

# HP SnapLED: LED Assemblies for Automotive Signal Lighting

James W. Stewart

Decreased packaging cost and improved performance have helped LEDs gain acceptance as light sources in automotive applications such as signal lighting. An assembly technique is described that allows the creation of thin taillamps that can be customized to conform to the shape of a particular vehicle.

**B**ecause of developments in high-brightness LED materials and high-power LED packaging, LEDs are more frequently being used in automotive signal lamps. A new product, HP SnapLED, combines the latest LED technology with a three-dimensional assembly technique to create a thin taillamp that conforms to the shape of the vehicle (see **Figure 1**).

## Background

The first LED signal lamp appeared on a passenger vehicle in 1985. The 1986 Nissan 300ZX center high mounted stop lamp (CHMSL) used 72 absorbing substrate AlGaAs, 5-mm LEDs assembled on a printed circuit board. From this start, LEDs have gained acceptance in the automotive industry because of a decrease in the cost of LED light sources. These cost reductions have come from an increase in the performance of the LEDs, which results in a reduction in the number of LEDs required for a function. As the number of LEDs required goes down, LED packaging cost and assembly cost are proportionally reduced. **Figure 2** shows the number of LEDs required to meet the CHMSL specification from 1985 to 1997.

The main factors that have contributed to the increased performance of LEDs are more efficient LED materials (see **Figure 3**) and improved LED packaging.

Since their introduction into automotive applications, LED efficiency has increased over 500%. In 1994, HP introduced a new LED package designed specifically for automotive lighting. This new package, called *SuperFlux*, was



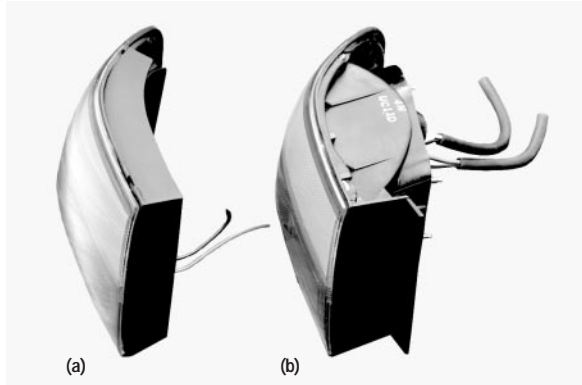
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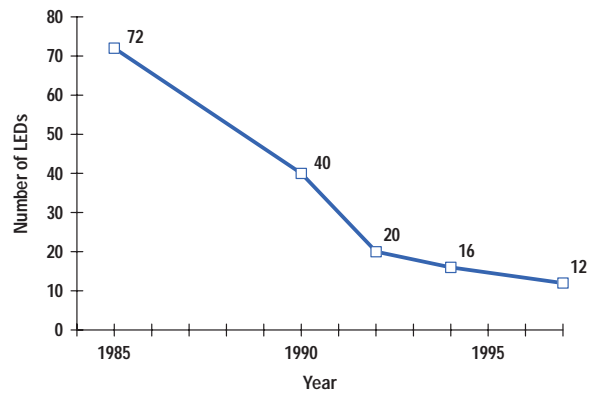
**Figure 1**

Automobile taillamps. (a) Contains LED technology. (b) Contains incandescent lamps.



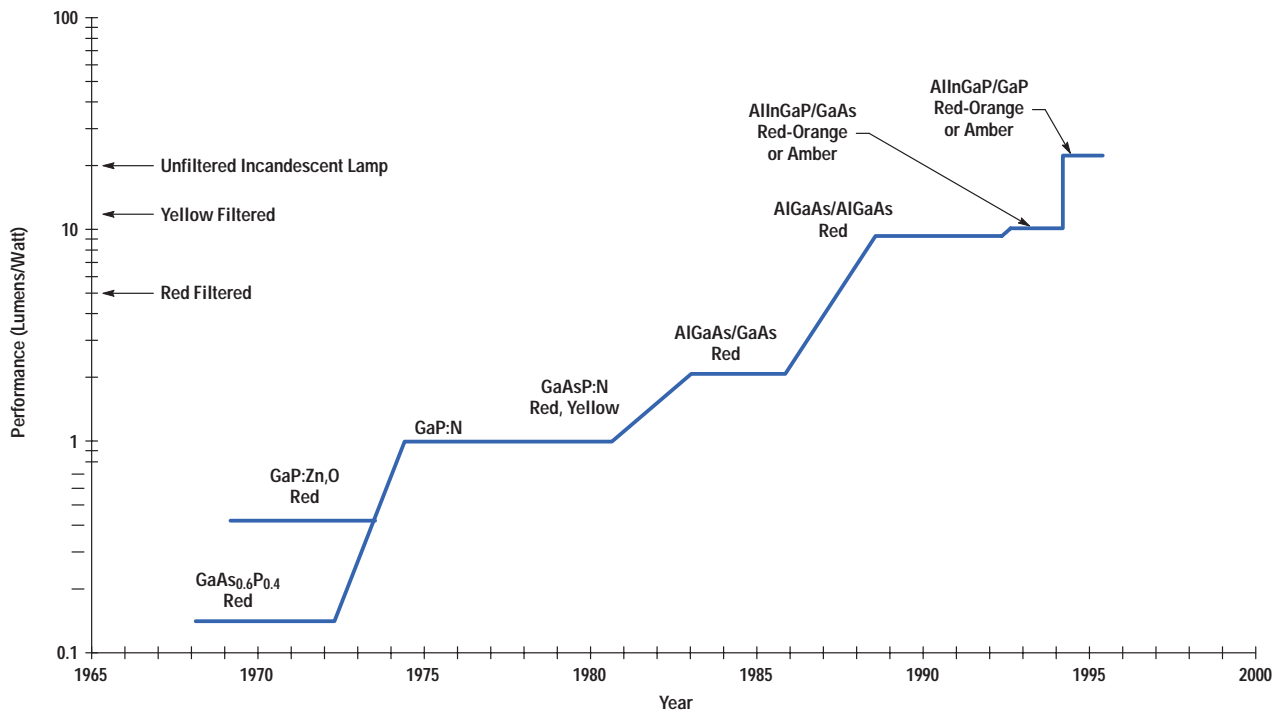
**Figure 2**

Number of LEDs required for center high mounted stop lamp (CHMSL) applications from 1985 to 1997.



