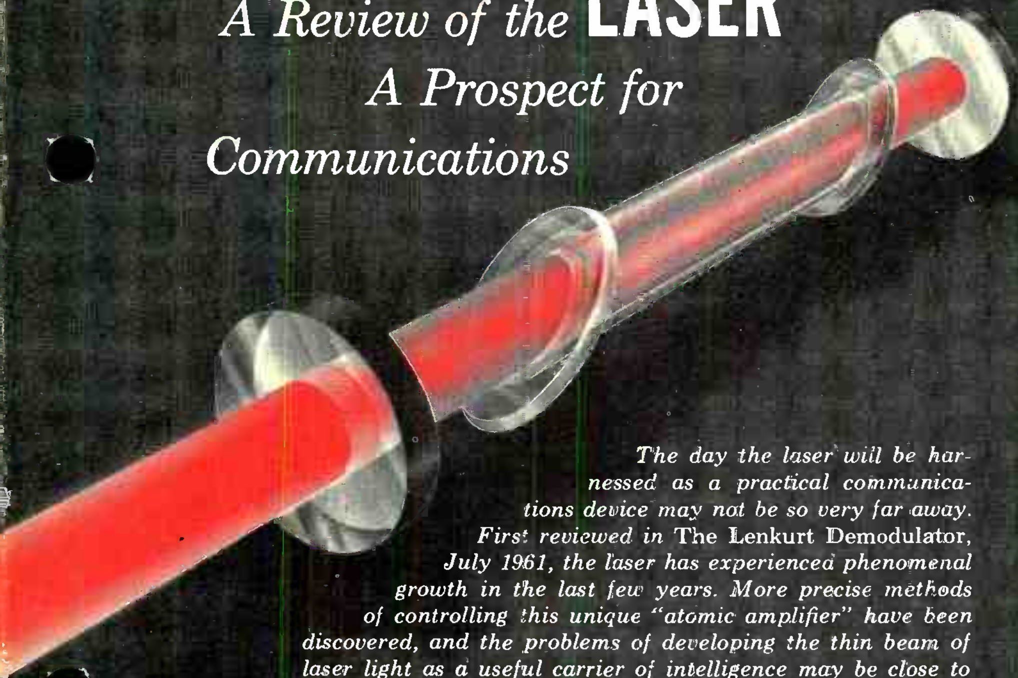
The Lenkurt® Demodulator

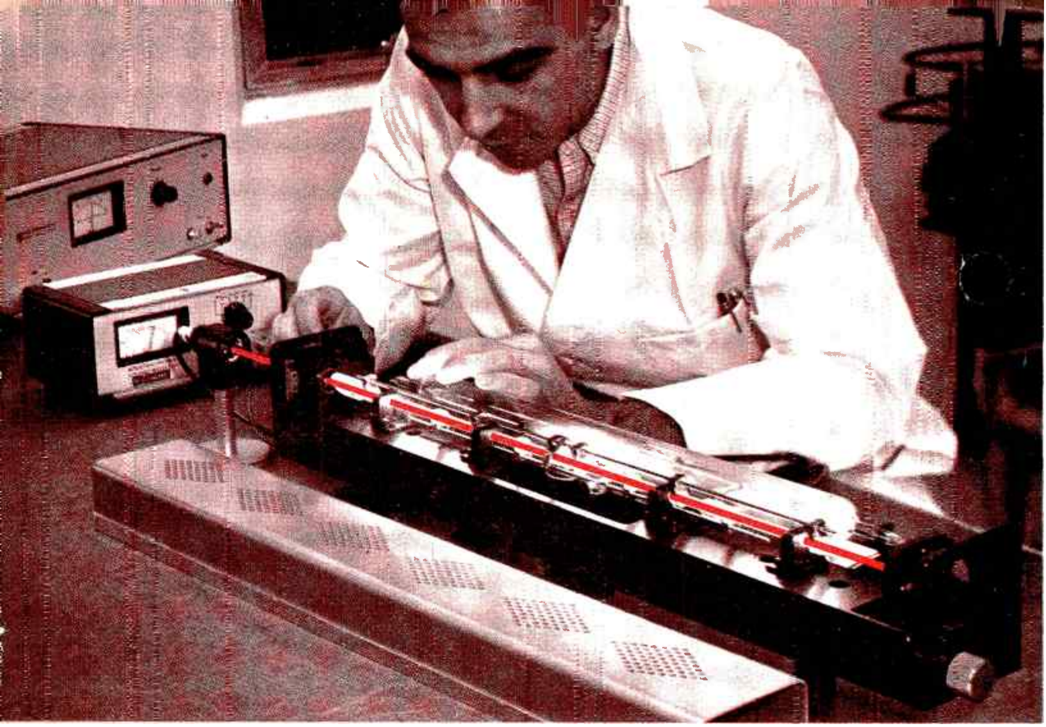
VOL. 14, NO. 11 NOVEMBER, 1965

A Review of the LASER
A Prospect for Communications



The day the laser will be harnessed as a practical communications device may not be so very far away. First reviewed in The Lenkurt Demodulator, *July 1961, the laser has experienced phenomenal growth in the last few years. More precise methods of controlling this unique "atomic amplifier" have been discovered, and the problems of developing the thin beam of laser light as a useful carrier of intelligence may be close to being solved. In fact, the field is advancing so rapidly as to make it almost impossible to complete a report that is not immediately out of date.*

This article is a discussion of some of the more recent developments in the use of the laser, especially as they apply to communication.



Courtesy of Spectro-Physics

Figure 1. Commercial helium-neon laser receives final inspection from optical technician. Sensitive mirror adjustments tune the laser, while output is monitored with a photocell power meter.

The laser is basically an oscillator operating at light frequencies. But instead of tapping the energy from a stream of electrons as in the common vacuum tube, the laser stimulates the emission of stored energy from the atom itself. An acronym for light amplification by stimulated emission of radiation, the term *laser* is accepted throughout most of the world to describe the action. Practitioners have even coined a new verb, *to lase*.

Common laser types may be catagorized as crystal, gas, liquid and semiconductor, each having properties identifying it with certain uses. A crystal laser, such as the ruby, can be pulse-operated at very high power outputs, measured in megawatts. Gas and the more recent liquid lasers provide less power, 10 to 20 watts, but are more suited for continuous operation. They also offer the advantage of single frequency operation. Semiconductor lasers are very small, operate at low power, but boast very high efficiency. Crystal and gas lasers may currently be purchased as off-the-shelf items, and are being pushed into service in a variety of fields.

