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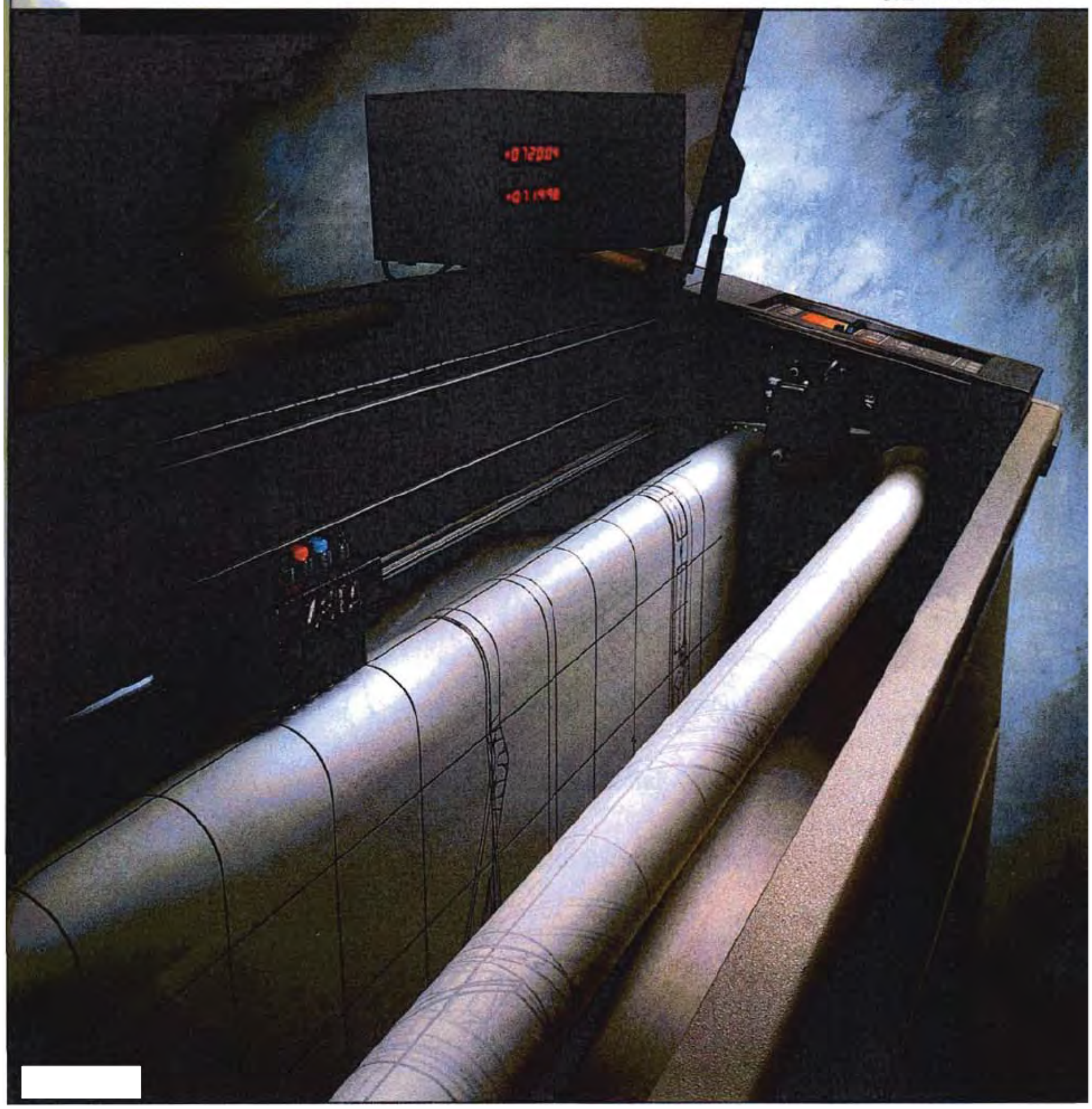

LEDs for exterior lighting

Until recently international regulations have mandated against the use of Light Emitting Diodes for exterior lighting on vehicles. A terminology change recently ratified would appear to remove this barrier. Does this now mean that LEDs will become as commonplace on the outside of vehicles as they currently are on the inside? Hewlett-Packard is a leading supplier of optoelectronic devices and Martin Lister of the company's Components Group reviews the developments made in LED technology and their applications in automotive engineering.

In the 1960's production processes were developed that allowed a p-n junction, traditionally only able to emit non-visible infra-red light, to emit light in the red area of the visible spectrum. This development led Hewlett-Packard to introduce, in 1968, the first commercially available Light Emitting Diode (LED) display and so launch the era of a completely new generation of lighting products. It seems that ever since the LED was first introduced there has been speculation on if and when it would be used in automotive lighting applications. Within the driver's compartment developments have certainly been made, however, the use of LEDs for exterior applications has been less prevalent.

