A Short History of Laser

Patricia Daukantas

For almost as long as visible-wavelength lasers have existed, artists have been inspired by their potential to create stunning visual displays.

As the clock ticked toward the end of the first half of Super Bowl XLIV, two teams huddled on the sidelines, waiting for the signal. Each had a single objective and a tight timeframe for achieving their goal.

But they weren't looking to score a touchdown. Rather, these teams were the special-effects technicians for the halftime show. They had nine minutes to ensure that 16 powerful lasers were hooked up and safely aligned to a 40-section platform in preparation for a laser show to accompany the performance of the rock group the Who.

More than 100 million people watched the Feb. 7, 2010, performance on television, making it one of the most-viewed laser shows ever. The special effects teams set up two "laser compounds," one at each 35-yard line on the New Orleans Saints' side of the gridiron. Each compound had two 50-W Nd:YAG pulsed lasers, cooled with a recirculating-water chiller, plus two air-cooled, full-spectrum units: a 25-W optically pumped semiconductor (OPS) laser and a 13-W diode-pumped solid-state (DPSS) RGB laser.

Laser shows have always held a universal appeal. People from all over the world have enjoyed them at planetariums, concerts, corporate meetings and other venues. In the United States, outdoor laser displays dance across the faces of the Grand Coulee Dam in Washington and Stone Mountain in Georgia. They illuminate the pyramids of Giza in Egypt and the night sky above the Hong Kong business district. Coherent beams of color formed pictures of Olympic athletes against the side of the Sydney Opera House in 2000, and, at the 2010 Olympic Winter Games in Vancouver, 20 lasers were used in a nightly light show in which people from around the world controlled the beams through public Internet access.

LASERFEST

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Light Shows

Touchdown Entertainment Inc. / Brad Duns

Guitarist Pete Townshend of The Who takes the spotlight amid green laser beams at the February 2010 Super Bowl XLIV halftime show in Miami, Fla., U.S.A.

How laser shows work

The stunning visual effects of laser shows rely on some of the simplest optical equipment and principles: moving mirrors and the effect known as persistence of vision—which refers to the after image that persists when a point of light moves faster than the eye can react to it. The after image lasts for roughly 1/25 of a second.

Anyone can create a crude version of a laser show: Just aim the beam of a laser pointer at the wall and quickly shake your hand side to side to create a colored line. Today's laser projectors basically do the same thing, only faster and with more precision. They contain prisms, mirrors and other components that laser-show pioneers would have had to have set up by hand.

Laserium/Laser Images Inc.

Laserium's vector drawing of a butterfly on a leaf.

To produce pictures on a screen or wall during a laser show, two galvanometers—dubbed "galvos" in the industry—use electrical signals to make small mirrors vibrate over a two-dimensional plane. The moving mirrors reflect the beam path fast enough to trace a shape on a target wall or screen. In the trade, this process is called "scanning."

Simple 2-D manipulations of the mirror make the laser trace the familiar Lissajous figures of complex harmonic motion. Another galvo—or, in some modern projectors, an acousto- or electro-optic modulator—can move a second mirror to deflect the beam to the side, so that it doesn't exit the projector. This type of modulation is known as "chopping," and it's the laser-show equivalent of lifting a pencil from the paper. Similarly, "blanking" modulates the beam by turning the laser on and off rapidly. Chopping and blanking separate line segments, curves and letters of the alphabet.

Laser displays are best suited for drawing outlines of familiar shapes, resulting in cartoon-like images. Today's laser artists use graphics software to draw the logo or picture they want to reproduce, and then a specialized program translates the image into commands for moving the laser beam with a refresh rate of 15 to 30 Hz, thanks to the persistence of vision of 40 ms (25 Hz). For comparison, most theatrical films run at 24 Hz.

Laser artists can also create "atmospheric" or beam effects, in which the audience can see the laser beams as they move through the air, thanks to Rayleigh scattering. The artist usually uses theatrical fog or smoke from pyrotechnics to create this effect. Sometimes ambient dust will suffice if the beams are very powerful.

"Lumia" is the collective term used for the textured glass or plastic filters that are used to distort the outgoing laser beam into abstract shapes. Galvos and motors usually move these filters to the laser artist's specifications. Diffraction gratings, both stationary and movable, cause the light to form multiple beams.

Laser art and the far-out 1960s

In the late 1960s and early 1970s, artists and scientists collaborated on projects for exhibits and concerts on both sides of the Pacific. Many fertile minds, some trained in art and others in science, were eager to explore the visual possibilities of the new medium.

It is difficult to define when the first laser show or laser-art exhibit took place. "The closer you look at it, the fuzzier it gets," said Patrick Murphy, executive director of the International Laser Display Association (ILDA), a trade association for laser display companies.