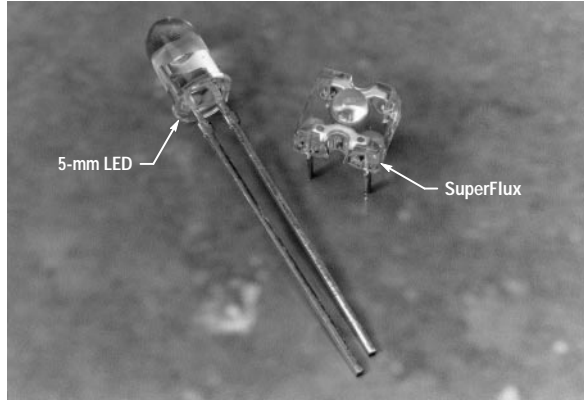
**Figure 3**

Time evolution of red and amber LED technology.



**Figure 4**

Superflux and 5-mm LED packages.

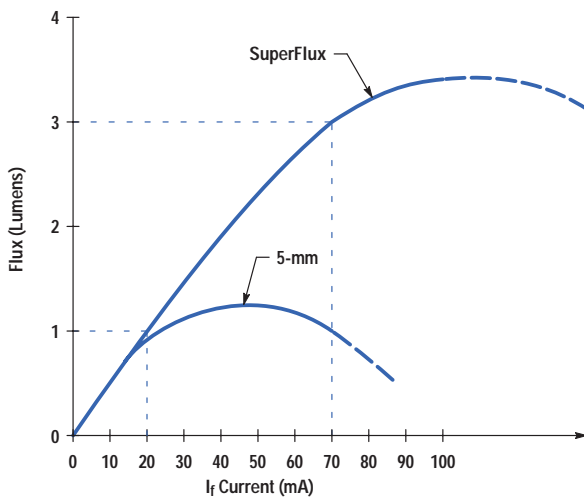


more optically efficient and could be operated at twice the drive current of conventional LED packages. The SuperFlux package and a conventional 5-mm LED are shown in **Figure 4**.

**Figure 5** shows the light-output performance of a SuperFlux package compared to the 5-mm package in an automotive application. Each package contains the same type of LED chip (TSAlInGaP/GaP).

**Figure 5**

Flux versus forward current for a SuperFlux LED package compared to a 5-mm LED package. Both contain AlInGaP LEDs.



The AlInGaP LED light output shown in **Figure 5** does not increase linearly with forward current ( $I_f$ ) in typical use conditions. **Figure 6** shows that AlInGaP demonstrates an exponential drop-off in light output as a function of increasing junction temperature ( $T_j$ ). At higher drive currents, more heat is created in the device and  $T_j$  rises. This rise in  $T_j$ , and the corresponding decrease in device efficiency, eventually offsets the increase in light output because of increased  $I_f$ .

The combination of AlInGaP materials and SuperFlux LED packaging are the basis for HP's automotive lighting products and the foundation for SnapLED. Today HP's LED technology can be found on approximately 15% of the cars in production and many heavy duty tractors and trailers.

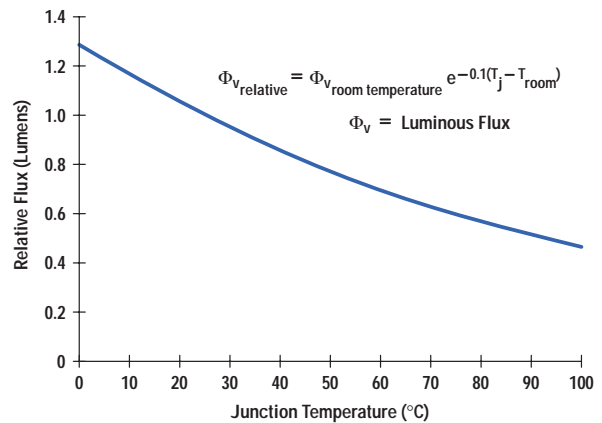
#### LED Rear Combination Lamps

The signal lamps at the rear corners of the vehicle, which combine tail, turn, stop, and often side marker and reverse functions in one package, are commonly referred to as rear combination lamps (RCLs). RCLs used in modern vehicles have complex 3D outer lens surfaces that follow the contour of the car body. An LED light source for this application must have the following attributes.

**Styling Flexibility.** RCLs are used to differentiate the look of a vehicle. An LED light source needs to accommodate the range of designs of conventional incandescent RCLs and at the same time offer additional styling flexibility.

**Figure 6**

Relative flux versus junction temperature for AlInGaP LEDs.



Low System Cost. System cost refers to the cost for the automobile manufacturer to purchase, install, and maintain a signal lamp on a vehicle. Some elements of system cost include warranty expenses, electrical power consumption, adding features to body panels to mount the lamp, wires, and other electrical connections. LED light sources are more expensive than their incandescent counterparts. However, the system cost of an LED signal lamp can be comparable to an incandescent signal lamp.

Power Consumption. Power use is of particular interest in modern vehicles because ever increasing electrical demands are resulting in excessive alternator loads. Many vehicle manufactures now assign a cost savings per ampere in the range of U.S. \$3 to \$5. A conventional incandescent RCL will consume approximately 2.5A to 5A in the stop mode. An LED RCL will consume 0.5A to 1.5A in the stop mode, saving approximately 2A to 3A, which correlates to a system cost savings of U.S. \$6 to \$15 per side and U.S. \$12 to \$30 per vehicle.

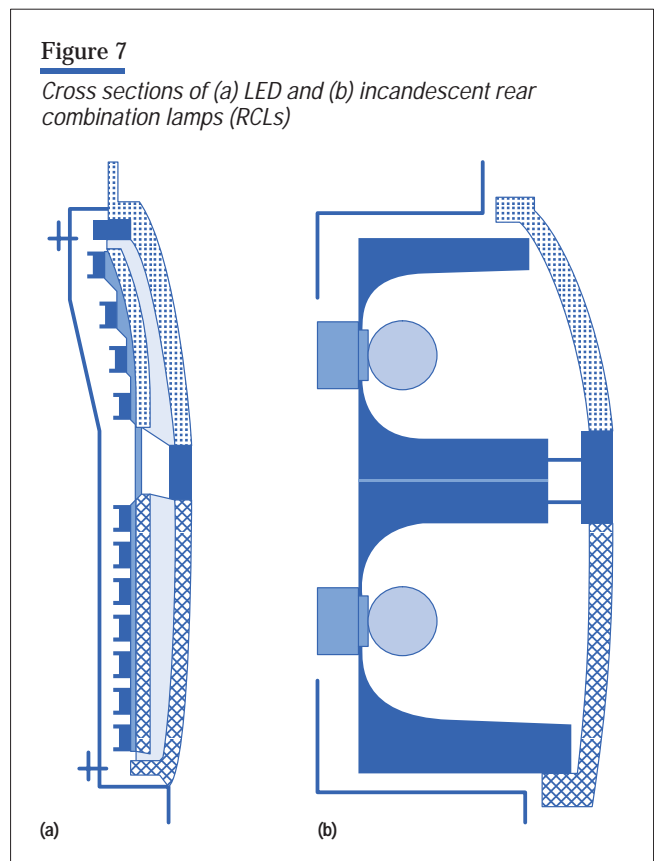
Space Savings. Saving space is another area of interest in modern vehicles. By creating a three-dimensional distributed light source, the thickness of the RCL can be reduced as shown in **Figure 7**.

