Guide To Retroreflection Safety Principles And Retroreflective Measurements

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Introduction

Retroreflectivity, or retroreflection, is an optical phenomenon in which reflected rays of light are preferentially returned in directions close to the opposite of the direction from which the rays came. This property is maintained over wide variations of the direction of the incident rays. Retroreflection is achieved through multiple reflections within a retroreflector. Common retroreflectors are cube corners and microspheres of glass or plastic.

Retroreflection is used for highway safety and measuring distance. The method used for measuring distance is called time-of-flight measurement, which can be used for great distances. In time-of-flight measurements, the distance from light source to target is determined by measuring the time it takes light to travel to the target and return to the sensor. Time-of-flight distance measurements can be made using pulse-type systems or modulated beam systems. Pulsed-type systems are used for measuring great distances, whereas modulated beam systems are typically used for intermediate range distance measurements. A cube corner array, for example, was left on the moon to allow accurate measurement of its distance from the earth.

The most common and practical use of retroreflection technology is its application to highway safety. Pavement markings and road signs are two of the most important means of ensuring the safety of motorists during their travels. Retroreflectivity, or nighttime visibility of signs and pavement markings, is essential for efficient traffic flow, driving comfort, and highway safety in general. Pavement marking and road signs are visible at night because the light from headlights is reflected back into drivers' eyes by retroreflectors embedded into the signs or road stripes.

Several factors determine the visibility of a sign or pavement marking::

Luminance - the total amount of light a driver receive from a sign or marking. Luminance of the sign or marking is directly proportional to the amount of light energy that is directed back towards your eyes.

Contrast - the ratio of luminance from the marking to luminance from its surroundings, as measured from the driver's position. Contrast is much more important for overall visibility than luminance because contrast defines how clearly a target stands out from its background. Contrast is a better measure of marking and sign visibility than is luminance.

Color - the color of highway marking signs are specified for different purposes. For example, white with black lettering is used for regulatory information such as speed and traffic flow direction; red is used for stop and wrong way signs; yellow and new fluorescent yellow are used for warning signs. Color can increase the perceived contrast of the sign with its surroundings.

Conspicuity - this refers to the likelihood that a driver will notice a selected object at a given distance. It is probably the best measure of visibility, but it is difficult to quantify. Unlike luminance and contrast, conspicuity is not an easily determined optical quantity. It is difficult to determine an estimate for the conspicuity factors, and very difficult to combine them in a way that yields a numerical measure of conspicuity. Conspicuity is a quantity that can only be determined empirically.

Legibility - this refers to the probability that the driver will understand the message that the roadway delineation or sign is meant to convey. Legibility relies upon many factors. In addition, the criteria by which legibility may be judged differ for different types of delineation. Legibility is an even less tangible quantity that conspicuity.

Visibility Distance - the range at which a marking or sign can be seen. Visibility distance only specifies the distance at which a given driver is capable of seeing a marking. It is not a guarantee that the driver will see it.

It is important that you keep the visibility factor in mind as you move into the application of retroreflectivity to highway safety.

Application of Retroreflectivity to Highway Safety

A popular saying in the light measurement industry is retroreflectivity is the optical equivalent of the phrase "right back at you". Basically, retroreflectivity is the measurement of efficiency of a highway safety marking to return light in the general direction from which it came. It is simply a ratio of the light visible to the driver compared to the light entering the highway marker.

Retroreflective sheeting was first introduced in the 1930's. However, it was not until the 1950's that the enclosed lens retroreflective sheeting became available and retroreflective signs became universally recognized. Since then, technological improvements have led to newer products with increased retroreflectivity and angularity. The types of sheeting material differ with regard to their level of intensity and method of retroreflection (e.g. enclosed, encapsulated or microprismatic materials).

Recognition by highway agencies of the importance of retroreflectivity has made the use of retroreflective highway markings nearly universal. According to the "Manual on Uniform Traffic Control Devices (MUTCD)," markings that must be visible at night should be retroreflective unless ambient illumination assures adequate visibility. Because the percentage of well-illuminated roadways is so small, the trend among highway agencies is to make all highway and pavement markings retroreflective.

Over time, retroreflective paints and materials degrade due to the effects of traffic and weather. In addition, we have a large aging driver population that needs brighter signs and pavement markings to maintain its mobility, especially at night. Unfortunately, inadequate and poorly maintained signs and markings are often cited as the contributing factor to nighttime accidents. To assess the effectiveness of safety measures, the Federal Highway Administration (FHWA) and others use the Highway Safety Information System (HSIS), a multi-state database that contains accident information and an inventory of road conditions and markings. This database and others show that while only 25 percent of travel occurs at night, it is then that about 55 percent of the fatal accidents occur.

It is not always easy to determine the best time to replace the retroreflected surfaces. If replaced too soon, maintenance costs are increased. If replaced too late, safety and driving comfort are compromised. Thus, strategies have to be developed and implemented to cost-effectively maintain minimum nighttime visibility requirements. There are four basic strategies that you can use to maintain a minimum level of highway reflectivity:

1. Total Replacement - every sign is replaced after a set interval of time.
2. Sign Inspection - all signs are periodically checked, those not up to standards are replaced.
3. Sign Management - a computerized database is used to monitor and predict when replacement is needed.
4. Sign Inspection combined with Sign Management - the collected field data is stored in a computerized database to more economically manage the minimum nighttime visibility requirements.

Sample sign inspection combined with computerized database and predictive algorithms seem to be the least costly method of maintenance.

There are two methods of evaluating traffic sign retroreflectivity under highway conditions. One is measurement using sensors and integrated documentation equipment (retroreflectometer). The other is making "measurements" using human observers. Research has been done to evaluate the accuracy of human observers in making retroreflectivity observations. Observer sign ratings and the sign rating calculated using a retroreflectometer were incorporated into a sign replacement decision model. The individual trained observers only made the correct observation/decision 74% of the time for warning signs and 75% for stop signs. This is a low number where human lives and traffic safety are concerned. In addition to being more accurate, instrument records can be used quantitatively by an agency to assist in defending tort claims.

What is Retroreflection and How It Is Used

Drivers and highway department personnel have long recognized that good pavement markings and legible road signs are essential for efficient traffic flow, driving comfort, and highway safety. This is especially true at night and during inclement weather.

A technology that has contributed significantly to improving the visibility of pavement marking and road signs is retroreflectivity. Many highway signs and pavement markings use special sign sheeting and pavement marking materials that send a large portion of the light from a car's headlights straight back along the same path from which it came. This is what retroreflection is all about. Retroreflection makes objects shine much brighter than those without the retroreflective surface.

The three types of reflection (mirror reflection, diffuse reflection and retroreflection) are illustrated in Figure 1. Retroreflection, as can be seen in the bottom illustration, is the phenomenon of light rays striking a surface and being redirected back to the source of light. By definition, light sources emit some amount of their energy in the form of visible light. An ideal point light source directs its light equally in all directions. If a perfect sphere light source were enclosed in a perfect sphere, every point on the sphere would be illuminated by an equal amount of brightness or light intensity.

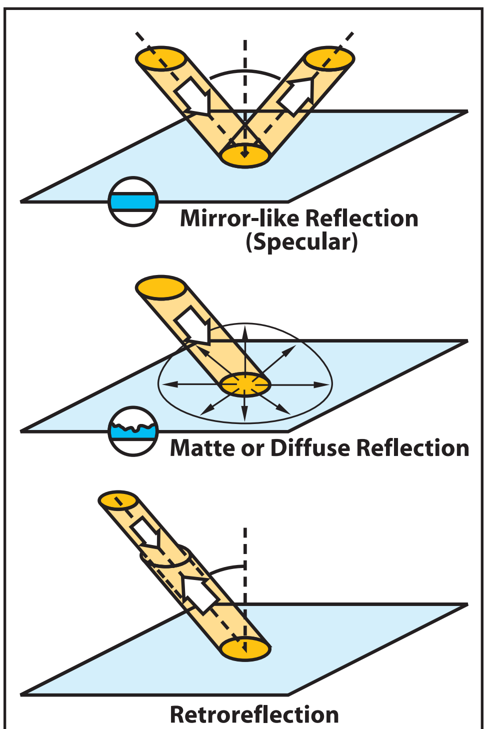


Figure 1 - Retroreflection returns the light to its source.

A directed light source, such as a car's headlights, directs its light in a cone around the direction that it is pointed. If one of your headlights put out a total amount of light energy equal to the point source, and it was enclosed in the same perfect sphere, the points on which your headlight shines would be brighter than each point illuminated by the point source.

This brings us to the discussion of light flux and brightness or light intensity. Light flux is a flow rate of light energy. Light flux can be compared to the flow rate of water; it describes how much light is flowing per unit of time. Brightness or light intensity is like the velocity of water flow. If there are two pipes that discharge equal amounts of water every second and the diameter of one pipe is half that of the other pipe, then the velocity of water in the smaller pipe must be twice as great as the water flowing through the larger pipe.

The same is true for light. If there are two directed light sources that release the same total light flux in the same angular distribution pattern and the first source radiating area is twice the area of the second, then the intensity of the second source will be twice that of the first. The radiating area of the second source will appear brighter, just as the water in the smaller pipe will have a higher velocity, thus flowing with more water per unit of area. This is the concept of **radiance** or **luminance**.

Now, if you move away from these two light sources to a distance over ten times the size of the source and look back at them, the two sources will be the same brightness. This is because the total amount of light filling the cone angle defined by your eye pupil and the apex at the surface of the light (now a point source for both lights) is the same for both lights. This is the concept of **radiant intensity** or **luminous intensity**.

Understanding these concepts will help you understand the phenomenon of retroreflectivity. It was stated that the point light source would have a uniform distribution of light flux in all directions around it. A perfect retroreflector, as shown in the bottom of Figure 1, would simply reverse the direction of the light that fell upon it. In this idealized case, the intensity of the light emitted from the reflector would be zero in all directions except that of the source.

A perfect retroreflector would not be useful for highway signs and lane markings, since all reflected light would be returned directly back to the headlights. The reality is that retroreflectors are not perfect. The distribution of this retroreflected light depends on the type of retroreflective material. In the case of retroreflectors that use beads, some light is absorbed by the reflector, and more importantly, light is scattered in the general direction of the light source. In the case of prismatic and microprismatic retroreflectors, light is reflected back toward the headlights in an pattern determined by the design and orientation of the microprismatic corner cubes and scattered from imperfections. This occurrence is depicted in Figure 2. It is this imperfectly retroreflected light that is useful for highway signage and stripes (delineation).

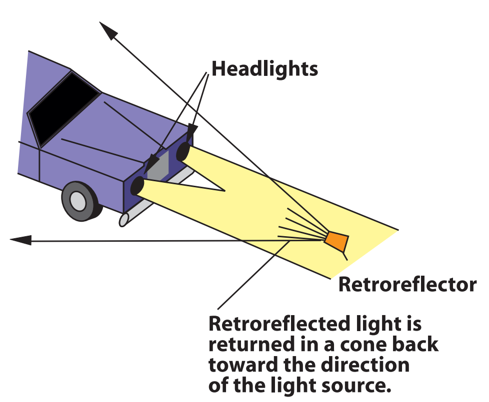


Figure 2 - General principle of retroreflection use.

What does this mean to the driver? It means that signs can be clearly seen from greater distances at night, giving drivers more time to plan lane changes and prepare for exits. It also means that road markings appear brighter and can be seen more clearly. All of this is making our highways much easier and safer to navigate at night

Glass Beads for pavement markings

Retroreflective highway signs and lane markers use special kinds of paints and materials. Most retroreflective paints and other pavement marking materials (PMM) contain many thousands of glass beads per square foot that are bonded to the highway with a strong binder. Instead of scattering light, as normal paints do, retroreflective paints containing glass beads turn the light around and send it back in the direction of your headlights. Figure 3 portrays how glass beads perform retroreflection. For beads to retroreflect light, two properties are necessary: transparency and roundness. Beads made of glass have both of these properties. The need for transparency and roundness can be seen to be important if you follow the path of light as it enters a bead embedded in an applied roadway marking. The glass bead must be transparent so that light can pass into and out of the sphere. As the light ray enters the bead it is bent (refracted) downward by the rounded surface of the bead to a point below where the bead is embedded in the paint or PMM. Light striking the back of the paint-coated bead surface is reflected from the paint surface, with only a small fraction of the light going back toward the illumination source.

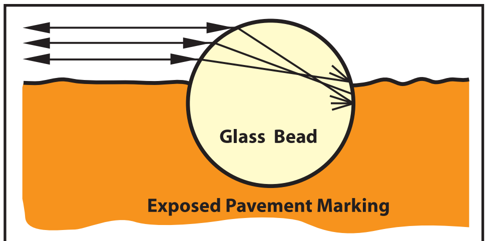


Figure 3 - Glass beads or microspheres embededded in paint provide effective retroreflective surfaces.

