

The powerful ***modulated visible beam*** of this sensor makes it compatible with all Banner ***plastic fiberoptic assemblies***. Banner plastic fibers are an economical alternative to glass fibers when environmental conditions allow (see below). Banner plastic fiberoptics are available in two core diameters and with various sensing tip styles. Standard length is 6 feet. More information on plastic fiberoptics may be found in the Banner catalog.









ENVIRONMENTAL FACTORS FOR PLASTIC FIBEROPTICS

OPERATING TEMPERATURE OF FIBEROPTIC ASSEMBLIES: -30 to +70° C (-20 to +158° F).
CHEMICAL RESISTANCE OF FIBEROPTIC ASSEMBLIES: the acrylic core of the monofilament optical fiber will be damaged by contact with acids, strong bases (alkalis), and solvents. The polyethylene jacket will protect the optical fiber from most chemical environments; however, materials may migrate through the jacket with long-term exposure. Samples of plastic fiberoptic material are available from Banner for testing and evaluation.

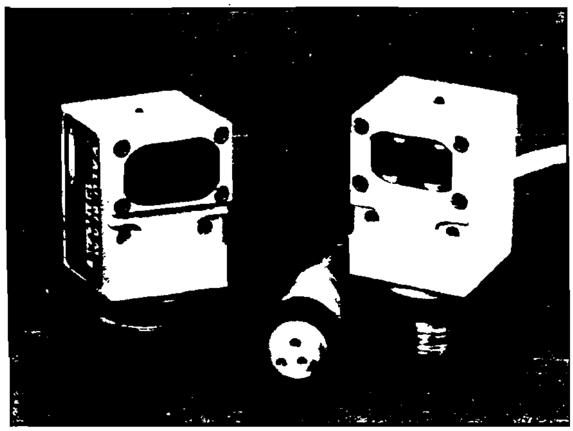
VALU-BEAM™ "912" Series

SM912 series dc sensors SM2A912 series 2-wire ac sensors

BANNER the photoelectric specialist

FEATURES:

- **SM912 series: 10-30V dc 3-wire operation**
  SM2A912 series: 24-250V ac 2-wire operation
- **All sensing modes available: opposed, retroreflective, diffuse (proximity), convergent, and fiberoptic**
- **Switch selectable light- or dark-operate**
- **Totally encapsulated circuitry in a rugged, molded plastic housing; NEMA 1, 2, 3, 3S, 4, 4X, 12, and 13**
- **Integral conduit fitting and 6' PVC-covered cable supplied on standard models; NEMA-4 Quick Disconnect ("QD") cable/connector combination optional**
- **Adjustable sensitivity** • **Versatile mounting options**



Banner "912" series VALU-BEAMs are a family of rugged, self-contained photoelectric sensors designed for especially demanding industrial applications where economy, performance, and durability are important.

"912" series VALU-BEAMs have solid state outputs and are available in either 10-30V dc-powered or 24-250V ac-powered models (see specifications, below). Powerful modulated LED light sources give "912" series VALU-BEAM sensors greater sensing range than competitive units and a high degree of immunity to ambient light. All models are totally epoxy-encapsulated and housed in molded Valox™ housings for the ultimate in shock, vibration, moisture, and corrosion resistance. All VALU-BEAM sensors conform to NEMA standards 1, 2, 3, 3S, 4, 4X, 12, and 13.

SM912 series DC sensors have one current sourcing (PNP) and one current sinking (NPN) open-collector output transistor, with each output capable of sinking 250mA continuous. SM-912 series DC sensors interface directly to PCs and other solid-state circuitry, including Banner "B" series modules, MICRO-AMP logic modules, and MULTI-AMP "CL" series modules (see hookup diagrams, page 6).

SM2A912 series 2-wire AC sensors connect in series with a load, exactly like a limit switch, and have a solid-state switching element which switches up to 500mA (60VA) continuous (4A inrush). SM2A912 series AC sensors interface directly to PCs, and also may be connected in series or in parallel with other sensors or relay contacts for applications requiring complex logic functions (see hookup diagrams, page 7).

All VALU-BEAM sensors have an easily-visible top-mounted red LED indicator to assist in alignment and system monitoring. SM912 series DC sensors have Banner's exclusive, patented AID™ system (Alignment Indicating Device, US patent #4356393) which lights the indicator LED whenever the sensor "sees" its modulated light source, and also pulses the LED at a rate proportional to the received light signal strength. This feature greatly simplifies alignment: in most situations, alignment becomes simply a matter of positioning the sensor for maximum LED pulse rate. On the SM2A912 series 2-wire AC sensors, the LED lights steadily whenever the load is energized.

VALU-BEAM "912" series sensors offer *a choice of light or dark operate in the same sensor*, switched via a convenient rear panel control.