Incandescent RCLs can be as deep as six inches compared to LED RCLs which can be as thin as one inch. Incandescent RCLs consume valuable trunk space and require the addition of deep-drawn pieces to the rear quarter panel of the vehicle to accommodate their depth.

#### SnapLED Design

The SnapLED assembly consists of a modified SuperFlux LED emitter, which is clinched to a metal frame called a clinch frame. The clinch joint mechanically and electrically attaches the emitter to the clinch frame. The clinch frame performs the task of a printed circuit board, providing the mechanical structure for the assembly and forming the desired electrical circuit. **Figure 8** shows a SnapLED emitter, a clinch frame, an assembled SnapLED array, and a formed array.

SnapLED Emitter Design. Both the SuperFlux and SnapLED emitters are manufactured on the same assembly line, and except for the lead frame, share the same materials and piece parts. The optical design and body outlines are identical. By using a proven emitter design (SuperFlux), the risk, investment, and time to market were minimized.



In addition, the combined volumes of SuperFlux and SnapLED emitters allow for reduced manufacturing costs.

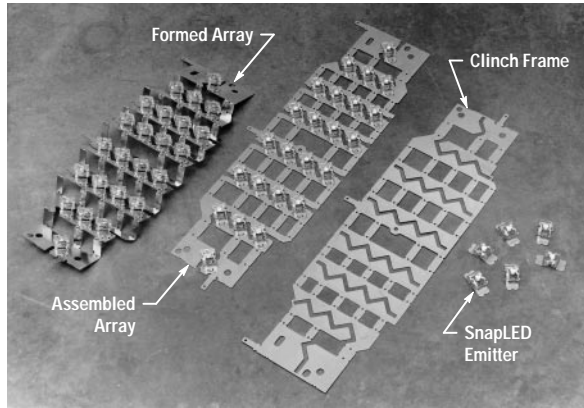
As can be seen in **Figure 8**, large pads extend from the anode and cathode leads of the device and serve as the areas for the clinch attachment. (A better view of these pads is shown in **Figure 14**.) The exposed portions of the leadframe, including the attachment pads, are nickel plated to prevent tarnish and corrosion.

SnapLED Clinch Frame Design. The clinch frame must provide adequate mechanical support, form the electrical circuit, and dissipate heat as efficiently as possible. The base material used for the clinch frames is the same copper alloy used for the emitter leadframe. The plating used on the clinch frame is a tin alloy, which resists tarnish and is well suited for slide-on electrical connectors. Special features are added at all bend locations to ensure well controlled, properly formed bends.

Drive Circuitry Design. Standard electronic components cannot be clinched to a SnapLED array. For this reason,

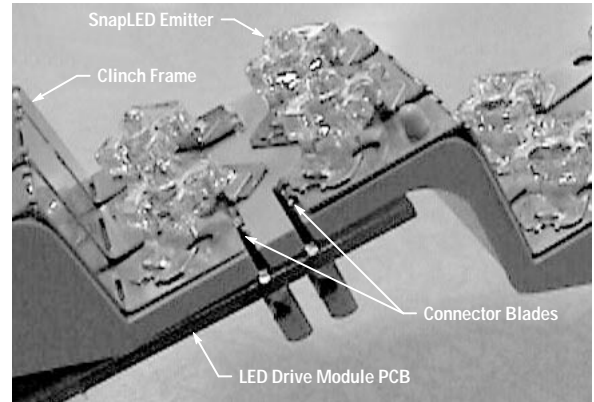
**Figure 8**

The components of a SnapLED array.



**Figure 9**

SnapLED assembly attached to the LED drive module PCB.



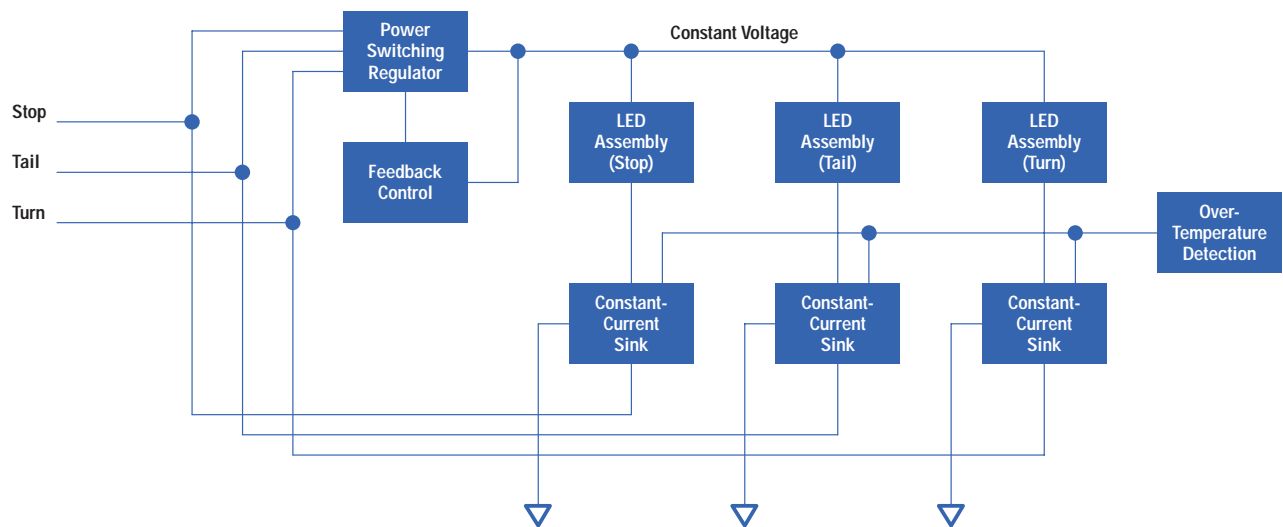
all drive circuitry is either mounted in the wire harness or on a remote printed circuit board. For CHMSL (center high mount stop lamp) applications, in which drive circuitry typically consists of a current-limiting resistor and a reverse-voltage-blocking diode, the drive circuit can be mounted in the wire harness. For RCL applications, current control drive circuits are recommended. These circuits are so complex that mounting the circuitry in the wire harness is impractical. For RCLs, a remote printed circuit board contains the drive circuitry. This LED drive

module is connected directly to two connector blades on the SnapLED assembly (see **Figure 9**).