Referred to by some as "an answer looking for a problem," the laser exhibits a number of qualities just now finding application in the fields of medicine, industry, physics, chemistry, optics, and electronics. One of the most pronounced of these qualities is the laser's ability to produce coherent light —of particular interest to the communicator wishing to find a new carrier for increasingly huge volumes of information.

Communicating with Light

The concept of communicating with light is certainly not a new one. For hundreds, if not thousands of years, men have met the need to "talk" over long distances by using light. In early history a torch served as a very effective semaphore. Flashing heliograph mirrors reflect the sun's brilliance for many miles, and the lighthouse certainly communicates a most urgent message. (Paul Revere's "one if by land, two if by sea" lantern code, incidentally, was not only an early use of light for communication, but illustrative of the binary code in primitive form.)

As early as 1880 Alexander Graham Bell transmitted voice by light, but only for a short distance. A variation of Bell's experiment is often used as a demonstration for budding high school scientists. Similarly, the sound tracks on many motion pictures today are produced on film by controlling a narrow source of light. But one major handicap prevents ordinary light from becoming a practical message carrier. It is *incoherent* light!

Light from common sources is very unsystematic, like the waves from a handful of pebbles thrown on a pond. An ordinary light bulb emits a literal jumble of light waves, completely at random and at different frequencies (or colors). Only the most gross pieces of information can be transported by these waves. The high school science demonstration, for example, does not attempt to tamper with the frequency of light, but merely varies the intensity of the beam proportional to the amplitude of an audio signal such as voice or music.

Coherent Light

Laser-produced coherent light is extremely stable and precise in frequency, with waves exactly in phase with each other. Like the waves from a single pebble dropped in the water—or more accurately like ranks of marching soldiers all in step—these coherent light waves are now potential information carriers. Just as one soldier out of step is immediately obvious among disciplined marchers, a laser light wave may be disturbed (modulated) and detected at another point (demodulated) in a very orderly manner.