VALU-BEAM sensors may be mounted from either the front or the rear using their two through-mounting holes, or by the outside threads of their base (mounting nut supplied), making them ideal for conveyor and other production line applications. A versatile 2-axis steel accessory mounting bracket (model SMB900) simplifies mounting and alignment. The bases of *standard* VALU-BEAMs have a 1/2" NPS integral internal conduit thread, and are supplied with a 6-foot PVC-covered cable. Models with a NEMA 4-rated quick-disconnect connector ("QD" models) are available optionally (page 8).

Specifications, SM912 series dc sensors:

SUPPLY VOLTAGE: 10 to 30V dc at 20mA, exclusive of load (except for SMA91E and EQD emitters, which operate from 10 to 250V ac or dc, 10mA max.).

OUTPUT CONFIGURATION: one current sourcing (PNP) and one current sinking (NPN) open-collector transistor.

(continued next page)

Specifications, SM2A912 series 2-wire ac sensors:

SUPPLY VOLTAGE: 24 to 250V ac (50/60Hz), except for SMA91E and EQD emitters, which operate from 10 to 250V ac or dc, 10mA max.

OUTPUT CONFIGURATION: solid-state switching element.

(continued next page)

VALU-BEAM "912" Series Sensors

(dc specifications, continued)

OUTPUT RATING: 250mA continuous, each output.

OUTPUT PROTECTION: protected against false pulse on power-up, inductive load transients, power supply polarity reversal, and continuous overload or short circuit of outputs.

RESPONSE TIME: 4 milliseconds ON, 4 milliseconds OFF (except reciever-only units, which are 8 milliseconds ON and 4 milliseconds OFF). 100 millisecond delay on power-up (outputs non-conducting during this time).

CONSTRUCTION: reinforced Valox™ housing, totally encapsulated, molded acrylic lenses, stainless steel hardware. Meets NEMA standards 1, 2, 3, 3S, 4, 4X, 12, and 13.

CABLE: 6' of PVC-jacketed cable standard; 2-conductor for emitters, 4-conductor for all other models. Quick-disconnect (QD) models available optionally.

ADJUSTMENTS: LIGHT/DARK OPERATE select switch and SENSITIVITY control potentiometer, both located on rear of sensor.

INDICATOR LED: exclusive, patented Alignment Indicating Device system (AID™, US patent #4356393) lights a top-mounted red LED indicator whenever the sensor sees a "light" condition, with a superimposed pulse rate proportional to the light signal strength (the stronger the signal, the faster the pulse rate). Model SMA91E emitter has a visible-red "tracer beam" which indicates "power on" and enables easy "line-of-sight" alignment.

OPERATING TEMPERATURE RANGE: -20 to +70 degrees C (-4 to +158 degrees F).

(ac specifications, continued)

OUTPUT RATING: 500mA (60VA) continuous, 4A inrush.

OUTPUT PROTECTION: protected against false pulse on power-up and inductive load transients.

RESPONSE TIME: 8 milliseconds ON, 8 milliseconds OFF (except receiver-only units, which are 8 milliseconds ON and 4 milliseconds OFF). 300-millisecond delay on power-up (outputs non-conducting during this time).

CONSTRUCTION: reinforced Valox™ housing, totally encapsulated, molded acrylic lenses, stainless steel hardware. Meets NEMA standards 1, 2, 3, 3S, 4, 4X, 12, and 13.

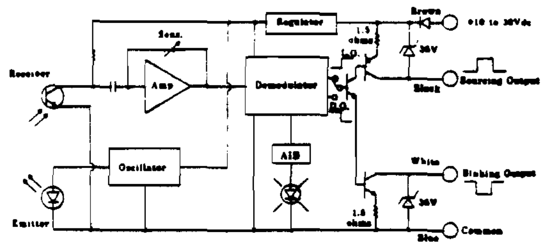
CABLE: 6' of PVC-jacketed 2-conductor cable standard. Three-pin quick-disconnect (QD) models are available optionally (one connector pin goes unused). Three-conductor cable for "QD" models must be purchased separately.

ADJUSTMENTS: LIGHT/DARK OPERATE select switch and SENSITIVITY control potentiometer, both located on rear of sensor.

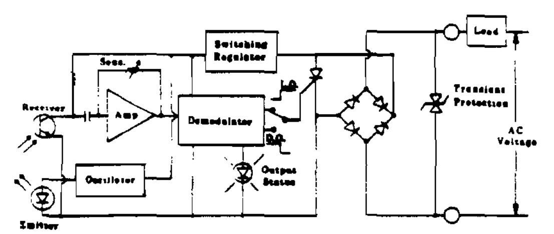
INDICATOR LED: top-mounted red LED indicator lights when output is conducting. Model SMA91E emitter has a visible-red "tracer beam" which indicates "power on" and enables easy "line-of-sight" alignment.

OPERATING TEMPERATURE RANGE: -20 to +70 degrees C (-4 to +158 degrees F).

