Video Based Light Measurement Techniques

1. **Scope**—Traditional methods of photometry rely on the use of a goniometer to rotate the test item around two axes at right angles. This method is satisfactory for most situations but has certain disadvantages:

   a. Point-by-point measurements with a goniometer may be slow. With more advanced requirements, particularly for headlamps, where the entire beam pattern is of concern, isocandela measurements are becoming increasingly needed. Such testing can be very time consuming.
   b. For production quality assurance, the speed of a goniometer may not allow testing to keep pace with the production line if a large quantity of lamps must be sampled.
   c. High Intensity Discharge (HID) lamps are becoming commonly used. Such lamps are orientation sensitive, changing in both lumen output and intensity distribution when tilted. This can introduce significant inaccuracies in test results when testing is performed using a goniometer.

There is a need for alternative test techniques which can achieve very high speed data acquisition, the capture of full isocandela distribution, and the elimination of lamp tilting. This SAE Informational Report describes fundamentals of video-based testing to address these concerns. Further information is required to provide all details needed to set up a laboratory using these techniques.

With the video-based system, the lamp is fixed in position and aimed at a receiving screen. A camera, of particular type and grade, views the screen and is able to perform measurement of the reflected light (luminance) at each point on the screen. Proper calibration of the system can provide the luminous intensity distribution of the light under test from the measured luminance values.

Numerous factors must be taken into account to produce an accurate measurement system. Under controlled conditions, it has been shown that the system can produce measurement of absolute intensity distributions with good accuracy. (Reference 2.1.1 and 2.1.2.)

The great advantage of this form of photometry is its extremely high speed, allowing the collection of isocandela diagrams in less than one minute. There are some accompanying disadvantages which are discussed later.

This document describes the basic techniques and the controls which are necessary for accuracy.

Comments are also provided comparing video based technology to conventional goniometer methods.

1.1 **Background and History—**The measurement of entire light distributions became a topic of research in the 1960's, when film cameras were used to perform photometry. (Reference 2.1.3.) Groundwork was laid which suggested that photographic photometry would be a viable technique if the chief source of the problem, the film itself, could be replaced by a more stable and reliable means of collecting the image. With the advent of the Charge Coupled Device, (CCD), most of the problems of the film cameras are removed. To produce an accurate system of photometry, however, it is essential to understand the characteristics of CCD camera systems. Proper calibration methods must be applied and controls must be exercised to ensure accuracy.

2. *References*

2.1 **Applicable Publications—**The following publications form a part of this specification to the extent specified herein.

2.1.1 Lewin, Ian, "Advances in Measurement Technology for Vehicle Lighting Systems," SAE Congress, Detroit, Michigan, Feb. 1996, Paper no. 960919, SAE, Warrendale, PA

2.1.2 Lewin, Ian, Lin, K. Frank, Sisson, Charles, "Accuracy Analysis of Video Based Photometry," SAE Congress, Detroit, Michigan, Feb. 1997, Paper no. 970231, SAE, Warrendale, PA

2.1.3 Lewin, Ian, and Bell William B., "Luminance Measurement by Photographic Photometry," Transaction of the Illuminating Engineering Society, Illuminating Engineering Vol. 63, no. 11, Nov. 1968, Illuminating Engineering Society of North America, New York, NY

2.1.4 Gallagher, Paul, "Selecting CCD Sensors." Lasers and Optronics, Vol. 14, no. 7, July 1995, Morris Plains, New Jersey

2.1.5 "Methods of Characterizing Illuminance Meters and Luminance Meters, Performance, Characteristics, and Specifications," Publication CIE no. 69, Commission Internationale de l'Eclairage, Vienna, Austria

3. *Definitions*

3.1 **Barrel Distortion—**A form of image distortion where each perimeter edge of the image field bows outwards.

3.2 **Bit—**A single digit in a binary number system (0 or 1).