In addition to excellent phase coherence, the beam leaves the laser as a "wall" or flat plane of light exactly parallel to the laser's face. The beam will diverge so very slightly that even in the earth's thick atmosphere it theoretically spreads out only about an inch per mile. And in space, where there is no dust or water vapor to deflect the laser beam, it conceivably would reach the surface of the moon, over 250,000 miles away, as a circle only a half-mile in diameter.

Of equal if not more interest to the communicator is that laser light contains only one frequency—and a very high frequency at that. The center of the visual spectrum is about 10^9 megacycles, or about 160,000 times higher than the 6 gc microwave band. Since available bandwidth increases with frequency, a tremendous bandwidth is available at light frequencies. Currently, laser modulators are being developed with bandwidth capabilities of 1 gc and higher. How much more bandwidth is possible remains for the experimenter to find out. But compare this with a common microwave system carrying 960 voice channels on a bandwidth of 4 mc. Even with current techniques, the laser's bandwidth is 250 times this size.

Stimulated Atoms

The inherently unique properties of laser light have their origin in basic atomic theories governing electrons, photons, and their energy levels. The same facts apply to the *maser,* or microwave version of the laser, but for clarity only the visible light spectrum will be used in this explanation.

Atoms in nature are usually in a relatively undisturbed or *ground* state. The energy of orbiting electrons is balanced with the energy in the nucleus of the atom. These electrons occupy specific orbits determined by their own energy, but when "excited" by an outside source of energy, may jump to a higher second level raising the total energy of the atom (Figure 2). In lasers, adding this outside energy is known as *pumping.*

The excited state for the atom is unnatural and it will tend to relax to its ground state. As this happens, the stored energy is dissipated by emitting a photon of radiant energy. The energy of the photon is exactly proportional to its frequency—the higher the energy, the higher the frequency.

The common neon tube is an example of this action. Molecules of gas are excited to upper energy states by high voltage. As the atoms drop to their ground state, they emit light of a characteristic color or frequency—various gases produce various colors.

If left uncontrolled, the atom's spontaneous relaxation occurs in a random manner and results in incoherent light. But during the period when the atom is still excited, it is possible to stimulate the drop to ground level by striking the atom with an outside photon of the same energy it would have otherwise emitted spontaneously. Relaxation is no longer random, and the emitted photons leave the system as coherent light.

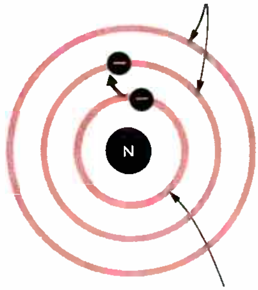


Figure 2. Atomic electrons normally occupy an orbit around the nucleus, representing a certain fixed energy level. A stimulated atom acquires energy as one of its electrons jumps to a higher level.

Another remarkable feature of laser action results when an emitted photon strikes another excited atom within the laser. As that atom returns to its ground state, another photon is added to the stream exactly in phase with the first, producing amplification.

Various methods have been discovered to improve the efficiency of the lasing action. The *three-level* method pumps atoms not to the second energy level, but to a still higher third level (Figure 3). The atoms are very unstable at this level, and quickly fall back to the intermediate, or second level. Here, by the nature of the laser material, the atoms tend to accumulate and are available in greater numbers for outside stimulation. Cooling the material, say to liquid nitrogen temperature (70°K), increases the effect. These techniques are typical of crystal lasers such as ruby. Gas lasers of the helium-neon type rely on the difference in energy levels between the two gases to provide for more effective pumping.

The Wave Grows

As emitted photons of light travel along the laser tube bumping into more excited atoms, the light wave continues to grow (Figure 4). These waves are reflected back and forth inside the tube by mirrors, one of which is slightly transparent. Forming a resonant cavity at light frequencies, the laser now builds up standing waves which continue to multiply on each pass through the cavity. When the gain is strong enough to overcome the loss in the mirrors, an intense beam is emitted from the partially transparent mirror. As the light bounces back and forth, any waves moving at angles to the axis between the mirrors will soon leave the system through the walls of the tube. Therefore, the output beam of the laser will be extremely parallel.

