

# LASERLUX®:

## AUTOMATED REAL TIME PAVEMENT MARKING RETROREFLECTIVITY MEASUREMENTS

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### ABSTRACT

Laserlux, an automated real time mobile retroreflectometer is being used to measure the retroreflectivity of pavement lane markings. This vehicle-mounted retroreflectometer provides the measurements needed for proper highway pavement marking management. Quick, simple, reliable, objective, and inexpensive measurements at highway speed are the key to getting a statistically representative sample, without hindering the flow of traffic, nor putting the human operators at undue risk. The Laserlux retroreflectometer has repeatability within a tolerance of 10% as measured under supervised testing by the FHWA. The system can be used for various applications, such as implementing pavement standards, planning re-striping strategies, measuring performance of different materials application methods, holding contractors accountable, and establishing a pavement marking management data base.

### KEYWORDS

Retroreflectivity, Pavement markings, Stripe measurement, Night visibility, Striping.

### ACKNOWLEDGMENTS

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## 1. INTRODUCTION

### 1.1 Pavement Markings

Pavement lane markings (stripes) are an invaluable mechanism to facilitate the guidance of vehicles along the highways of the nation. They bring comfort to drivers who know that these markings can be relied on to keep them from driving off the road, to indicate when passing maneuvers may be safe, and to keep vehicles in organized

queues under multilane conditions. Pavement markings are so valuable that virtually any road with significant traffic is marked, and driving on roads that are not marked or poorly marked, results in more driver stress and fatigue, and potentially more vehicular mishaps. According to the Manual on Uniform Traffic Control Devices (1), markings have definite and important functions to perform in a proper scheme of traffic control. Section 3A-2 of the MUTCD states "Before any new highway, surfaced detour, or temporary route is opened to traffic, all necessary markings must be in place."

Millar (1) indicates that pavement markings reduce crashes by 21% and improve traffic flow, and concludes that on average every \$1 spent on pavement striping yields \$60 in benefits, with returns of up to \$103 on some classes of roads.

During daylight hours and under dry pavement conditions almost any type of marking would suffice. Under good ambient light conditions, simple painted lines would be adequate, reflecting and scattering light in every direction, so as to be visible from all angles. After dark however, the situation changes. Typically, the only source of lighting is directional, emanating from the headlamps of the vehicle travelling down the highway. In the case of simple painted lines, this light would then typically reflect off the pavement marking paint, in the direction of travel, not back to the vehicle where it can be seen by the operator. Consequently, painted markers may be difficult if not impossible to see at night, and are typically not used. Gu and Hubert (3) cite U.S. Department of Transport statistics showing that 56% of traffic fatalities occur at night, even though there is much greater traffic density during the day. According to the Traffic Control Devices Handbook (1), pavement markings must define the path of safe travel and must be clearly visible in daylight, in darkness and periods of adverse weather, such as rain or fog.

Highway administrators and engineers have improved this by embedding glass beads in the pavement markings, so the directional light from the headlamps is retro-reflected, with much of the light energy being retro-reflected back in the direction of the approaching vehicle (Figure 1). This solves the problem of poor night visibility, and even reduces the problem of poor visibility under wet conditions, providing of course that the film of water covering the road is not thick enough to cover and obscure the beads. Consequently, striped roads with properly emplaced beads offer a tremendous improvement in nighttime, and some improvement under wet weather conditions.

Unfortunately, pavement markings deteriorate with time. Ultraviolet light and heat from the sun can deteriorate the binder, releasing the beads. Abrasion from traffic, snowplows, and sand can wear off the beads. The action of chemicals (primarily road salt) can result in significant deterioration. Ultimately, all or most of the beads will disappear, and the beneficial effect of the beads is also gone. Ultimately, each road must be re-striped. The decision of where and when to re-stripe has in the past been rather arbitrary and unscientific in the absence of reliable data.

## **1.2 Measurement of Pavement Markings**

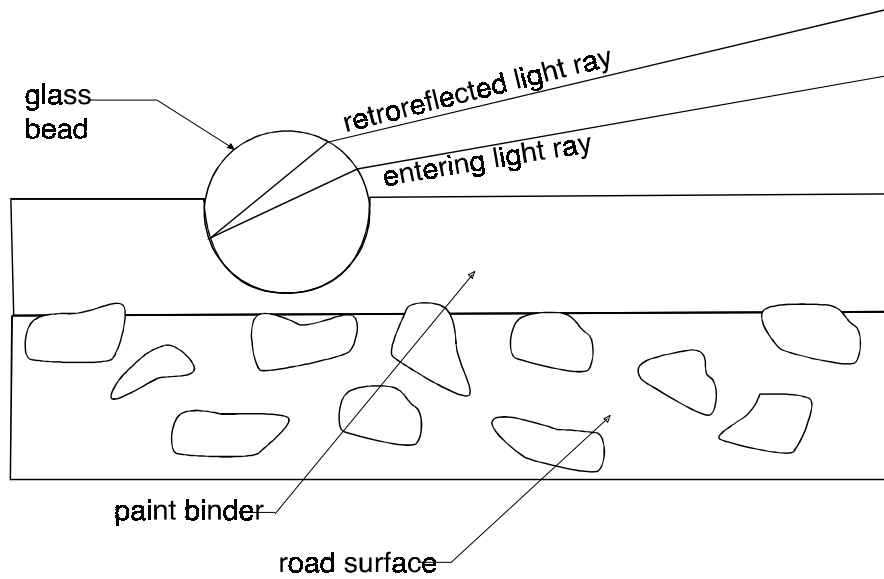
The science of measuring pavement markings is relatively young. Portable hand-held units have had mixed success in the past. Gu and Hubert, (3) give reviews of various handheld units. These measurements were in the past better than no measurements, but the measurements were highly variable. There was typically poor correlation between measurements made by different units, because of different geometries or different hardware implementations. It was also difficult to get reproducibility, because of the typically high spatial variability of the pavement stripe.