3.3 **CCD Camera—**A type of camera that utilizes a silicon based light detector termed a Charge-Coupled Device that consists of an array of individual detector elements.

3.4 **CIE V(λ)Curve—**The sensitivity response curve of the human eye to light of differing wavelengths.

3.5 **Digitization—**The process by which analog data are converted into numerical data.

3.6 **Goniometer—**A photometer for measuring the directional light distribution characteristics of sources, usually consisting of a mechanism for rotating the source.

3.7 **Luminance—**The ratio of the luminous intensity in a given direction of an infinitesimal element of surface containing the point under consideration, to the orthogonally projected area of the element on a plane perpendicular to the given direction expressed in units of candela per unit area. Sometimes referred to as photometric brightness.

3.8 **Pincushion Distortion—**A form of image distortion where each perimeter edge of the image field bows inwards.

3.9 **Pixel—**Picture element. This is the basic unit of an electronically coded picture image.

3.10 Video Based Photometry—The measurement of photometric quantities with the use of an electronic instrument that uses a two-dimensional array detector suitable for the recording of images.

4.   Basic Principles—The basic principle of the video camera system is shown in Figure 1. The light to be tested is placed on a fixed stand. Mechanisms for aiming adjustments can be provided; no rotation of the device during testing is required. A screen, painted with diffuse white spectrally neutral paint, receives the light distribution. The test light HV axis is normally aimed to be perpendicular to the screen center.

A scientific grade CCD camera is located in close proximity to the test light, with its axis aimed parallel to the HV axis. This is not essential but it simplifies the conversion of the measurements to intensity data. Camera lensing selection is such that the entire screen area is viewed by the camera. The camera is a digital system which electronically collects the image it views and transmits it to a computer.

Geometric conditions are known, including the X, Y, and Z distances separating the camera and test device. Using appropriate software, a spatial transposition can be applied such that the system operates and displays data as if the camera were located at the center point of the lamp under test. To perform measurements, an exposure occurs under software control. Each pixel or "electronic bin" of the camera collects a charge which is in proportion (within limits) to the luminance of the corresponding point on the screen. The camera's CCD array typically will consist of several hundred thousand pixels, a large array of data points is measured.
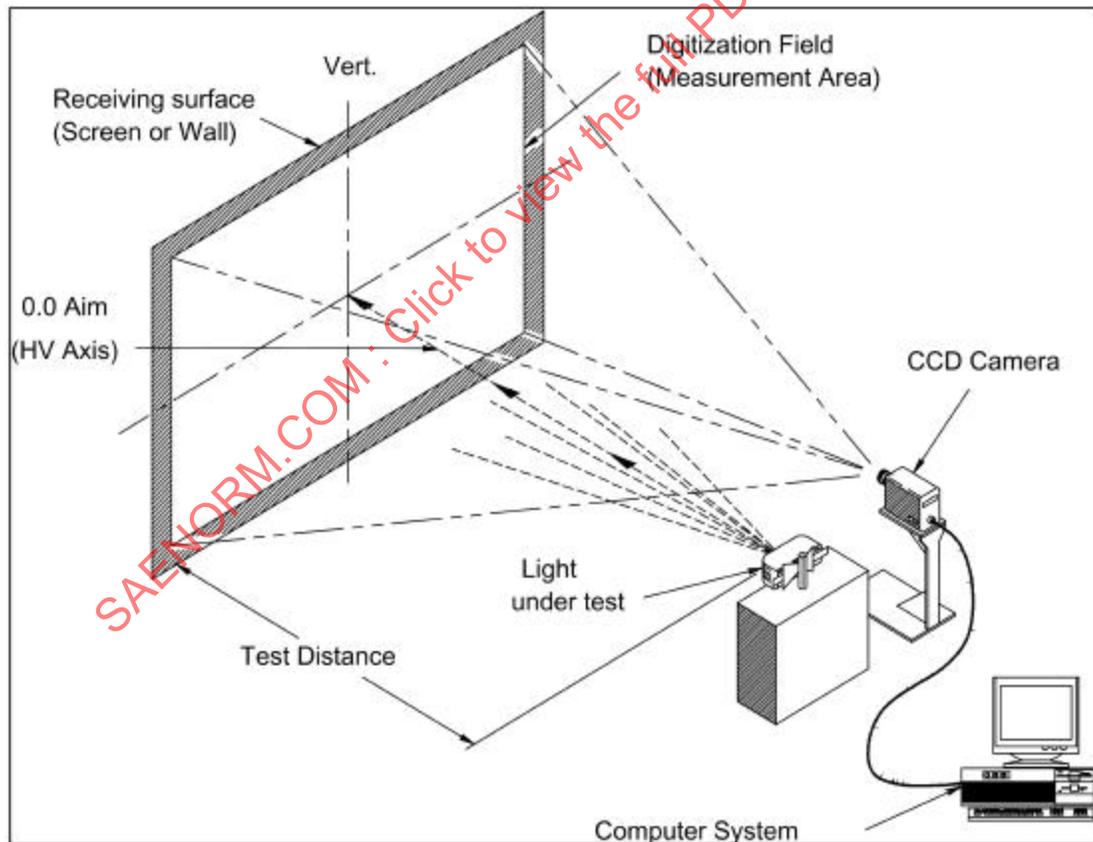