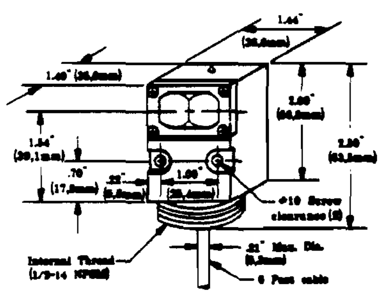
FUNCTIONAL SCHEMATIC, SM912 SERIES DC VALU-BEAM SENSORS:



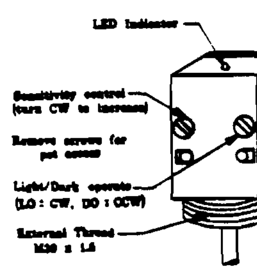
FUNCTIONAL SCHEMATIC, SM2A912 SERIES AC VALU-BEAM SENSORS:



DIMENSION DRAWING:

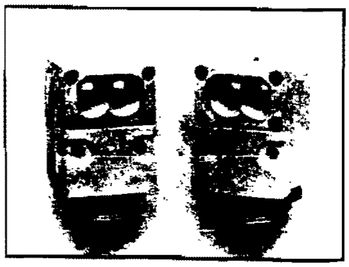


REAR VIEW:

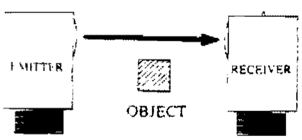


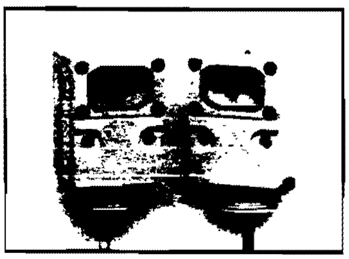
VALU-BEAM "912" Series Sensors

Sensing Mode | *Models* | *Excess Gain* | *Beam Pattern*



OPPOSED MODE





SMA91E & SM91R

Voltage: 10 to 30V dc, ("E": 10-250V ac/dc)
Range: 200 feet (60 m)
Response: 8ms on/4 off
Beam: infrared, 880nm; visible red tracer beam
Effective beam: 0.5" dia.

SMA91E & SM2A91R

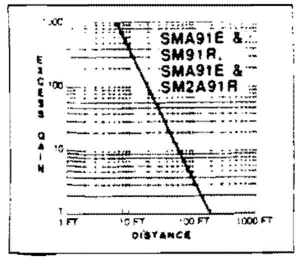
Voltage: 24 to 250V ac, ("E": 10-250V ac/dc)
Range: 200 feet (60 m)
Response: 8ms on/4 off
Beam: infrared, 880nm
Effective beam: 0.5" dia.

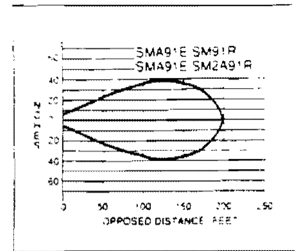
SMA91ESR & SM91RSR

Voltage: 10 to 30V dc, ("ESR": 10-250V ac/dc)
Range: 10 feet (3 m)
Response: 8ms on/4 off
Beam: infrared, 880nm
Effective beam: .12" dia.

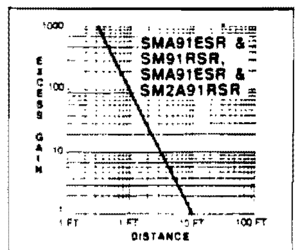
SMA91ESR & SM2A91RSR

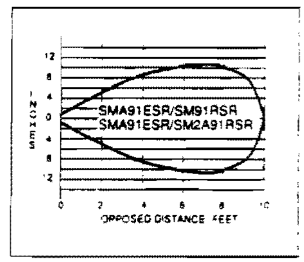
Voltage: 24 to 250V ac
Range: 10 feet (3 m)
Response: 8ms on/4 off
Beam: infrared, 880nm
Effective beam: .12" dia.

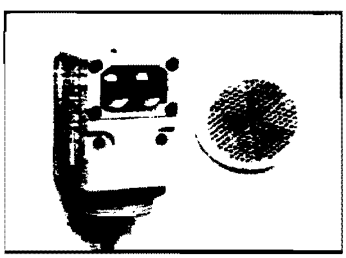




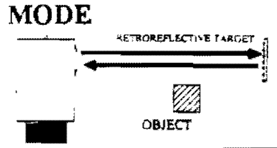
Opposed mode sensors have higher excess gain than other models, and therefore should be used whenever possible. The small size of these sensors makes them ideal for many conveyor applications, and their small effective beam size (particularly of the ESR/RSR models) enables them to reliably detect relatively small objects. VALU-BEAM opposed mode sensors have a visible red "tracer beam" which greatly simplifies sensor alignment. ESR/RSR models have a *wide* beam angle for very forgiving alignment within the 10 foot range. E/R models have a *narrow* beam spread and should be used when it is important to minimize optical "crosstalk" between adjacent emitter-receiver pairs at close range in multiple sensor arrays.