The remote location of the LED drive module isolates the heat generated by the drive circuit from the LED array. This is advantageous because light output in AlInGaP LEDs degrades with elevated temperatures. It is also advisable to use low-dropout, low-power, current control circuitry to minimize the heat generated. Switching current regulators are ideal because of their high efficiency.

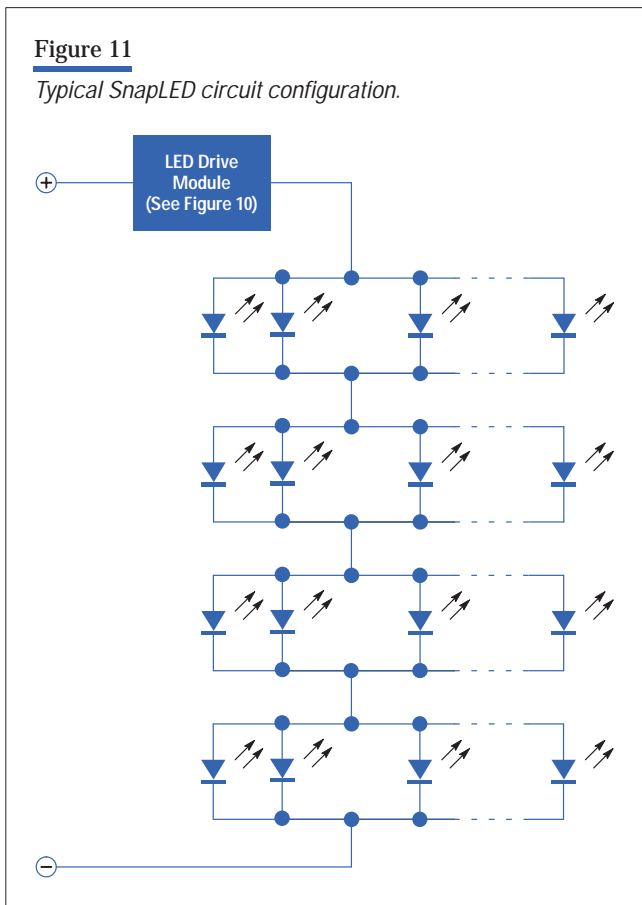
**Figure 10**

Block diagram of a switching power supply for LED rear combination lights (RCLs).



**Figure 11**

*Typical SnapLED circuit configuration.*



However EMI and added cost and complexity have limited their use. A block diagram of a switching power supply for LED RCLs is shown in **Figure 10**.

Clinch frames cannot accommodate the complexity of printed circuit board circuit designs. In addition, all drive circuitry must be located remotely. For these reasons, SnapLED circuits are generally parallel-series configurations as shown in **Figure 11**.

With conventional drive circuitry, no more than three to four LEDs are run in series so the LED array will operate under low-voltage conditions (9V). This is not true in the case of switching drive circuits in which the input voltage can be converted to a higher or lower level. To operate LEDs in parallel, the LED emitters within a parallel string must be voltage matched. HP sorts and categorizes its automotive LEDs into 120 mV bins for this purpose.

### SnapLED Clinch Process

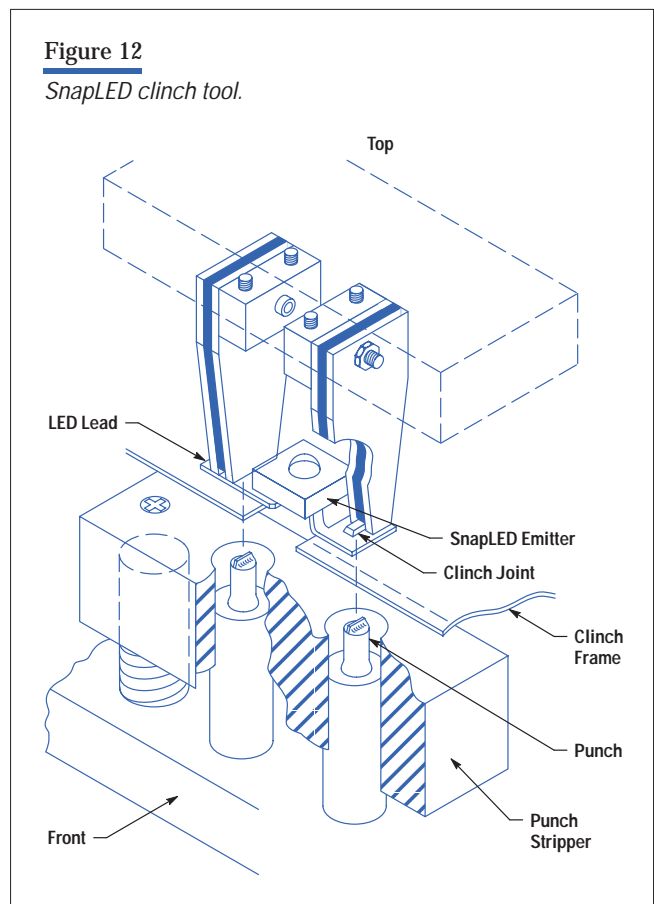
Clinching is a method for mechanically joining nonferrous metals. In a typical application, several clinch joints are used to attach two metal sheets together. Because of space constraints, there is no redundancy in clinch joints on SnapLED, and each joint performs a critical mechanical and electrical function. This new clinching application required extensive process development.

Among several clinching methods available, a pierce and form clinch joint was chosen for SnapLED because of its compact size and the simplicity of tooling. **Figure 12** shows a perspective view of the clinch tool used for SnapLED joint formation.

