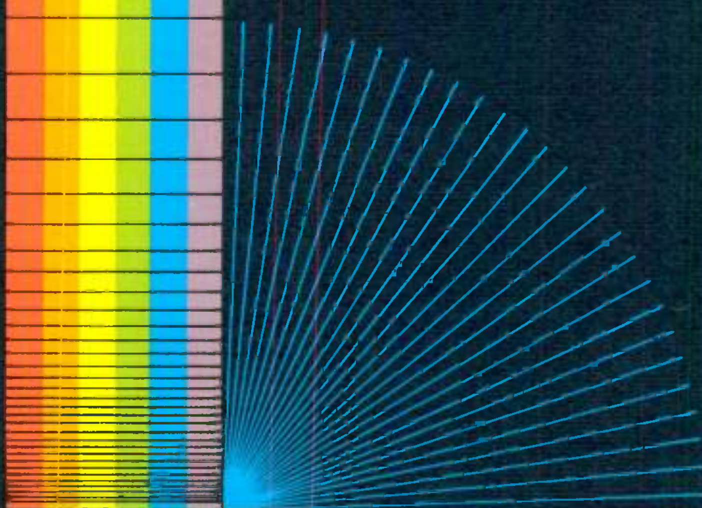
The Lenkurt.

JANUARY 1970

DEMODULATOR



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 will emit a photon of still another wavelength.

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.

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

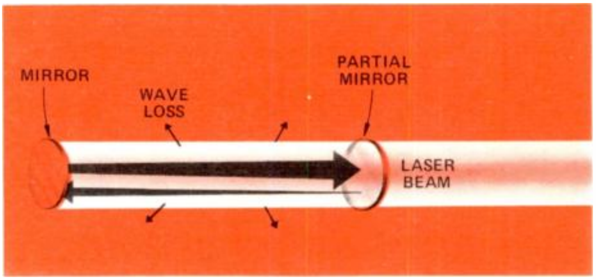


Figure 2. The growing photon stream bounces back and forth, emerging as brilliant, coherent light. Extraneous waves are lost through the wall of the laser tube, leaving only parallel light.

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.

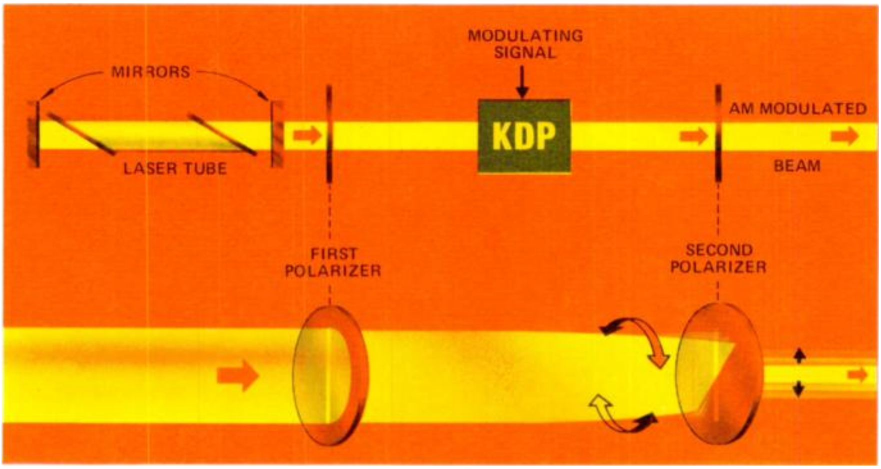


Figure 3. As the laser beam passes through a KDP modulator, it may be visualized as a "ribbon" of light twisting in proportion to a signal applied to the KDP crystal.

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

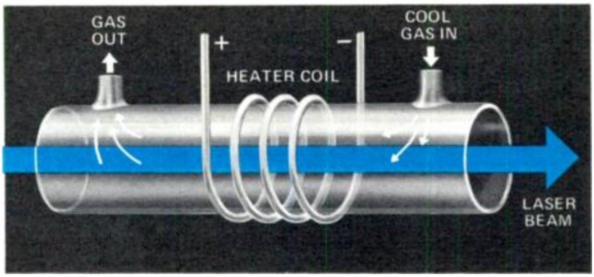


Figure 4. Cool gas forced through a heated pipe produces a lensing effect due to the refractive index of the gas at different temperatures. This type of lens has a soft surface and, therefore, less attenuation than a solid lens.