The glass beads are applied to pavement marking materials in one of three ways. They can be premixed in marking materials before application, or they can be dropped or sprayed into the wet paint directly behind the paint sprayer, or a portion can be dropped onto premixed two-part epoxy or thermoplastic materials. The top surface of beads is enveloped by the paint, with the wicking action of the paint rising up to above the midpoint of the bead. This provides two actions. It locks the glass beads into the paint and allows the paint to act as a diffuse reflecting surface for retroreflection, with the paint color affecting the color of the retroreflected light. The light entering the glass bead is bent and focused towards the back of the bead and reflected back out towards the headlights and driver. A good application of beads results in the top layer of glass beads being embedded to about 60% of the diameter of the bead. There should be consistent quality of both glass beads and paint so that the paint thickness and bead coverage promotes even retroreflectivity across both directions of road travel. Too little paint results in under-embedded beads. This will result in improperly anchored beads that will fall out prematurely, and thus will not be effective retroreflectors. Under-embedded beads cause a large percentage of the light that enters them to exit out the back. Too much paint results in over-embedded beads. While over-embedded beads may remain in the binder, light cannot enter them and thus no retroreflection can occur.

The retroreflected light from glass beads is a function of three variables:

- Index of refraction of the glass beads
- Bead shape, size, and surface characteristics
- The number of beads present and exposed to light rays

The bead's Refractive Index (RI) is an important physical parameter. The higher the RI of the bead and the fewer impurities in the glass material, the more costly it is to manufacture. The RI is a function of the chemical makeup of the beads. The higher the RI, the more light is retroreflected. Beads used in traffic paint commonly have a RI of 1.5. There are some 1.65 RI beads used with thermoplastics, and 1.9 RI beads are often used in retroreflective airport markings. Despite the increased brightness gained with the higher refractive index, most state and local highway agencies find it is more cost-effective to use 1.5 RI beads.

Glass beads range in size from 60 micrometers (0.0024 inches) to 850 micrometers (0.034 inches). Bead size is usually expressed in terms of U.S. sieve number, or the size of mesh screen that a bead will pass through. For example, a U.S. Sieve Number 20 will permit beads with a diameter of 840 micrometers (0.033 inches) or less to pass through the mesh, whereas a Number 200 mesh will allow only those beads of 74 micrometers (0.0029 inches) or less to pass. A typical application of drop-on beads will use from 20 to 100 mesh. The specified mix of bead size (called in the industry gradation) is usually a local policy decision based on several factors:

- Uncertainties in material control: there is always some spread in the size of beads in any production run.
- Drying time of the marking material (affects settlement of beads in to the binder): a distribution of sizes assures that some of the beads will have an optimum binding in the marking material.
- Uncertainties of weather control: another factor affecting drying time.
- Service life requirements: as the pavement marker wears, beads that were too deep in the binder will increase in their retroreflectance ability.
- Number of beads applied: a mix of sizes increases the possible coverage.

Prismatic Cube Corner Retroreflection for pavement markings

The most common use of prismatic cube corner retroreflection is in Raised Pavement Markers (RPMs). Prismatic materials are also used for retroreflective buttons for post-mounted delineators and sign lettering. Raised Pavement Markers take on a variety of configurations. Some have the characteristic wedge shape, some have round or oval markers, and some have markers with and without replaceable retroreflective inserts. Most RPMs employ prismatic cubecorner reflectors to achieve retroreflectivity. Prismatic retroreflection is achieved through the use of many tiny cube corner retroreflective elements in an insert or sheeting. Each element is a tiny cube corner open in the direction of incoming light. When a light ray enters the cube, it bounces off each of the three-mirrored faces of the corner cube element, essentially reversing its direction. The cube corner reverses all three components of direction and the exit direction of the incident light ray is nearly opposite to that of entry. Figure 4 provides a graphic representation of prismatic cube corner optics. Figure 5 shows the typical distribution of retroreflected light from a cube corner.

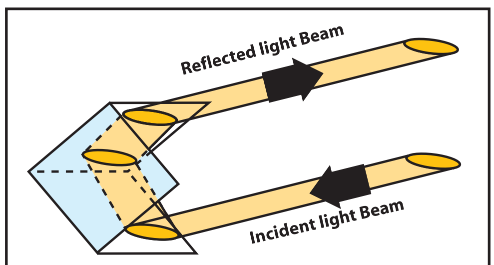


Figure 4 - Prismatic cube corners return the incident light back towards the source.

Micro-Prismatic Cube Corner Retroreflection

Arrays of tiny cube corner retroreflectors can be formed into large sheets of material with integral reflective and adhesive layers added in the manufacturing process. These materials can be engineered to have a different distribution pattern, shown in Figure 5, by adjusting the relative orientation of each individual cube corner and changing the angles between the three faces that form the cube corner. These types of changes prevent the sheeting material from retroreflecting the majority of the light directly back to the source, and cause the material to retroreflect the light into angles and areas more readily seen by the driver.

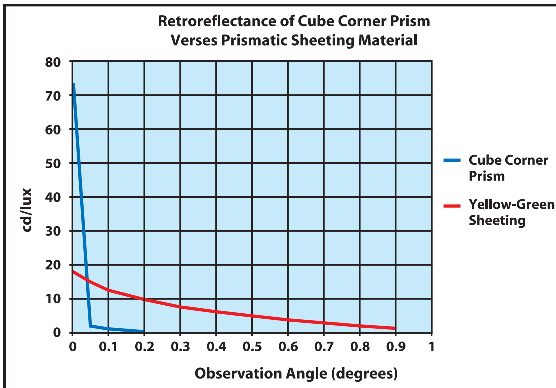


Figure 5 - Angular distribution of light from a cubecorner verses microprismatic sheeting.

Quality Assurance of Retroreflectors

One of the problems with pavement markings is their inconsistency. Because of this inconsistency, highway agencies cannot reliably predict the performance of pavement markings. Listed below are some actions, resources and procedures that have been developed and instituted to remedy inconsistency and ensure quality of materials:

- Vendor certification - qualification
- Laboratory testing
- Field testing
- Two Regional Test Facilities Exist
  - Northeast - Northeastern Association of State Highway and Transportation Officials (NASHTO)
  - Southeast - Southeastern Regional Test Facility (SRTF)
- Standardization
  - Improved testing standards
  - Improved material standards
  - Uniform marking systems between agencies

Due to the factors outlined above and the degradation of retroreflective materials, it is important to have a basis for knowing when to replace signs and repaint highways. The main goal of replacing and repainting highway signs and delineations is to maintain their visibility (defined as the properties and behavior of light waves and objects interacting in the environment to produce light signals capable of evoking sensation). The measurement of visibility becomes complex very quickly in that both physics and human factors are jointly involved. The human element is complicated in itself, with numerous contributing factors. These include, attributes of the sign (position, placement, size-here size does count, material type, legend type, script font, and color); roadway (posted speed, number of lanes, and density of traffic); vehicle (headlight-beam pattern and height); and driver (visual and cognitive capabilities). Consideration of all of these factors results in a multitude of cases that must be addressed by the physics side of the solution.

Measuring Retroreflection

It seems intuitively correct to measure retroreflection as a ratio of the intensity of light returned in the direction of the driver to the intensity of their car's headlights. This ratio would give a scale for retroreflection that consisted of a similitude (dimensionless number) between 0 and 1. Unfortunately there are practical problems with this approach. In addition, there must be a system of units to define light flux, intensity and other optical quantities.

The first unit that you need to know is that of a 'solid angle'. A familiar example of a solid angle is an ice cream cone. The tip of the cone is the apex, the distance from the apex to the open end is the radius (r) and the open end has some defined surface area (S). Solid angles are measured in units called steradian (ω, the Greek letter *omega*). Steradians are defined simply as the ratio of the area of the open end of the cone over the radius squared (r^2). In strict math terms the area of the opening is a spherical surface, so you can imagine the ice cream cone and a ball just big enough to fit in the open end of the cone. Increasing the size of the cone until it is a flat disk would give you 2π Steradians, so there are a total of 4π steradians in a complete sphere around a source. This is analogous to the two-dimensioned case where 2π equals a complete circular angle in a plane around a point.

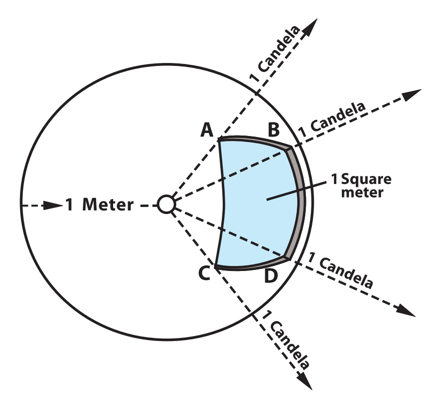


Figure 6 - The basic optical measure of luminous intensity is the 'candela'.

In Figure 6, the solid angle subtended by the Area "ABCD" is equal to the area of "ABCD" divided by the total area of the concentric sphere multiplied by the total number of steradians in the sphere.

The equation looks like:

$$= \frac{\mathbf{1m^2 \times 4\pi\ (\omega)}}{\mathbf{4\pi\ (1m)^2}} = \mathbf{1\ steradian}$$

With the understanding of solid angles, the definition of optical quantities can be made. The basic optical quantity is the 'candela', which is a measure of luminous intensity. The candela is the luminous intensity of a source emitting a monochromatic radiation in a given direction of frequency 540 x 10^{12} Hertz or wavelength 555 nanometers. The radiant intensity of which, in that direction, is 1/683 watts per steradian. This definition, while not helpful for an intuitive grasp of the nature of luminous intensity, does give us a physical means to establish optical units.

The next important unit is the unit associated with 'flux'. Flux is a measure of the total light energy emitted per unit of time. The unit of visible flux or 'luminous flux' is called the 'lumen' (the unit of flux independent of the human eye sensitivity is the watt). One lumen is defined as the amount of light energy flowing through a solid angle of one steradian from a source having a luminous intensity of one candela.

Illuminance is defined as the luminous flux per unit area. It is measured in units of 'lux', or lumens per square meter. Thus, when a uniform light flux of one lumen falls on an area of one square meter the illuminance at any point on the surface is one lux. The sphere in Figure 6 has a total area of $4\pi r^2$ or 12.57 square meters. So if the point source output has an intensity of one candela, the total power output of the source is 12.57 lumens.

The next terms to work with are intensity and illuminance. Intensity measures the flux of a source in a given direction. Illuminance measures the flux density of light on a surface that is illuminated. These are not the same because the emitted light spreads out over a larger and larger region as it radiates through space. The intensity remains constant since the same amount of flux fills the same angular cone, but because the light is spread out with distance over a larger and larger region of space, illuminance gets smaller as the distance to the illuminated surface increases. For a spatially uniform point source the illuminance decreases proportionately to the square of the distance from the source.

Candelas and lumens are identical in the metric and English measurement systems. Illuminance, however, is measured with units of lumens per square foot rather that per square meter. One lumen per square foot is a foot-candle and one foot-candle equals 10.76 lux (lumens per square meter).

Measurement of Roadway Markings

Coefficient of Retroreflected Luminance (R_L) is the most commonly used measurement of retroreflectance in highway marking. R_L is the ratio of the luminance (L) of a surface to the normal illuminance (E) on the surface. In the laboratory this definition works well with testing procedures.

In the applied world of roadway marker measurements, life is not so simple. In this situation R_L translates into measuring the luminance of the marking against the normal illuminance of the incident light on the marking. In addition, the luminance would be the luminous flux of a light ray from the marking to the driver, per unit of projected area of the marking in your direction, per unit of solid angle. Also, since luminous intensity is just luminous flux per unit solid angle, the luminance is simply the luminous intensity of the light returned by the marking per unit area. The normal illuminance (E) is the illuminance of a car's headlights on the marking, measured on a plane perpendicular to the direction of the headlight beams. Figure 7 will help you visualize these quantities. If the car shown is taken as a snapshot in time, then the observation and illumination angles are fixed. The headlights direct light of a specific intensity along the illumination axis. Since the quantities defined in the standards are directional, a single point must be identified on the marking where R_L will be examined. This will be point B in the above figure. Having established this, a precise definition of the illumination axis is possible, directed along line AB.

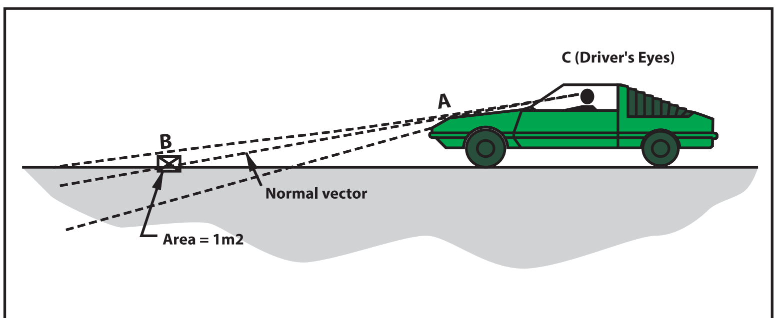


Figure 7 - Retroreflected light is returned in a cone in the direction of the light.

By the time the light reaches point B, it has spread out through space and has a certain illuminance associated with it. If a plane is placed at point B with an area of one square meter and a normal vector in the same direction as line A, then the value of illuminance at B will equal the amount of light that would fall on this plane if the plane was illuminated entirely by the same intensity of light as that directed at point B. The light will be reflected back in a cone shape around the direction of the headlight. It will have a specific luminous intensity in the observation direction along line BC.