**Figure 13** shows the clinch process. **Figure 13a** shows the materials to be joined positioned under the clinch tooling. **Figure 13b** shows the punch and stripper position after piercing the clinch frame and LED lead. **Figure 13c** shows the compression and expansion of the displaced

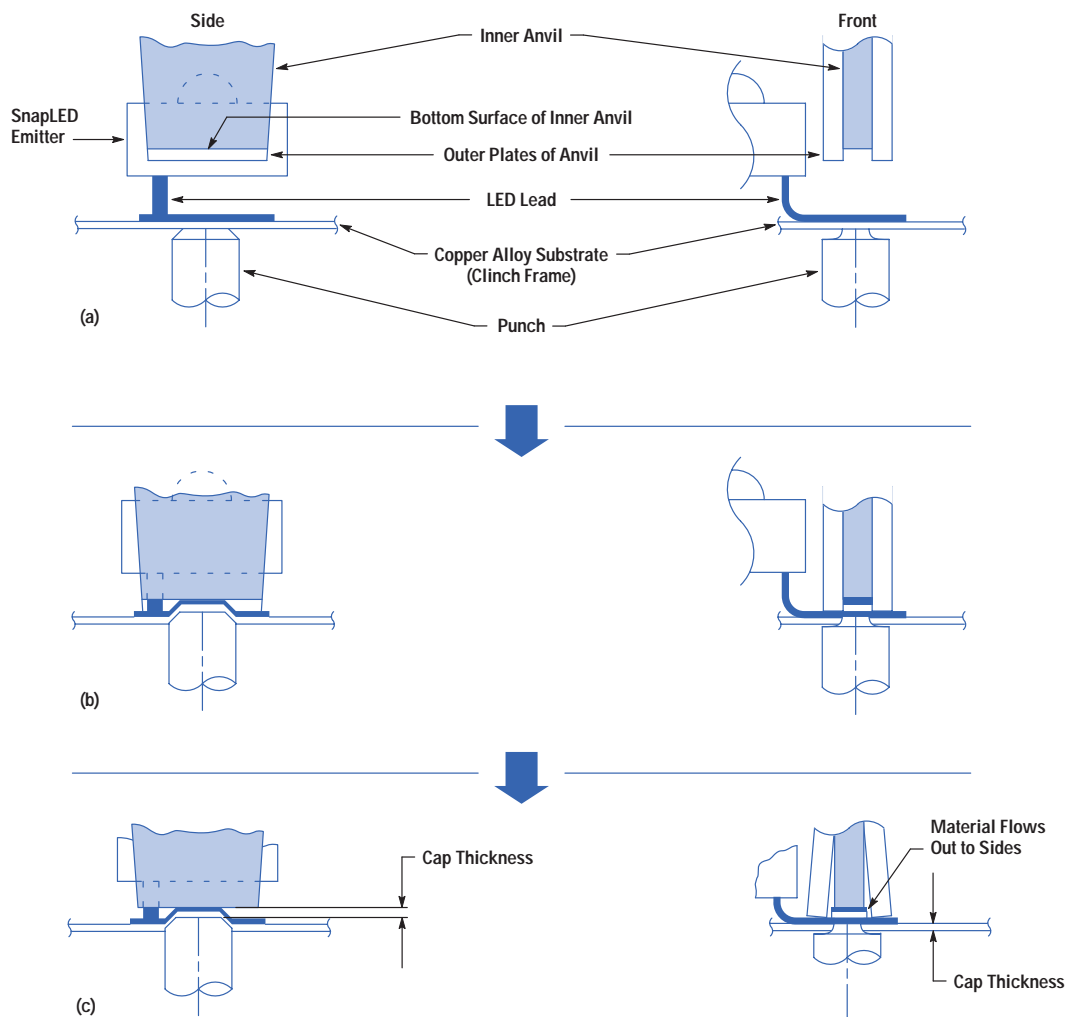
**Figure 12**

*SnapLED clinch tool.*



**Figure 13**

The clinching process. (a) Placement of components. (b) Punch pierces substrate and LED lead. (c) LED lead is clinch-locked to substrate.



material as the punch continues its travel. A photograph of an individual clinch joint is shown in **Figure 14**.

Many parameters must be controlled to ensure a proper clinch joint. The following is a list of critical parameters.

**Cap Thickness.** The thickness of the upset material, or cap, must be controlled to within 0.10 mm. If the cap is too thick, this indicates that it has not been compressed enough to ensure proper material expansion and interlocking. If the cap is too thin, this indicates over compression which results in weakening of the base material. Over compression also results in premature wear of the

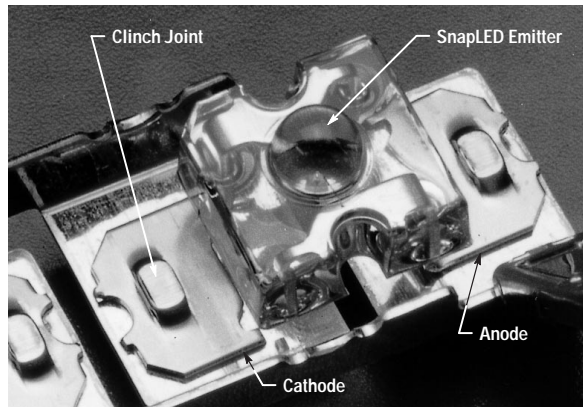
tooling. Inductive position sensors are used to monitor cap thickness on production assembly equipment.

**Tooling Alignment.** If the top and bottom halves of the SnapLED tooling are not properly aligned, the clinch joint will not be properly formed. The joint becomes D-shaped because shearing only takes place on one side of the joint. Sample inspection is currently used to detect this defect. An investigation is under way to use dynamic force data to monitor tooling alignment.

**Material Hardness.** The hardness of the materials to be joined must be matched and controlled. If the materials

**Figure 14**

*A close-up view of a clinch joint.*



are too soft, the joint will be weak. If the materials are too hard and brittle, they may fracture during clinching or may not flow together during compression. If the hardness of the materials is not matched, the two materials will not flow evenly, again resulting in a weak joint. Hardness of base materials is monitored on a sample basis. In addition, piezoelectric force sensors monitor the force during the clinching process. If the force required to form the joint is too high or too low, this indicates a base material that is too hard or too soft.

### SnapLED Manufacturing

SnapLED required the development of special electronic assembly equipment and processes. A flow chart of the SnapLED manufacturing process is shown in **Figure 15**.