Today, the inadequacies of handheld units are obvious. They are too slow and cumbersome to acquire the large number of samples required, and their use puts the operators of the units at undue risk from traffic

Handheld units operate in a static mode. Consequently they are severely limited in the number of measurements that can be made. Typically, the units must be positioned, the measurement taken, and then recorded. Even with digital data logging equipment, manual measurements are limited and require a full time operator and result in only 500-1000 measurements per man-shift. This is certainly not cost effective, and provides a sample that is far too small for large road networks.

In addition, the use of handheld units requires that the road/lane being measured be closed to traffic. In many jurisdictions this is unthinkable. Equally unthinkable is the prospect of putting the operator of handheld equipment at risk by making measurements without closing the road/lane to traffic.

More recently, measuring units using laser light rather than incandescent sources have been used. An Ontario Ministry of Transportation study indicated that there was a very good correlation between the two light sources (3).



**Figure 1. Geometry of retroreflectivity. Light ray enters the glass bead, gets refracted, travels through the bead, and gets internally reflected off the rear of the bead, and exits the glass bead and gets refracted back into the general direction of the incoming light ray.**



**Figure 2. Picture of a Laserlux unit mounted on the side of a Roadware data acquisition platform.**

### 1.3 Laserlux

Laserlux, a real time scanning retroreflectometer (Figures. 2-4) was developed for the purpose of providing simple, reliable, objective, and inexpensive high speed marking surveys, needed for the management of highway infrastructure.

The Laserlux hardware is typically installed in a van that can be driven at highway speeds while collecting data a rate of up to 32,000 measurements per hour. The system utilizes a laser beam, and consequently can be used under all ambient light conditions, from bright sunlight to total darkness. The unit uses 1/3 scaled geometry using either standard North American or European (CEN) geometry.

The Laserlux software<sup>®</sup>, uses the QNX<sup>®</sup> real time operating system to facilitate approximately 9 stripe measurements per second, consisting of 200 sampling points for each measurement, with an incoming data frequency of approximately 100 MHz during each measurement. In real time, (9 times per second) the Laserlux software identifies the stripe within a 1.07 m scan width, calculates the peak retroreflectivity, displays it to the user console, and retains the retroreflectivity measurement. Over the distance of a user selected station interval, the mean retroreflectivity is reported, as well as the variability. The user video console display can be superimposed on a video image of the actual stripe being measured (Figure 5). Optionally, event codes for different conditions can be entered by keyboard, and become part of the record.

In terms of productivity, the Laserlux unit is up to 400 times as efficient as a handheld unit.

## 2. LASERLUX HARDWARE

### 2.1 Principle

The Laserlux retroreflectometer was developed by Potters Industries Inc., who hold the patent for this unit. The unit uses the principle of a scanning laser to deliver a beam of coherent light to the pavement stripe. The laser light is retroreflected back to the unit ( Figures 3, 4), where it is detected by an optical detector. Units of measurement are millicandella per meter squared per lux ( $\text{mcd}/\text{m}^2/\text{lx}$ ).

The Laserlux unit is designed to use a 1/3 scaled geometry, measuring the pavement markings at a distance of 10 m (Figure 4). The co-entrance angle can be set at either the Old North American Standard of  $1.5^\circ$  (4), or the European Committee for Normalization angle of  $1.24^\circ$  (5). The observation angle is fixed at  $1^\circ$ .

The window of measurement on the pavement covers an area of approximately 1.07 m wide by 0.20 m deep.

### 2.2 Laser Path

The Laserlux unit utilizes a 10 milliwatt 632 nm coherent light source to measure retroreflectivity. The beam is transmitted or reflected through a series of lenses and mirrors (Figure 6), including a double sided rotating mirror, which acts to “sweep” the beam across the forward field of view at a rate of about 9 rotations per second

Whatever portion of the beam is retroreflected from the pavement markings, (and typically a very small amount of direct reflection off pavement components) returns to the Laserlux unit, and is again transmitted or reflected through a series of lenses, filters and mirrors, including the back of the rotating mirror.

Synchronization of the outgoing beam and the return beam is facilitated by the simultaneous use of both sides of the rotating mirror. The mirror also triggers a hardware interrupt to indicate the beginning of the active sweep.

The return beam moves through a series of interference filters, used to reject ambient light, and is measured by an optical detector. The signal is then conditioned by a specially designed high gain amplifier, and sent to the central data acquisition computer (CDAC).

### 2.3 Data Acquisition

The electrical signal is digitized by a 12-bit 100 kHz analog to digital (A/D) converter in the CDAC. This is a continuous process, with each scan consisting of 200 samples being digitized in short 2 millisecond bursts, with approximately 9 scans per second. The initiation of digitizing is triggered by a hardware interrupt from the rotating mirror.