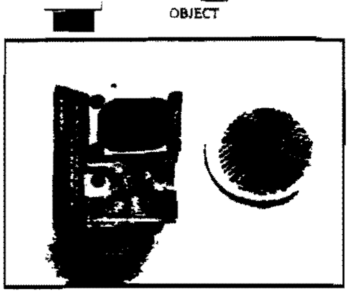






RETROREFLECTIVE MODE





SM912LV

Voltage: 10 to 30V dc
Range: 30 feet (9 m)
Response: 4ms on/off
Beam: visible red, 650nm

SM2A912LV

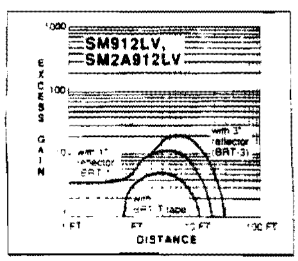
Voltage: 24 to 250V ac
Range: 30 feet (9 m)
Response: 8ms on/off
Beam: visible red, 650nm

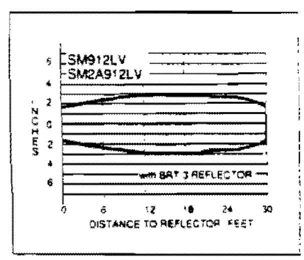
SM912LVAG

(anti-glare filter)
Voltage: 10 to 30V dc
Range: 15 feet (4,5 m)
Response: 4ms on/off
Beam: visible red, 650nm (with polarizing filter)

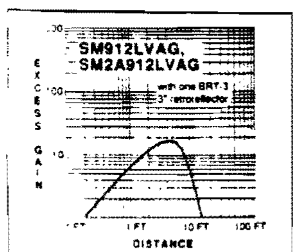
SM2A912LVAG

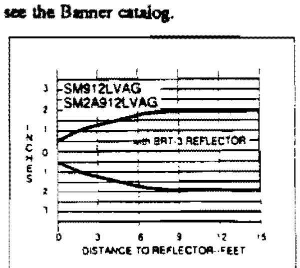
(anti-glare filter)
Voltage: 24 to 250V ac
Range: 15 feet (4,5 m)
Response: 8ms on/off
Beam: visible red, 650nm (with polarizing filter)





A visible-red light beam reduces the potential for false signals from highly reflective objects ("proxing") and simplifies alignment. *AG (anti-glare) models polarize the emitted light and filter out unwanted reflections,* making their use possible in applications otherwise unsuited to retroreflective sensing (when reduced excess gain is acceptable). Maximum range with "LV" units is attained when using the model BRT-3 3" corner cube reflector. For details on retroreflective target materials, see the Banner catalog.





VALU-BEAM Sensors

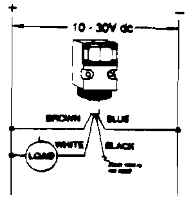
Hookup Diagrams for dc "SM912" Series Sensors

For emitter hookup, see below

NOTE: each output has a maximum load capacity of 250mA.

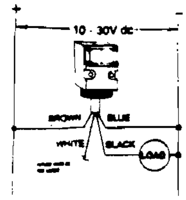
HOOKUP TO DC RELAY OR SOLENOID (using sinking output)

The diagram below shows hookup of a dc VALU-BEAM to a dc load using the sensor's *sinking* output, which is rated at 250mA maximum. The BLACK wire is not used.



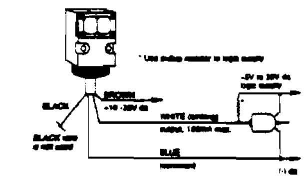
HOOKUP TO DC RELAY OR SOLENOID (using sourcing output)

The diagram below shows hookup of a dc VALU-BEAM to a dc load using the sensor's *sourcing* output, which is rated at 250mA maximum. The WHITE wire is not used.



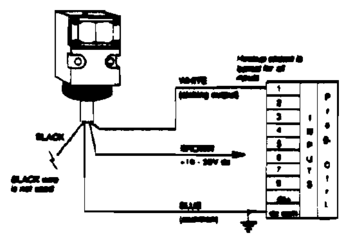
HOOKUP TO LOGIC GATE

The diagram below shows hookup of a dc VALU-BEAM to a logic gate. A logic zero (0 volts dc) is applied to the gate input when the VALU-BEAM output is energized. When de-energized, a logic one is applied. The logic supply negative must be common to the VALU-BEAM supply negative.



HOOKUP TO PROGRAMMABLE CONTROLLER (sinking output)

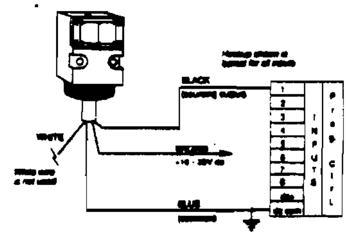
This diagram shows hookup of a dc VALU-BEAM to a programmable controller requiring a current sink, using the sensor's *sinking* output. The BLACK wire is not used.



Hookup shown is typical for all inputs.