Clinching. Two types of clinching automation have been developed. First, there is clinching equipment that is dedicated to a single product, is fully automated, and incorporates clinch frame feeding, emitter placement and clinching, and shearing. The second type of automation involves flexible clinching equipment that automates only emitter placement and clinching but can accommodate a wide variety of array designs. Flexible equipment is preferred for automotive products because taillight designs change every three to five years as new vehicles are designed. An example of a flexible clinch machine is shown in **Figure 16**.

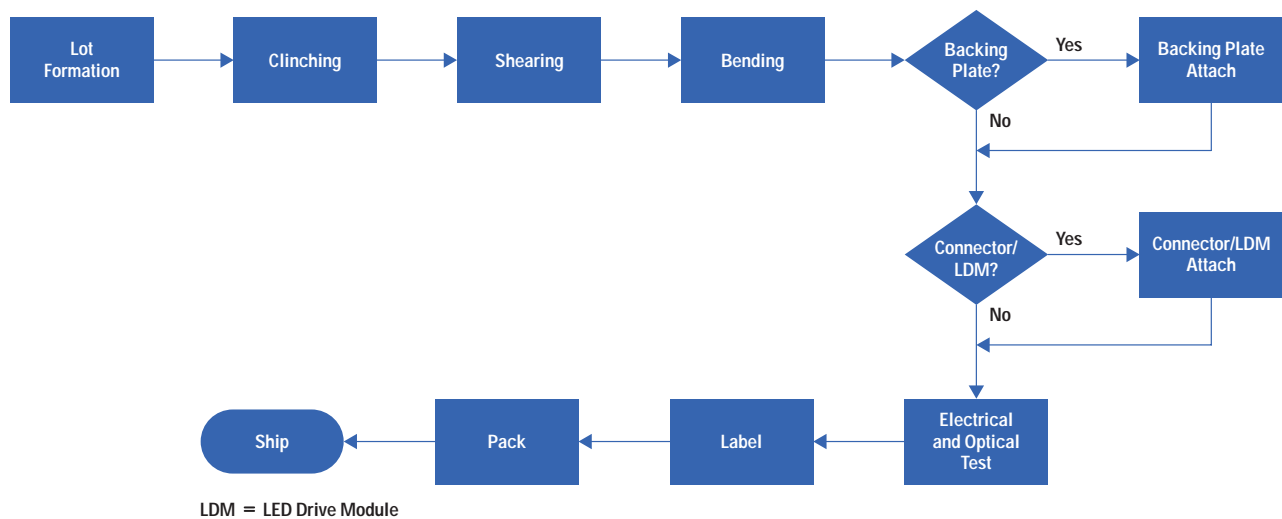
In this design, one or more clinch frames are loaded into a clinch fixture. Several clinch fixtures can be loaded and staged before clinching. SnapLED emitters are positioned under the clinch tooling by the pickup turret as the clinch frames are positioned by the x-y positioning stages.

**Figure 17** shows the emitter placement mechanism.

SnapLED emitters are packaged in tubes and fed into a track. Parts slide down the track to a rotary stage where the part is tested and oriented to the proper polarity. Parts are then staged in a buffer zone at the end of the track.

**Figure 15**

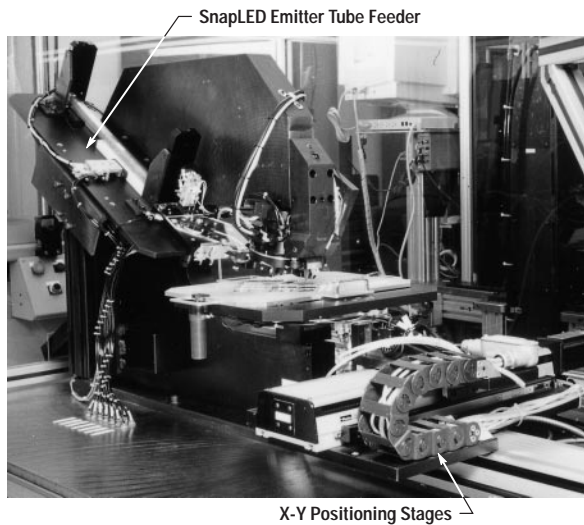
*SnapLED manufacturing process.*





**Figure 16**

*A flexible clinch machine.*



The vacuum pickup turret picks the part from the end of the buffer and rotates it 45 degrees. As the turret rotates, the emitter at the other side of the turret is positioned under the clinch tooling. In parallel, the clinch frames are positioned by the linear stages. Once the emitter and clinch frame are in the proper orientation, the press is actuated and the punches rise to form the clinch joint shown in **Figure 14**. When all the emitters have been clinched into position, the stages return to a home position so another clinch fixture can be loaded.

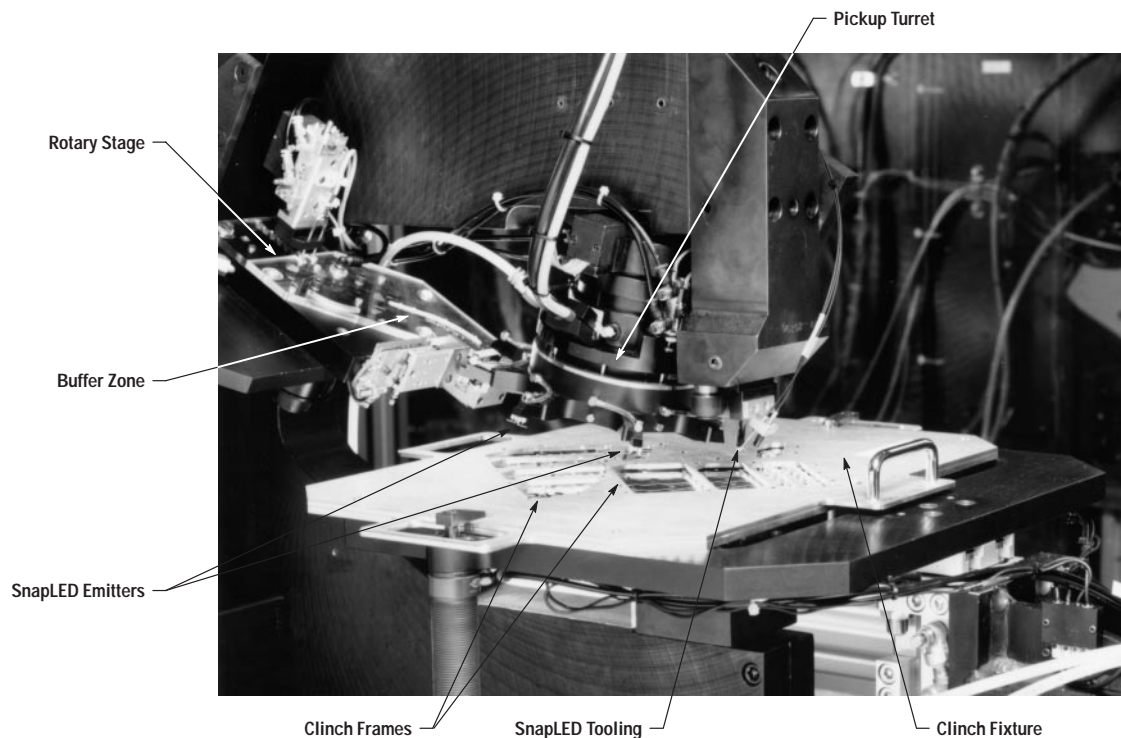
**Testing.** SnapLED emitters are tested and separated into flux, color, and forward voltage ( $V_f$ ) categories. Typically, a single category of emitter is used to create an array to ensure proper performance and uniformity. However, for some applications, different color and  $V_f$  bins may be used.

