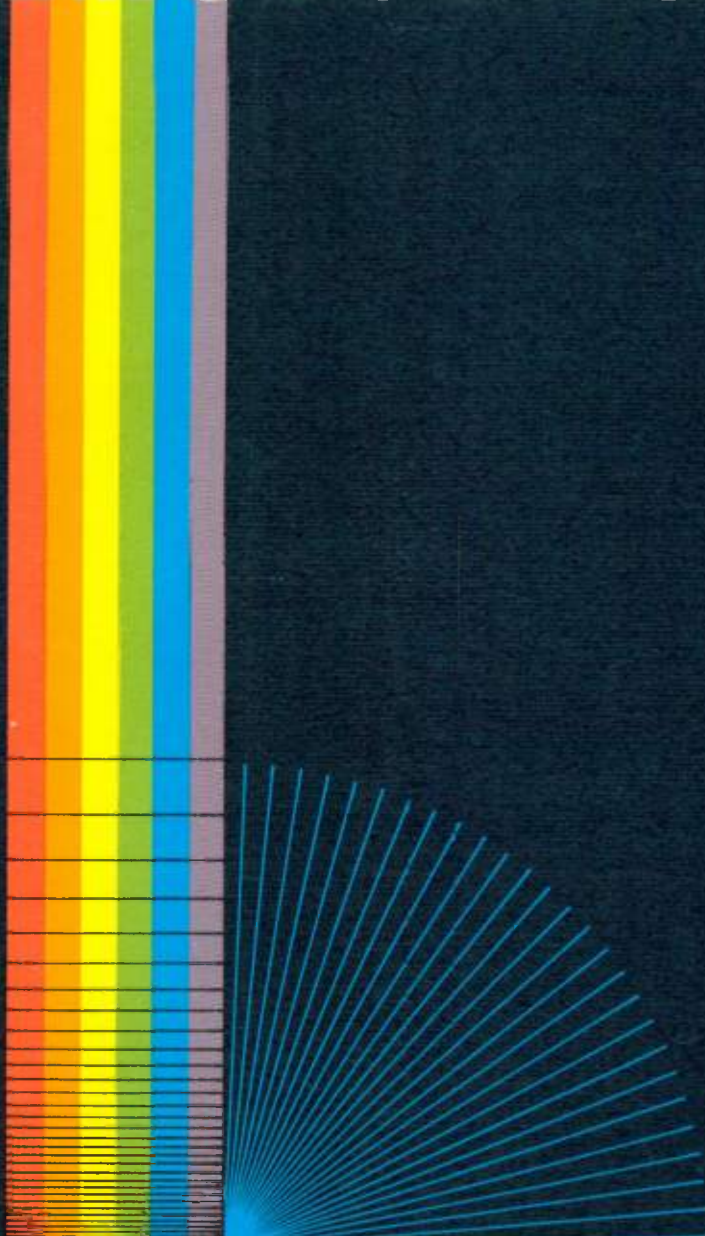
The Lenkurt DEMODULATOR

JANUARY 1970



LASERS FOR COMMUNICATION

Since the first Light Amplification by Stimulated Emission of Radiation (LASER) was demonstrated in 1960, this new kind of light has stirred the imaginations of almost everyone. The wide interest in lasers and their possible applications has produced devices that are used for everything from delicate eye surgery to taking "pot-shots" at the moon. There is an almost endless list of laser uses, but the one which has received major interest is the potential of the laser in the development of a high-density communications system. Engineering interest in this pursuit has been marked by almost a decade of growing optimism. Only in the last year or so has this enthusiasm begun to show signs of diminishing.