This is not primarily due to the lack of technological development in LEDs as high-brightness devices now exist in a number of different colour combinations whose performance clearly fit them for exterior lighting applications. The bigger challenge to the take-up of LEDs has been regulatory. The lighting on vehicles is governed by a large body of international legislation. Up until recently this legislation has been specific in its recommendations for exterior lighting; it has unequivocally specified that incandescent lamps should be used. With this terminology in place it seemed that despite the technological developments taking place there would never be an opportunity for the use of LEDs on the outside of vehicles.

However, over the past 12 months there has been a change to the terminology used in this legislation that appears to have removed the regulatory barriers. In amendments to the legislation, the terminology has been changed from 'incandescent lamp' to 'light source'. This now means that lighting devices other than filament bulbs can be used in exterior applications and this obviously includes devices such as LEDs. So if the regulatory barriers have now been removed does this mean there will be a rush to design in solid state lighting on all new cars? To answer this question it is perhaps first appropriate to review the benefits to the vehicle designer of using these devices.

The first and overwhelming advantage of course is that of reliability. LEDs generate their light output from a solid state device as opposed to a white hot glowing filament. Intrinsically this implies greater reliability and this is borne out by the data. LEDs are typically rated for over 50 000 hours of operating life compared to a few thousand at best for incandescent lamps. In addition cars and trucks provide a very extreme environment for any electrical device. Resistance to vibration and shock and extremes of temperature and humidity are essential for good reliability. The solid state LED easily outperforms the incandescent lamp with its fragile filament in this environment.

One of the benefits to the vehicle manufacturer that result from this reliability advantage is greater freedom in styling. LED lighting panels can be located on areas subject to shock and vibration where traditionally incandescent lights would not be appropriate.

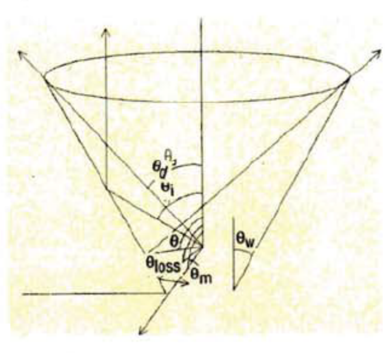

Fig 1. Critical reflectance angles for conical straight walled reflector cavity

The reliability of the devices also means that they can be incorporated into the vehicle on a sealed-for-life basis so designers do not have to make provision for access to the device for changing. It can thus be integrated into the body panels making for a smoother, more aesthetically-pleasing design. Also since LED lamps for vehicles use multiple light sources designers can experiment with lamp appearances from discrete 'points' of light to evenly lit panels for cosmetic lights or appliqués.

On a direct part-for-part comparison a LED light source is higher priced than its incandescent counterpart. However, price is not necessarily the best basis for comparison. LEDs promote cost savings in other areas. This reliability reduces design complexity. This reduces sheet metal, additional piece parts, labour and other costs. They use significantly less power, up to one tenth of that used by incandescent lamps. This gives the potential for lower cost, lower weight electrical systems. They generate lower levels of heat than incandescent lamps, eliminating the need for specialised high temperature resistant epoxies in the lamp housing. Finally, of course, a sealed for life lighting system can significantly reduce warranty costs and improve customer satisfaction.

There is one other advantage that appears to be given by the use of LEDs in exterior lighting and this is something not necessarily expected originally by their manufacturers', they turn on quicker than incandescent lamps. Tests have shown that when used in a stop light they give an earlier warning to other drivers. The difference is between 130 and 200 ms. At motorway speeds this equates to a car's length in stopping distance. This can contribute directly to safety and has the potential to reduce the probability and severity of rear end collisions.

Recent technology advances

Light is emitted from an Light Emitting Diode due to the recombination of electrons and holes inside the p-n junction. Each recombination results in the release of a photon of light. The materials whose properties are well suited to exhibiting this phenomenon are those found in the third and fifth columns of the Periodic Table, the III-V materials. Not all of the light released is seen by the observer, losses occur, typically in three areas. The first of these is loss due to absorption within the LED material. The photons released are emitted in all directions. If the substrate on which the junction is grown is opaque (as with Gallium Arsenide) only those photons emitted upwards and within a critical angle can be utilised as light output.

The second cause of loss is referred to as Fresnel loss. Fresnel loss is introduced in the packaging of the LED. It occurs when light is reflected back at the interface of two materials whose index of refraction differ. The third cause of loss is Critical Angle loss. The effect of this is seen when an observer moves in relation to the LED. When the observer moves off the axis of the device the light output decreases markedly. Since the phenomena that result in these losses cannot be overcome LED development has focused on making advances in the production of the III-V materials and on the packaging used. For example, Hewlett-Packard has developed devices using Aluminium Gallium Arsenide (AlGaAs) in which the substrate is etched away to eliminate photon absorption internally. The result is a Transparent Substrate device designated TS-AlGaAs. Using transparent substrate technology HP has produced LEDs that give a light intensity 100 times brighter than the traditional LED.