Using the two values just mentioned, a value for coefficient of luminous intensity can be calculated. To calculate luminance and derive a value for RL, the luminous intensity per unit area must be found. The problem is that the luminous intensity per unit area must be determined to provide an appropriate area to use as a divisor. Up to this point, all the quantities have been directional, dealing with infinitesimal areas. The challenge is to accurately illuminate the sample at the proper angle, 88.76 degrees, and collect the light at the proper angle, 1.05 degrees, from the illumination axis. These angles simulate the illumination of the pavement marker by a car with headlights 0.65 meters above the pavement and 30 meters in front of the car and the driver's eye 1.2 meters above the pavement. By precisely setting this measurement geometry, you minimize the largest error-contributing factor, since the projected measurement area changes a large amount for a small change in the 88.76-degree illumination angle.

In practice, retroreflective or other materials are measured in a laboratory using a photometric range system. These material samples are used as transfer standards. A precision photometric range system consists of a projection light source, a photoreceptor, a method of setting the distance between these two components with precision and repeatability, and a retroreflective material sample holder with precise and repeatable angular setting mounted at least 10 meters from the light source and the photoreceptor. The projection light source is a precision instrument in itself, providing a less than 3% non-uniform illumination area with a tungsten halogen lamp operated at the correct 2855.6 degrees Kelvin color temperature stable over hundreds of hours of operation. The photoreceptor detector matches the human eye sensitivity at different colors throughout the visible region of the spectrum. Measurements of both the illumination at the retroreflection sample position and the retroreflected light from the sample are measured by the photoreceptor. The ratio of these two readings, including the projected area of the sample, is a direct determination of the coefficient of retroreflection. These laboratory-measured samples can then be used in the field as calibration standards to accurately set the intensity scale of the portable measurement instruments.

The decision on sample area in portable instruments differs from one manufacture to another, thus care must be taken when there is non-uniformity of the retroreflection of sample on the road. A typical example of this is with pavement stripes. It is not unusual to obtain a stripe where the center of a 4-inch wide retroreflected stripe will have a 2-inch wide stripe down the middle that has a coefficient of retroreflection value much greater than 1-inch to either side. If you used an instrument that only measured a 2-inch wide section of a stripe and compared it to an instrument that measured a 3-inch wide section of a stripe you would get a reading much lower with the 3-inch wide sample, which would agree much more closely with the true value and what the eye would see since the eye sees the whole 4-inch wide stripe. The instrument that measures only a 2-inch wide stripe would give a higher and thus faulty retroreflection value based on one measurement. The two instruments would agree more closely if 3 side-by-side measurements covering the full width of the stripe were made and averaged with the 2-inch wide instrument and then compared with the 2 measurements made and averaged with the 3-inch wide instrument. Typically, data from most modern instruments is reproducible if not accurate.

The unit used in roadway measurements is millicandelas per lux per square meter (mcd/lx/m²). This is equal to 0.001 of the basic unit, which was given before as candelas per lux per square meter (cd/lx/m²). When equipping a retroreflectance program, it is important to use a reliable and well-established instrument vendor that can support instrument calibration with a precise and repeatable laboratory measurement capability.

Measurement of Road Signs

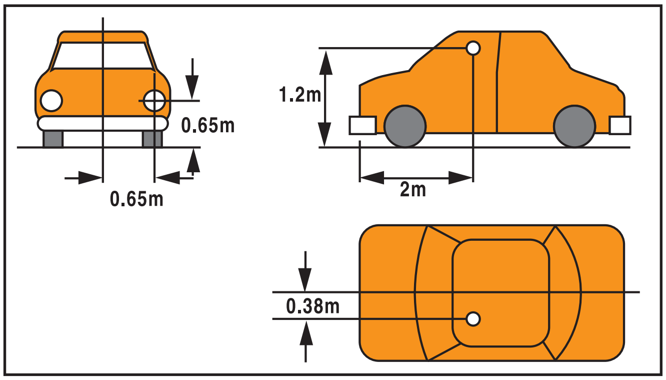
The standard used for signs is the Coefficient of Retroreflection (R_A). A description of this can be found in ASTM Standard E808-91. It is defined as the coefficient of luminous intensity, R_I, of a plane retroreflecting surface to its area. The metric unit for RI is candelas per lux per square meter (cd/lx/m²).

The coefficient of luminous intensity is the ratio of the luminous intensity of the retroreflector in the direction of observation, E^, to the illuminance at the retroreflector on a plane perpendicular to the direction of the incident light. After taking into account all of the units and other considerations, R_A is conceptually identical to the coefficient of retroreflected luminance but simpler to implement for signs. One must note that the English units for R_A (candelas per foot-candle per square foot) are often used. It is also often referred to as Specific Intensity per unit Area (SIA) in older documents and specifications; use of this term should be discouraged.

R_A is still a ratio of returned intensity to incident illumination divided by the area of the retroreflector. Signs make the measurement of these quantities simpler because they have a fixed area. In addition, the measured geometry is arranged so that the plane of the sign is perpendicular to car headlights, thus the area does not change as fast as angles near horizontal. This makes the measurement much simpler and more accurate.

Practical Applications of Retroreflectometers

Laboratory measurement of retroreflective materials is accomplished using tightly controlled procedures. These procedures are defined and controlled by the American Society for Testing of Materials (ASTM). The ASTM procedures for laboratory measurements require the use of a tungsten lamp operated at a correlated color temperature of 2855.6 degrees Kelvin. The spectral power distribution of a tungsten lamp operated at this color temperature approaches the ideal CIE (the international standards generating organization for illumination and color) Illuminant A, which is an internationally agreed upon standard type of illumination used for comparison and specification of colors. The photoreceptor used to measure the illuminated retroreflective surfaces must match the CIE 1931 human eye response function within a tolerance of 3% defined by the f_1' (f-one-prime) analysis method given in CIE publication 69. The CIE 1931 human eye response function is also called the photopic response, photometric response function or the Y-bar function. This level of precision in the measurement instruments yields a precision and bias of about 6% between well-maintained and well-staffed laboratories. It is not practical to apply these very rigorous standards in the field. ASTM has developed standard procedures that provide for the use of portable instrumentation for measurement of retroreflective materials in the field. These standard procedures allow the use of illumination sources quite different than those used in the laboratory. The procedures allow compensating the detector response by the amount the light source deviates from 2855.6 degrees Kelvin. Field measurements and laboratory measurements taken over many years



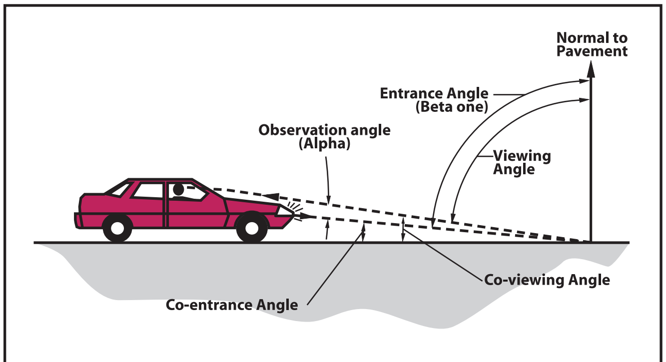


Figure 8 - The ASTM E1710 geometry is required for all hand held retroreflectometers to be used on the public roads

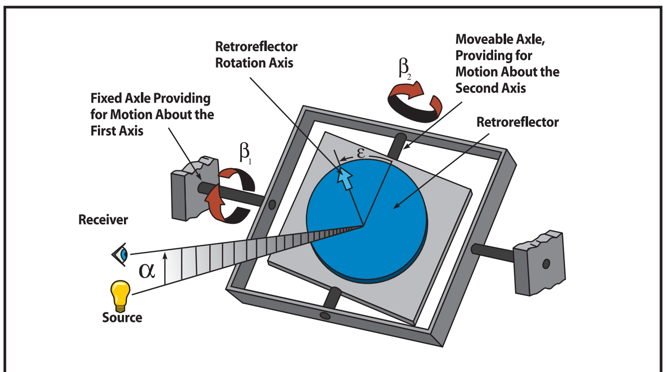


Figure 9 - Laboratory measurement setup duplicates the vehicle headlamp and driver position geometry.

have shown that the combination of the spectral power distribution of a light source and the detector spectral sensitivity must match the combination of the CIE Illuminant and photometric response functions. Filters can be used to compensate for temperature differences and to provide the required match to the CIE photometric response function.

For pavement markings, the Federal Highway Administration has adopted the 30-meter observation distance geometry used in Europe, defined in ASTM E1710-95, Figure 8. It represents what a driver in an average height U.S. automobile would see during inclement weather conditions at night. ASTM has recently adopted E1710, which establishes the parameters for 30-meter geometry retroreflectometers.

The international standard geometry for measurement of retroreflective materials is shown in Figure 9. Given that the characteristics of retroreflectors change so quickly according to variations in lighting and viewing angles, one of the most important factors affecting retroreflector measurements is the accurate setting of angles. Laboratory measurement equipment can simulate the exact angles at which drivers view safety marking materials. The angle marked α (alpha) represents the angle between the vehicle headlamps and the driver's eyes. Similarly, the ε (epsilon), β_1 (beta one) and β_2 (beta two) angles simulate the angles that the sign or other retroreflective element make with respect to the illumination source.

The four important measurement attributes are:

- **Accuracy -** this is the bottom line for measurements. If they aren't accurate, they tell nothing, so don't take them.

- **Reproducibility/Repeatability -** instruments can drift as a function of time and use. Keep batteries charged, instruments clean, calibrate frequently, service regularly, and operate within specified limits.
- **Reliability -** an instrument that fails in the field wastes time and money. The actions taken to keep an instrument reproducible will help keep the instrument reliable.
- **Traceability -** before any instrument can be used in the field it must be calibrated. Accuracy and reliability revolve around the traceability of the calibration standards and robust calibration procedures.

Types of field instruments include:

- **Pavement marking retroreflectometers -** this tool is used for measuring pavement-marking retroreflectivity. It measures or determines how bright the markings appear at night to motorists. There are two types:
  - **Handheld -** employed widely in field to spot-check the condition of selected retroreflective pavement markings.
  - **Mobile equipment -** takes continuous retroreflective readings while driving down the road at highway speeds
- **Sign retroreflectometers -** this tool is used for measuring sign retroreflectivity. It determines if the sign meets nighttime retroreflectivity requirements. There are two types:
  - **Handheld -** this is an instrument capable of accurately and reliably measuring the retroreflection properties of road signs and retroreflective sheeting materials.
  - **Mobile -** mobile sign retroreflectometers are in the development stage and are not yet commercialized.
- **Raised Pavement Marker (RPM) retroreflectometers -** this tool measures the retroreflectance of these important roadway delineators in their regular and snowplowable mounting configurations.

Learn from the experts

For over three decades Gamma Scientific and Advanced Retro Technology developed innovative products to measure retroreflective materials. The companies forged their leadership position in cooperation with the Federal Highway Administration and through active membership in ASTM, ASHTO, ITE and other organizations associated with the measurement of retroreflective materials.

Today the consolidated product lines of both companies are sold under a new name, RoadVista. The unique union of precision laboratory measurements, design expertise, manufacturing capability and commitment to highway safety places RoadVista as the premier supplier of retroreflective measurement equipment. We manufacture and distribute the only complete line of retroreflectometers on the market today.

For complete measurement instrument information, turn to Appendix A. There you will find a list of the product data sheets included in the back of this document.

Minimum Sign Retroreflectivity Guidelines

The United Stated Department of Transportation Federal Highway Administration funded research to determine what level of sign sheeting retroreflectivity provides adequate visibility. As with all studies involving subjective assessments of what was considered "adequate visibility", this study showed a statistical distribution of the responses of the people participating in the study.

Research teams used a three-stage model known as CARTS (Computerized Analysis Retroreflective Traffic Sign) to help develop the Minimum Sign Retroreflectivity Guidelines. In the first stage, CARTS calculates the shortest distance at which a sign must be visible enough to enable the driver to respond safely and appropriately. This distance is called the Minimum Required Visibility Distance (MRVD). The second stage determines the sign luminance required at the MRVD. This determination uses DETECT, a visibility model. This model is based on contrast threshold data; it calculates the luminance needed for a driver to detect and recognize a specified sign at a specified distance. In the third and final stage, the CARTS model converts the calculated sign luminance to an equivalent retroreflectivity value at a standard measurement geometry. This stage takes into account the characteristics of the sheeting material type and headlight-beam pattern and does not involve the human factors considerations.

On December 21, 2007, revision 2 of the 2003 Manual on Uniform Traffic Control Devices (MUTCD) was published in the Federal Register. It became effective January 22, 2008, and includes the Minimum Maintained Retroreflectivity Levels. The tables were designed to provide a framework for field implementation of the requirements. It is estimated that the values developed for these tables should accommodate about 80 percent of the drivers. The minimum sign retroreflectivity guideline values are presented as shown in the MUTCD in tables 1 and 2 below.