Scientists and engineers, in their pursuit of the laser as a practical communications system, have built an impressive technology and solved a number of problems. Workable methods of modulation and demodulation have been developed and are still being refined. Operating laser communications systems have been designed and demonstrated – in the laboratory. Many laser sources are now available, solid-state, gaseous and liquid, which are more compact and more efficient than the early solid ruby type. A complete system can be put together with equipment now stocked by several manufacturers. The problem which remains to be solved is the development of an efficient, inexpensive transmission technique which can compete with existing microwave and cable systems. This challenge is compounded by the fact that microwave and cable techniques are constantly being improved. Although the skeptics may not represent the majority, their attitude does explain the leveling-off of enthusiasm.

In spite of the obstacles, it seems certain that the search to find a workable, economically feasible method of harnessing the laser's tremendous message potential will continue until it is either accomplished or discarded as impossible. Prognostications of a system capable of transmission rates of 2×10^{14} bits per second are too tantalizing to put aside.

The Basic Principle

The laser theory is based on atomic physics and dates back to 1917 when Albert Einstein pointed out that controlled radiation could be obtained from an atom (or molecule) under certain conditions.

Atoms in nature are usually in a relatively undisturbed or "ground" state. The energy of orbiting electrons is balanced with the energy in the atom's nucleus. These electrons occupy specific orbits determined by their own energy. As Einstein suggested, "pumping" energy into these electrons raises their orbits to the second, third or fourth level depending on the energy applied (see Figure 1).

Since the excited state is unnatural for an atom, it tends to return to its "ground" state, emitting a photon of radiation in the process. The energy of the photon is exactly proportional to its frequency – the higher the energy the higher the frequency. A system which produces more than one energy shift will produce an equal number of light frequencies.

Coherent Light

When atoms return randomly to their ground state, they produce incoherent light. In the laser, however, the controlled bombardment of excited atoms, by photons of equal energy, regulates the return to the ground state, producing coherent light. This process of controlled stimulation creates an internal amplifying effect. The moving photon wave front forces excited atoms to return to the ground state contributing their own photon of equal energy — exactly in phase with the moving wave. This process produces a coherent light wave whose amplitude continues to grow.

High energy photons produce X-rays or ultraviolet radiation, while low energy photons produce visible light of any color, radiant heat or radio waves. The precise amount of energy absorbed or emitted by an electron jumping from one energy level to another varies with each material and its atomic shell structure. The wavelength of an emitted photon depends on the magnitude and the specific location of the electron jump. Thus, an electron moving from the second to the first energy level will emit a photon with one wavelength, while an electron moving from the third to the second energy level will emit a photon of another wavelength, and an electron moving from the third to the first level

Figure 1. Pumping energy into an atom stimulates its electrons into higher energy levels. As they return to their "normal" state, this energy is emitted in the form of photons. More electrons available at the second level improves laser action.

will emit a photon of still another wavelength.

Many methods have been developed to improve laser efficiency. In the three-level method, atoms are pumped beyond the second level to the third where they are very unstable and quickly fall back to the second level. Here, the atoms tend to accumulate and are available in larger numbers for external stimulation. Four-level pumps offer even greater efficiency.

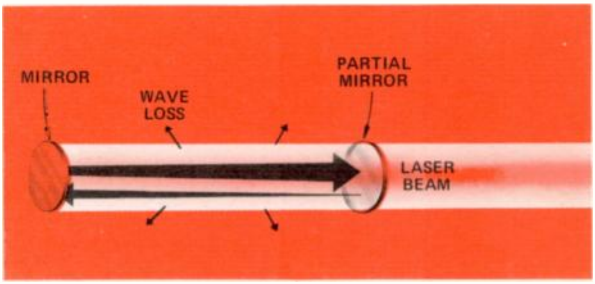
As the emitted photons travel along the laser tube stimulating the emission of other photons, the light wave continues to grow (see Figure 2). This wave is reflected back and forth between the ends of the tube by two mirrors, one of which is slightly transparent. A standing wave builds up within this resonant cavity increasing its amplitude with each successive pass. Any light moving at angles to the axis between the mirrors exits the system through the walls of the tube leaving only a parallel beam to pass through the partial mirror. This spatially coherent light beam can be focused, through properly constructed lenses, to a spot no wider than 0.0001 cm (approximately the wavelength of light). The intense heat produced by this kind of focusing explains the use of the laser as a precision cutting tool.