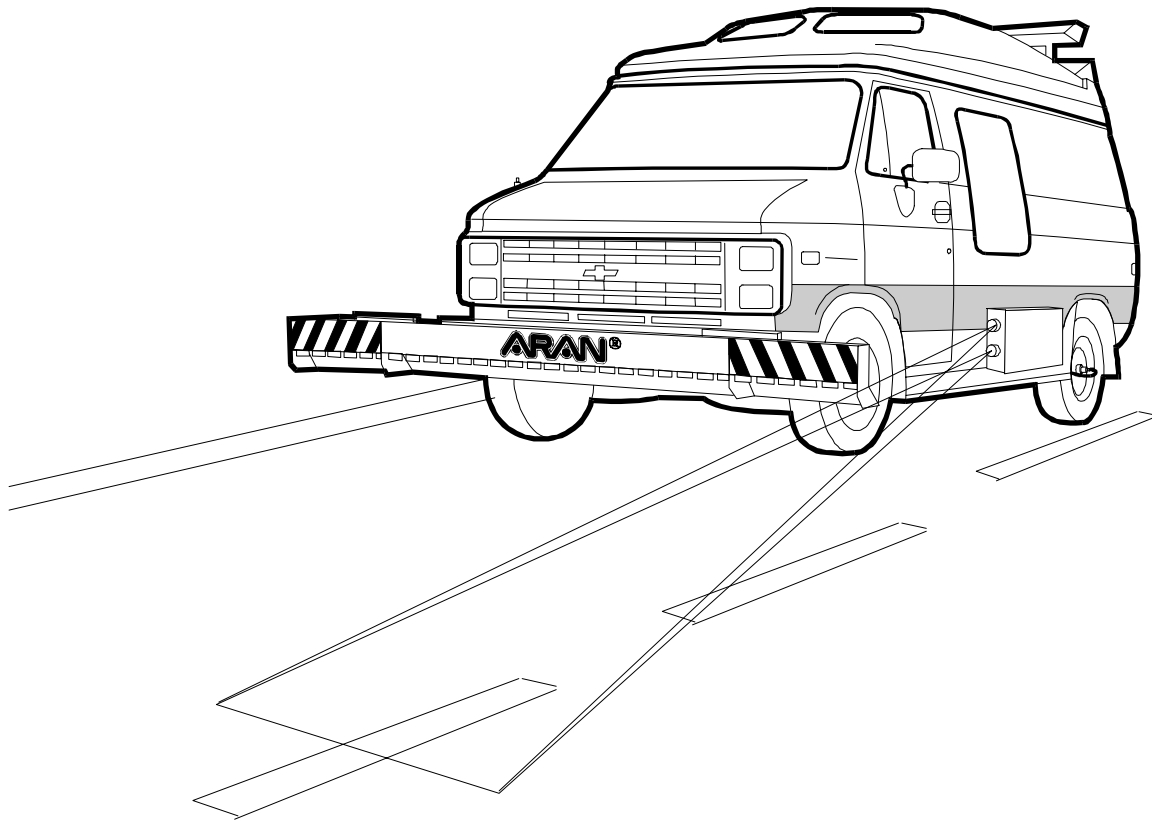


Figure 3. Schematic of the scanning laser path.

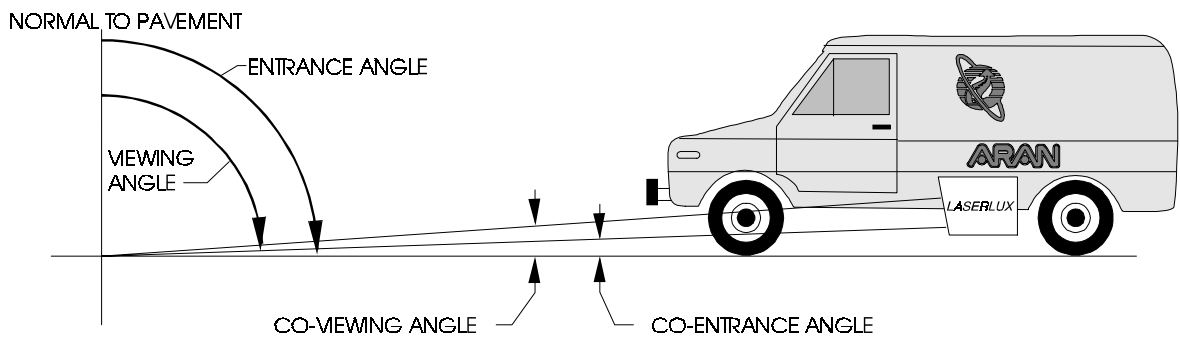


Figure 4. Laserlux geometry. The co-entrance angle can be set at either the Old North American Standard of  $1.5^\circ$ , or the European Committee for Normalization angle of  $1.24^\circ$  (CEN, 1995, ASTM, 1995). The observation angle is fixed at  $1^\circ$ .

The Laserlux unit features digital controls on the mirror rotation, laser, and a tilt motor to adjust the vertical alignment of the unit. It has a feedback signal to indicate the tilt position, and a temperature signal to indicate operating temperature.

The unit also features a distance measuring instrument (DMI) attached to the wheels of the vehicle. This DMI unit provides electrical pulses to the CDAC, correlating to distance traveled. A timer/counter card in the CDAC accumulates distance traveled (chainage) in the form of a cumulative tick count.

## **2.4 Video**

The Laserlux unit has video camera incorporated into the unit, which images the exact part of the roadway being scanned by the laser. In conjunction with a dash-mounted monitor, the video camera is normally used to aim the Laserlux unit, and can be used by the driver for vehicle guidance in terms of centering on the stripe.

Alternatively the video image can be recorded on video tape during data collection, with the Laserlux data screen superimposed over the image of the stripe, using a video overlay card.

## **3. LASERLUX SOFTWARE**

### **3.1 Operating System**

The Laserlux software<sup>®</sup> is based on the QNX<sup>™</sup> operating system. QNX is a UNIX-like operating system, however, with the additional ability to prioritize tasks. QNX is considered a “real-time” operating system because of its advanced interrupt handling and task prioritization capabilities. This makes it ideal for the complex data handling requirements of the Laserlux system.

The software is coded in the “C” language, and uses a text based interface (Figure 7). This is to reduce computational overhead on the CDAC.

### **3.2 Data Acquisition**

The acquisition of retroreflectivity measurements from the A/D converter to the CDAC is done by the use of an interrupt handler, which has the highest priority of any of the tasks on the system. Consequently, the CDAC is always prepared to handle the stream of 200 data points over a 2 ms timeframe every 1/9 sec. The synchronization of the data stream with the data acquisition system is achieved by the use of a hardware interrupt.

Periodically, the CDAC will call for temperature and retroreflectometer tilt position measurements. These measurements are also handled through the A/D converter. However, they are sequenced so as not to interfere with the primary data acquisition of the retroreflectivity data. If the tilt is out of position, it is corrected by the software in real time using digital control signals.