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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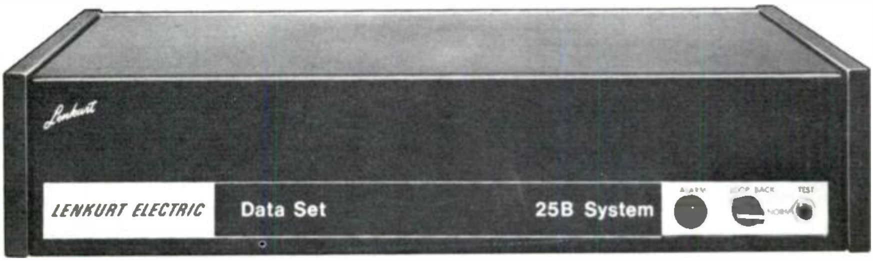

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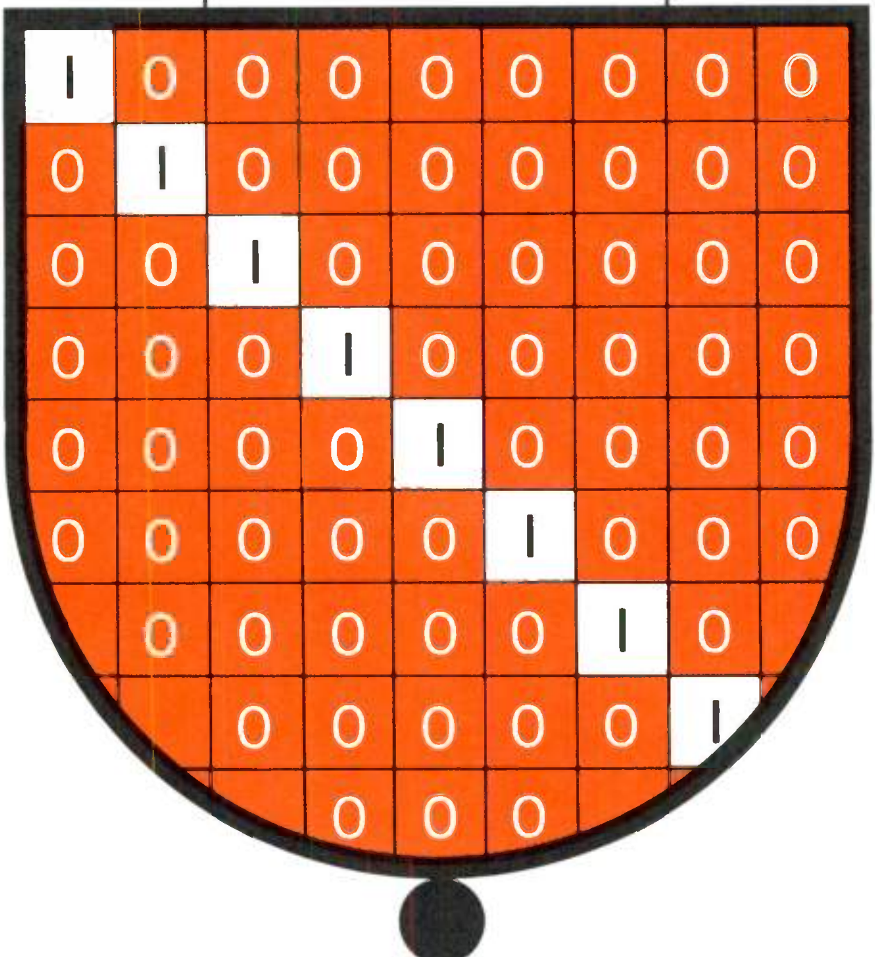
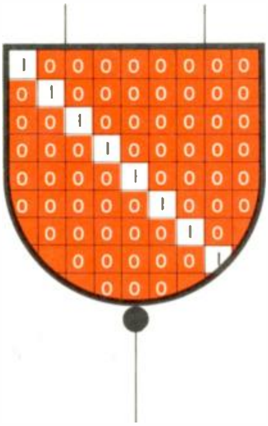


BINARY LOGIC AND PCM



Aristotle, in 330 B.C., to explain his philosophies, developed a logic system dealing with statements that were either true or false. In 1847, George Boole reduced Aristotle's logic to a mathematical shorthand that has become a universal logic language.

Binary logic is a way of thinking that can be applied to the design of *any* system where the "inputs" and "outputs" are just on-off actions. The invention of transistors led to the development of a series of logic modules capable of performing basic binary logic functions in electronic systems.