Types of Lasers

Although there are several basic types of lasers (solid, gas, semiconductor, chemical, and liquid), gas lasers have more mode purity and higher stability and appear to be better suited for wideband communications.

The gas laser operates in a somewhat different manner than the early pink ruby laser. Instead of a solid crystal, a gas (such as neon) is used. Neon has several groups of energy levels, one of which is suitable for laser action. The problem presented by the use of neon was in finding a way to

Figure 2. The growing photon stream bounces back and forth, emerging as brilliant, coherent light. Extraneous waves are lost through the wall of the laser tube, leaving only parallel light.



pump electrons to the upper level without also filling the lower levels, such as happens in the illumination of common neon light. One solution to this problem was achieved by mixing helium with the neon. The helium could be stimulated to a high energy state by radio frequency, having almost no effect on the neon. The excited helium atoms were then able to transfer their energy to the neon atoms at the desired level, forcing the neon's electron population into the most efficient configuration for laser action. Such juggling makes a wider range of laser materials available.

One of the newest and most powerful lasers presently available is the carbon dioxide laser. This gas laser, when properly cooled, has a typical efficiency between 5 and 10% (with some reports over 20%) and, as far as communications systems are concerned, has the lowest beam attenuation under light precipitation conditions. This is of particular interest because the earth's atmosphere is quite hostile to electromagnetic waves in the visible region. This problem can be demonstrated easily by shining a flashlight into a fogbank.

Modulation

The most generally useful optical modulation techniques take advantage of the linear electro-optic effect of certain crystals. This effect refers to the alteration of refractive properties of these crystals in the presence of an electrical field.

One of the first successful devices for amplitude modulating a laser beam makes use of the polarization properties of clear crystal postassium dihydrogen phosphate (KDP). As shown in Figure 3, KDP amplitude modulates the laser beam passing through it. The first polarizer blocks all light polarizations except, for example, the vertical. This divides the beam into parallel "ribbons". The KDP crystal has the unique property of effectively twisting the polarized "ribbons" in direct proportion to the voltage applied to it. The second polarizer, the analyzer, interprets the twist as a decrease in amplitude. If the voltage applied to the crystal is a modulated signal, the output from the second polarizer varies accordingly, producing an amplitude modulated light pattern. Commonly available optical modulators operate from DC to 100 MHz.

A laser beam in theory can be modulated in phase, frequency, amplitude and polarization. A great deal of comparative data is required, however, before the most efficient modulation technique is determined. The use of noncoherent detection methods, which lose the phase information of the carrier, makes phase and frequency modulation impractical. A method of PCM/PM (pulse-code modulation/polarization modulation) is presently receiving the most favorable attention.

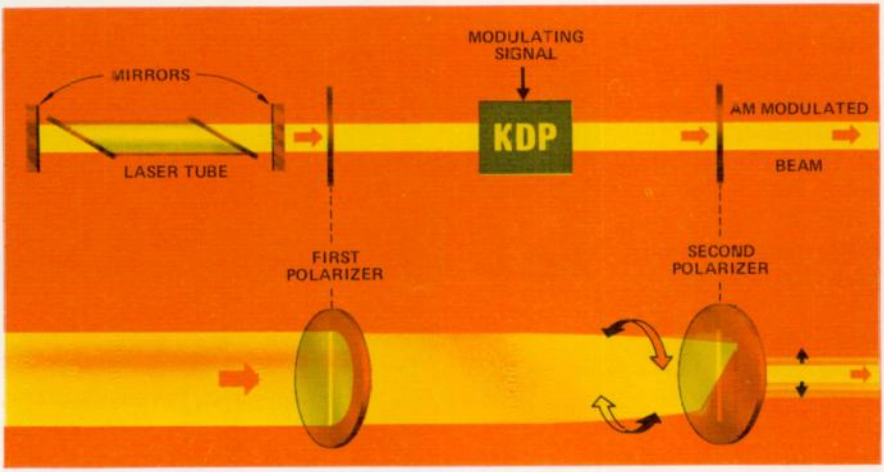


Figure 3. As the laser beam passes through a KDP modulator, it may be visualized as a "ribbon" of light twisting in proportion to a signal applied to the KDP crystal.