Periodically, the CDAC will call for chainage measurements. These are available on the accumulator of the timer/counter card.

### **3.3 Data Reduction**

The timing of the reduction of the scan data of 200 sampling points to summary data for each scan takes place using two different methods. For skip lines, the data reduction is done immediately after acquisition. For continuous lines, the data reduction is done only for the last scan during a “sampling interval”, which is typically about 3 m of travel down the highway. The purpose of this methodology is to make the measurement as independent as possible of vehicle speed.

The actual data reduction consists of identifying the peaks in the scan, choosing the one or two most prominent and calculating the average peak retroreflectivity across each stripe. Figure 8 shows a single scan, indicating dual stripes. Each scan is displayed to the CDAC screen (Figure 7) and the peak retroreflectivity is reported below the graph. Scan data is normally discarded after peak retroreflectivity has been calculated, but samples can be recorded by the computer for later review of the retroreflectivity profile.

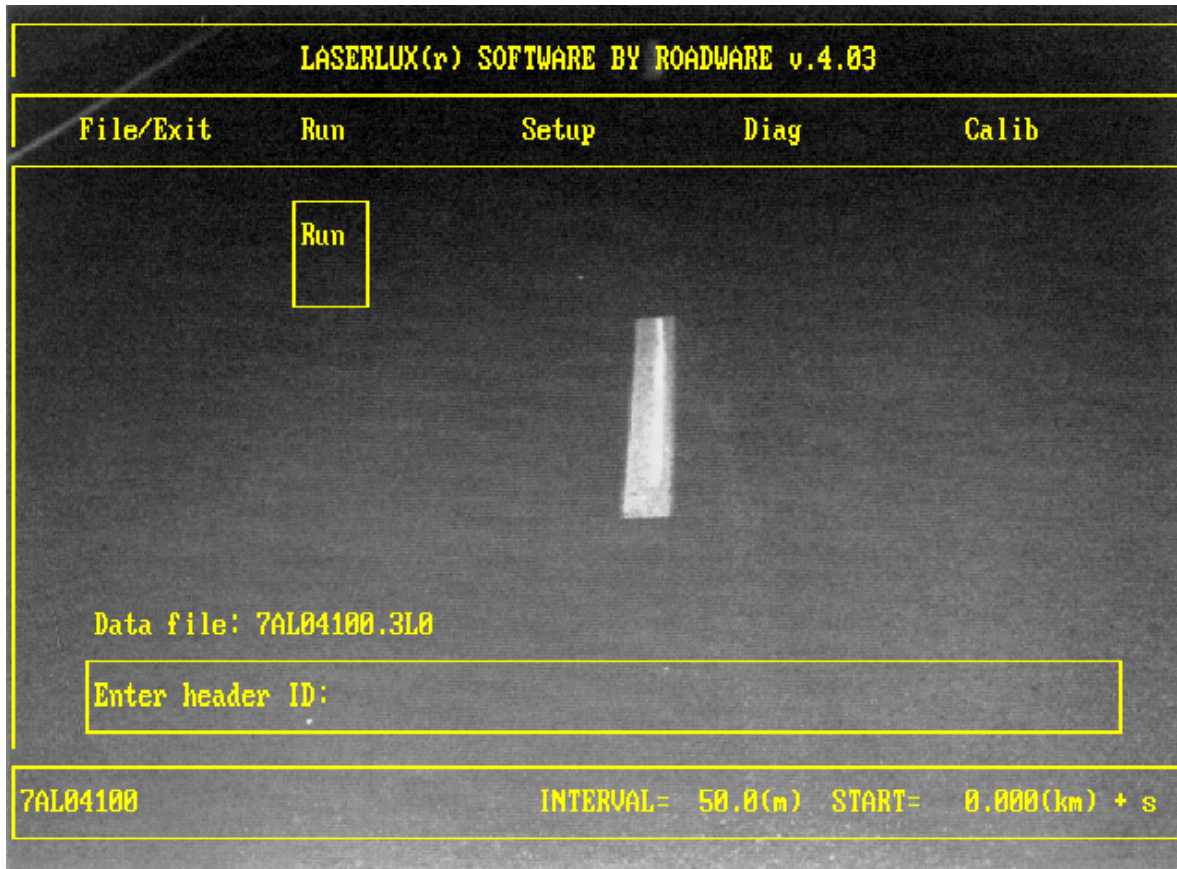


Figure 5. Overlay of the Laserlux console display on the road video.

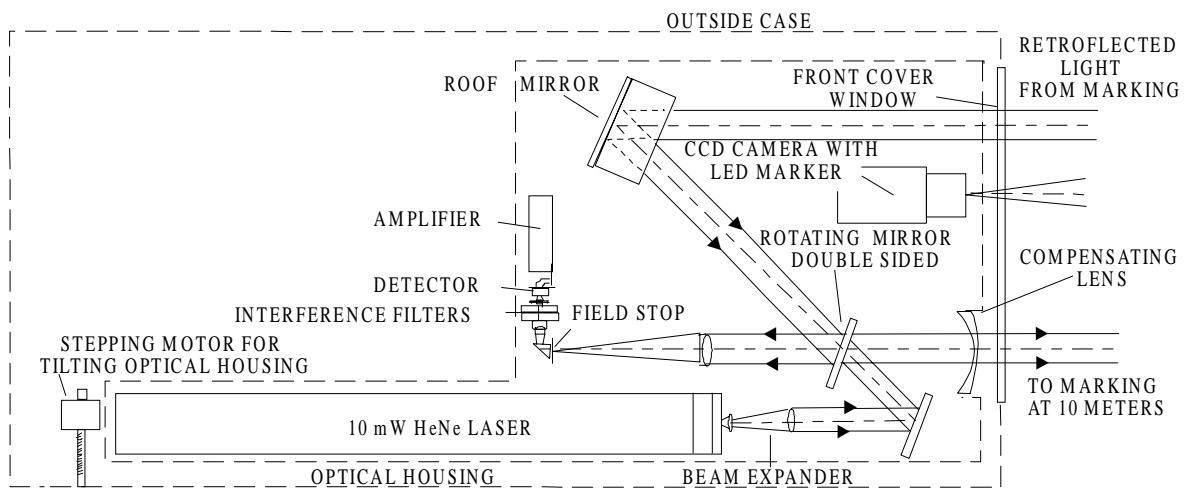


Figure 6. Optical diagram of the Laserlux unit.