The minimum maintained retroreflectivity levels shown in this table are in units of $cd/lx/m^2$ measured at an observation angle of 0.2° and an entrance angle of -4.0°					
SIGN COLOR	ADDITIONAL CRITERIA	Sheeting Type (ASTM D4956-04)			
		Beaded Sheeting			Prismatic Sheeting
		I	II	III	III, IV, VI, VII, VIII, IX, X
White on Green	Overhead	White * Green ≥ 7	White * Green ≥ 15	White * Green ≥ 25	White ≥ 250 Green ≥ 25
White on Green	Ground-mounted	White * Green ≥ 7	White ≥ 120 Green ≥ 15		
Black on Yellow or Black on Orange	For text and fine symbol signs measuring at least 1200 mm (48 in) and for all sizes of bold symbol signs.	Yellow * Orange *	Yellow ≥ 50 Orange ≥ 50		
	For text and fine symbol signs measuring less than 1200 mm (48 in).	Yellow * Orange *	Yellow ≥ 75 Orange ≥ 75		
White on Red	Minimum Sign Contrast Ratio greater than or equal to 3 to 1 (white retroreflectivity divided by red retroreflectivity)	White ≥ 35 Red ≥ 7			
Black on White		White ≥ 50			

* This sheeting type should not be used for this color for this application.

Table 1 – Minimum Maintained Retroreflectivity Levels

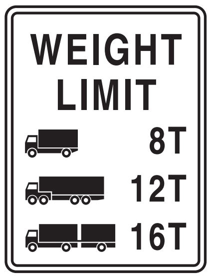
Bold Symbol Signs		
• W1-1,-2 Turn and Curve • W1-3,-4 Reverse Turn and Curve • W1-5 Winding Road • W1-6,-7 Large Arrow • W1-8 Chevron • W1-10 Intersection in Curve • W1-11 Hairpin Curve • W1-15 270 Degree Loop • W2-1 Cross Road • W2-2,-3 Side Road • W2-4,-5 T and Y Intersection • W2-6 Circular Intersection • W3-1 Stop Ahead	• W3-2 Yield Ahead • W3-3 Signal Ahead • W4-1 Merge • W4-2 Lane Ends • W4-3 Added Lane • W4-5 Entering Roadway Merge • W4-6 Entering Roadway Added Lane • W6-1,-2 Divided Highway Begins and Ends • W6-3 Two-Way Traffic • W10-1,-2,-3,-4,-11,-12 Highway-Railroad Advance Warning • W11-2 Pedestrian Crossing	• W11-3 Deer Crossing • W11-4 Cattle Crossing • W11-5 Farm Equipment • W11-6 Snowmobile Crossing • W11-7 Equestrian Crossing • W11-8 Fire Station • W11-10 Truck Crossing • W12-1 Double Arrow • W16-5p,-6p,-7p Pointing Arrow Plaques • W20-7a Flagger • W21-1a Worker
Special Cases		
• W3-1 Stop Ahead: Red retroreflectivity $\geq$ 7 • W3-2 Yield Ahead: Red retroreflectivity $\geq$ 7; White retroreflectivity $\geq$ 35 • W3-3 Signal Ahead: Red retroreflectivity $\geq$ 7; Green retroreflectivity $\geq$ 7 • W3-5 Speed Reduction: White retroreflectivity $\geq$ 50 • For non-diamond shaped signs such as W14-3 (No Passing Zone), W4-4 (Cross Traffic Does Not Stop) or W13-1,-2,-3,-5 (Speed Advisory Plaques), use largest sign dimension to determine proper minimum retroreflectivity level.		

Table 2 - Definition of Bold Symbol Signs. Fine Symbol signs are all those not listed as Bold Symbol Signs.

The Federal Highway Administration has issued a brochure that identifies the U.S. Road Symbol Signs. This can be obtained from either the FHWA or the Government Printing Office (Brochure Stock No. is 050-000-00152-1). Commonly used signs are depicted on the following pages.

Commonly Used Regulatory Signs

Commonly Used Warning Signs



Commonly Used Guide Signs

Recommended minimum performance of newly installed pavement marking materials.

In May 1999, Jonathan Dan Turner gave a presentation at the annual conference of the Council of Optical Radiation Measurement (CORM) in Gaitherburg, Maryland. In his presentation Mr. Turner outlined the Federal Highway Administration recommendations for minimum values for retroreflectance of newly installed pavement markings.

> Section 406(a) of the 1993 Department of Transportation Appropriation Act required the Secretary of Transportation to revise the Manual on Uniform Traffic Control Devices to include a standard for a minimum level of retroflectivity that must be maintained for traffic signs and pavement markings. The Federal Highway Administration (FHWA) R&D made recommendations for proposed levels of retroreflectivity for signs in 1994, and recommendations for levels of retroreflectivity for pavement markings was recently submitted to the FHWA policymakers.
>
> Two FHWA sponsored studies were conducted to address the issue of pavement marking retroreflectivity. The first study entitled "Evaluation of All-Weather Pavement Markings" was an effort designed to assess the current state of pavement markings in the U.S. and to determine the impact of recommended retroreflectivity values. Graham-Migletz Enterprises submitted a draft report in February 1998 entitled, "Field Surveys of Pavement Marking Retroreflectivity."

The final report dated October 2000 summarizes an exhaustive field survey conducted in 21 states. Over a span of nearly four years, about 2,660,000 individual measurements were made with a vehicle mounted Laserlux retroreflectometer. The average level of retroreflectivity in the fall of 1994 was 170.4 mcd/m²/lux with standard deviation of 123.6. The retroreflectivity readings were found to be 15-24% less in the spring than in the fall.

> The second study entitled "Enhancements to the CARVE Computer Model for Pavement Marking Visibility" was an effort aimed at determining the amount of retroreflectivity required to support adequate driver performance. Ohio University's Helmut Zwahlen has finalized his pavement marking visibility model, CARVE (Computer Aided Road-Marking Visibility Evaluator), which predicts visibility requirements for various pavement marking types for measurements at 30 m. The underlying assumptions of the model were tested using an eye-scanning study, and the model was calibrated with a series of end detection field experiments. The research recommended a retroreflectivity level of 170 mcd/m²/lux at 55mph and 340 mcd/m²/lux at 65 mph. These values would accommodate both young and old drivers.

A report that included an overview of supporting research and a recommendation for minimum pavement marking retroreflectivity was presented to FHWA's Office of Highway Safety on December 2, 1998. The supporting research and recommendations were presented at three workshops across the United States in 1999. As with the sign retroreflectivity workshops, the input of the workshop participants will be considered in the final recommendation leading to rulemaking. A summary report generated by Hawkins Engineering describes the concerns raised at the workshops.

ASTM Standards Dealing With Retroreflection

E 808	Practice for Describing Retroreflectivity
E 809	Practice for Describing Measuring Photometric Characteristics of Retroreflectometers
E 810	Test Method for Coefficients of Retroreflection for Retroreflective Sheeting
D 4061	Test Method for Retroreflectance of Horizontal Coatings
E 811	Practice for Measuring Colorimetric Characteristics of Retroreflectometers Under Night Time Conditions
E 1896	Specifications for Daytime Pedestrian Visibility Enhancement

E 1709	Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer
E 1809	Test Method for Measurement of High-Visibility Retroreflective-Clothing Marking Material Using a Portable Retroreflectometer
E 1696	Test Method for Field Measurement of Raised Retroreflective Pavement Markers Using a Portable Retroreflectometer
E 1743	Practice for Selection and Use of Portable Retroreflectometers for Pavement Marking Measurement
E1710	Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer
D 4280	Specification for Extended Life-Type, Nonplowable, Prismatic, Raised Retroreflective Pavement Markers
D 4383	Specification for Plowable, Raised, Retroreflective Pavement Markers
D 4505	Specification for Preformed Plastic Pavement Marking Tape of Extended Service Life
D 4592	Specification for Preformed Plastic Pavement Marking Tape of Limited Service Life
D 4956	Specification for Retroreflective Sheeting for Traffic Control
E 1501	Specification for Nighttime Photometric Performance of Retroreflective Pedestrian Markings for Visibility Enhancement
D 6359	Specifications for Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable hand-Operated Instruments
F 923	Guide to Properties of High Visibility Materials Used to Improve Individual Safety

References on Light and Color Measurements of Traffic Safety Materials

1. Handbook of Applied Photometry, American Institute of Physics, AIP Press, ISBN 1-56396-416-3
2. Minimum Retroreflectivity Requirements for Traffic Signs, FHWA-RD-93-077
3. Service Life of Retroreflective Traffic Signs, FHWA-RD-90-101
4. Implementation Strategies for Sign Retroreflectivity Standards, NCHRP #346
5. An Implementation Guide for Minimum Retroreflectivity Requirements for Traffic Signs, FHWA-RD-97-052
6. Impacts on State and Local Agencies for Maintaining Traffic Signs within Minimum Retroreflectivity Guidelines, FHWA-RD-97-053
7. CIE Publication:
   #39: Surface Colors for Visual Signaling
   #54: Retroreflection: Definitions and Measurements (revision 54.2 undergoing voting)
   #72: Guide to the Properties and Uses of Retroreflectors at Night
   #73: Visual Aspects of Road Markings
   #74: Road Signs
   #100: Fundamentals of Night Driving
   #107: Colors of Signal Lights

#113: Maintained Night-time Visibility of Retroreflective Road Signs

#115: Recommendation for the Lighting of Roads for Motor and Pedestrian Traffic

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4) Lagergren, Edwin, "Traffic Sign Retroreflectivity Measurements Using Human Observers", December 1987

5) U.S. Department of Transportation, "Manual on Uniform Traffic Control Devices", U.S. Government Printing Office, Washington DC, 1988

6) U.S. Department of Transportation, "Summary Report - Minimum, Sign Retroreflective Guidelines", Publication No. FHWA-RD-97-074, June 1997

7) U.S. Department of Transportation, "Roadway Delineation Practices Handbook", Publication No. FHWA-SA-93-001, August 1994

8) "Uniform Vehicle Code and Model Traffic Ordinance", National Committee on Uniform Traffic Laws and Ordinances

9) U.S. Department of Transportation, "Standard Highway Signs Book", Stock No. 950-044-00000-4

10) Federal Test Method Standard 370, "Instrumental Photometric Measurements of Retroreflective Materials and Retroreflective Devices", General Services Administration, March 1977

11) Hatzi, Peter, "TE-29 Retroreflectivity", Power Point Presentation, FHWA - Office of Technology Applications

12) Hatzi, Peter, "Retroreflectivity: Raising the Nighttime Brightness of Traffic Sign and Markings", Power Point Presentation, FHWA - Office of Technology Applications

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14) Nelson, Eric J. and Austin, Richard L., "Comparison of Spectral Measurement Systems for Retroreflectance Color", Power Point Presentation, Council of Optical Radiation Measurements (CORM) Annual Conference May 1999, Gaithersburg, Maryland

15) Turner, J. Dan, "Update on Pavement Marking Retroreflectivity Research and Recommendations Leading to Rulemaking", Power Point Presentation, Council of Optical Radiation Measurements (CORM) Annual Conference May 1999, Gaithersburg, Maryland

16) Austin, Richard L., "A Short Look at a Long History of Retroreflection Measurement", Power Point Presentation, Gamma Scientific, February 2000

17) Migletz, J. and Harwood, D. W. et al, "Field Surveys of Pavement Marking Retroreflectivity", U.S. Department of Transportation, Federal Highway Administration, April 2000

RETROREFLECTION GLOSSARY OF TERMS

Abrasion: A condition manifested in highway markings by more or less gradual surface erosion, thinning, and degradation due to wind, water, sand and/or vehicle tire ware.

Applied Lines: Pavement marking material in place on the substrate.

Binder: In painted markings, the binder is the hard base material that is left on the road after the solvent has evaporated. Common paint binders are alkyd resins and chlorinated rubber materials. In thermoplastic markings, the binder is the actual thermo-plastic material that melts when heated and hardens into the film that is left on the road. Binders are also often referred to as the base material or base vehicle.

Bisymmetric: Having double symmetry, i.e. in floating bead context it means that the bead surface embedded in the paint is symmetrical with the exposed surface.

Brightness: The quality of radiating or reflecting light. The continuous visual ordering from light to dark which is correlated to light intensity. This term refers to human perception of luminance. Whereas luminance is a photometrically measured quantity, brightness describes how intense a light source or lighted surface appears to the human eye. Brightness of most retroreflective materials is maximum when the observation angle is zero.

Candela: The basic unit for optical quantities in the visible, the candela is a measure of luminous intensity. One candela is defined as the luminous intensity in a given direction of a source emitting a monochromatic radiation of frequency 540×10^{12} Hertz, the radiant intensity of which in that direction is 1683 watts per steradian.

CIE, Commission Internationale de l'Ecairage: the International Commission on Illumination is the worldwide organization of experts in light and color perception and measurements. The CIE is responsible for the generation of standards in Illumination and Color used world wide and adopted as ISO (International Standards Organization) standards.

CIE Illuminant A or CIE Standard Illuminant A: The ideal colorimetric illuminant, representing a full blackbody radiator at 2855.6 degrees Kelvin, defined by the CIE in terms of a relative spectral power distribution, normalized to 100 at 560 nanometers.