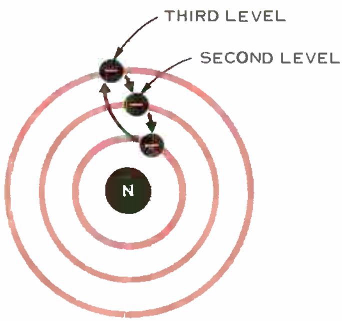


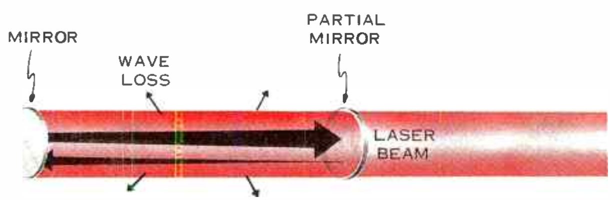
Figure 3. Atoms can be pumped to higher third level, allowed to fall back and accumulate at second level, then controlled in their return to ground state. More atoms available at second level improves laser action.

Because of the coherence of laser light, it is possible to construct extremely efficient optical lenses to further focus the beam. A laser can be focused into a spot no wider than a wavelength of light, or about 0.0001 cm. The result is intense heat at the focal point, useful as a precision cutting tool; for micro-welding; in delicate surgery, such as eye operations; and in chemistry, where individual molecules may be subjected to the unique radiant energy. The laser should also provide an invaluable laboratory tool for research in optical physics.

Communications Problems

The communications industry, faced with an already overflowing radio spectrum and the ever increasing demand for more and more communications service, quickly became interested in the laser's ultra-high information carrying potential. But engineers found that before the laser could compete with microwave radio for point-to-point

Figure 4. Growing photon stream bounces back and forth, emerging as brilliant, coherent light. Extraneous waves are lost through laser walls.



communications on earth, many problems remained to be solved.

The most serious of these problems is finding a suitable transmission path. The earth's atmosphere presents many natural barriers to light—haze, rain, snow—which do not seriously affect microwaves. Several studies have been undertaken to establish path reliability over relatively short ranges. To date, television pictures have been transmitted over a few miles without serious losses, but any system matching microwave reliability and quality over 25-mile links seems improbable with current techniques.

A number of *covered* transmission paths have been proposed, including the use of fiber optics, shiny hollow tubes, and tubes with regularly spaced lenses to re-direct the beam around mild corners. Among these is a unique suggestion for a continuous gas-lens tube. A simplified arrangement (Figure 5) would pump a steady stream of cool gas into a warm tube. The heated gas near the surface of the tube would be less dense than the cooler gas at the center. This difference, represented by a varying refractive index, would be enough to produce a positive lens for the laser beam.

The slight divergence of the laser's beam—advantageous for keeping energy concentrated theoretically over vast distances—does become a problem in transmitter to receiver visual-path alignment. Experimenters have plotted the expansions and contractions of a building caused by heat from the sun by monitoring changes in signal strength between a laser mounted in the building and a receiver nearby. In the communications field this could be a definite problem. But to others this sensitivity to angular change makes the laser an extremely good device for measuring minor physical displacements. For instance, a system using lasers has been proposed to record instantaneously the land shift around California's infamous San Andreas fault. The same capability is being used to detect micromovement in laboratory experiments.

The laser's prime contribution to communications may come in space, where interference from a *dirty* atmosphere ceases to be a problem. Optical links from known positions, such as earth-orbiting space stations and the moon, could carry tremendous quantities of information on a single laser channel. Tracking of vehicles moving freely in space could be more of a problem for the thin-lined laser beam. But techniques developed here could also apply to laser radar, producing a highly sensitive system with greater resolution than ever before possible. Military applications now being tested include a laser fire control radar system to permit low-flying aircraft to see

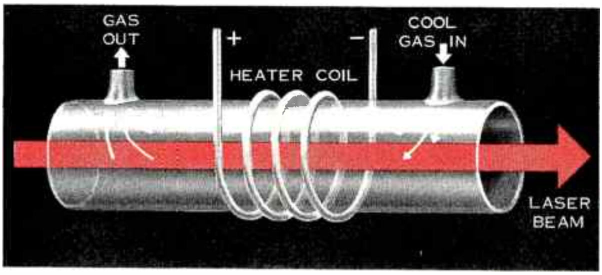


Figure 5. Cool gas forced through a hot tube can form a continuous positive lens, suggested as a means of "piping" laser beams between cities.

targets normally obscured by ground clutter on microwave radar.