After assembly, the array must pass a final electrical and optical test. Here, the array is checked for current compliance at the designed voltage input, light output uniformity\* between the individual LED emitters, and

\* Ratio of dimmest to brightest LEDs anywhere on the array.

**Figure 17**

*Parts of the SnapLED assembly machine.*



overall light output. Light output uniformity is controlled within a ratio of 1:1.9 (dimpest : brightest) for red devices and approximately 1:1.7 for amber devices. Overall light output is determined by averaging the light output of the individual emitters.

The testers are modular to maintain a high degree of flexibility. The modules consist of a PC, power supply, optical detector array, and test fixture (see **Figure 18**).

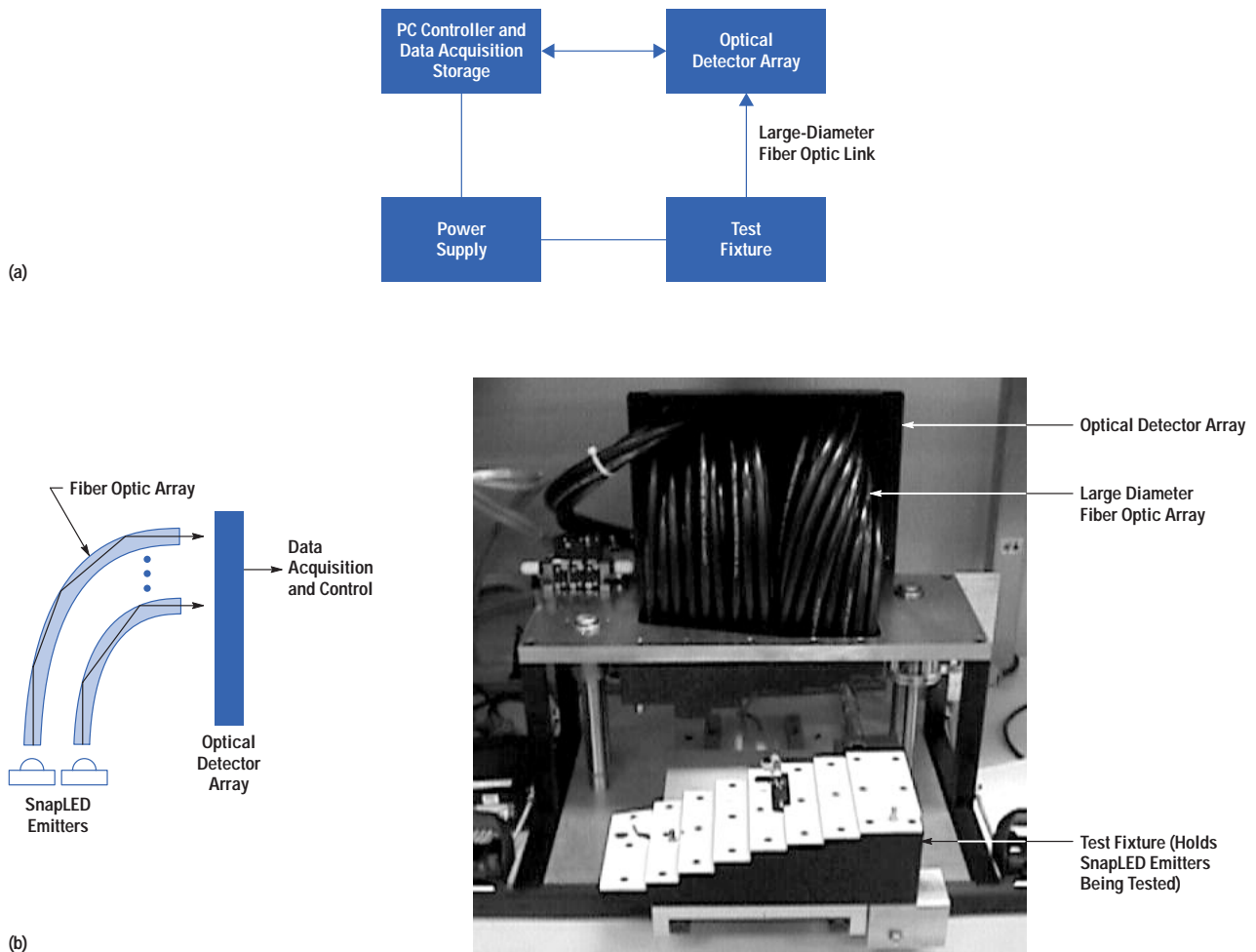
The PC is used to provide control, data acquisition, data storage, and a user interface for the system. The test fixture properly positions the array under a large-diameter, fiber-optic array. The fiber-optic array channels the light from the emitters to the optical detector array. The

optical detector array consists of a 10 by 12 grid of surface mount optical detectors attached to a printed circuit board contained in a housing. The top plate of the housing accurately positions the fibers over the detectors and allows the individual fibers to be installed and removed as needed.

Because the clinch frames must conform to different tail-light designs, each SnapLED array must have a dedicated test fixture, but all other test hardware can be shared. In addition, minor modifications to the tester's software are needed for each array to account for different test limits, number of LEDs, and type of LEDs used.

**Figure 18**

(a) Block diagram for a SnapLED tester. (b) SnapLED test station.