HOOKUP TO PROGRAMMABLE CONTROLLER (sourcing output)

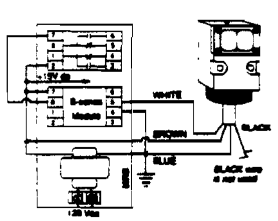
This diagram shows hookup of a dc VALU-BEAM to a programmable controller requiring a current source, using the sensor's *sourcing* output. The WHITE wire is not used.



Hookup shown is typical for all inputs.

HOOKUP TO "B" SERIES LOGIC (MRB chassis)

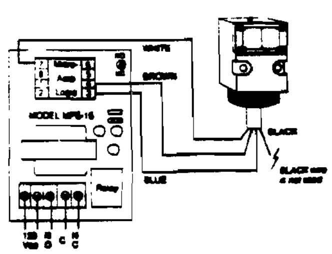
The current sinking output (white wire) of the VALU-BEAM is shown connected to the input (pin 5) of a "B" series module. It may be connected to the auxiliary input (pin 3) if desired. (See description of module for function of aux. input). Any Banner PLUG LOGIC module may also be used. However, Plug Logic modules require addition of a 250 microfarad (or greater) capacitor rated at 25 working volts (or greater) across the transformer secondary.



HOOKUP TO MICRO-AMP LOGIC (MPS-15 chassis)

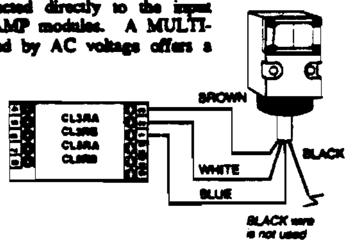
The current sinking (white) output of the VALU-BEAM is shown connected to the primary input (pin 7) of a MICRO-AMP logic module. It may be connected, instead, to the other inputs (see logic module descriptions in the Banner catalog). The following logic modules may be used:

MA4-2	One-shot
MA5	On/off delay
MA4G	4-input "AND"
MA4L	Latch

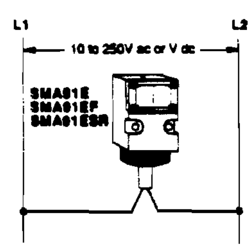


HOOKUP TO "C" SERIES LOGIC

The current sinking output(s) of VALU-BEAM sensors may be connected directly to the input of CL-series MULTI-AMP modules. A MULTI-AMP which is powered by AC voltage offers a DC supply with the capacity to power one VALU-BEAM sensor (see hookup diagram). When emitter/receiver pairs are used, the emitter should be powered from a separate power source.



EMITTER HOOKUP



DC polarity is without regard to wire color.

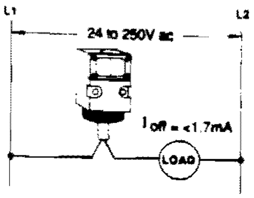
VALU-BEAM Sensors

NOTE. maximum load capacity of output is 500mA.

Hookup Diagrams for ac "SM2A912" Series Sensors

BASIC AC HOOKUP

VALU-BEAM 2-wire ac sensors wire in series with an appropriate load. This combination, in turn, wires across the ac line.

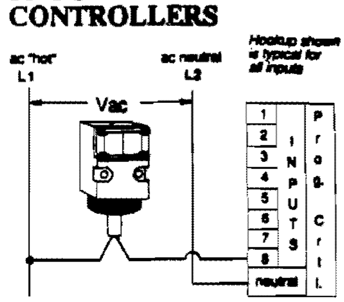


These sensors operate in the range of 24 to 250V ac, and may be programmed for either normally open (N.O.) or normally closed (N.C.) operation by way of the light-dark operate switch on the back of the sensor. A 2-wire ac sensor may be connected exactly like a mechanical limit switch.

The sensor remains powered when the load is "off" by a residual current which flows through the load. The off-state leakage current (Ioff) is always less than 1.7mA. The effect of this leakage current depends on the characteristics of the load. The voltage which appears across the load in the off-state is equal to the leakage current of the sensor multiplied by the resistance of the load: V(off) = 1.7mA x R(load).

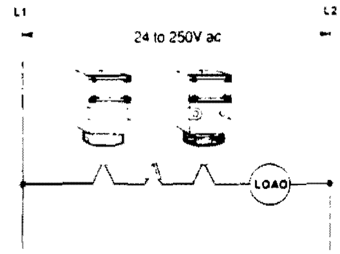
If this resultant off-state voltage is less than the guaranteed turn-off voltage of the load, then the interface is direct. If the off-state voltage causes the load to stay "on", then an artificial load resistor must be connected in parallel with the load to lower the effective resistance. Most loads, including most programmable controller inputs, will interface to 2-wire sensors with 1.7mA leakage current without an artificial load resistor. *These sensors are not polarity sensitive: all hookups are without regard to wire color.* ***WARNING: VALU-BEAM 2-wire ac sensors will be destroyed if the load becomes a short circuit!!***

CONNECTION TO PROGRAMMABLE CONTROLLERS



AC SENSORS IN SERIES

Multiple 2-wire ac VALU-BEAMs may be wired together in series for "AND" or "NOR" logic functions. The maximum number of sensors which may be wired in series to a load depends upon the level of the line voltage and the switching characteristics of the load. Each sensor connected in series adds an amount of voltage drop across the load. The amount of voltage drop that each sensor adds depends upon the current demand of the load. Each sensor in series adds approximately 5 volts drop across a 500mA load. A 15mA load will see about a 10 volt drop from each sensor added in series. To determine compatibility, compare the resultant on-state voltage across the load against the load's guaranteed turn-on voltage level (from the manufacturer's specifications).