The basic component needs of a laser communications system are the same—in name at least—as any similar radio device. The information to be transmitted must be amplified, modulated, demodulated, and recreated in its original form. The techniques needed here are not all new. For example, earlier developed masers operating at microwave frequencies have for some time been employed as amplifiers in radio astronomy because of their ability to provide high gain and very low noise.

Modulation

Apart from the extensive pure research being done with lasers, considerable effort is being put into finding suitable modulators and demodulators. Modulation of the relatively new semiconductor or injection-type laser is easily accomplished by simply controlling the pumping current. However, semiconductor lasers, such as gallium arsenide (GaAs), have a low output power and are not as coherent as other sources. Also, the output is a less desirable flat sheet of light as opposed to the solid round beam of other lasers. For the present, communicators are putting more faith in gas and crystal lasers for communications purposes, with further study being given liquid lasers.

One of the first successful devices for amplitude modulating a laser beam uses the polarization properties of the clear crystal potassium dihydrogen phosphate (KDP). As illustrated in Figure 6, the KDP device amplitude modulates a laser beam projected through it. The first polarizer blocks all light wave polarizations except, for example, the vertical.

The resulting beam may be thought of graphically as a number of ribbons of light, all parallel to each other and at right angles to the direction of propagation. For simplicity of illustration, this example treats the polarized light as only one *ribbon*. It is characteristic of the KDP crystal to shift polarization

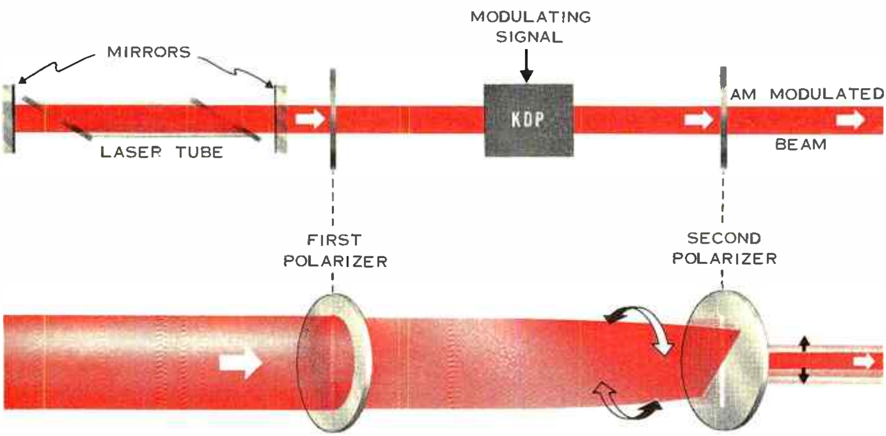
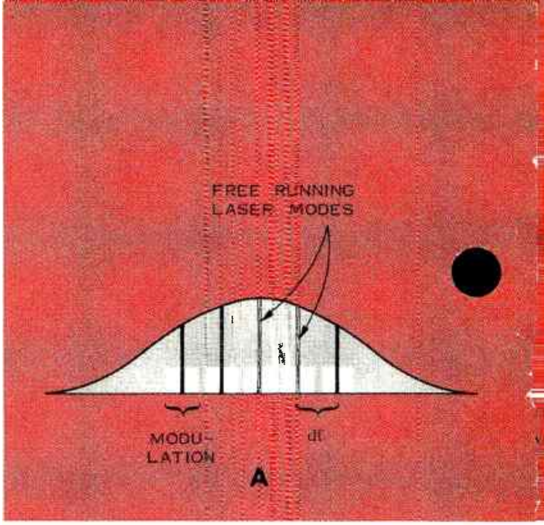


Figure 6. As beam passes through an AM laser modulator, it may be visualized as a ribbon of light twisting proportional to a signal applied to the KDP crystal.