### SnapLED Array Design

The SnapLED array design process begins with design reviews with the automobile manufacturer and lighting supplier to make sure the lamp design is optimized in terms of style, performance, manufacturability, and economics. Once the RCL design is complete, the SnapLED array can be designed.

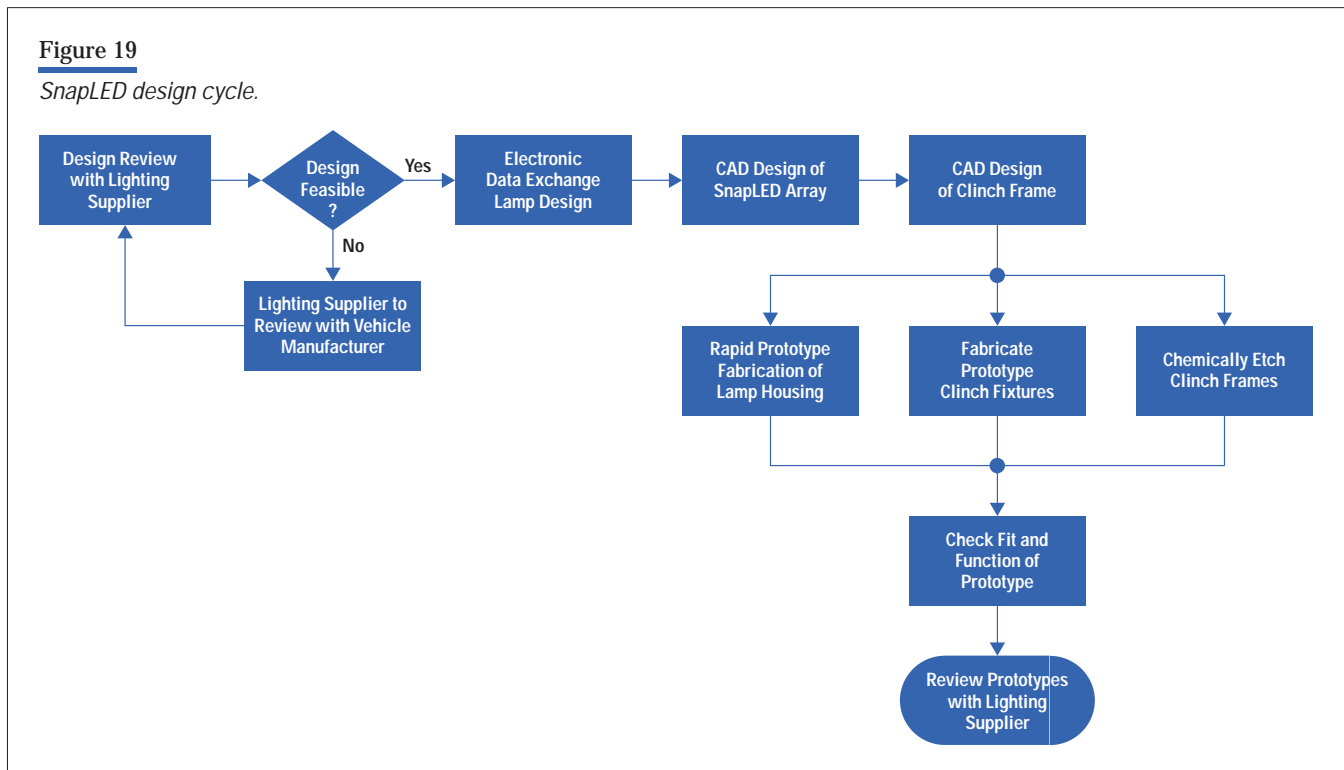
Solid models of the RCL housing, provided by the customer, are imported into the PE/Solid Designer CAD system. The LED array is then created with the LEDs in their proper locations. Attachment and alignment features, electrical connectors, bend lines, and electrical traces are then added. After completing the three-dimensional model, the clinch frame is “unbent” into its two-dimensional form using Sheet Advisor (a module in PE/Solid Designer). The two-dimensional clinch frame is then modified to include supporting structures needed to fix and stabilize the part during array assembly.

Early prototypes are created using chemically etched clinch frames. The prototype parts are bent, sheared, and tested using flexible tooling and equipment. Prototype arrays can then be checked for fit and ease of assembly using plastic housing prototypes fabricated by rapid prototyping techniques.

A flow chart of the SnapLED design cycle is shown in **Figure 19**.

### SnapLED on the Road

The first SnapLED array in production appeared on the center high mounted stop lamp of the 1998 Ford Explorer. SnapLED has been designed into other vehicles slated for late 1998 production. They will be used in applications ranging from the world’s first LED turn signals to rear combination lamps.

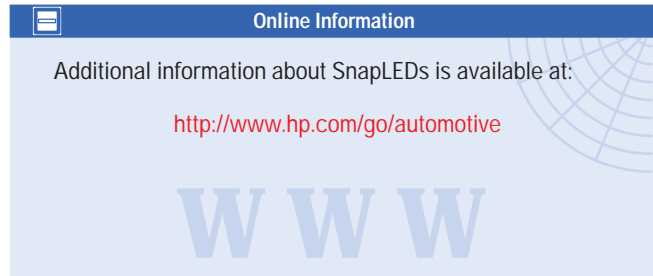


## Acknowledgments

The original concept and much of the pioneering work in clinched LED arrays was conducted by Dick Klinke and Gary Sasser. Wayne Snyder and Jim Leising provided unwavering management support throughout the project, and for this, the author is grateful. Much of the credit for the development and commercialization of SnapLED belongs to Dave Brandner, Todd Swanson, Douglas Woolverton, Chris Togami, and Leong Ak Wing. Many others, too numerous to acknowledge individually, have contributed to the development of SnapLED and SnapLED arrays for specific vehicles.

## Bibliography

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2. *Multiple Light Emitting Diode Module*, U.S. Patent #5,404,282.
3. *Moldable Nesting Frame for Light Emitting Diode Array*, U.S. Patent #5,519,596.



Online Information

Additional information about SnapLEDs is available at:

<http://www.hp.com/go/automotive>

WWW

The graphic features a blue header with a document icon and the text 'Online Information'. Below the header, the text 'Additional information about SnapLEDs is available at:' is followed by the URL 'http://www.hp.com/go/automotive' in red. At the bottom, the letters 'WWW' are displayed in a large, light blue font. A faint globe graphic is visible in the background on the right side.