### 3.4 Data Summary

Data is summarized on the basis of operator selected station intervals. All peak retroreflectivity measurements are stored until the end of the station interval, at which time these data are summarized, and the peak retroreflectivity measurements are discarded.

### 3.5 User Interaction – Event Codes

During the course of data collection, the user interacts with the Laserlux system via the CDAC keyboard. There are two classes of events. The first class is series of events that affect the data collection process:

- Stripe color, (W)hite or (Y)ellow—Software switches between white and yellow calibration factors
- Number of lines, (O)ne or (T)wo—Software switches between single and dual line modes.
- Line type, (S)kip or (C)ontinuous—Software switches between chainage based sampling, and time based sampling with probabilistic correction.
- (L)eft skip—Software assumes left line is skip and right line is continuous if two lines are found.
- (R)ight skip—Software assumes right line is skip and left line is continuous.
- Data Validity (V)alid or (I)nvalid data—Software switches between processing the incoming data and ignoring it.

The second class of events are user defined. These have no affect on the operation of the software, and are used rather for the purpose of clarification of output charts only. Examples of such events could include such things as concrete or asphalt pavement, construction zones where pavement markings may be obscured, bridges, exits, or intersections, where pavement markings may be missed due to driving wander, or the need to avoid traffic.

### 3.6 Reporting

A report in the form of an ASCII file is made at the end of the run, when data acquisition is shut down. The following items are reported at the end of each station:

- the chainage (distance traveled, in the units specified at the beginning of the run)
- the mean retroreflectance over the last station interval
- the number of valid scans (scans returning appropriate data)
- the number of invalid scans (scans not returning appropriate data)
- the number of dual valid scans (scans returning appropriate data for dual lines)
- the mean retroreflectivity of the right line
- the mean retroreflectivity of the left line
- the mean speed (in km/h or mph) over the station interval
- the mean retroreflectivity of the road pavement
- the event code
- the standard deviation of the average retroreflectivity
- the standard deviation of the average right retroreflectivity
- the standard deviation of the average left retroreflectivity
- the number of invalid scans due to raised pavement markers
- the temperature inside the measurement unit in degrees Celsius

In addition, the overall mean retroreflectivity and standard deviation of all valid measurements over the length of the run are reported.

A graphical plot of the data can be generated from this report (Figure 9).

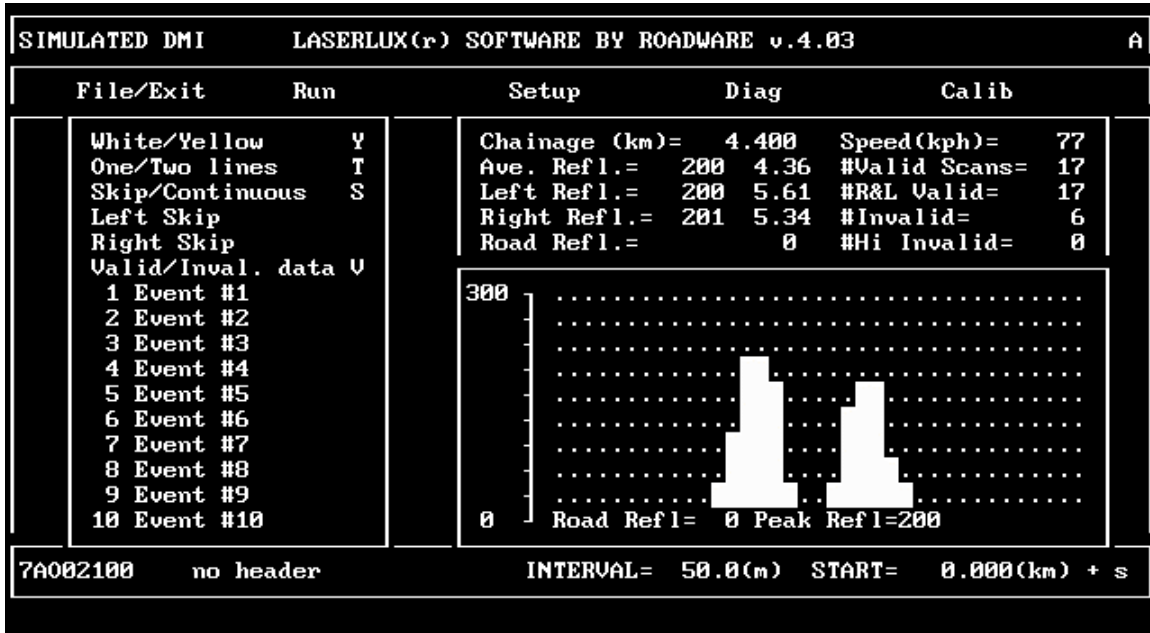


Figure 7. Main runtime Laserlux screen .