Figure 7. Laser modes representing the (A) free-running laser, (B) laser with FM modulator inside the cavity, and (C) super-mode laser, where power in the FM sidebands is combined into one output frequency



in a circular direction proportionate to a stimulating voltage. For a higher voltage, there will be more circular change in polarization. If a signal is applied to the KDP crystal and the now vertically polarized laser beam shone through it, the beam will be what might be called *polar modulated.* In the diagram, the ribbon will be twisted in accordance with the modulating signal. The second polarizer, known as the analyzer, will sense this twist as a decrease in amplitude. The output intensity will then vary in relation to the signal, hence, amplitude modulation.

Bandwidth in the order of 200 mc can be achieved with amplitude modulation, but this by no means takes full advantage of the capabilities of coherent laser light. On the other hand, frequency and phase modulation methods are producing bandwidths of over 1 gc. One such device, known as a wideband traveling wave phase modulator, consists of two parallel brass rods about one meter in length, with an electro-optical material (such as KDP) sandwiched between. A microwave signal voltage applied to the device varies the velocity of light in the crystal, resulting in phase modulation. The length of the modulator allows longer interaction time between signal and light beam, and hence greater depths of modulation.

Laser Modes

It should be noted that since the laser cavity is thousands of times longer than any wavelength at light frequencies, a number of frequencies will resonate in the tube at the same time. This results in the laser having in its output a number of separate and distinct frequencies or modes (Figure 7). The separation of these modes is determined by the mirror placement in the laser, and may be calculated by the formula:

$$df = \frac{c}{2L}$$

where:

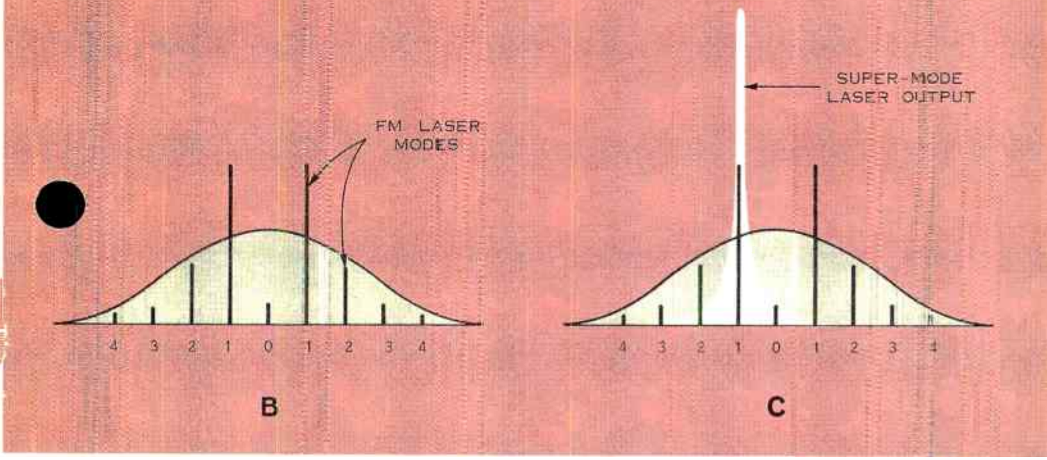
df = the difference frequency between modes

c = speed of light, and

L = length between the mirrors.

Since the obvious desire is to transmit only one frequency, power distributed in modes other than the one to be used is wasted. Likewise, each mode acts as a carrier frequency for any modulation. As sidebands are added to each mode (Figure 7A), it can be seen that the bandwidth of modulation on any one mode is limited by the difference in frequency between the modes.

One solution is the super-mode laser (Figure 8). By inserting a phase modu-



lator inside the laser tube, driven at a frequency nearly equal to the difference frequency between modes *(df)*, the output is converted to a typical FM configuration with sidebands occupying the positions formerly held by the various modes (Figure 7B). By using this method, the bandwidth limitation in the mode structure has been eliminated. Another phase modulator outside the tube will additionally affect the beam by compressing all the modes together into a single frequency. The final output contains most of the power formerly held in the many modes, plus the highly desirable single frequency (Figure 7C). This "super-mode" beam can be successfully modulated by any chosen method with much superior performance.

