Research Notes

Optical Switches

The use of optical signals in communications systems and in computer design has aroused considerable interest among engineers because optical systems, in theory, are faster than electric ones, they can handle more information through their multiplexing capabilities, and they minimize unwanted feedback. The major restrictions to the use of optical signals, however, have been the large amount of electrical power required to modulate them and the lack of efficient guiding systems.

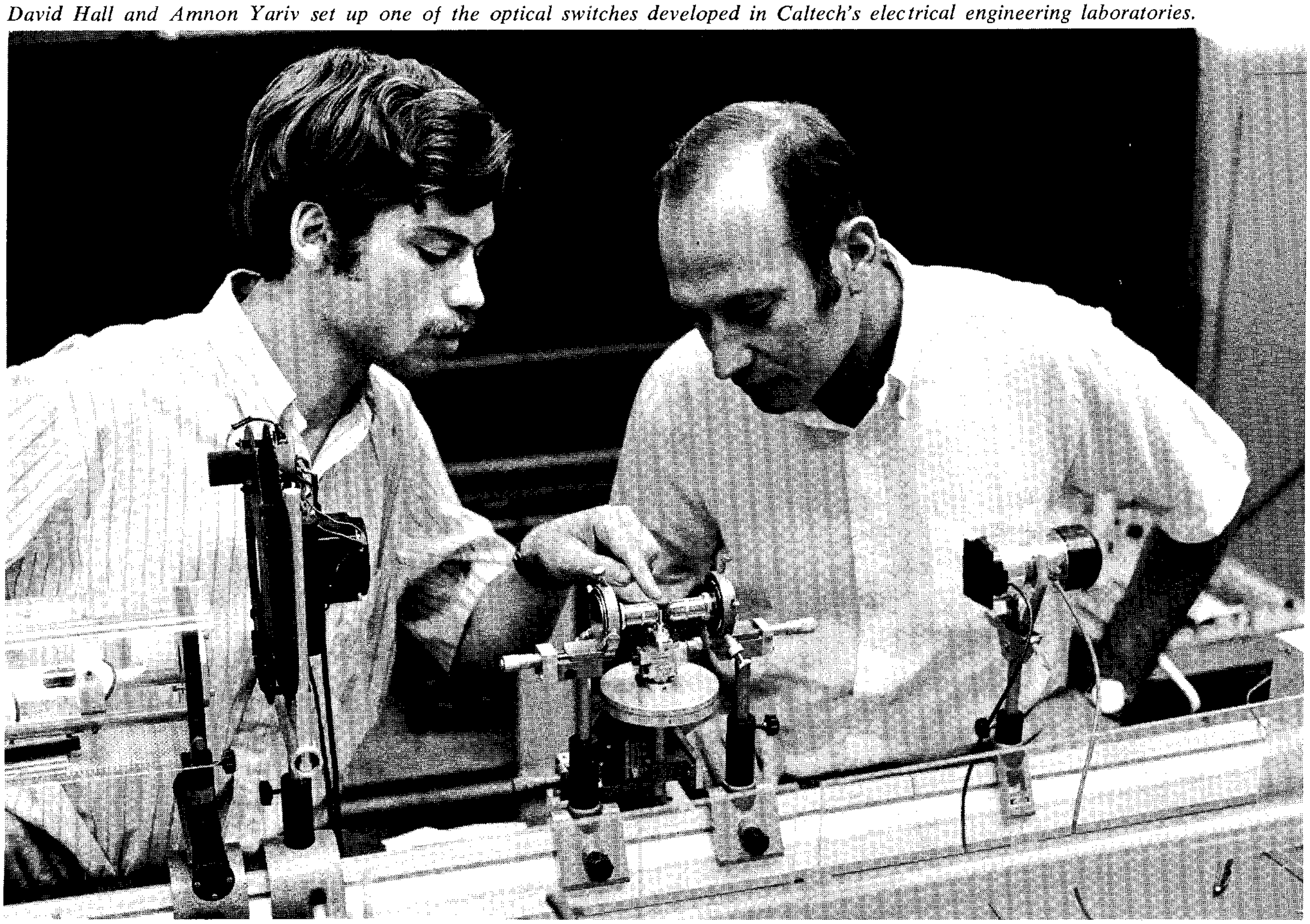
Amnon Yariv, Caltech professor of electrical engineering, has now developed unique crystal modulators that permit compact integrated circuits and reduce by more than a thousandfold the electric power requirements.