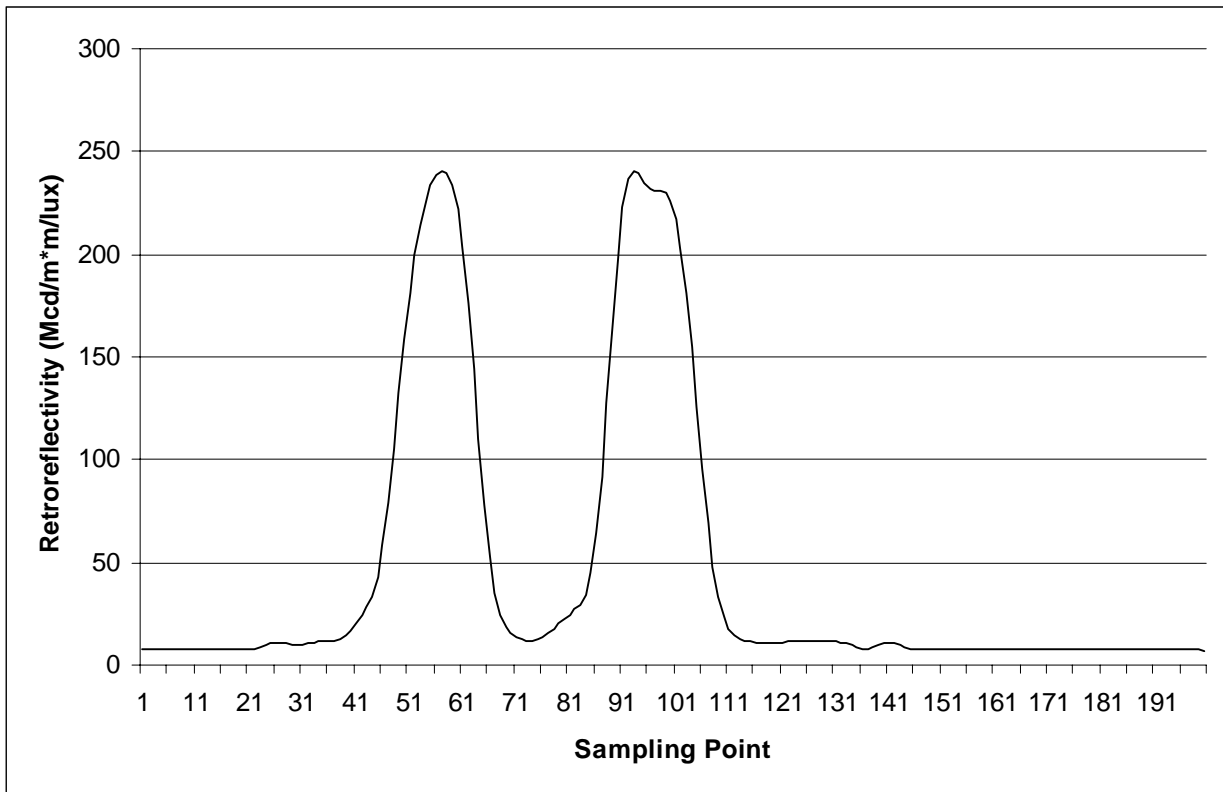


Figure 8. Example of a raw single Laserlux scan across a 1 m section of pavement, showing the retroreflected signal from a double painted stripe, plus reflectance from the road surface, uncorrected for residual ambient light.

## 4. PERFORMANCE

### 4.1 Accuracy and Repeatability

Standards of accuracy for measuring retroreflectivity of pavement markings are evolving. Currently, there are no absolute “ground truths” or benchmarks with which to measure retroreflectance. While various manufacturers of handheld and mobile instruments produce repeatable results amongst their own devices, no single traceable standard has been yet established. Laboratory instruments often measure test panels in a manner that cannot be easily duplicated by handheld or mobile devices with complete assurance. Some standardization of methods has been established for handheld instruments by ASTM (7). Not only do different instruments measure the same test panel with different results, but also test panels themselves may vary significantly from one manufacturer to another.

Until such time as a universal standard is available, working standards must be used by agencies seeking to establish performance specifications for pavement marking quality and instruments. These working standards have been established by several states by specifying a particular instrument or test panel as the truth. This is an important issue both to establish safety levels, as well as to monitor performance levels of materials and contractors.

In whatever way these standards, or ground truths, are established, there must be correlation between readings of one manufacturer and another. Laserlux was engineered with a software calibration capability that provides the confidence that markings measured by one model of handheld instrument can be repeated by the mobile instrument. This calibration can be performed in the field as frequently as desired by the operator or as department policy dictates. A test panel, representing the truth, is used to set the Laserlux calibration during the initial setup before a measurement mission. This takes approximately 10 minutes. Separate calibrations can be made for yellow or white markings if desired. The test panel is usually a one meter metal panel which has its retroreflectance value marked on the back and the direction that the measurements must be made. It is important that this panel is measured at regular intervals by the handheld or laboratory instrument to ensure its value remains unchanged due to handling or mechanical damage. It should be as uniform along its linear length as possible to prevent variation. Periodic comparisons with field markings should also be made to be certain the mobile unit continues to correlate with the handheld instrument. Obviously, it is not possible to take most laboratory instruments to the field or take a field marking to the laboratory so a hand held unit is the most realistic method of checking consistency.

The precision required of this type of measurement is up for debate. A 10% error level is commonly talked about in terms of a standard. This type of precision is, however, still much greater than is can be perceived by the human eye. A recent study has confirmed that there are significant human physiological differences that result in large differences in perception between, for instance, a group of old and a group of young drivers (8). This particular study cited 50 to 60% differences in the distance that a marking was first observed between the old and young drivers.

The results to date confirm that Laserlux does, in fact, produce repeatable measurements well.

### 4.2 Roadware Tests

Tests conducted at the Roadware facilities in Paris, Ontario, Canada typically result in repeatability within 5%, for the same two-km stretch of road measured on three consecutive runs with the same Laserlux unit. Figure 10 shows an example of 3 sequential measurement runs conducted recently, in which overall run average retroreflectivities were measured at 275, 276, and 274 mcd/m<sup>2</sup>/lux. This resulted in 95% confidence limits of less than 1%. Differences between vehicles can usually be attributed to the effects of driving wander (Figure 10).