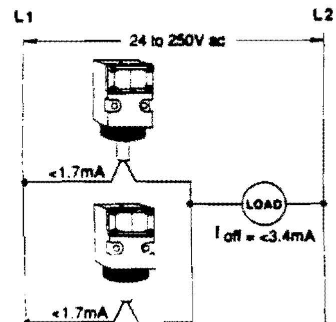


Most non-compatibility of series-connected sensors with loads occurs in low-voltage applications (e.g. 12, 24, or 48V ac circuits) where the on-state voltage drop across the load is a significant percentage of the supply voltage. The power-up inhibit time (up to 300 milliseconds per sensor) is also additive.

AC SENSORS IN PARALLEL

Multiple 2-wire ac VALU-BEAMs may be wired in parallel to a load for "OR" or "NAND" logic functions. With sensors wired in parallel, the off-state leakage current through the load is equal to the sum of the leakage currents required by the individual sensors. Consequently, loads with high resistance like small relays and solid state inputs may require artificial load resistors.

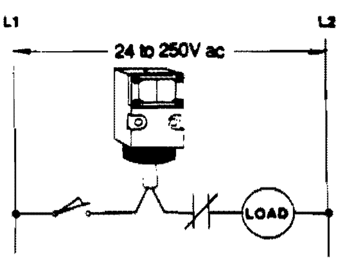
AC VALU-BEAMs wired together in parallel will *not* cause momentary drop-out of the load, as is experienced when wiring in parallel with contacts (see below). However, it is likely that the power-up delay feature will cause a momentary drop-out of the load if an ac VALU-BEAM is wired in parallel with a different brand or model of 2-wire sensor.



Contact the Banner applications group to verify compatibility.

AC SENSORS WITH SERIES CONTACTS

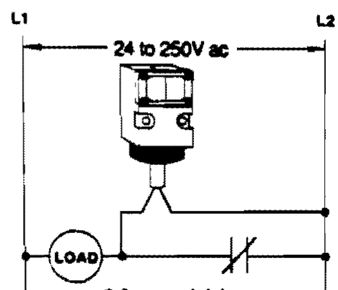
When 2-wire ac sensors are connected in series with mechanical limit switch or relay contacts, the sensor will receive power to operate only when all of the contacts are closed. The false-pulse protection circuit of the sensor will cause a 0.3 second delay between the time the contacts close and the time that the load can energize.