A similar means of arriving at the same end is found by placing a device known as a *Fabry-Perot etalon* (not shown) inside the tube, along with the FM modulator. The output frequency is determined by the spacing of two highly reflective mirrors forming the etalon, creating a resonance at the desired frequency. The beam leaving the tube will be of single frequency if the etalon is

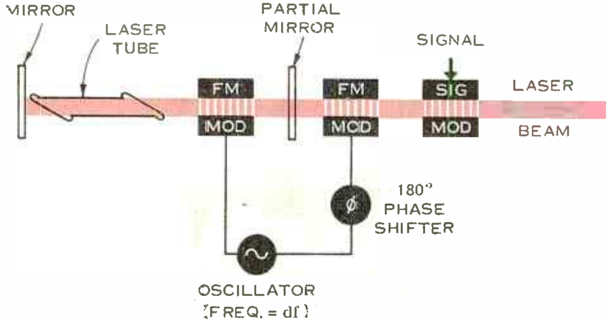


Figure 8. Super-mode laser has single frequency output of comparatively high energy. Oscillator frequency is nearly equal to the difference frequency between free-running laser modes.

tuned to one of the FM sidebands, and will be at the laser's full power. The device combines the power of the other sidebands into the output. This can be done because the FM laser modes are sidebands of a single carrier, rather than a set of independent oscillations.

Demodulation

Demodulation of optical radiation is typically accomplished with either a photomultiplier tube or a microwave phototube, each relying on the secondary emission of electrons from a cathode when struck by light photons. The photomultiplier technique redirects emitted electrons onto other secondary-emitting surfaces, producing considerable amplification. The current is eventually collected on an output electrode. The photomultiplier tube has a range from d-c to many megacycles, thereby detecting signals directly to baseband frequencies. The microwave phototube (Figure 9) is designed with a traveling wave tube helix output, and is effective at the higher microwave frequencies. A modification of the microwave phototube, known as the crossed-field electron multiplier, amplifies the signal before the electrons reach the helix. In both cases, since light frequencies are outside the bandwidth capabilities of the phototubes, the electron stream represents only the original modulation placed on the laser beam.

Optical heterodyning is also possible using the photomultiplier tube, as seen in Figure 10. A laser local oscillator beam beats with the incoming laser signal in the phototube, resulting in an IF frequency equal to the difference between the two light frequencies. This IF signal is typically in the microwave region and may be amplified and demodulated by conventional methods. A discriminator supplying a control signal to the laser local oscillator maintains frequency stability.

Other Applications

Interest has been shown in using lasers, possibly of the semiconductor type, for inter-component communication in high speed computers. The technique would eliminate the delay asso-

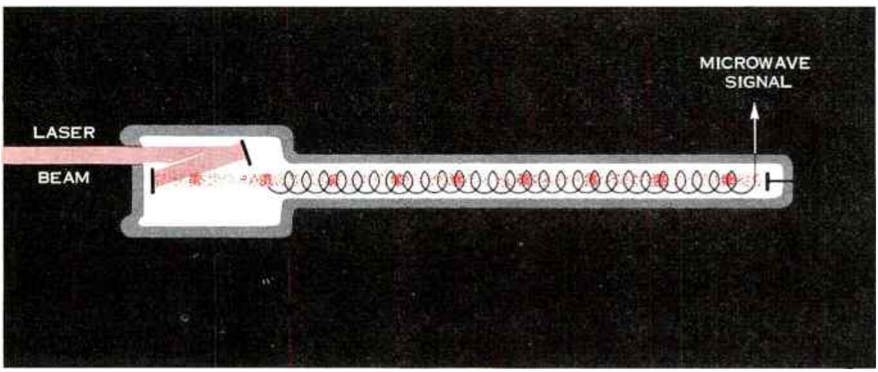


Figure 9. The microwave phototube converts laser light to electrons, bunched proportionate to the original modulation. The current induced in the helix is then processed by usual microwave techniques.

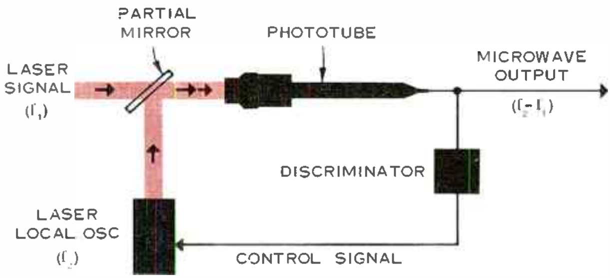


Figure 10. Optical heterodyning combines laser signal with that of laser local oscillator at phototube. Microwave output at IF frequencies is then amplified and demodulated.

ciated with placement of components and connections, and would offer much faster switching speeds than now possible with ordinary electronic computer circuits.