His crystal devices, only a few thousandths of an inch across, modulate and switch laser light on and off at speeds up to a billion times a second, much as transistors do for electric current. They operate in miniature integrated optical circuits that carry light instead of electricity in thin crystal films acting as wave guides. Working with Elsa Garmire, research fellow in applied science, and graduate student David Hall, Yariv has spent three years developing these optical switches.

The switches are based on electrodes attached to wave guides. The wave guide—which plays a role similar to that of a wire in an electrical circuit—consists of a crystal on which a very thin layer of another crystal (a few thousandths of an inch thick) has been grown, using heat and evaporation. The very thin layer will guide light, provided it has a greater ability to refract light than the substrate crystal layer.

Light from a laser is fed into this wave guide, which can carry light around corners and for considerable distances

David Hall and Amnon Yariv set up one of the optical switches developed in Caltech's electrical engineering laboratories.



with little loss of intensity. A thin coat of metal is evaporated onto the top and bottom of the composite crystal so that voltage may be applied to the crystal at one or more locations where switches are desired. Wires are attached to both spots of metal. Operation of the switch depends on the semiconducting properties of the thin film and the electro-optical effect.

The electric field causes minute changes in the crystal's atomic arrangement which, in turn, induces a slight change in the refractive index—that is, the velocity of light. This electrical control of the index of refraction can be used in several ways for modulating the light flowing through the wave guide.

Some of the applications envisaged for the new optical circuit element include: putting many channels of information on optical carriers to transmit information; developing compact optical circuits for information processing; and developing electrically controlled optical scanners and lenses for maneuvering the direction and amount of spread of optical beams.

The work of the research team is supported by the Office of Naval Research and the Advanced Research Projects Agency. The unique crystals used in the research were grown by the United Aircraft Research Laboratories.

Dancing Honeybees

Honeybees communicate with each other through their dancing. This conclusion by three young biologists may end a long-standing scientific argument over how bees direct other bees to sources of nectar and pollen.

Jim Gould and Mike Henerey, both 1970 graduates of Caltech, and Mike MacLeod, a 1969 Caltech graduate now attending the University of Oregon, conducted this research in the summer of 1969. The results were reported in the August 7, 1970, issue of *Science*.

The three students set up a series of carefully controlled experiments to test the validity of two opposing theories on the language of bees. One theory was developed in the 1940's by an Austrian zoologist, Karl von Frisch. Noting that bees danced after returning to their hives, he found a correlation between the directions of the dance and the food source, and between the tempo of the dance and the distance of the source. He concluded that the dance was used to tell other bees the direction and the distance of the food source.

The opposing theory, originally formulated by Von Frisch in 1920, was given new impetus in 1967 when Adrian M. Wenner and Dennis L. Johnson of the University of California at Santa Barbara repeated Von Frisch's work with some modifications and concluded that, under their conditions, the behavior which Von Frisch attributed to communication by dancing could be explained on the basis of the sense of smell alone. The hive bees, in other words, could have smelled the odor of the food source on the bee that had found it, and, after leaving the hive, they could look for the same odor outdoors.

The three students became interested in this controversy after it was discussed in a Caltech behavioral biology class by Seymour Benzer, professor of biology. He said that it was time for an objective third party to examine the question.

Neither hypothesis, the students agreed from the beginning, need exclude the other, and both might apply in different circumstances.

"Since there is general agreement that the dances do contain both distance and direction information, the real question is whether this symbolic information can be communicated to other bees."

Upon returning to the hive, a forager bee who has found food often performs a dance. He runs a short distance in the direction of the food, waggling his abdomen. He then runs in a semicircle back to the starting point and duplicates the maneuver, which may be repeated as many as 200 times. The dance excites the other bees to leave the hive in search of the food source.