An artist named Lowell Cross started visualizing electronic music as a graduate student at the University of Toronto in the mid-1960s. At first he connected an RF modulator to a television receiver to interpret his own music as well as the works of composers John Cage and David Tudor. In 1969, Cross and University of California at Berkeley laser physicist Carson D. Jeffries collaborated on a visual project, and the resulting public performance of sound and music at Mills College in Oakland, Calif., used multiple laser colors with 2-D scanning.

Around the same time, a Washington, D.C., sculptor named Rockne Krebs joined a group of artists who were experimenting with the bold colors of acrylic paint. In 1967, Krebs purchased a He-Ne laser and then worked with a University of Maryland scientist to figure out how to use it. After designing a 1968 exhibit of one laser and two mirrors at a Washington art gallery, he wound up working alongside Hewlett-Packard engineers in Palo Alto, Calif., on a display destined for Expo '70, the world's fair near Osaka, Japan.

That futuristic international exposition attracted a collective group called Experiments in Art and Technology, or E.A.T., whose members brought their cross-disciplinary optical experiments into the public spotlight. The Pepsi Pavilion at Expo '70 contained the world's largest spherical

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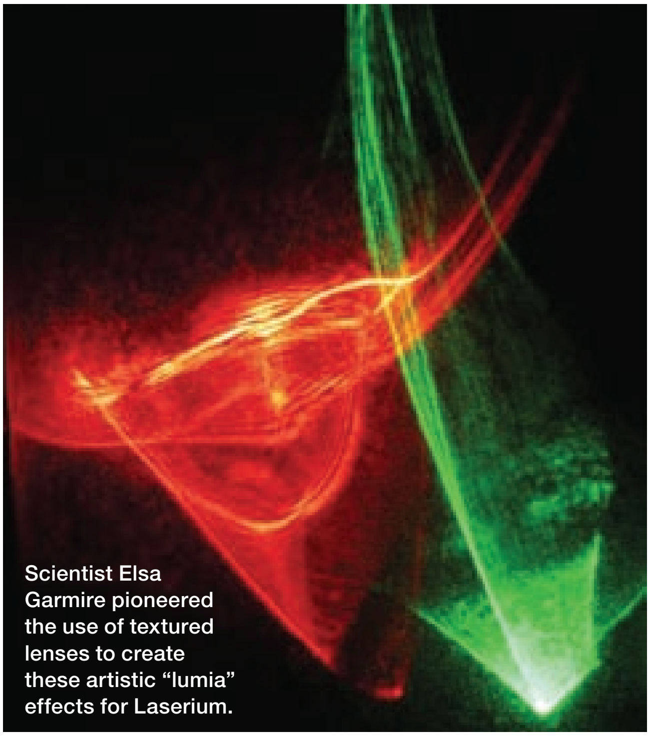
mirror—which was made of aluminized Mylar and spanned 90 feet across. In the main hall, visitors could see their reflections hanging upside down above their heads. To get to that hall, they walked through a dark clam-shaped room illuminated by sound-activated laser beams shining downward and tracing Lissajous figures on the floor. E.A.T. commissioned Cross and Jeffries to design the laser-and-sound display.

An estimated 2 million people visited the Pepsi Pavilion during the six months of Expo '70. However, according to Cross's website, company officials were not able to maintain the technical exhibits to the artists' standards, and the building was demolished soon after the exposition ended. Cross moved to the University of Iowa and created a mixed-gas argon-krypton ion laser show—complete with symphony orchestra, soloists and electronic music—for the opening of a new campus auditorium in 1972.

Elsa Garmire



Scientist Elsa Garmire pioneered the use of textured lenses to create these artistic "lumia" effects for Laserium.

Garmire explores her artistic side

Toward the end of the 1960s, Elsa Garmire, a postdoc at Caltech who had received her doctorate at MIT under OSA Honorary Member Charles H. Townes, found that her research into ultra-short laser pulses had become stalled. So, for a few years, she turned her attention to experiments that brought art and technology together.

As part of Caltech's celebration of the first moon landing in 1969, Garmire designed a laser light "wall" that people could walk through. In another experiment, she and her friends hauled an argon laser all the way to the top of the campus library and staged a light show. Garmire was assisted by a graduate student who held a mirror to reflect the beam.

Although she knew how to make Lissajous figures, Garmire was more interested in creating abstract diffraction patterns through textured glass and plastic. "I wanted to be a pure artist," she said. Through her experimentation, she discovered that Duco household cement formed bubbles when it dried on glass and made the most interesting patterns when a laser shone through those handmade filters.