CIE Illuminant A Standard Source: A gas-filled tungsten filament lamp operated at a correlated color temperature of 2855.6 degrees Kelvin.

Coefficient of Line Retroreflection - (R_m) of a retroreflection stripe: The ratio of the coefficient of luminous intensity (R_I) of a retroreflecting stripe to its length expressed in candelas per lux per meter.

Coefficient of Luminous Intensity (R_I): The ratio of the luminous intensity (I) of a retroreflector in the direction of observation to the illuminance E at the retroreflector on a plane perpendicular to the direction of the incident light, expressed in candelas per lux. Also called coefficient of (retroreflected) luminous intensity.

Coefficient of Retroreflected Luminance (R_L): A measure of retroreflection most often used to describe the retroreflectivity of pavement markings. Coefficient of retroreflected luminance is the ratio of the luminance of a projected surface of retroreflective material to the normal illuminance at the surface on a plane normal to the incident light. It is expressed in candelas per square meter per lux.

Coefficient of (Retroreflected) Luminous Flux, R: The ratio of the flux per unit solid angle coming from the retroreflector measured at the observation point to the total flux incident on the effective retroreflective surface. It is expressed in candelas per lumen.

Coefficient of Retroreflection (R_A): A measure of retroreflection used often to refer to the retroreflectivity of highway signs. Coefficient of retroreflection is defined as the ratio of the coefficient of luminous intensity (R_1) of a plane retroreflecting surface to its area (A), expressed in candelas per lux per square meter.

Conspicuity: A measure of the likelihood that a driver will notice a certain target at a given distance against a certain background.

Contrast: The ratio of luminance from a target to the luminance from the target's surroundings.

Cooperative Target: A target that is designed to reflect light to the detector of a sensor. Cooperative targets include glass corner cube retroreflectors and retroreflective tape made by several manufactures. In some applications mirrors may be used as cooperative targets.

Corner Cube: Three mutually perpendicular plane surfaces brought together to form the corner of a cube. A light ray striking one of these three planes will reflect off of the other two planes and the final reflected ray direction is in the opposite direction of the original ray direction.

Co-viewing Angle: The complement of the entrance angle.

Datum Mark: An indication on the retroreflector that is used to define the orientation of the retroreflector with respect to rotation about the retroreflector axis.

Depth of Field: The span of distances over which a sensor can accurately measure. This is limited by the focal length and the diameter of the light collection optics. These two factors will determine how the sensor's sensitivity changes with distance.

Detector Spectral Response: The sensitivity of a detector at each wavelength throughout the range of wavelengths where it has sensitivity.

Diffuse Reflection: When light strikes a target and is scattered over a wide angle. Plain white paper or flat (not glossy) wall paint are good diffuse materials. Diffuse targets are the best uncooperative targets, and may be measured to over a wide range of incident angles (up to 80 degrees for some materials).

Durability: A measure of traffic lines' resistance to the wear and deterioration associated with abrasion and chipping. For standard methods of evaluation of durability, refer to the ASTM Bulletins D913 for Chipping and D821 for Abrasion (erosion).

Entrance Angle (or Incidence angle): The angle between the light source to a point on the retroreflector and a line normal (perpendicular, forming a 90-degree angle) with the retroreflector surface. Defined by β_1 (beta one) and β_2 (beta two) in the CIE system of geometry.

European Geometry (for sign sheeting material): Entrance angle (β_1) -5 degrees, observation angle (α) 0.33 degrees.

European 30-meter Geometry: Represents what a driver from an average U.S. automobile height would see during inclement weather conditions at night. This is also called the "30 meter observation distance geometry". The Federal Highway Administration (FHWA) and American Society for Testing of Materials (ASTM) have adopted this geometry as the standard for measuring retroreflection of pavement markings.

First Axis: The axis through the retroreflector center and perpendicular to the observation half-plane.

Floatation Bead: A retroreflective glass bead coated with a special chemical substance so that it will float to half of its diameter in a pavement marking.

Foot-candle: The English system's unit of illuminance, one foot-candle is the illuminance on a surface that is everywhere one foot from a uniform point source of light of one candle and equal to one lumen per square foot. One foot-candle equals 10.76 lux (lumen per square meter).

Fractional Retroreflectance, RT: The fraction of unidirectional flux illuminating a retroreflector that is received at observation angles less than designated value, max.

Glass Beads: Spheres used in conjunction with binder to produce retroreflectivity in pavement markings and some sign sheeting materials

a) Conventional - glass composition with approximate refractive index of 1.52 with no surface treatment.
b) Low refractive index - spheres with refractive index between 1.5 and 1.64.
c) Medium refractive index - spheres with refractive index between 1.65 and 1.89.
d) High refractive index - spheres with refractive index greater than 1.89.
e) Plastic - spheres manufactured from organic materials.
f) Glass - spheres manufactured from a soda lime glass material.
g) Retroreflective - spheres that return light along a path nearly parallel to the entrance path

Goniometer: An instrument for measuring or setting angles.

Illuminance, E: Luminous flux falling on a surface per unit area.

Illuminance Axis: A line from the effective center of the source aperture to the retroreflector center.

Incidence Angle (or Entrance Angle): The angle between the light source and a line normal to the retroreflector surface.

Incident Light: The total (amount of) light from a specified light source striking an object or target that is available for reflecting.

Index of Refraction: For a given material, the index of refraction is equal to the ratio of the speed of light in a vacuum to the speed of light as it travels through the material. Describes the 'light bending' property of a glass as the light wave passes from the air to the glass or vice versa.

Laser Power: The optical power level emitted by the laser in a sensor. The power may be specified as an average power or as a peak power as well as an average if the laser emits pulses or intermittent light output. All other factors being equal, the maximum range increases in proportion to the square root of the laser power. If the power is quadrupled, the maximum range will be doubled. Laser power is expressed in milliwatts (mW) or Watts.

Light: The visible part of an electromagnetic radiation, which travels in a vacuum with a speed of about 186,000 miles per second. The electromagnetic radiation, which is included in the same wavelength range as visible light, is infrared, ultraviolet, and X-rays. To humans it is the sensation aroused by stimulation of the visual receptors.

Lumen: The unit of luminous flux, one (1) lumen is equal to the luminous flux emitted within one (1) steradian by a point source having a spatially uniform luminous intensity of one (1).

Luminance: The luminous flux in a light ray emanating from a surface in a given direction, per unit of projected area of the surface as viewed from that direction, per unit of solid angle.

Luminance contrast: The ratio of luminance from a target to the luminance from the target's surroundings.

Luminous intensity: Light flux per unit solid angle.

Lux: The metric unit of illumination, one (1) lux is equal to the illuminance corresponding to a luminous flux density of one (1) lumen per square meter.

Manual on Uniform Traffic Control Devices (MUTCD): A Federal Highway Administration publication intended to standardize traffic control devices throughout the nation.

Marking: That portion of an object that retroreflects.

Maximum Range: The maximum distance to which a sensor can pick up reflected light and obtain an accurate distance measurement. The maximum range will depend upon the power of the light source, the amount of light reflected, and the sensitivity of the detection device.

Microsphere: A minute sphere (a glass sphere approximately 30 microns in diameter).

Monochromatic: A light source consisting of one color or consisting of radiation of a single wavelength or very small range of wavelengths.

Nanometer: A unit of measurement used in measuring wavelength of light. A nanometer is 1 billionth of a meter.

Normal Illuminance (E): The illuminance on a retroreflective surface measured in the plane that passes through the retroreflective center and is perpendicular to the axis of incident light (illumination axis).

Observation Angle: The angle (CIE definition α, alpha) formed by a line extending from the light source to a point on the retroreflector and a line extending from the eye to the same point on the retroreflector (light-sign-eye angle). Brightness is maximum when observation angle is zero.

Orientation Angle, (see also Rotation Angle): This angle (CIE definition ω, omega) is related to rotation of the retroreflective unit in its own plane relative to the plane normal to the line of illumination.

Photometer: An instrument for measuring light similar to the way the eye "sees" light.

Photoreceptor: The sensor portion of a photometer -that is used to detect and measure the amount of light in a retroreflectometer. For retroreflection measurements, photoreceptors must match the CIE 1931 human eye response function (also called the Ybar, photopic or photometric function).

Presentation Angle: The dihedral angle from the entrance half-plane to the observation half-plane, measured counter-clockwise from the viewpoint of the source.

Preview Distance: The distance that the delineation provides the driver to see upcoming changes in roadway alignment.

Prismatic Cube Corner Marker: A raised pavement marker that employs prismatic cube corner elements to achieve retroreflection.

Receiver: The portion of the photometric instrument that receives the viewing beam from the specimen, including a collector such as an integrating sphere, the monochromator or spectral filters, the detector, and associated optics and electronics.

Reflectance: The amount of light an object or "target" reflects, expressed as a percentage of the incident light. Reflectance will depend upon the object or target color and composition and on the wavelength of the light being reflected.

Reflected Illuminance, ER: Illuminance at the receiver measured on a plane perpendicular to the observation axis.

Refraction: The deflection from a straight path undergone by a light ray in passing obliquely from one medium (such as air) into another medium (such as glass) in which its velocity is different.

Response Time: The delay between the time of a change in the target position and the time the sensor's output changes. This can be longer than one sample interval, if the sensor is processing or calibrating intermediate samples while transmitting the previous sample and taking the next measurement.

Refractive Index (RI): For a given material, the index of refraction is equal to the ratio of the speed of light in a vacuum to the speed of light as it travels through the material. Describes the "light bending" property of a glass as the light wave passes from the air to the glass or vice versa.

Retroreflectance Factor of a Retroreflecting Surface, R_F: The dimensionless ration of the coefficient of luminous intensity of a plane retroreflecting surface having an area "A" to the coefficient of luminous intensity of a perfect reflecting diffuser of the same area under the same conditions of illumination and observation.

Retroreflection: The reflection of light off an object or "target" back in the direction from which it came, for a wide range of angles or direction of the incident rays. Retroreflection is achieved through multiple reflections within a retroreflector. Retroreflectors include corner cubes or microspheres. A high-quality corner cube retroreflector will return virtually all the light entering it to its source. Some types of retroreflectors will return more than 1000 times the light returned by typical surfaces or targets. A corner cube retroreflector array was left on the moon to allow accurate measurement of its distance from the earth.

Retroreflective: Capable of returning light to its source.

Retroreflective Element: A single optical unit, which, by refraction or reflection, or both, produces the phenomenon of retroreflection.

Retroreflective Material: A material that has a thin, continuous layer of small retroreflective elements on or vary near its exposed surface (for example: retroreflective sheeting, beaded paints, highway sign surfaces, pavement striping).

Retroreflective Sheeting: A retroreflective material pre-assembled as a thin film ready for use.

Retroreflectivity: The efficiency of a highway marking to return light in the general direction from whence it came. When expressed for nighttime visibility, it is simply a ratio of the light visible to the driver compared to the light entering the pavement.

Retroreflectometer: An instrument designed to measure reflectivity of a target. Typically, a retroreflectometer sends a laser beam to a target where the light is retroreflected (reflected back towards the light source) by glass beads or corner cubes. An internal sensor measures the retroreflected light.

Retroreflector: A reflecting surface or device from which, when directionally irradiated, the reflected rays are preferentially returned in directions close to the opposite direction of the incident rays, this property being maintained over wide variations of the direction of the incident rays.

Retroreflector Axis: A designated line segment from the retroreflector center that is used to describe the angular position of the retroreflector.

Retroreflector Center: A point on or near a retroreflector that is designated to be the center of the device for the purpose of specifying its performance.

Rotation Angle: The angle indicating the orientation of the specimen when it is rotated about the retroreflection axis.

Sample Rate: The frequency with which a sensor updates its range output. The sample rate capability of distance sensors varies widely, depending on the measurement method and design of the device. Sample rates may be as low as one sample every few seconds and run up to millions of samples per second.

Sensitivity: A measure of the ability to obtain a reading on a dark target or with low laser powers. Sensitivity decreases at long ranges.

Silica: Silicon dioxide is one of the major oxide constituents of glass used for manufacturing glass beads.

Source: An object that produces light or other radiant flux.

Specific Intensity per Unit Area (SIA): An old term replaced by coefficient of retroreflectance R_A. Coefficient of retroreflection is defined as the ratio of the coefficient of luminous intensity (R_I) of a plane retroreflecting surface to its area (A), expressed in candelas per lux per square meter.

Specular Reflection: Specular reflection occurs when light strikes a shiny or mirror-like surface and is reflected away at one angle. Glass, liquid surfaces, and polished metals are specular, and generally require a sensor configured specifically for specular surfaces.

Steradian: The unit by which solid angles are measured. There are 4π steradians in a complete sphere.

Target: The surface that a light source hits, or radiates to, from which light is reflected to the detector in an optical sensor.

Threshold Contrast: The minimum difference in luminance of a target and luminance of that target's background at which the target is visible.

Viewing Angle: The angle between the retroreflector axis and the observation axis.