FIGURE 1—BASIC PRINCIPLE

4.1 The Video Camera—CCD Cameras range from the simple and inexpensive which are used for applications such as surveillance and camcorders to the highly accurate and sophisticated (Reference 2.1.4). For accurate and repeatable photometry, a very high quality system is essential. The following should be noted:

   a. CCD Defects—Defective pixels will produce erroneous readings. Cameras should be scientific grade 0, having no defective pixels.
   b. Cooling—Internal electronic cooling of the CCD chip is required for accuracy and stability, particularly at low light levels.
   c. 14 or 16 bit electronics are highly desirable, otherwise the dynamic range needed for automotive devices may not be achievable with accuracy.
   d. Spectral Correction—The camera must be provided with a spectral correction filter to provide an accurate correlation with the CIE $V(\lambda)$ curve, in order to match the spectral response of the human eye. (Reference 2.1.5.) This requires the use of a specially designed filter for the particular type of CCD chip in use.

5. Camera Calibration Factors—When operated under proper conditions, the response of each pixel of the CCD has near-perfect linearity. The charge stored for each pixel after exposure thus is directly proportional to the light received. Digitization of the charge provides a measure of the luminance level of the object, normally expressed as a bit count.

Conversion of the bit count of a given pixel to the absolute luminance of the corresponding point on the screen requires consideration of several factors. Techniques also exist which provide bit count conversion that provide a measure of the absolute intensity of the light under test in a direction towards the measured point on the screen. Calibration methods can be used which provide near-instantaneous calibration of the entire screen area and the equivalent array of CCD pixels so that complete intensity distributions are provided.

5.1 Lens Distortion—A camera lens does not produce a perfect image due to distortions caused by the lens itself. The effects are classed either as "barrel distortion" or "pincushion distortion." These effects are particularly noticeable with wide angle lenses needed in automotive applications.

Conventional methods are available to determine the effect of lens distortion. A correction equation can be then introduced into the software to provide undistorted data.

5.2 Flat Fielding—The ratio of object luminance to pixel bit count changes from point to point over the field of view. For a field of uniform luminance, the bit count generated in the center region of the CCD array is stronger than that at the edge of the display. This is caused by vignetting and $\cos^4$ (Reference 2.1.4) law fall-off, both of which are well known in photographic technology.

By exposing the camera to a field of uniform luminance the variation can be measured and corrected. A technique known as "flat fielding" can be applied, where a data file of correction factors is stored, which can then be used to correct the measured data.

When the camera is calibrated as described below for luminous intensity measurements, a separate effort for flat fielding is unnecessary as the effect is removed as part of the measured individual pixel calibration factors.