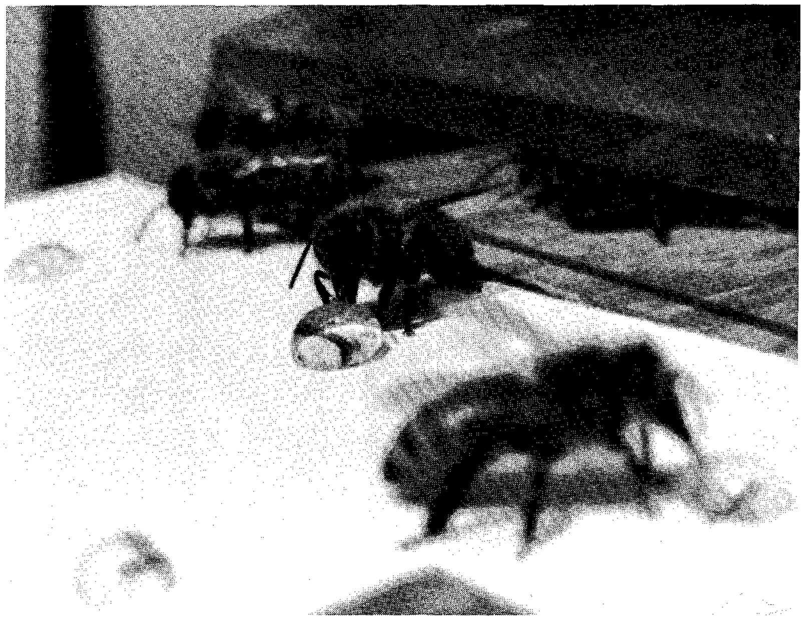
Gould, Henerey, and MacLeod decided to test the theory that the bees communicate with their dancing. They traveled to eastern Oregon where they found a flat, desert-like area 20 miles east of the town of Burns that was not near the orchards, lakes, cities, trees, or other topographical features, frequently found in earlier research, that might distract the bees.

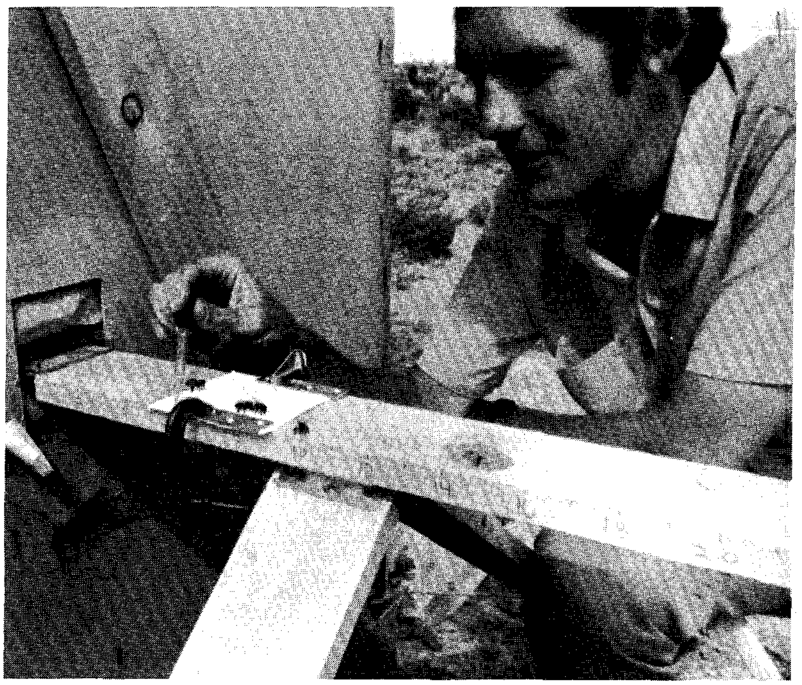
After establishing a camp, the team set out a glass-covered hive which they had designed and built so they could see the dancing inside. Four hundred feet from the hive they built four feeding stations, each at a different point on the compass in relation to the hive. Each station contained, at times, a sucrose sollution palatable to the bees.

The researchers tagged about 4,500 members of the colony for identification by gluing small tags of different colors and numbers on the bees' backs. This involved cooling each bee to immobility, to reduce the risk of stings.