### 4.3 FHWA Acceptance Tests

Tests conducted during acceptance trials by the FHWA in 1995 are reproduced in Figure 11. FHWA had purchased five Laserlux equipped vehicles as demonstration units and required them to pass a series of tests on delivery. It was important that not only should each unit prove repeatable with itself over several passes on the same section of highway, but that measurements made by other Laserlux vehicles also show good correlation.

The tests were conducted at the Roadware facility in Kylertown, Pennsylvania, USA, using the five different Laserlux vehicles, measuring a one mile stretch of interstate highway, showed overall run average retroreflectivities of 169, 158, 153, 162, and 176 mcd/m<sup>2</sup>/lux (Figure 11). This results in 95% confidence limits of about 11%. Measured differences between vehicles in this case were systematic, most likely as a result of differences in calibration.

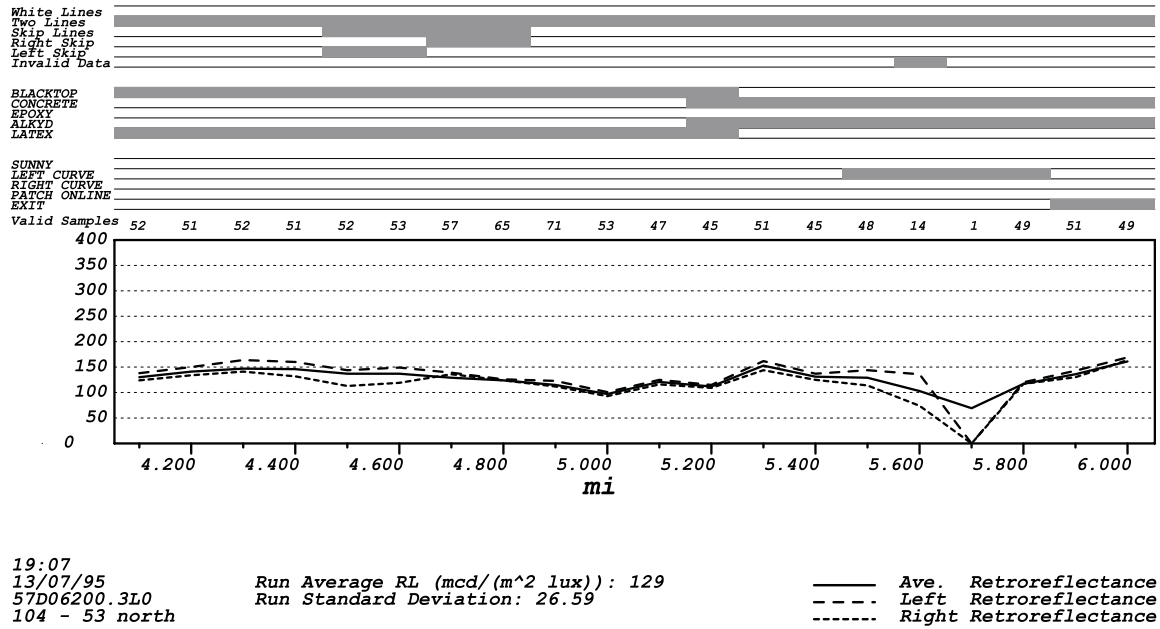


Figure 9 Graphical output of a Laserlux report, showing the left and right stripe retroreflectance values and superimposed event tracks.

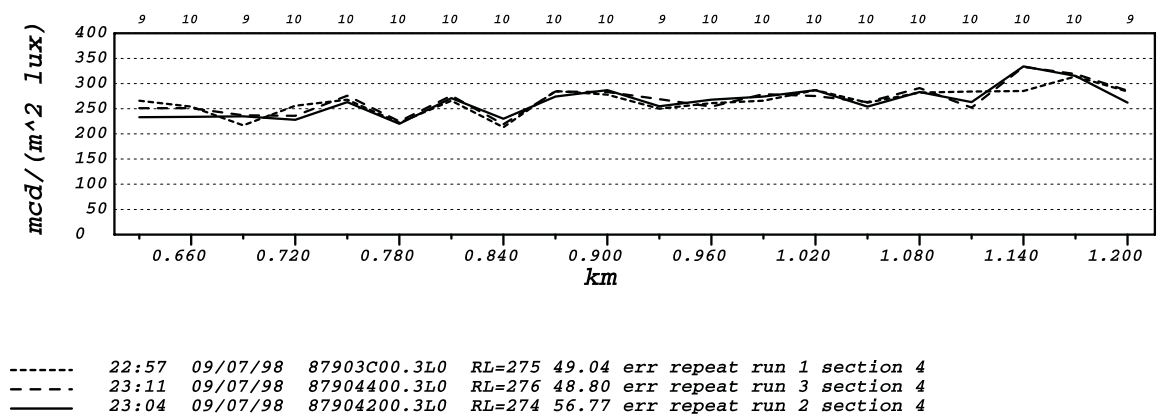
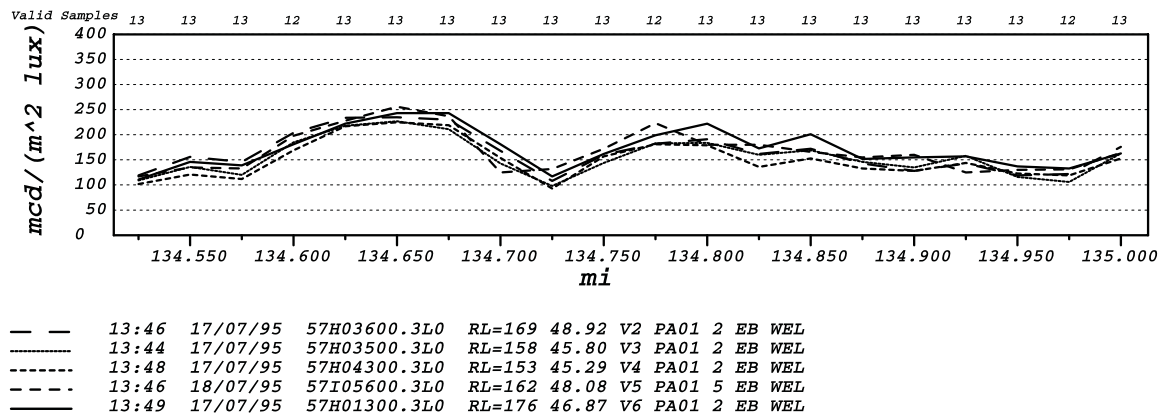


Figure 10. Graphical output of a report for a single Laserlux unit doing repeat runs along the same stretch of highway. Legend shows time, date, file identifier, average retroreflectance in Mcd/m<sup>2</sup>/lux, standard deviation, and test identifier.