Visibility: The properties and behavior of light waves and objects interacting in the visual environment to produce light signals capable of evoking visual sensation.

Visible Spectral Region: The range in nanometers that the human eye can detect light. Light can be visibly seen in the range of 360 to 830 nanometers.

Wavelength: The distance in the line of advance of a wave from any one point to the next point of corresponding phase.

Appendix A

Page

Data Sheets

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Model 922 Handheld Sign Retroreflectometer

PRODUCT SUMMARY

The RoadVista model 922 is a handheld sign retroreflectometer designed for use in the field. It is designed to measure the retroreflection (R_A) of road signs and other materials.

Since a significant portion of the vehicles on the road in the USA are now SUV's and pickup trucks, ASTM has issued a new specification to require measurements to be performed at an observation angle of 0.5 degrees. The 922 is the perfect instrument for this addition. Utilizing the ASTM standard "annular" geometry, the 922 measures observation angles of 0.2 and 0.5 degrees *simultaneously,* with an entrance angle of -4 degrees. This patent-pending design allows you to know, with the press of a button, exactly how bright your sign will appear to most drivers. Plus, the annular geometry means you will not have to take an average of 2 measurements with prismatic-type materials, further simplifying the measurement process. A version is available with a standard 0.33 degree observation angle and +5 degree entrance angle to meet the European specifications.

The Model 922 comes standard with an internal global positioning system (GPS) and an internal barcode reader. The internal memory has the capacity to store more than 4500 measurements. Uploading the data to a computer is easy with the USB interface.

The sensitive light sensor meets ASTM E1709 and ASTM E2540 requirements with the CIE standard human eye response in conjunction with the CIE illuminant "A" lamp. Our world-class photometric filter fit is unmatched by the competition and allows extremely accurate measurements of other colors using the single white reference standard with no correction factors.

If field measurement is needed for high-mounted traffic signs, the Model 922-EPK extension pole kit with remote IrDA trigger is recommended.

FEATURES

- *Measures all types of retroreflective materials with a single measurement*
- *Meets ASTM, CIE, BS, EN & DIN specifications*
- *Utilizes annular measurement geometry – no averaging of measurements on micro-prismatic material necessary*
- *Dual observation angles of 0.2° and 0.5° for simultaneous measurements*
- *European geometry also available*
- *World-class photopic-corrected detector and source "A"*
- *Requires only 1 reference standard without any correction factors*
- *Self-contained commercially available battery*
- *Digital liquid crystal touch-screen display*
- *Built-in WAAS-enabled GPS*
- *Built-in programmable barcode reader*
- *USB Computer Interface*
- *Built-in averaging*
- *Internal storage for approximately 4500 measurements*
- *Foam-lined carrying case*
- *Optional extension pole kit with IrDA remote control*

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Model 922 Handheld Sign Retroreflectometer

SPECIFICATIONS

Geometry

Model 922 (ASTM E1709 and E2540)		Model 922D (DIN 67520 & EN 12899-1)		Model 922E (EN471 for safety clothing)	
Entrance Angle:	-4°	Entrance Angle:	+5°	Entrance Angle:	+5°
Observation Angle:	0.2° and 0.5°	Observation Angle:	0.33°	Observation Angle:	0.2° and 0.5°
Light Source angular aperture	0.1°	Light Source angular aperture	0.1°	Light Source angular aperture	0.1°
Receiver angular aperture (annular)	0.1°	Receiver angular aperture (annular)	0.1°	Receiver angular aperture (annular)	0.1°
Field of Measurement	1 inch (25 mm) diameter spot	Field of Measurement	1 inch (25 mm) diameter spot	Field of Measurement	1 inch (25 mm) diameter spot

Specifications (apply to all models)

Detector Responsivity	Photopic response in accordance with ASTM E1709 paragraph 6.4.2 and ASTM E2540 paragraph 6.4.2
Range (cd/lx/m^2)	0-2000
Data Memory	> 4500 measurements
Computer Interface	USB
GPS	12-Channel WAAS Enabled for <3 meter position fix uncertainty
Barcode Reader	Programmable Symbologies Laser Scanner
Power Supply	removeable12 VDC, 2.4 Ah battery (DeWalt P/N DC9071)
Charger	110 VAC, 60 Hz (add -1 after model number) 12 VDC cigarette lighter (add -2 after model number) 220 VAC, 50 Hz (add -3 after model number)
Operating Temperature	0°C to 50°C (32°F to 122°F)
Operating Humidity	0 to 95% non-condensing
Length	Approx. 11.5 inches (290 mm)
Width	Approx 4.5 inches (115 mm)
Height	Approx 12.75 inches (325 mm) with battery
Weight	Approx 5.9 lbs (2.7 kg) with battery

Accessories

Standard Accessories

- Foam-lined Carrying Case
- Measurement Area Reducers
- Battery Charger
- Two (2) Batteries
- Calibration Standard
- Calibration Certificate
- Windows Software with Mapping

Optional Accessories

- Annual Calibration Service
- 922-EAA Adjustable Entrance Angle Attachment (allows the entrance angle to be adjusted from -40 to +40 degrees continuously)
- 922-EPK Extension Pole Kit with remote IrDA trigger

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Model 1200F Handheld Retroreflectometer for RRPM's

PRODUCT SUMMARY

The RoadVista model 1200F is the next generation retroreflectometer designed for use in field measurements of Raised Retroreflective Pavement Markers. It is designed to measure the retroreflection (R_I) of all RRPM's.

The lightweight 1200F has an RS-232C interface that allows data to be downloaded into any traffic inventory system.

Based on the successful MX-30 Stripemaster design, the 1200F is designed for quick and easy measurements with the touch of a button. The instrument is lightweight and comes with wheels to make the measurement process a breeze. An internal GPS and printer come standard allowing the field user to quickly verify the data. Measurements can be made in 0.2 seconds and the instrument is ready for the next measurement in less than 2 seconds. This means the user spends less time on the road, which increases worker safety.

The internal memory will store up to 10,000 measurements before downloading to a computer. The data transfer is simple with our data-logging software. The 1200F connects to any standard computer using an RS-232C interface.

The 1200F has an internal GPS and printer. This allows the field user to quickly verify the data printout. The user can also plot the data on a clickable and printable map to quickly identify problem areas that need attention using our mapping software.

All 1200F's come with standards calibrated in our world-class photometric lab. The calibration is directly traceable to the American national standards lab, and the equipment used is held to the level of accuracy to ensure compliance with ANSI/NCSL Z540-1-1994.

FEATURES

- *Measures all types of raised pavement markers with a single measurement*
- *Meets ASTM, CIE & DIN specifications*
- *Light weight for easy handling*
- *Top mounted LCD for direct view of readings*
- *World-class photopic-corrected detector and source "A"*
- *Stores up to 10,000 data points*
- *Self-contained commercially available battery*
- *Built-in GPS*
- *Built-in thermal printer*
- *RS-232C Computer Interface*
- *Foam-lined carrying case*
- *Graphical Mapping Software*

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Model 1200F Handheld Retroreflectometer for RRPM's

SPECIFICATIONS

Geometry	ASTM E1696
Entrance Angle	0 degrees
Observation Angle	0.2 degrees (model 1200F) 0.3 degrees (model 1200FE)
Light Source angular subtense	0.1 degrees
Receiver angular subtense	0.1 degrees
Field of Measurement	5 x 1.2 inches (125 x 30 mm)
Specifications	
Range (cd/lx)	0-2000
Data Memory	~10,000 measurements
Computer Interface	RS-232C
Power Supply	removeable12 VDC, 2.4 Ah Ni-Cd battery (DeWalt P/N DC9071)
Charger	Standard 110 VAC / 60 Hz Optional 220 VAC / 50 Hz Optional 12 VDC with cigarette lighter adaptor
Operating Temperature	0°C to 50°C (32°F to 122°F)
Operating Humidity	0 to 95% non-condensing
Dimensions	
Length	Approx. 10.5 inches (267 mm)
Width	Approx 6.5 inches (165 mm)
Height	Approx 37 inches (940 mm)
Weight	Approx 23 lbs (10.5 kg) with battery
Additional Options	
Spare Battery	Annual Calibration Service

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StripeMaster I and II Pavement Marking Retroreflectometers

PRODUCT SUMMARY

The StripeMaster I and II portable retroreflectometers measure retroreflectivity of pavement markings per ASTM E1710 and EN 1436 utilizing the CEN 30-meter geometry. They also provide accurate measurements on wet (per ASTM E2176 and ASTM E2177) or dry surfaces. The lightweight StripeMasters have an RS-232C interface that allows data to be downloaded into any traffic inventory system.

The StripeMaster I is designed for quick and easy measurements with the touch of a button. This lightweight instrument comes with wheels to make the measurement process a breeze. Measurements can be made in 0.2 seconds and the instrument is ready for the next measurement in less than 2 seconds. This means the user spends less time on the road, which increases worker safety.

The internal memory will store up to 10,000 measurements before downloading to a computer. The data transfer is simple with our datalogging software. The StripeMaster connects to any standard computer using an RS-232C interface.

The StripeMaster II includes all the features found on the Stripemaster I and adds an internal GPS and printer. This allows the field user to quickly verify the data printout. The user can also plot the data on a clickable and printable map to quickly identify problem areas that need attention using our mapping software.

All Stripemasters come with a tile calibrated in our world-class photometric lab. The calibration is directly traceable to the American national standards lab, and the equipment used is held to the level of accuracy to ensure compliance with ANSI/NCSL Z540-1-1994.

Microprocessor-controlled calibration, with optional internal GPS and printer, makes the StripeMaster I and II the finest instruments of their kind in the industry.

FEATURES

- *ASTM E1710 and EN 1436 compliant*
- *Measures retroreflectivity of pavement markings*
- *Light weight for easy handling*
- *Convenient trigger height minimizes operator fatigue*
- *Top-mounted LCD permits direct viewing of readings*
- *Removable battery pack and 1-hour charger*
- *Stores up to 10,000 data points*
- *Measures on wet or dry surfaces*
- *Internal printer on StripeMaster II*
- *Internal GPS on StripeMaster II*
- *Microprocessor- controlled calibration and auto-zero*
- *Calibration standard traceable to the USA national standards lab*
- *Quick turn-on and rapid repeat readings*
- *Removable wheels for extended measurements*
- *Stabilizer supplied for rough surface situations*
- *Foam-lined watertight carrying case*
- *RS-232C computer interface with user-friendly software*

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StripeMaster I and II Pavement Marking Retroreflectometers

SPECIFICATIONS

Model	StripeMaster I (part number 71000)	StripeMaster II (part number 75000)
GPS	Not Available	12-Channel WAAS Enabled
Printer	Not Available	Direct Thermal, 2 inch (50mm) roll paper
Instrument	37" x 10.5" x 4.4" (93cm x 27cm x 11cm)	37" x 10.5" x 4.4" (93cm x 27cm x 11cm)
Carrying Case	46" x 18" x 6" (117cm x 46cm x 15cm)	46" x 18" x 6" (117cm x 46cm x 15cm)
Instrument Weight	21lbs (9.5kg)	21lbs (9.5kg)

The following specifications apply to all models:

Entrance Angle	88.76° (ASTM E 1710)
Illumination Angle	1.24° (EN 1436)
Observation Angle	1.05° (ASTM E 1710)
Observation Angle	2.29° (EN 1436)
Field of Measurement	2.4 x 7.9 inches (200 x 600 mm)
Wet Measurements	Meets ASTM E2176 and ASTM E2177
Detector/Light Source Response	Meets ASTM E 1710, paragraph 6.3.2
Range (mcd/m^2/lx)	0-2000
Data Memory	10 000 measurements
Computer Interface	RS-232C
Power Supply	removeable12 VDC, 2.4 Ah battery (DeWalt P/N DC9071)
Charger	110 VAC, 60 Hz (add -1 after part number) 12 VDC cigarette lighter (add -2 after part number) 220 VAC, 50 Hz (add -3 after part number)
Operating Temperature	0°C to 50°C (32°F to 122°F)
Operating Humidity	0 to 95% non-condensing
Wheels	User installed, included in carry case
Automatic Shutoff	5 minutes if inactive
Display:	2 x 16 character LCD

Accessories (apply to all models)

Standard Accessories

- Foam-lined Carrying Case
- Battery Charger
- Two (2) Batteries
- Calibration Standard
- Windows Software with Mapping

Optional Accessories

- Annual Calibration Service
- Calibration Certificate

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Model 930C Laboratory/Field Retroreflectometer

PRODUCT SUMMARY

The requirement for inspection of new retroreflective materials and signs as well as determination of the degradation resulting from weathering at many different observation and entrance angles normally involves time-consuming measurement in a photometric range (FTMS 370, LS-300C, ASTM E-810, Gamma Scientific Model 940D). While the photometric range system provides the lowest uncertainty in determining the coefficient of retroreflectance, the Model 930C system allows the materials and test engineer as well as the quality control inspector to conveniently measure these materials. The accuracy of these measurements is more than adequate for over 90% of the cases with the included photometric range calibrated reference samples.