Also, because the optical flux emitted by a LED is fairly low, LED manufacturers in the past have introduced multiple LED die in a single package. Devices with 2 die have been common and some years ago HP introduced a device with 4 die. These devices produced sufficient optical flux to be used in high brightness applications but unfortunately their cost mandated against them. An alternative approach used by the company to package the single die is a 5 pin DIP. Four of the pins are then used to conduct heat away from the cathode of the device allowing the lamp to operate at up to 100 ma of drive current without exceeding its power rating. In these series of Brewster lamps the LED die is mounted in an optical reflector providing improved optical performance over conventional packaging techniques. The lamps use a deeper reflector dish allowing them to catch the light emitted from the sides of the diode and direct it upwards, where a convex lens further collimates the light. The resulting optical output and radiation pattern provides significant improvements over conventional indicators using the technology.

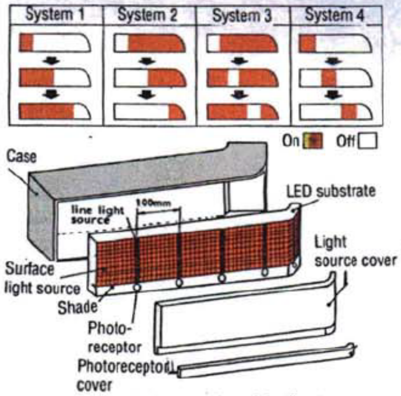

Fig 2. 'Sweeping' turn-signal indicator proposal by Stanley Electric with, below, their proposal for a combined LED rear lamp and proximity sensor

The use of LEDs in high brightness applications requires good optical design principles to be followed in the design of the housing surrounding the lamps. The housing is more critical for diodes than for incandescent bulbs for a number of reasons. Firstly the lower optical output of these devices requires that none of this be wasted, care is need to ensure that the maximum amount of light from the unit strikes the legend area. Secondly incandescent lamps tend to have a radiation pattern in which light is emitted equally in all directions whereas, as noted above, the luminous intensity tends to peak in one direction.

A properly designed white reflective optical cavity can utilise most of the optical flux emitted by a light source, the cavity redirects the light emitted at wide angles so that it strikes the rear of the legend. The performance of the cavity depends upon its geometry and equations can be derived to calculate the amount of light output exiting the housing after reflection from the cavity walls. For any optical cavity critical angles exist and these are shown in Fig 1 for a conical straight walled cavity. At angles less than Q_d light rays emitted from the light source will not interact with the cavity at all. Some rays will strike the cavity wall and reflect at zero degrees; this angle Q_i is twice the cavity wall angle, Q_w. At one angle Q_1 light rays will strike one cavity wall and graze the top of the other side of the cavity. Some fraction of the light will be trapped by the cavity, for angles greater than Q_{loss}, light will be reflected downwards. Finally some light, at angles greater than Q_m, will miss the entrance to the cavity altogether.

Hewlett-Packard has conducted experiments with a number of cavity geometries including round and square conical. As a result of these experiments a cavity was developed for use in a high mount brake light. The housing comprises a white, rectangular injection moulded cavity made from titanium dioxide filled polycarbonate. The cavity had straight walls with a 19 deg wall angle. The exit aperture was 15 mm x 15 mm and the entrance was 2.2 mm square. The performance of the cavity was characterised using a variety of LED lamps each measured with 50 ma of drive current. For all lamps measured, luminous intensities in excess of 1000 candela/m^2 were recorded at legend centre with 300 to 400 cd/m^2 at the corners.

The combination of developments in the materials, die packaging, and design of the optical cavity together mean that LEDs can now provide the performance required for exterior lighting applications. Colour potential has also changed; originally LEDs only emitted light in the red area of the spectrum. Developments made in the technology have meant that today devices are available in red, high efficiency red, orange, amber, yellow and green. Further developments being made also promise the availability of blue LEDs giving the potential, when combined with the other primary colours, of a solid state indicator that emits white light.

Exterior applications

Virtually all of the major vehicle manufacturers now have projects under way today that are either investigating or developing exterior lighting solutions based on LEDs. One of the first of these is for high-mount stop lights; their small size, resistance to shock and low heat output (reducing nuisance to rear passengers) favouring their use here. With convertible cars there is no rear windscreen in which to mount the device; resistance of diode lamps to shock and vibration means that they can be mounted on the boot lid and several manufacturers, for example, áre currently developing lights incorporated into the rear spoiler.

Another application being actively investigated is for side markers on heavy goods vehicles, a harsh environment for lighting products. As sealed for life units LEDs outlast incandescent lights, keeping vehicles on the road. A related application is for direction indicator repeaters on cars. Ford in the US has recently announced their intention to use LEDs on the new Thunderbird model: in this case for cosmetic purposes, as appliqué lighting made possible through the use of the low profile. It provides an example of how the use of solid state devices can expand the applications of lighting on vehicles and how LEDs need not be viewed as replacements for incandescent lights. *Enter 169* □