This technique is based on the representation of bits of either right or left circular polarization.

Gas and impurity-ion lasers require external optical modulators, based on electro-optic, magneto-optic and acousto-optic effects, in order to accept high frequency modulation. For semiconductor type lasers, it is possible to accomplish internal modulation by way of the current wave form. The Gallium arsenide laser, which has an efficiency rating of 5%, is a promising laser of the semiconductor, internally modulated type.

Most light modulators still require too much power or have inadequate bandwidth, and have been limited to visible and near infrared regions. On the brighter side, a lithium tantalate modulator has recently been developed which is capable of 80% modulation over a 220 MHz bandwidth with only 1/5 watt drive power. A Gallium-doped Yttrium-iodide garnet modulator has even achieved a 40% modulation over a 200 MHz bandwidth with 1/10 watt drive power.

A great deal of work is still to be done. The solution to the problem of efficiently modulating the laser's beam is closely related to new developments in the field of electro-optical crystals and this is a slow and expensive proposition.

Demodulation

Laser demodulation can be accomplished with either a photomultiplier tube, a microwave phototube or high-speed solid-state detectors, each relying on the secondary emission of electrons from a cathode when struck by light photons. The photomultiplier technique redirects electrons onto other secondary emitting surfaces, causing amplification. This current is eventually collected on an output electrode. The photomultiplier tube has a range from DC to beyond 3 GHz, thereby detecting signals directly to baseband frequencies. The microwave phototube is designed with a traveling wave tube helix output, and is effective at the higher microwave frequencies. A modification of the microwave

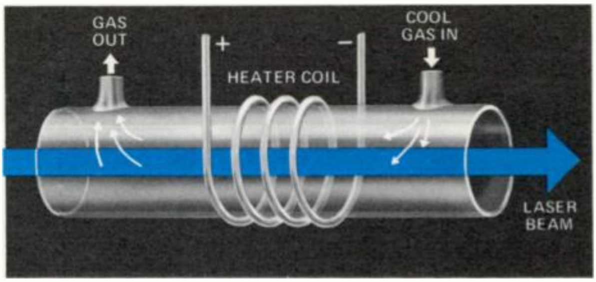


Figure 4. Cool gas forced through a heated pipe produces a lensing effect due to the refractive index of the gas at different temperatures. This type of lens has a soft surface and, therefore, less attenuation than a solid lens.

phototube, the cross-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 hetrodyning, using photomultiplier tubes, is also being explored. In this approach a laser local oscillator beam beats with the incoming laser signal in the phototube, producing 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. Frequency stability is maintained by a discriminator which supplies a control signal to the laser local oscillator.

Laser Modes

The laser cavity is thousands of times longer than any wavelength at light frequencies, therefore a number of frequencies will resonate in the tube at the same time. This results in the output of a number of separate frequencies or modes. The separation of these modes is determined by the mirror placement in the laser. Since the transmission of only one frequency is desired, power distributed in modes other than the one to be transmitted is obviously wasted. Also, each mode acts as a carrier frequency for any modulation. As sidebands are added to each mode, the bandwidth of modulation on any one mode is limited by the difference in frequency between the modes.

This problem can be solved by inserting a phase modulator inside the laser tube, driven at a frequency nearly equal to the difference frequency between modes, the output is converted to a typical FM configuration with sidebands occupying the positions formerly held by the various modes. This supermode approach eliminates the bandwidth limitation in the mode structure. Another phase modulator outside the tube will additionally compress all the modes together into a single frequency. The end result of this technique contains almost all the power of the various modes, plus a highly desirable single frequency. This super-mode beam is one approach which can be successfully modulated by any chosen method – with superior performance.