The Model 930C system consists of an optical head with three ranges of sensitivity, a control unit, an entrance angle attachment and two sets of standards of all colors in engineering and high intensity types. The 930C optical head observation angle is continuously adjustable from 0.2° to 2.0°.
The sensitive light sensor meets the requirements of a match to the CIE standard human eye response in conjunction with the lamp output match to the CIE illuminant "A", 2856° Kelvin correlated color temperature requirement. A new photometric filter fit allows accurate measurements of other colors when the 930C is standardized using the white calibration reference.

The system comes standard with a 110/220 VAC supply for convenient laboratory use and a 12 VDC battery pack with battery charger for field measurements. The Model 930C system is also provided with a foam-lined carrying case.

If field measurement is needed for high-mounted traffic signs, the Model 907-30 extension pole kit is recommended.

FEATURES

- *Variable observation and entrance angle*
- *Meets LS-300C, ASTM, CIE & DIN specifications*
- *Three measurement ranges*
- *Photopic-corrected detector and source "A"*
- *Reference standards included*
- *Solid-state electronics*
- *Digital liquid crystal display*
- *Long-life battery and charger*
- *Foam-lined carrying case*

Model 930C Laboratory/Field Retroreflectometer

SPECIFICATIONS

Observation Angle	Continuously variable from 0.2° to 2.0°
Entrance Angle	Continuously variable from -40° to +40°
Light Source Angular Subtense	0.1°
Receptor Angular Subtense	0.1°
Measurement Area	Approximately 1 in. (2.6 cm) diameter
Dimensions	(Optical head without handle) 18 x 5 inches (45 cm x 13 cm)
Weight	Instrument with handle = 4.5 lbs (2.04 kg)
Control Unit	10 x 4.5 x 2.5 inches (25 cm x 11.5 cm x 6.5 cm)
Temperature Range	0° C to 50° C
Humidity	Non-condensing 0 to 95%
Calibration	Multi-color standards - Model 902 & 903 reference standard sets. Engineering and high-intensity grades in 6 colors, caps stored in a foam-lined carrying case
Measurement Range	0.001 to 1999.9 cd/lux/m^2 in 3 electrical ranges
Controls	Zero (dark), calibrate, range switch and low battery indication
Detector Light Source	Silicon photodiode with photopic filter combined with light source at CIE Illuminant "A" (2856°K)
Power Supply	110 or 220 VAC, and rechargeable battery 12 VDC

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The Laserlux® CEN 30 Mobile Retroreflectometer.

RoadVista

Pavement-Marking Retroreflectivity Measurement At Highway Speeds.

The Laserlux® CEN 30 Mobile Retroreflectometer System is the most powerful pavement-marketing retroreflection measurement system on the market today.

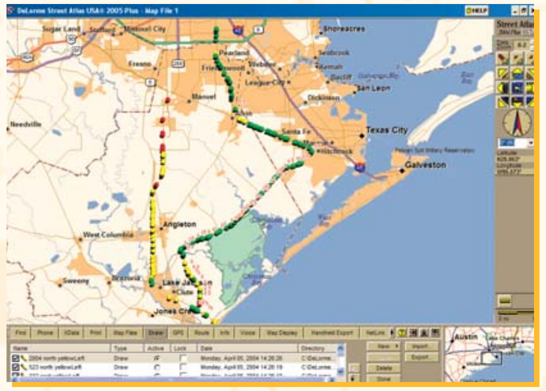
The Laserlux CEN 30 captures 1150 measurements per mile at 60 MPH.

Extensively fielded on four continents, this vehicle-mounted system provides reliable, objective and cost-effective measurements at highway speeds – night or day – without hindering traffic flow or putting operators at undue risk.

Designed to match the CEN 30-meter geometry, the Laserlux shines a scanning laser beam 10 meters in front of the instrument. This laser light is retroreflected back to a photoreceptor by the road stripe, and the coefficient of retroreflected luminance is calculated. Simple, yet exceptionally powerful.

Cover up to 300 line-miles per eight-hour shift. Perform more pavement-marking retroreflection measurements in a single day than you previously could in weeks. The Laserlux CEN 30's measurement speed – 1150 measurements per mile (at 60 miles per hour) – enables a two-person crew to cover up to 300 measurement miles per eight-hour shift. The unit features a scan width of 1.1 meters, and provides both contrast and retroreflectivity measurements within that width. Further, collected data is more statistically representative than standard techniques; each measurement consists of 200 unique datapoints.

Real-time data acquisition and analysis. The Laserlux CEN 30 features a rich, graphical software interface that makes it easy to acquire and analyze data – all in real time. For more data analysis power, consider the optional video and data overlay that can be recorded to DVD or VHS to show real-time measurements with actual road conditions. Also consider the optional mapping software that plots pass-fail measurement data for quick overview.



Optional mapping software plots pass-fail measurement data.

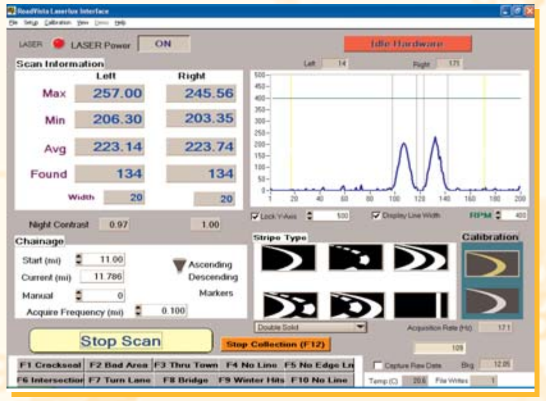
Global positioning system.

Was that a pavement-marking flaw near milepost 376, on Highway 50, deep in the Nevada desert? Pinpoint this level of positioning data quickly and easily via the Laserlux CEN 30's global positioning system (GPS). All measurement data is time and position stamped for fast search, identification and retrieval.

The Laserlux CEN 30 Advantage.

- *World Standard 30-meter geometry with six-inch ground clearance.*
- *Proven and accepted pavement marking management tool.*
- *High-speed, real-time measurement – 1150 measurements per mile at 60 MPH.*
- *1.1-meter scanning width.*
- *GPS provides exact vehicle location with stripe data.*
- *Powerful data acquisition and analysis software.*
- *Optional mapping software.*
- *Optional forward-looking video camera with cab-mounted monitor.*
- *Optional cab-mounted video recording camera with data overlay.*
- *Simple set up and operation.*
- *Custom integration with your truck or van is available.*
- *Eliminates lane closures and crew-safety issues.*
- *Ideal for holding contractors accountable.*

Fast set up, easy operation. Set up is nearly instantaneous. The Laserlux CEN 30 crew simply mounts the unit, adjusts its height to the proper level and aims the laser beam on the pavement 10 meters in front of the unit. Operation is even easier. Everything is automated; one crew member drives while the second crew member monitors data down-loading real time into the onboard computer.



Windows-based data acquisition software.

Customize your retroreflection operation. From cabin layout to type of vehicle, there are endless customizable options from which you can choose. Options include a forward-looking video camera with cab-mounted monitor for driver guidance and a cab-mounted video recording camera with data overlay.

Custom integration with your truck or van is available.

Eliminate lane closures and crew-safety concerns. Eliminate the biggest obstacles to pavement-marking retroreflection measurement – lane closures, traffic snarls and crew safety. What was once a major production is now a simple cruise down the highway. Plus by reducing manpower needs, you further save your department a bundle of money.

Optional video and data overlay shows real-time measurements with actual road conditions.

Ideal for holding contractors accountable. The Laserlux CEN 30's reliable and objective measurements are ideal for holding contractors accountable, implementing pavement standards, planning re-striping strategies and establishing a pavement-marking management database.

Specifications

Geometry	ASTM E1710 and CEN 30 meter
Entrance Angle (beta)	88.76° ± 0.01°
Observation Angle (alpha)	1.05° ± 0.01°
Aperture Size	0.1°
Sample Rate	>1150 measurements/mile @ 60 MPH >720 measurements/km @ 100 km/h
Operating Temp. Range	35 to 110 °F (2 to 43 °C)
Operating Humidity Range	5 to 95% R.H. non-condensing
Weight	55 lbs (22 kg)
Size	8x15x31 in. (22.3x38.1x78.7 cm)
Data Acquisition System & Software	Windows 2000/XP based
Vehicle Platform	Van or truck

Global service and support.

The Laserlux CEN 30 is backed by our highly trained and responsive global-support team. With sales and service offices in many countries, you'll enjoy the localized service you demand – from installation through deployment and beyond – to ensure your continued success.

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Model 940D Computerized Photometric Range System

PRODUCT SUMMARY

The RoadVista Model 940D computerized photometric range system is the ultimate in photometric testing of retroreflective materials, devices and light sources. The Model 940D allows the material engineer and the light source designer to characterize their products — to verify the quality of products both purchased and developed in-house.

When used in conjunction with Gamma Scientific's Model FM-100 flash measurement photometer or Model DR-2000 photometer, the system allows photometric measurements that determine the effective intensity of red and white strobe type anti-collision lights for aircraft and integrated illuminance energy in units of LUX seconds (lumen/m^2 • second) and luminous intensity energy (candela second) for barricade and other flashing lamp sources.

The new Model 940D system software features a user-friendly 32-bit graphics user interface with the ability to generate measurement sequence macros. With this feature, a single operator can now perform highly accurate measurements in a matter of minutes. Absolute measurements such as those recommended by ASTM, the Federal Highway Administration (FHWA), National Institute of Standards and Technology (NIST) and the Federal Aviation Administration (FAA) can be performed with ease using the 940D computerized photometric range system.

For retroreflectance, the Model 940D software allows default measurement sequences conforming to ASTM E809 procedures A and B for retroreflective materials. The intuitive software simplifies measurements of devices such as warning signs, raised pavement markers (RPMs), pavement markings and post delineators. The system also allows SAE configurations for measuring light sources such as headlights, taillights and message and warning lights. Single, vector and matrix measurements are possible with easily programmed data collection macro sequence files.

FEATURES

- *Provides complete and accurate retroreflection measurements*
- *Three-axis goniometer with 6.5" resolution - $\beta 1$, $\beta 2$ AND ε conforms to international standards.*
- *Observation Angle Positioner (OAP) with 3 ARC SECONDS conforms to ASTM and international recommendations*
- *Photoreceptor with a photopic-corrected silicon detector, $f_1' < 3\%$*
- *Stable and uniform illuminant A projection light source*
- *Variable separation from 10 to 30 meters*
- *Measurement capability for all types of retroreflective materials and light sources*
- *Night time retroreflection* ***color*** *and lamp* ***color*** *with optional Gamma Scientific C-11 or RadOMA spectroradiometer system*

ROADVISTA

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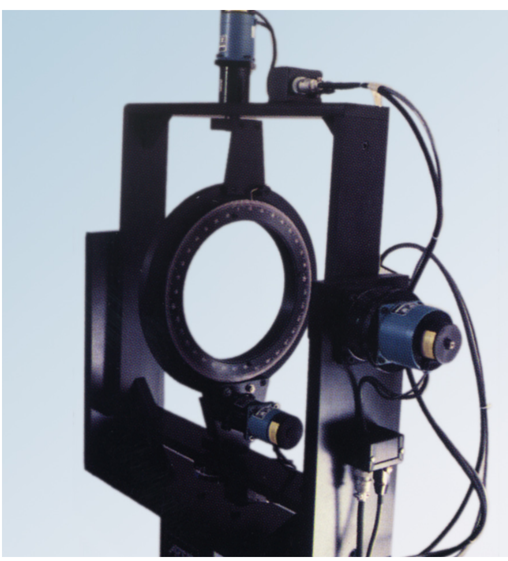
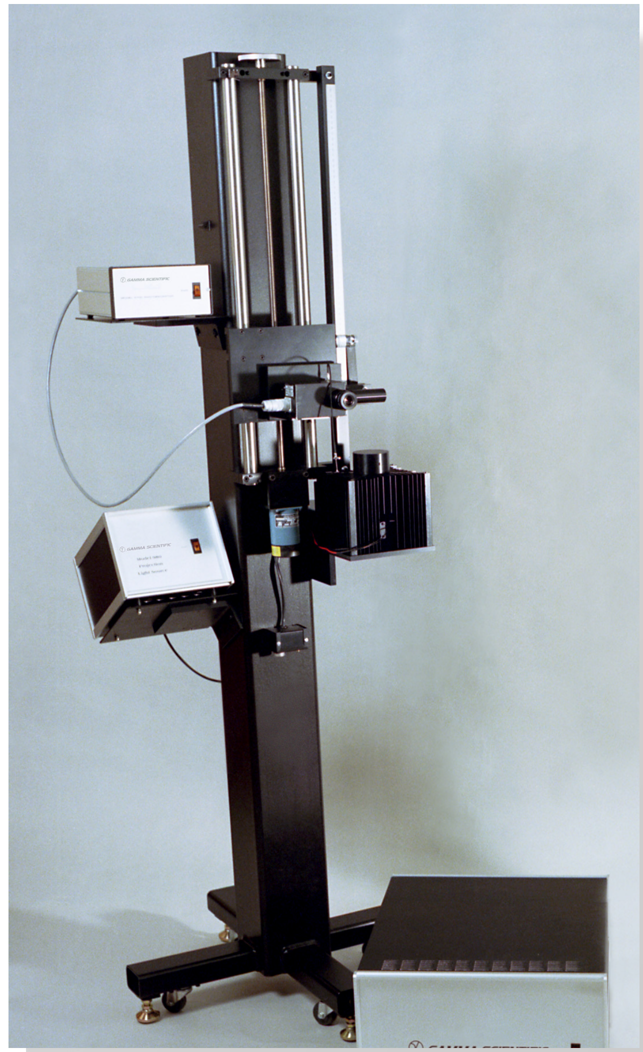
Model 940D Computerized Photometric Range System

PRODUCT SUMMARY

The Model 940D system consists of a Model 940 OAP observation angle positioner (OAP) with a Model 940 PR photoreceptor and a projection light source, an indexer control unit shown at right, a measurement sample 3-Axis goniometer shown below and a PC running Windows 2000 or Windows XP. Micro-stepped stepping motors with a zero backlash harmonic drive system drive the Model 940 DG 3-Axis goniometer's beta one (horizontal) and beta two (vertical) axes to achieve angular resolutions measured in seconds of arc shown below. The rotation axis is a ring, so various support fixtures can be used to test different device samples. A stepping motor drives the rotation axis. A closed-loop indexing control unit controls each stepping motor, thus assuring that no steps will be lost. For those with the Model 940C manual system, upgrades to an automated system are available.