5.3 Standard Lamp—The system may be calibrated by the use of an intensity standard lamp in a manner equivalent to a goniometer. However, the standard lamp must be calibrated over a wide range of H and V angles rather than a single direction. The angular range should cover the full screen area. The intensity standard should produce fairly even illumination of the screen, free from spots and striations. Calibration values should be available every 2.5 degrees, in both the H and V directions and over the full angular range to be measured.

This standard lamp is mounted on the test stand and used to illuminate the screen. The intensity falling at all points on the screen is known either directly from the goniometer measurements or by interpolation. After the system captures the image, a calibration factor (bit count per candela ratio) is determined for each pixel. These factors are placed in a calibration file and applied to subsequent test readings to convert the values to absolute candelas.

This method is independent of the screen reflectance. The screen paint can vary in its reflectance without any effect upon measured intensity values.

The calibration source itself is calibrated on a goniometer and thus can be NIST traceable, (National Institute of Standards and Technology).

6. *Camera Adjustments*

6.1 **Sensitivity Adjustment—**To accommodate all the various intensity ranges from low power lights to headlamps, an overall sensitivity adjustment is required. This can be achieved by control of the exposure time. This can be software automated in advanced systems.

The relationship between exposure time and bit count for a given luminance should be checked to verify that it is linear. Figure 2 shows example data. Caution should be exercised particularly with very short exposure times of less than 1/10th second as the linearity relationship may not hold. A "latent exposure time" usually occurs, which can be measured and a compensation made in the software.
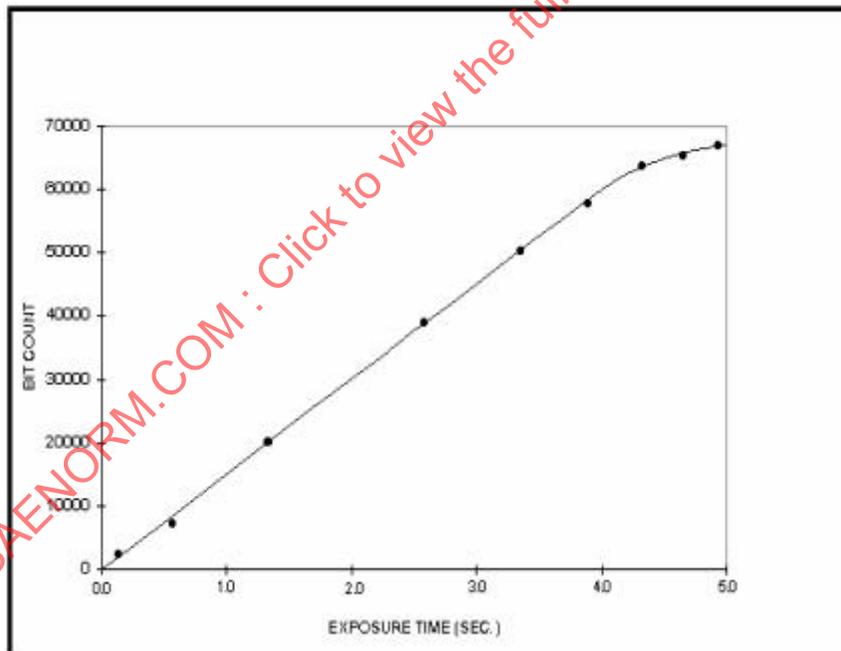

FIGURE 2—EXPOSURE TIME VERSUS BIT COUNT.

6.2 **Dynamic Range**—CCD camera systems are available in 8, 12, 14, and 16 bit forms. These have theoretical dynamic gray scales of 256, 4096, 16384, and 65536 respectively. In practice, however, the full dynamic range is not useable.

For low signals (bit counts), readings will be affected by system noise. This can be greatly reduced by using a camera which provides digitization in the camera itself rather than transmitting an analog signal to be digitized in the computer.