Some bees were then selected as "foragers." After

The first step in training a honeybee to fly to a feeding station is to introduce him to a sucrose solution placed near the hive entrance. Jim Gould (below) helped develop the technique.





training, each forager flew only to "his" particular feeding station. Training proceeded by first placing sucrose at the hive entrance, and then moving it farther and farther away, coaxing the bees at last to the feeding station. The forager's task was to load up on sucrose at his feeding station, then return to the hive and dance, thus informing the bees in the hive of the availabilty of food, stimulating them to venture out in search of it.

Unlike previous research relating to the controversy, great care was taken in the experiments to eliminate differences in odors and visual cues which might prejudice the results.

In one series of experiments with recruits captured within four minutes after attending the dance of a forager bee, 90 percent of the bees arrived at the feeding station indicated by the forager's dance. However, of the recruits caught 12 or more minutes after a dance, ony 50 percent arrived at the station indicated by the dance, as would be expected by random chance. The researchers lay some of the blame to forgetfulness.

In a second series of experiments, foragers regularly visited two stations located in opposite directions. By offering only dilute sugar water at one and very sweet sugar water at the other, only the foragers that visited the latter station performed a dance; the ones that got the weak solution did not. Thus, potential recruit bees attending the dances received scent information valid for either station, but directional information for only one. If only odor cues were used, one would expect the stations to attract equal numbers of recruits. If, on the other hand, direction information from the dance were utilized, one would expect more recruits to go to the station indicated by the dance. In fact, 96 percent of the recruits were captured at the station indicated by the dancing of returning foragers.

The results therefore confirm the idea that the information in the dance is communicated from forager to recruit and is subsequently used by the recruit.

Carefully pointing out that their experiments do not exclude the possibility that, under certain circumstances, odor cues alone might suffice, the Caltech team noted that bees use light, gravity, odor, and an internal clock system in the food-gathering behavior. These experiments lend credence to the notion that, in addition, the honeybee is able to communicate precise abstract information through its dances.

The research was supported by a U.S. Public Health Service grant and by a grant from the Ford Foundation through the Caltech Associated Students Research Center.

Radio Astronomy—Marking Time

Radio astronomy is a rapidly developing field, and major new radio telescopes are being completed in Europe and in other parts of the world—but not in the United States. American radio astronomers have proposed construction of a number of new instruments, and several of these have been approved by review committees of the National Academy of Sciences and the National Science Foundation—but none of them has been funded.

At the dedication of the Westerbork Synthesis Radio Telescope at Groningen, Netherlands, last spring, 11 astronomers and physicists took the occasion to compose a letter pointing out that the United States is falling behind in radio astronomy and urging that "construction of some of the proposed instruments be commenced." Three signers of the letter (published in the June 19 issue of *Science*) are from Caltech: William A. Fowler, professor of physics; Alan T. Moffet, associate professor of radio astronomy; and Maarten Schmidt, professor of astronomy.

Until several large instruments were built in the late 1950's and early 1960's, radio astronomy was virtually nonexistent in the United States. With those instruments this country was able to move rapidly to the forefront. However, the scientists say: "Our instruments of the 1950's cannot compete with the new ones now coming into use in other countries."

West Germany is completing the world's largest fully steerable dish antenna this year—328 feet in diameter. Italy and Australia have large new radio astronomy instruments. A major new instrument is being built in Cambridge, England.

Recognizing the problem for American radio astronomers, Caltech's Jet Propulsion Laboratory has made some of the equipment in its Deep Space Network available for ground-based radio astronomy experiments. About 5 percent of the time on the 210-foot antenna at Goldstone, California, will be allotted to qualified radio scientists. Eventually, some time may be available at other DSN facilities. Proposals for use of this equipment will be evaluated by a six-man committee from the major radio astronomy centers in the U.S. The panel is headed by Jesse Greenstein, Caltech professor of astrophysics.

Caltech's Owens Valley Radio Observatory has two 90-foot dish antennas, which have been in operation since 1958. A 130-foot dish, added in 1968, was the first of a proposed network of eight units.