At an E.A.T. conference at the University of Southern California in November 1970, Garmire displayed photographs of her artwork and invited the filmmaker Ivan Dryer to visit her lab. Dryer set up a 16-mm movie camera, but when he saw the brilliant patterns of laser speckles on the wall, he realized that "film would not cover the intense color and scope" of the laser effects and became convinced that live lasers would be better than any motion picture.

A onetime college astronomy major, Dryer had volunteered off and on for a decade as a guide at Griffith Observatory, a public science center in downtown Los Angeles. So, using a single He-Ne laser and one of Garmire's lumia for creating interference patterns that made an "undulating, kind of organic image among the stars," he prepared a demonstration show for Griffith officials and proposed calling the show Laserium, or "house of the lasers."

Undaunted by Griffith's initial rejection, in January 1973 Dryer formed a company called Laser Images Inc., with Garmire as president. The company provided some laser effects for a rock-music documentary called Medicine Ball Caravan, as well as some live concerts by Alice Cooper and a building's grand opening.

Garmire eventually decided to return to scientific research. After her stint at Caltech, she spent two decades at USC—during which she served as OSA's 1993 President. She is now an OSA Fellow and engineering professor at Dartmouth College in New Hampshire.

In June 1973, the Laserium team borrowed a 1-W krypton laser from SpectraPhysics and set up another demonstration in a vacant Caltech lab. Of the 120 invitees, only two showed up—but one was the new Griffith director, William J. Kaufmann III, a young science popularizer and a "pretty hip

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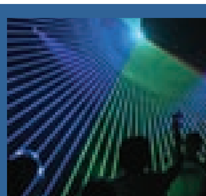

Safety First at Laser Shows

Safety is a major concern for the International Laser Display Association (ILDA), which publishes extensive safety guidelines on its website, according to Patrick Murphy, the trade group's executive director. "We want to make sure people use lasers responsibly," he said.

In some countries, fans and cones of moving laser beams are shined directly into the audiences. "It's like being in the middle of a fireworks display," Murphy said. However, the artist must use low-powered continuous-wave lasers for audience scanning. "At the distances that we're using lasers, there are very few accidents," said Murphy, who estimated that more than 10 million people have gone to concerts and nightclubs where laser lights were shining into the audience.

In one of the rare accidents attributed to a laser show, technicians at a July 2008 "rave" in Russia apparently pointed a Q-switched pulsed Nd:YAG laser improperly into the audience, and nearly 30 partygoers later reported vision problems at local hospitals. The pulsed beams even damaged digital cameras and camcorders at the venue.

Laser pulses can pack 100 times the power of an equivalent continuous-wave beam, ILDA officials said in a statement. Following the accident, the trade group asked its 150 members in 34 countries to review safety guidelines and its ethics code. For safety's sake at Super Bowl XLIV, the powerful laser beams had to be terminated in an audience-free area (such as one of the scoreboards) or above the stadium, according to the show's laser technical director, Victor Tomei. The crew had to notify the U.S. Federal Aviation Administration of the show's location and laser plans, although the Super Bowl's designation as a national special security event probably led to airspace restrictions around Miami's Sun Life Stadium.

In the mid-1990s, some federally approved laser shows in Las Vegas were bothering pilots and had to be halted, Murphy said. Since the public isn't always clear on the differences between show lasers and laser pointers, ILDA developed a separate website, www.laserpointersafety.com, to educate the public.

guy," according to Dryer. With the go-ahead to do four shows on Monday nights when the planetarium would normally be closed, Dryer and his new partner, Charles McDanald, spent $10,000 on their own krypton laser and finished building their projector at 5 a.m. on the day of their first show. Thanks to an AM radio show on which Dryer appeared, the Laserium had two half-full houses on its inaugural night in November 1973. By the fourth Monday, 500 prospective attendees had to be turned away from the sold-out shows.

Dryer's Laserium kept renewing its 30-day entertainment license for the next 28 years. Dryer said that he was always proud that Laserium shows incorporated Griffith's star projector, so that the laser effects danced on a background of celestial objects. In the 1970s, Laserium shows expanded to 46 cities on five continents, and the company produced the first theme park laser show in 1975 (Magic Mountain, Calif.) and the first of the Stone Mountain summer laser shows in 1977.

Eventually, many planetariums either hired their own laser-show producers or stopped holding such events because they were attracting the "wrong element." "They needed us for our money, but they didn't like having us there," Dryer said.

In 2002, Griffith Observatory closed for a four-year-long modernization project. When it reopened, it was dedicated solely to education—not entertainment. Dryer and his colleagues went back to the drawing board to develop a new version of the Laserium that wouldn't rely on a domed ceiling.