For high signals, usually at 95% or greater of the maximum bit count, linearity is lost due to saturation of the CCD electronics.

Software controls can prevent readings being collected in these low and high signal ranges. This can produce a response with good linearity throughout a defined useable dynamic range. Figure 3 shows a response curve for a 16 bit system. The actual linearity achieved will be dependent upon the type of camera and its electronics. Users should determine the useful linear dynamic range before using any camera system.
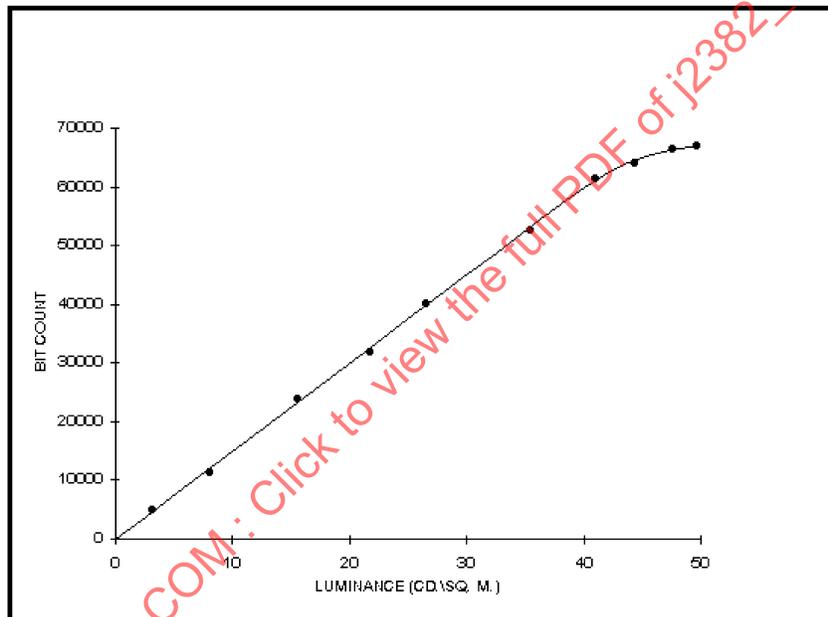

FIGURE 3—LUMINANCE VERSUS RESPONSE (BIT COUNT)

The useable dynamic range of an 8 bit camera is actually about 100:1. This is generally unsuitable for automotive applications. A 16 bit system will have a practical dynamic range of about 60 000:1, sufficient to capture all normal automotive lighting patterns.

Experiments have been run using 8 bit cameras using a series of exposures with different exposure times. Data within the useable range from each exposure can be extracted and merged together to give a wider dynamic range. For the long exposures in this series, the high signal areas are likely to saturate and the image will "bleed." Saturation is caused by the filling of the electronic bins used to store the charge for the individual pixels, creating a non-linearity between luminance and bit count. Bleeding is caused by the excess charge spilling over into adjacent pixels. The errors produced can be major, particularly where low light level areas are close to high intensity areas. Therefore, this technique should be avoided.

6.3   Dark Field—In a manner similar to silicon photocells, a CCD device will produce a small signal even when no light is present, "dark field". This is greatly reduced and stabilized by the use of a camera with internal cooling (Reference 2.1.4.) Operation of the CCD chip at a temperature in the range of –20 °C to –30 °C is advisable.

Dark field must be measured and subtracted off the test readings. This also can be software automated.

7.   System Accuracy—CCD video photometry is in its infancy, but indications are that these techniques can be highly accurate providing the proper precautions are taken. As in all photometry, proper aiming is required, and suitable screening must be provided to prevent light from reflecting surfaces reaching the screen.