Propagation

Although laboratory experiments have been very encouraging, the erratic attenuation of the earth's atmosphere appears to preclude any kind of reliable atmospheric transmission without having repeaters spaced so close together they become economically unrealistic. Electromagnetic waves begin to have some problems with the moisture content of the atmosphere just beyond 8 GHz. In general, the higher the frequency, the greater the attenuation. There is, however, a band of frequencies in the infrared region which is much less susceptible than any in the visible or ultraviolet range. This "window" in the infrared portion of the spectrum is centered at about 3 X 10^{13} Hz and is 40 GHz wide. This happens to be the operating frequency of the powerful carbon dioxide laser.

Although atmospheric attenuation, along the earth's surface, is too severe for reliable transmission of a laser beam it may be possible to take advantage of the infrared window by using a carbon-dioxide laser as the up and down link of a satellite communications network. Serious proposals for a system of domestic satellite relays using lasers are presently under intensive study.

On the ground, it has been clear for some time that a closed pipe may be the only reliable way to transmit a message-bearing laser beam any significant distance. A number of approaches are being explored but all have serious cost disadvantages.

Optical waveguide can be devised which makes use of the latest developments in fiber optics, but resolution and signal attenuation are both unacceptable. Experiments with silvered pipes and solid lenses have not been much more encouraging.

While the parallel nature of the laser's beam is one of its most exciting characteristics, it creates inordinate demands for precise path alignment. The curvature of the earth, would still require several refocusing steps for the unbending laser beam. A waveguide pipe laid over a hilly terrain would require an unrealistic number of refocusing lenses. Even if quality lenses were inexpensively available, this technique will probably not be chosen because of the cumulative attenuation of the solid lenses.

A unique approach has been the suggestion for a continuous gas-lens tube. Figure 4 shows a simplified arrangement of this concept. A steady stream of cool gas is pumped through a heated portion of the tube. The difference in the refractive index of the cool center of the gas stream and the warmer edges produces a "soft" lens for focusing the laser beam. This soft lens offers less attenuation than a solid lens, but if such lenses are spaced every 300 ft., the cost for a long-haul system becomes unrealistic.

It is safe to say that it would be possible to build a "workable" laser communication system across the country with the present level of technology. The problem is transmission cost. The rigid alignment requirements of laser beam transmission, plus the cost of closely spaced repeaters, do not give a very optomistic outlook for the laser's future in longhaul transmission – at least, not on the ground. However, it is conceivable that exceptionally dense population areas may, one day, be able to use the laser's extraordinary message potential for short hops where the cost of critical alignment and many repeaters can be acceptably maintained.

One thing is certain, the tremendous potential of the laser as a high-density communications system has not yet materialized. A great deal of work has been done and many obstacles have been overcome, but the basic problem of devising a suitable transmission technique is a dilemma awaiting a solution. The broad enthusiasm of the 1966 era could be reactivated by a major breakthrough, but for now it seems quite clear that, in the field of communications, microwave and cable are still the leading contenders.

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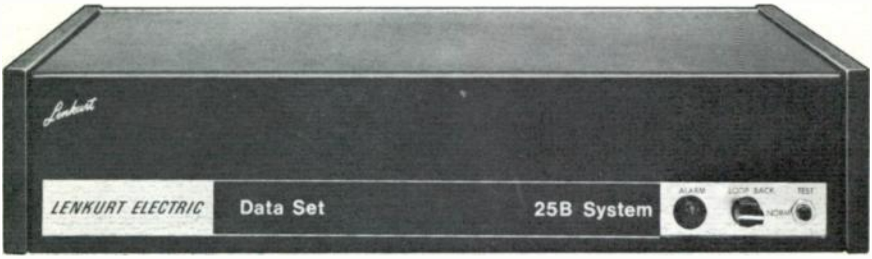

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