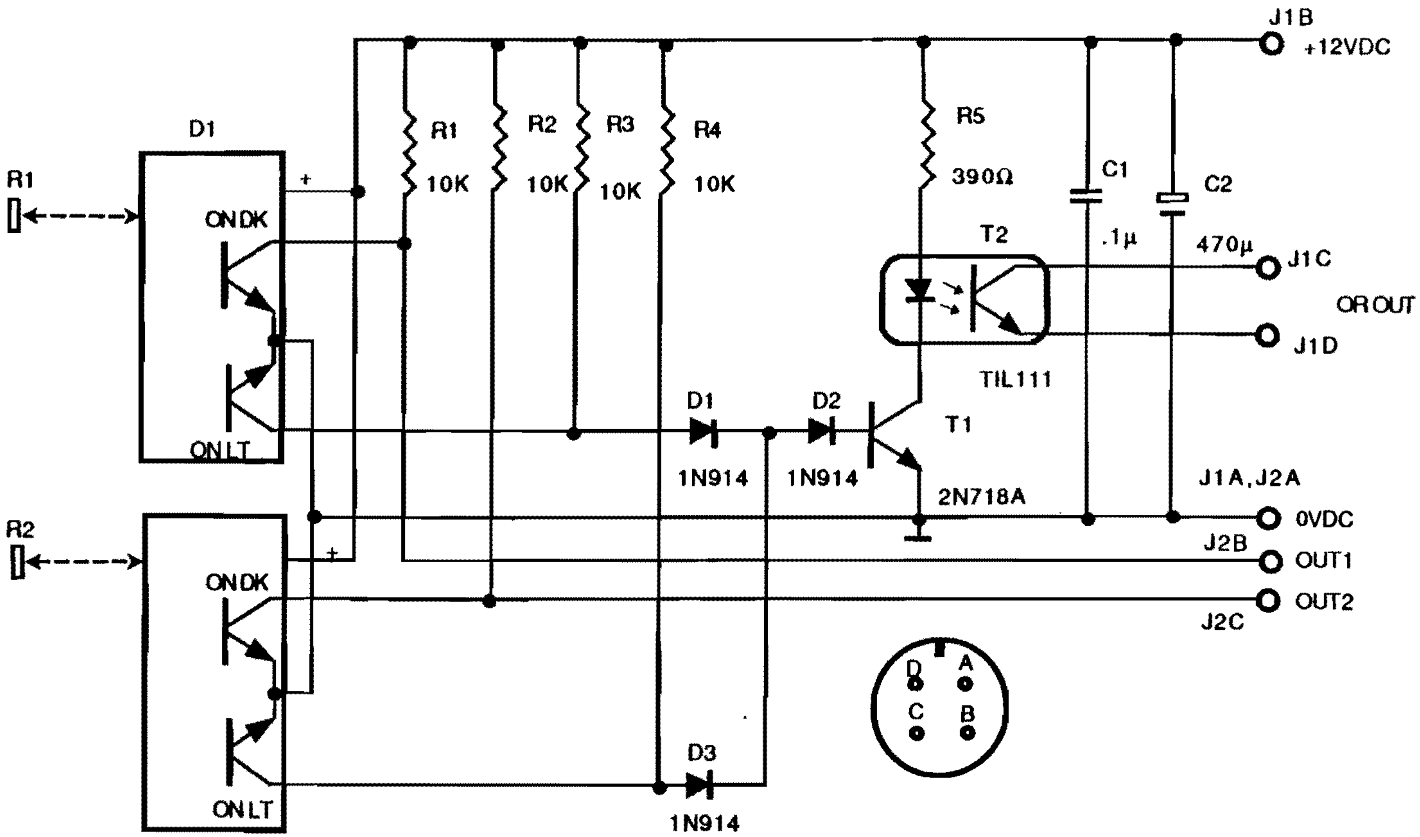
0.3 second delay when contact closes

AC SENSORS WITH PARALLEL CONTACTS

When 2-wire ac sensors are connected in parallel with mechanical switch or relay contacts, the sensor loses the current it needs to operate while any contact is closed. When all of the contacts open, the sensor's 0.3 second power-up delay may cause a momentary drop-out of the load.



0.3 second delay when contact opens



OR Gate Circuit Diagram of Infrared Sensors			
DESIGN	Huang, Liren	DATE	Jun. 4, 1990
Center for Transportation Research, University of Texas at Austin			

J1: A 0VDC
B +12VDC
C Isolated Solid State Output (Collector)
D Isolated Solid State Output (Emitter)

Fig A.7. Circuit diagram for HOV lane in Houston.