Tests conducted on headlamps with a conventional goniometer and a video-based system have been shown to indicate close correspondence. (Reference 2.1.2.) Figures 5 and 4 illustrate typical test results for a high beam headlamp. In general, video-camera photometry will reproduce goniometer data to approximately 5%, providing all of the above-described factors are properly taken into account and if test conditions are identical. This difference may be due to inaccuracies either in the goniometer or the video-based system. It is possible that the accuracy may improve in the future as more development and experience occurs.

Repeatability of test results should be within ±2%, providing no aiming errors are introduced.
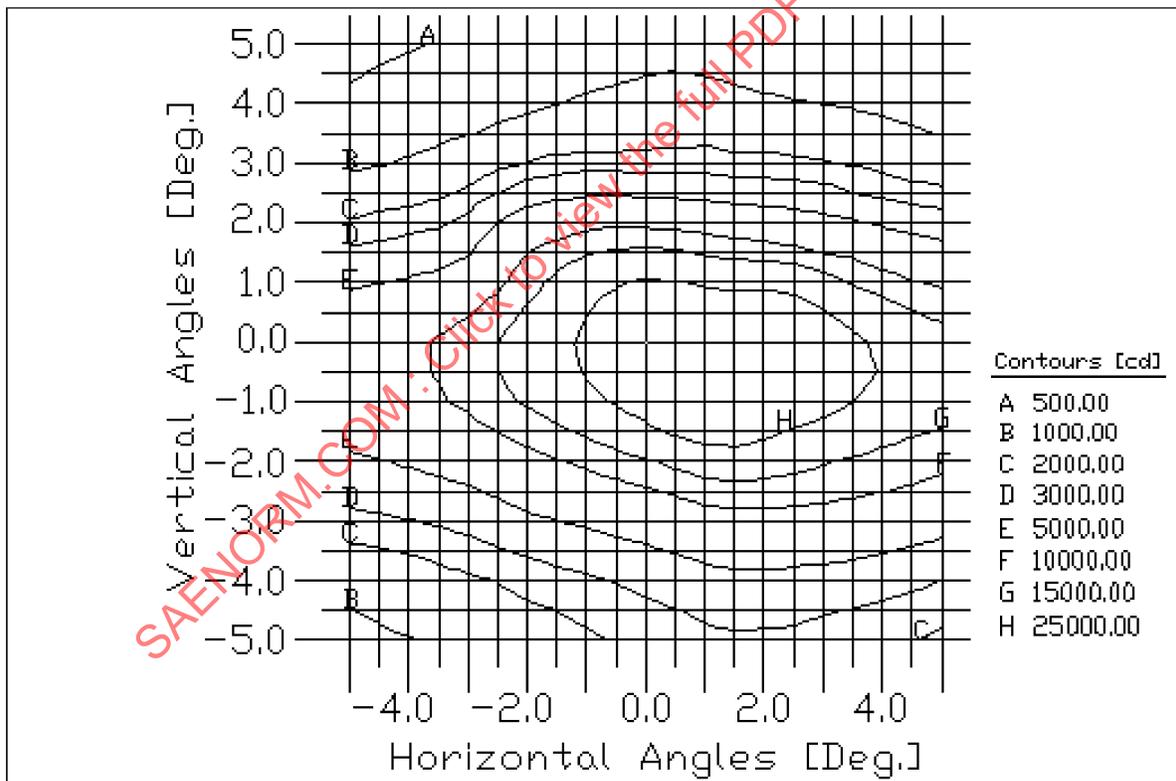