**Figure 11. Graphical output of a report for 5 Laserlux units running sequentially along the same stretch of highway. Legend shows time, date, file identifier, average retroreflectance in Mcd/m<sup>2</sup>/lux, standard deviation, and vehicle and test identifier.**

### 4.3 Independent FHWA Tests

Independent tests conducted by The Federal Highway Administration (6) on three Laserlux units, concluded that the Laserlux retroreflectometers are capable of achieving good levels of repeatability, within the limits of 10 percent tolerance.

## 4. PAVEMENT STRIPE MANAGEMENT OPPORTUNITES

### 4.1 Pavement standards

“The U.S. DOT shall revise the Manual on Uniform Traffic Control Devices to include a standard for minimum retroreflectivity for markings and signs and to define the roads that must have center lines and/or edge lines.” ISTEA, Intermodal Surface Transportation Efficiency Act of 1991. The concept of ensuring nighttime visibility on striped roads via legislation has resulted in much research into the needs of drivers of all ages and abilities. While debates occur about what the minimum retroreflectivity should be, how the improvements are to be paid for, and what the overall savings to society by the improvements might be, it has become clear to many researchers that accurate, efficient, statistically significant data collection will be a key to ensuring success of the ISTEA concept.

States that have in place minimum initial quality standards, typically, have used previous standard of use instrumentation, the handheld instrument MiroLux 12. Additional state DOTs (Departments of Transportation) are moving towards initial quality standards of reflectivity. The move towards 30 meter geometry has led to new instrumentation and the minimum initial quality standards for contractor and state applied markings. The shift away from paints that emit VOCs (Volatile Organic Compounds), as required by law, has led to a proliferation of new marking materials. Claims of retroreflectivity and performance life-span are unknown. States are forced to rely on manufacturers claims and independent research. Correlation between test deck performance and actual road performance is conjectural. Incorrect selection of material for a given states ADT (Average Daily Traffic), weather, and budget, can result in poor stripe performance in a much shorter time span than advertised.

Mobile reflectometers, like Laserlux, are essential to the evaluation process by allowing for the evaluation of significantly large samples.

## **4.2 Re-striping strategies and priorities**

Many states still stripe based on the life cycle of alkyd based paints in their area. This limits the state's ability to respond to improvements in life-cycle of new materials, longer or shorter, resulting in re-striping of good markings or not replacing poor markings in a timely manner. Time based re-striping strategies do not incorporate quality as a performance benchmark of striping, only time and labor on an annual basis. This can result in measuring effective performance of a striping operation by line miles per day, rather than how well the markings are visible to the driver over the desired lifetime. States that do re-stripe based on need can save money in the long run. Surveying roads to determine their current reflectivity level, comparing past performance of that material on that type of road, and prioritizing roads that need striping is a plan that is easily accomplished using Laserlux. States that build quality into the striping performance, as a primary objective, find that their stripes last longer.

## **4.3 Contractor performance.**

Minimum initial quality standards appear to be the driving force in changes in reflectivity instrumentation. States are able to place standards to ensure that contractors achieve desired performance over the engineered life span by measuring reflectivity initially, and thereafter. In many cases the cost of the measurement is incorporated into the striping contract. Although the minimum initial retroreflectivity value varies, the concept is the same. Test for acceptability on the road performance rather than testing an incoming material's ability to conform to a laboratory test that may be obsolete. Since the on the road performance test involves only one simple document that is established at the beginning of the contract, it is easier to set up than to change the incoming quality test methods multitude of material tests.

## **5.4 Emplacement Strategies**

While the initial investment in a Laserlux system appears high, a review of the overall use of these systems incorporated into a statewide pavement marking management system, shows that the increase in overall quality of the pavement markings more than pays for the system. Incorporating monitoring of reflectivity and striping log data allows for planning of re-striping based on needs that serve the ultimate customer, the driver. An increase in reflectivity of the pavement markings makes roads safer, saving lives.

Warranty contracts take this concept further, allowing for the monitoring of performance over the engineered life of the marking, allowing for better planning and cost savings. This shift toward monitoring on the road performance rather than incoming material quality, allows states to minimize expensive laboratory testing, saving additional funds. In the end, the driver is really only concerned about the visibility of the pavement marking, not the material.

## **6. SUMMARY**

The ability for quick and efficient measurement of pavement marking retroreflectivity is an important aspect of highway management. It allows standards to be set and maintained, and provides the management tools to do so efficiently and economically. The performance of materials and contractors can be specified and evaluated. Re-striping priorities can be managed as to improve substandard marking, while delaying the re-striping of markings which still meet standards.

Laserlux, a truck-mounted retroreflectometer provides the measurements needed for proper highway pavement marking management. These measurements are quick, simple, reliable, objective, and provide measurements at highway speeds, at data rates high enough for adequate statistical characterization, and without hindering the flow of traffic, nor putting the human operators at undue risk.

This retroreflectometer has demonstrated repeatability within a tolerance of 10% as measured by independent testing. Laserlux measurements provide the accurate and statistically reliable data required for designing pavement standards, implementing striping and re-striping strategies, and evaluating the performance of materials and contractors.

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