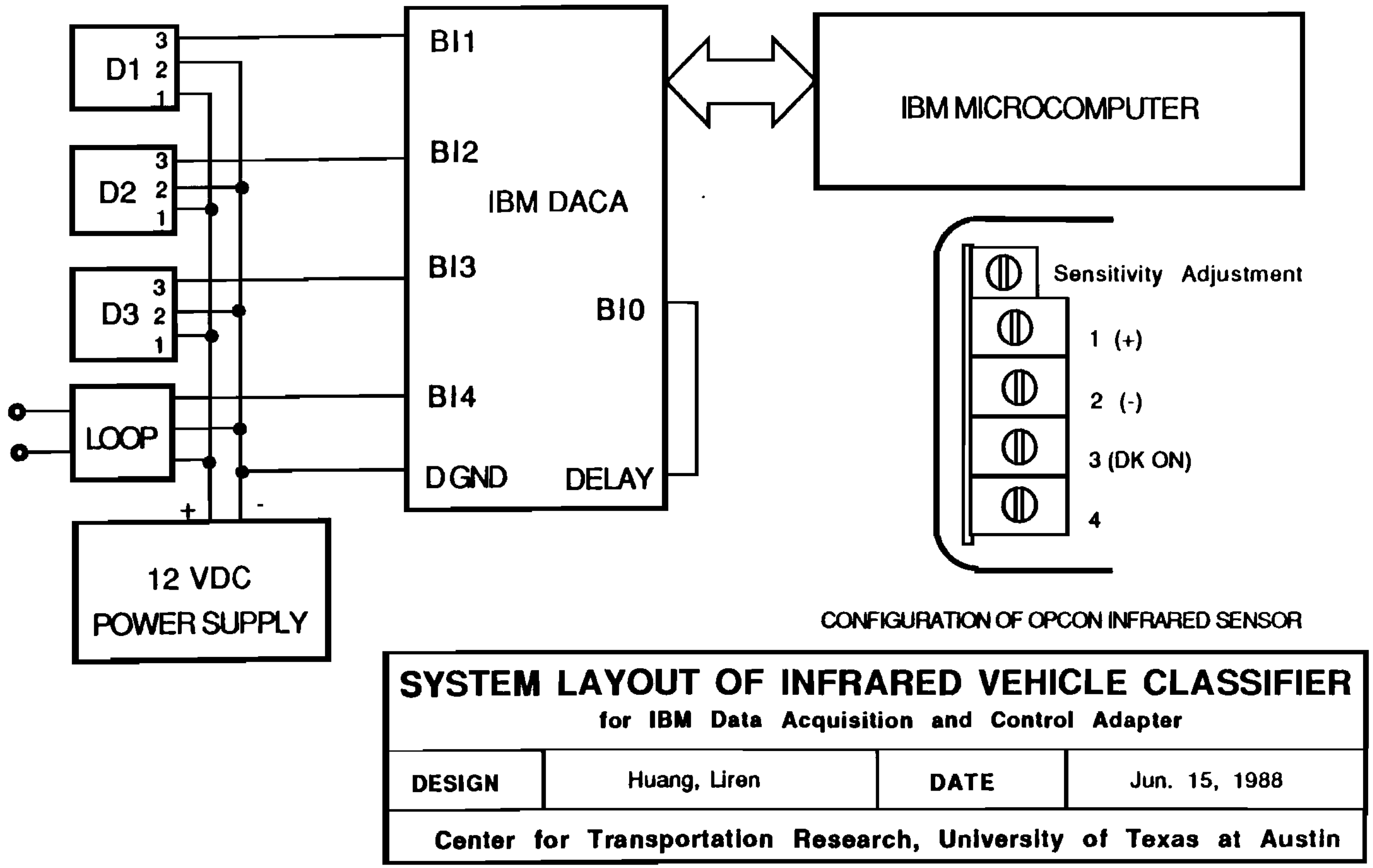
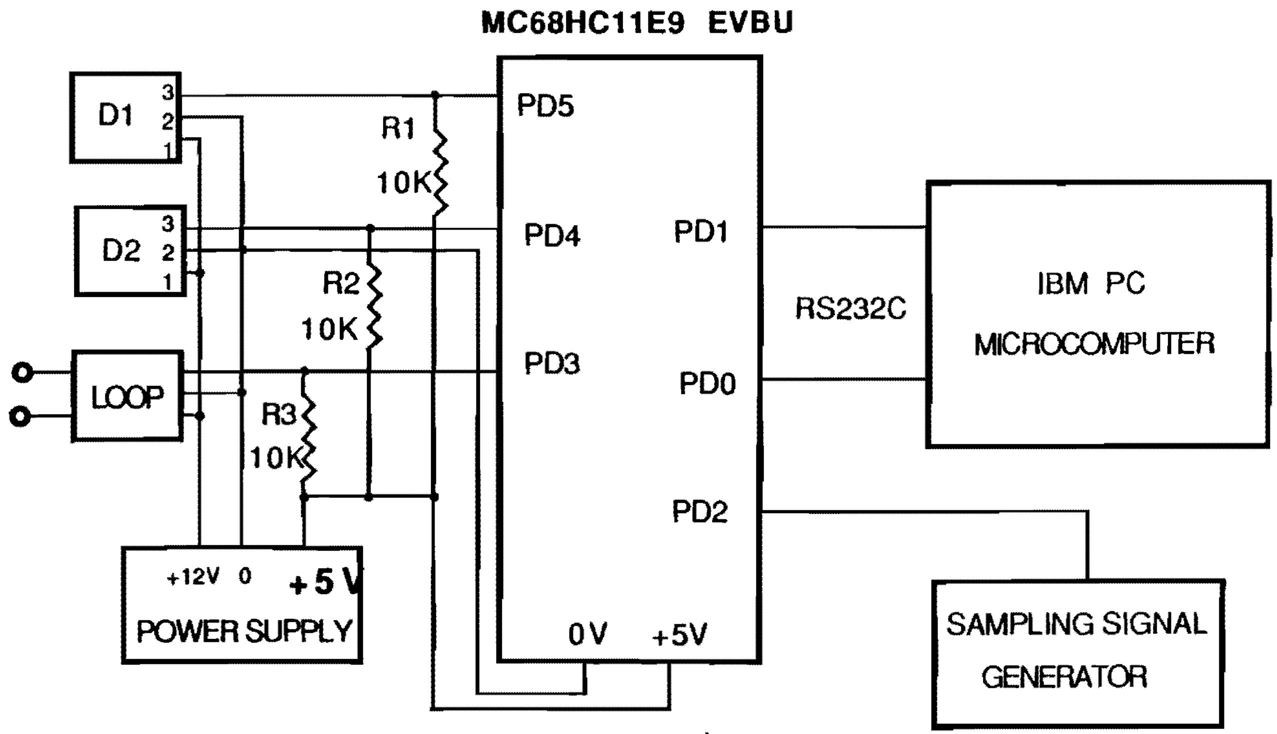


Fig A.8. System layout for three-sensor vehicle classification system.



SYSTEM LAYOUT OF INFRARED VEHICLE CLASSIFIER FOR MOTOROLA MC68HC11E9 EVBU			
DESIGN	Huang, Liren	DATE	Jan. 11, 1990
Center for Transportation Research, University of Texas at Austin			

Fig A.9. System layout for two-sensor vehicle classification system.