Model 940 DG 3-axis Goniometer showing the clear opening for mounting various devices.



Model 940 OAP (observation angle positioner) Left with Model 940 PR photoreceptor telescope and electronics box, Model RS-50 projection lamp system and Model 940 IC stepper motor indexer control unit, right foreground.

ROADVISTA

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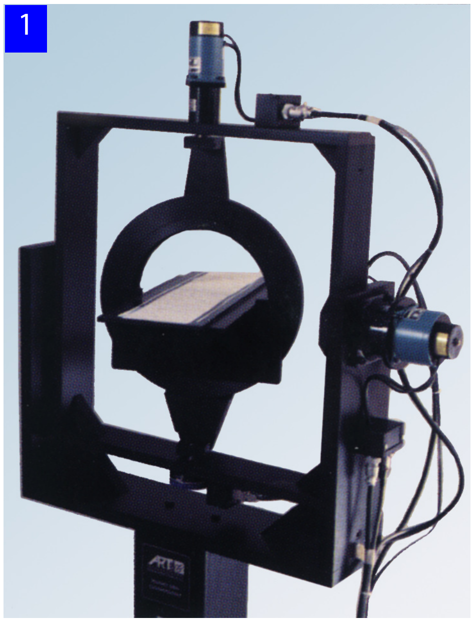
Website: www.RoadVista.com

Model 940D Computerized Photometric Range System

PRODUCT SUMMARY

1



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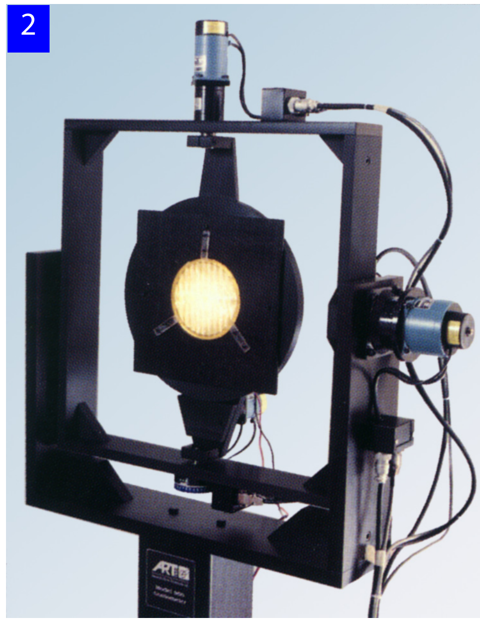

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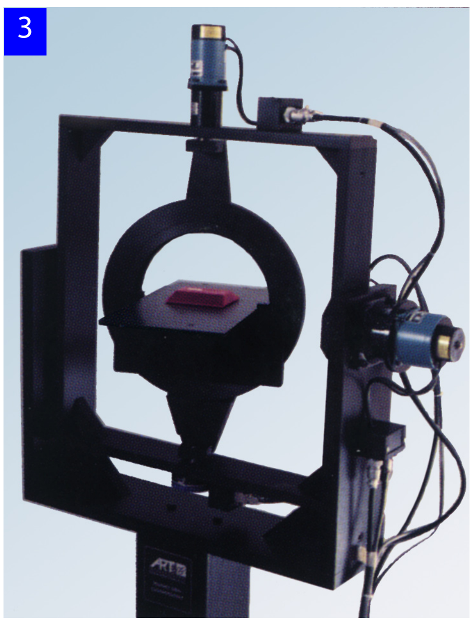

1. Measuring a horizontal coating (pavement marker)
2. Measuring an arrow board lamp.
3. Measuring a raised pavement marker.

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Model 940D Computerized Photometric Range System

SPECIFICATIONS

General Description:	RoadVista's precision laboratory photometric range system meets international standards for measuring retroreflection properties of materials and lamps. Now offered with a modern and easy to use Graphical User Interface (GUI), the system has proven durable in even continuously daily operation. The complete system provides all the measurement components required in the ASTM E809, E810 and E811 with optional color measurement systems.

Model 940 OAP **Observation Angle Positioner**	Observation angle range 0.1 to 2.0 degrees at a 15-meter separation with the goniometer. It has an angular resolution of 3 arc-seconds (0.0008 degrees).
Model 940 DG **3-Axis Goniometer**	Angular range for CIE Geometry Beta1 and Beta2 axes +/- 90 degrees with an angular resolution of 6.5 arc-seconds (0.0018 degrees). The angular range of the rotation (Epsilon) axis is 0 to 360 degrees with an angular resolution of 36 arc-seconds (0.01 degrees). Accommodates sample sizes up to 36 by 36 inches (91 by 91 cm).
Model 940PR **Photoreceptor**	Entrance pupil diameter = 25 mm Auto-ranging with seven decades of dynamic response Power: 110/220 VAC Photopic-corrected silicon detector, V(λ) f_1' <3% Viewing system with six different field stops to reduce stray light
Model RS-50 with RS-3 **Projection Light Source**	Exit pupil diameter = 25 mm Illumination diameter – continuously variable from 15 cm (6 in.) to 100 cm (39 in.) at 15 meter distance. Illuminance uniformity +/-3% over 100 cm (39 in.) diameter Correlated Color Temperature = 2856 +/- 20 K Power: 110/220 VAC constant flux output by constant current control
Model 940 IC **Indexer Control Unit**	Contains the closed-loop indexing controllers for the stepping motors, RS-485 computer interface and Windows XP / Vista control software. Power: 110 VAC Requires 940IC-VC Voltage Converter for 220/240 VAC operation
Options: **RadOMA RRC Retroreflected Color Spectral Measurement System**	When coupled to the 940D system, the RadOMA RRC is used worldwide for measuring the colorimetric characteristics of retroreflectors under nighttime conditions as recommended by ASTM E811. The RadOMA RRC consists of a high-resolution, visible-region, 1024 element CCD array spectroradiometer. The system offers high-speed measurements for all types of retroreflectors.
Options: **Model 940LUPR** **Low-Uncertainty Photoreceptor**	The 940LUPR takes advantage of Gamma Scientific's world-class candela standard that is supplied to national standards labs around the world. It includes temperature stabilized photopic filter and silicon detector with a high-precision amplifier to measure light levels down to 10 nanolux. The 940LUPR replaces the 940PR above. Entrance pupil diameter = 25 mm Auto-ranging with eight decades of dynamic response Power: 110/220 VAC Photopic-corrected silicon detector, V(λ) f_1' <1.5% Viewing system with six different field stops to reduce stray light
Options: **Model 940DGS** **3-Axis Goniometer**	Same as 940DG above, but smaller in size. Accomodates sample sizes up to 10 by 10 inches (25 by 25 cm)

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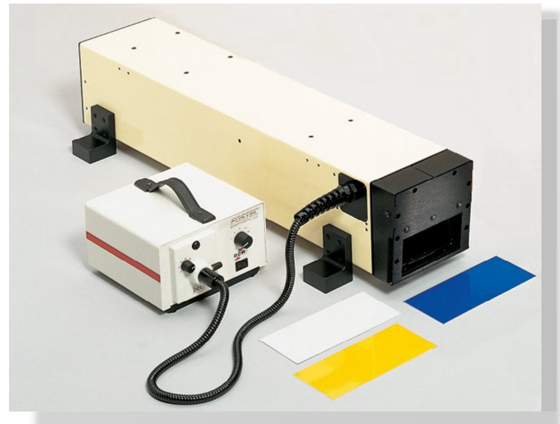
Model 1000 Online Retroreflection Monitoring System

PRODUCT SUMMARY

The Model 1000 retroreflection online monitoring system is a measurement system specially designed for retroreflective sheeting material production line monitoring. The system optionally comes with powerful computer-controlled data acquisition, display and recording capabilities. That option (Option 1) includes a Microsoft Windows-based computer, a data acquisition board that is plugged inside the computer, a chassis box, connection cables and user-friendly control software. It can perform analog to digital data conversion, system calibration that converts the voltage to retroreflection unit, graphical data display and data storage. Optionally, production line parameters such as conveyer position, speed and material thickness can be recorded with the appropriate sensors. Option 1 can read a rank file provided by the user and rank the measurement results. If the result is below the lower rank, or above the higher rank then option 1 can send out an alarm signal.

The Model 1000 has one projection light source and two observation angle photodetectors. Both the projection and receiver optics are collimated. The optical design meets both ASTM and CIE specifications for retroreflection measurement. The entrance angle axis is parallel to the instrument's centerline. Typically the entrance angle is set to either 5 degrees or 30 degrees and can be obtained by setting the position of the instrument. The observation angles are 0.2 and 0.5 degrees. With different optics, the observation angle could be modified to other angles. The industrial retroreflectometer output is 0-10 VDC analog voltage from each detector. The analog signal can be either connected to a chart recorder, an oscilloscope, a data logging device, display voltmeters or a computer data acquisition system.



FEATURES

- *Continuous retroreflectivity measurements of sheeting material*
- *High-speed data logging capabilities*
- *Meets both ASTM and CIE specifications*
- *Two observation angles of 0.2 and 0.5 degrees are simultaneously measured*
- *User-adjustable alarms to alert of any production line problems*
- *External light source for easy lamp replacement*

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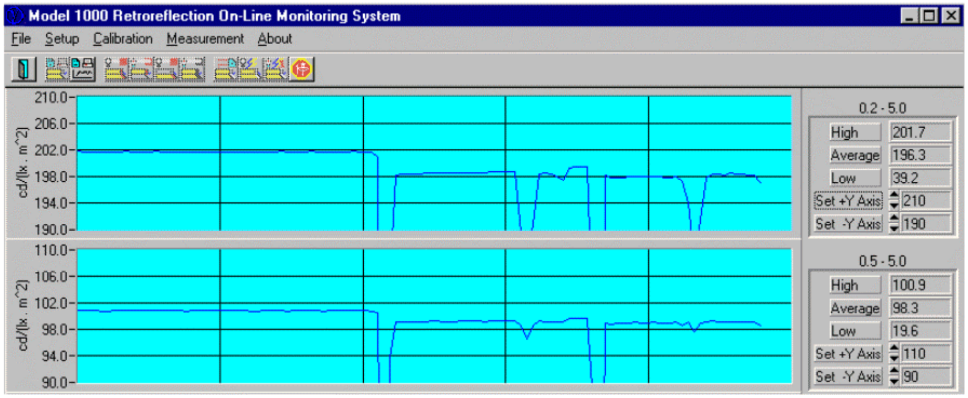
Model 1000 Online Retroreflection Monitoring System

SPECIFICATIONS



Sample data acquisition software screen capture

Length	29 inches
Width	6 inches
Height	6 inches
Measurement Area	100 x 50 mm
Detector Angular Diameter	0.1 degrees
Light Source Angular Diameter	0.1 degrees
Illumination Source	Tungsten-Halogen approximately 2856 K (Illuminant A)
Observation Angles	0.2 and 0.5 degrees
Entrance Angles	Typically +5 or +30 degree options (Others available upon special request)
Signal Output	0 to 10 VDC analog output
Power Requirements	100 to 240 VAC / 50 to 60 Hz
Data Acquisition	Via oscilloscope, voltmeter, or computer using a National Instruments PCI-6025E DAQ card

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Photometric Range Calibrations

RoadVista offers an extensive range of highway safety calibration services in our 15-meter photometric range that exceed the specifications of ASTM E810. Our calibrations meet the specifications of various test methods, including ASTM, SAE, ITE, ITS, CEN and many others.

Retroreflection measurements of pavement markers, sign sheeting, clothing, raised pavement markers

- Daytime color
- Nighttime color
- Retroreflection (ASTM R_L, R_A, R_I)

Lamp, Traffic Signal, and Message Board Measurements

- Angular luminous intensity
- Angular illuminance
- Angular luminance
- Angular color and chromaticity

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