Last June, the Laserium started up again in a renovated vintage theater in Los Angeles, but it closed again a few months later. Its opening day coincided with the unexpected death of pop star Michael Jackson. That day, hordes of devastated fans flocked to Jackson's star on the Hollywood Walk of Fame, blocking travel to the theater down the street. In addition, Dryer said that the startup's overhead costs were too high and the location was at the seedy end of Hollywood Boulevard. He is still looking for a new home for the Laserium in southern California.

The evolution of light displays

The optical components that create laser effects haven't changed much over the years. The biggest improvements over the past five decades have been in the lasers themselves.

Up until the turn of the 21st century, light shows required bulky argon and krypton ion lasers. Most models required 240 V of three-phase electrical current to power them and 2.2 gallons per minute of water to cool them. "They were just beasts," said Murphy from ILDA. The maintenance and expense restricted these lasers to major rock concerts and well-heeled venues.

Today's artists, especially those designing for smaller venues, can choose DPSS or OPS lasers for portability and the ability to run off of household current. However, gas lasers, which can offer other spectral regions, still have a place in laser shows, especially at outdoor events and permanent installations.

"White-light" argon-krypton ion lasers give off many different wavelengths of light, which a projector can separate into green, red and blue beams for the laser artist to blend for all kinds of colors. Ion lasers have some colors that one still can't get with diode lasers, said John Borcherding, a laser artist at the Seattle Laser Dome. Modern projectors also may incorporate a polychromatic acousto-optic modulator, which provides high-speed blanking and color control in a single device.

The bigger the venue, the more power the laser artist needs to use. Laser-show audiences are typically looking at laser reflections off of materials with low reflectivity. Thus, the light has to make it to the screen or wall over long distances, The optical components that create laser effects haven't changed much over the years. The biggest improvements over the past five decades have been in the lasers themselves.

inefficiently reflect off the surface and then propagate back to the viewers' eyes. A 1-W laser can show patterns in a movie theater or hotel ballroom, but larger indoor halls can require up to 20 W of power. The largest sports arenas and outdoor stadiums can require 50 to 80 W of power.

Laserium founder Dryer stuck with the water-cooled argon-krypton lasers because they exhibit better beam quality and less divergence than low-end DPSS systems. For a long time, he said, solid-state lasers didn't make the really small dots that laser artists prize.

With the original water-cooled lasers, Dryer would sometimes experience what he calls "the john effect." If enough toilets in the Griffith building were flushed during the show, the lasers would shut down. Fortunately, the plumbing was eventually upgraded to eliminate the problem.

Modern laser shows

The Seattle Laser Dome produces its shows in-house with live laser artists who will create short custom messages for audience members—even a few marriage proposals over the years, according to Borcherding.

The Laser Dome started as the Boeing Spacearium, a cubical building containing a perforated-aluminum interior dome designed by the American architect Buckminster Fuller for the 1962 Seattle World's Fair. (The 80-foot-diameter dome is hung from the inside of the building.) It showed science-themed films for years after the world's fair, but once the film stock began deteriorating, the Pacific Science Center, which owns the complex, wanted to put the unusual space to another good use.

Unlike the original Laserium and other laser shows at planetariums, the Seattle venue has no constellations in the background. "The only thing we have in our theater is a laser projector," Borcherding said. He and his colleagues sometimes do educational shows—a five-minute piece on how lasers create light—but mostly the dome provides entertainment.

The Laser Dome's arsenal includes two water-cooled, mixed krypton-argon ion lasers. They provide a full range of colors, mixed inside the projector. The dome also has one water-cooled Nd:YAG laser, frequency-doubled to 532 nm.

Over the last 10 years, the best advances have been in computer control, Borcherding says. But in his opinion, live performances by laser artists are far superior to plug-and-play designs. "The computer's very cold and the colors are hard-edged," he said. "People don't know what they're missing."

The future of laser shows

Borcherding believes that laser shows peaked in the 1990s. That is when there was the greatest diversity in laser companies and the most live shows, he said. After that, smaller venues computerized shows that could be played repeatedly. However, it's harder to attract repeat visitors to preset shows, he added.

On the other hand, the operations manager for the laser effects at the halftime light show at Super Bowl XLIV is more optimistic. Victor Tomei, who works for Pyrotek Special Effects Inc., associated with Laser Design Productions of Markham in Ontario, Canada, said he believes that the success of that show will fuel interest in laser displays and boost the industry.

Just as the laser itself was seen as "a solution without a problem" when newly invented, laser shows are taking visual effects to heights that could have never been imagined a few decades ago. The continuing evolution of laser technology could give rise to even more spectacular effects in the future. The brilliant, focused colors of laser beams offer endless possibilities for ongoing innovation at the intersection of art and science. ◭

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ONLINE EXTRA: See www.osa-opn.org for more photographs and video clips of laser light shows.

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