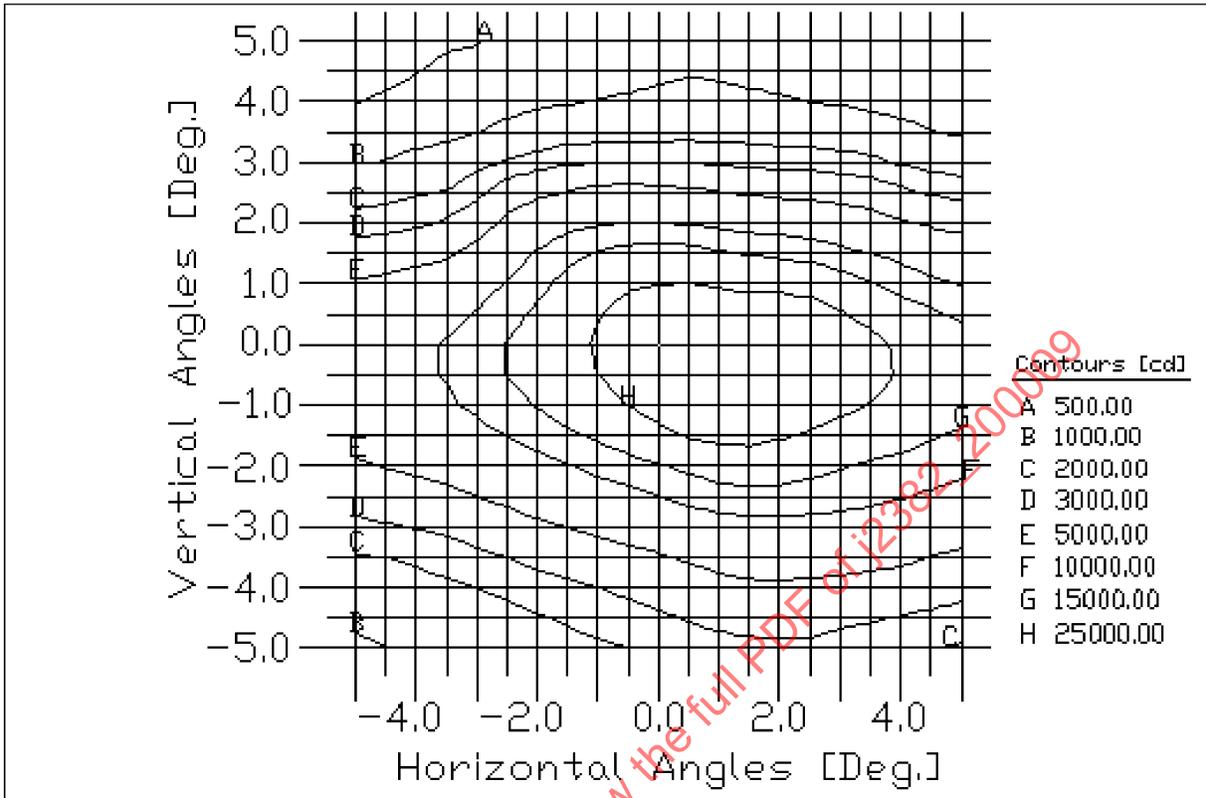FIGURE 4—HIGH BEAM HEADLAMP, GONIOMETER DATA

FIGURE 5—HIGH BEAM HEADLAMP, VIDEO-BASED PHOTOMETRIC DATA

8. *System Limitations*—Video-based photometric systems have an inherent limitation. For the receiving screen to be a practical size, the angular range of the data collected will be limited. Also, the test distance normally will be restricted by the screen size. This is not a problem for devices tested at 3 m (10 ft), but the 18 m (60 ft) test distance normally used for headlamp testing may not be achievable. A flat screen of 6 m (20 ft.) width and 2.7 m (9 ft) height will capture a light pattern of 20L to 20R, 10U to 10D at a test distance of 7.6 m (25 ft). Measured headlamp performance at this test distance may be different from that at 18 m (60 ft), but indications are that such differences may be small. (Reference 2.1.2.) Care must be taken in analyzing intensity gradients at different distances.

Lighting devices, typically those with focusing optics, may exhibit "beam crossover" or convergence within the beam. Thus they may produce different intensity distributions at different test distances. Using reduced test distances for such devices may cause significantly deviations from goniometer testing which uses a 18m (60 ft.) test distance. More testing and evaluation is required to determine the significance of these effects.

A curved screen can be used. While construction is more difficult, an increased angular range can be achieved in a given space.