Closer to the communications field, coherent laser light has opened a "magic window" to successful wavefront reconstruction photography, known as *holography*. Holograms record both amplitude and phase variations of laser light reflected from a subject, allowing near-perfect three-dimensional reproduction. Interference patterns between the reflected light and a reference beam are recorded on film without the use of lenses. Applications of the future may include three-dimension color television, and medical or industrial X-ray holograms for studying the interior of an object.

Conclusion

While the laser is becoming a valuable tool in many pure-science areas and may have useful military and industrial applications, its high information-carrying potential for communications seems barely tapped. Techniques for the use of the laser in communications are gaining in sophistication, but a great number of obstacles must be overcome before a practical system becomes feasible. Only a continuing refinement of the art will take the laser out of the laboratory and into the field.

Bibliography

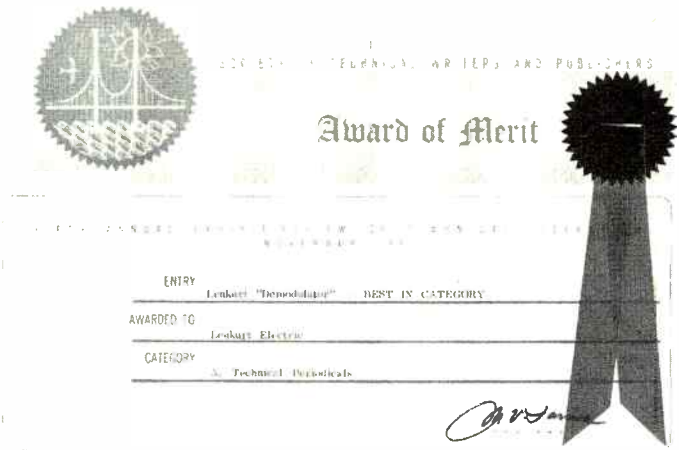
1. Brotherton, M., *Masers and Lasers*, McGraw-Hill, 1964.
2. Gordon, J. P., "Optical Communication," *International Science and Technology*, No. 44 (August, 1965), pp. 60-64.
3. Leith, Emmett N., and Juris Upatnieks, "Photography by Laser," *Scientific American*, Vol. 212, No. 6 (June, 1965), pp. 24-35.
4. Reed, John S., "The Wonderful World of the Laser," *Telephone Engineer and Management*, Vol. 68, Nos. 6, 8, 9 (March 15, 1964 pp. 43-47, April 15 pp. 64-67, May 1 pp. 40-43).
5. Schawlow, Arthur L., "Optical Masers," *Scientific American*, Vol. 204, No. 6 (June, 1961), pp. 52-61.

Lenkurt Electric Co., Inc.
San Carlos, California

Bulk Rate
U.S. Postage
Paid
San Carlos, Calif.
Permit No. 37

MR. E. A. GARCIA
CHIEF OPERATOR
% MILWAUKEE ROAD DEPOT
SAVANNA, ILL.
R-24948 6B

RETURN REQUESTED


Award of Merit

ENTRY Lenkurt "Demodulator" BEST IN CATEGORY

AWARDED TO Lenkurt Electric

CATEGORY 3. Technical Periodicals

DEMODULATOR WINS AWARD

A "Best of Category" award for technical periodicals has been won by *The Lenkurt Demodulator* in competition sponsored by the Golden Gate Chapter of the Society of Technical Writers and Publishers. The Palo Alto, California chapter annually conducts the literature review from entries submitted by firms in the area. With chapters throughout the United States, the STWP helps to promote and develop the overall aspect of technical communications.

LENKURT ELECTRIC San Carlos, California, U.S.A.
SUBSIDIARY OF
GENERAL TELEPHONE & ELECTRONICS GT&E

Lenkurt Offices

San Carlos
Atlanta
Dallas
New York City
Washington, D.C.
Chicago

The Lenkurt Demodulator is a monthly publication circulated free to individuals interested in multi-channel carrier, microwave radio systems, and allied electronic products. Permission to reproduce material from the *Demodulator* will be granted upon request. Please address all correspondence to the Editor.

LITHO IN USA