The complex PCM (pulse-code modulation) system can be broken down into subsystems whose inputs and outputs are simply on-off actions. This subsystem equipment is then designed using the principles of binary logic and implemented with corresponding logic modules.

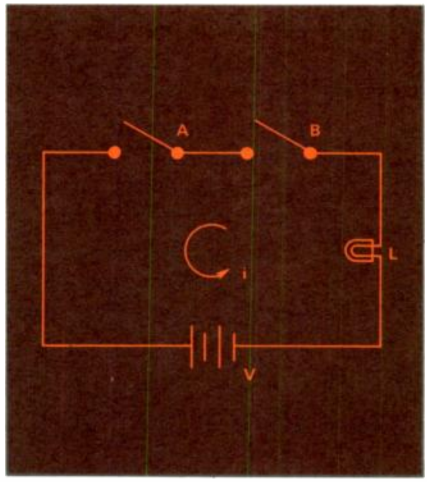


Figure 1.

Logic Modules

Basic logic modules are called AND gates, OR gates, and INVERTERS. These modules can be combined to obtain NAND and NOR gates. Logic building blocks called flip-flops can be made from these gates.

AND, OR, and INVERTER

Consider the circuit with two switches (A and B) connected in series, a voltage supply (V), and a light bulb (L) shown in Figure 1.

The light will be on, if, and only if, switch A *and* switch B are closed. The logic AND gate gets its name from this simple circuit analogy.

The "switching" circuit described above can be implemented with relays or diodes as well as with switches. All these circuits are cumbersome for the logic designer, so shorthand logic symbols have been developed. The logic symbol for the AND gate is shown in Figure 2.

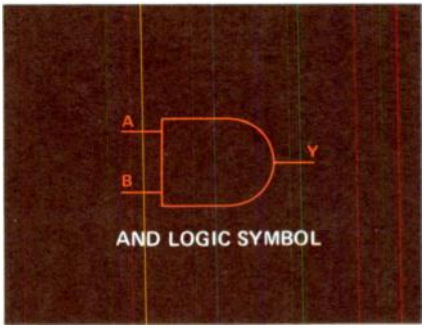
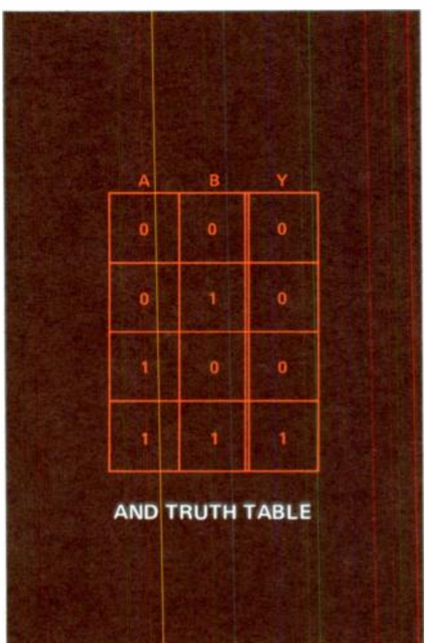


Figure 2.

Using a truth table and representing an "on" condition as a "1", an "off" condition as a "0", and the AND gate output as "Y", the combination of states for an AND gate is graphically displayed (Figure 3).



A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

AND TRUTH TABLE

Figure 3.

Using the "switching" circuit analogy again, put the two switches in parallel rather than in series (Figure 4).

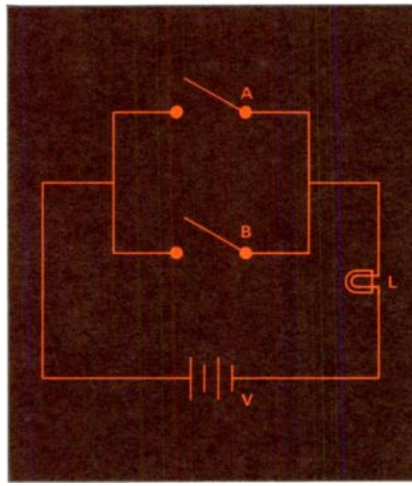


Figure 4.

With this arrangement, the current flows in the circuit and the bulb is on, if switch A *or* switch B *or* both are closed. The logic OR gate gets its name from this type of an arrangement. Figure 5 shows the logic symbol and truth table for an OR gate.

Logic functions can be implemented with diodes for electronic applications. But, diodes have two weaknesses. First, the output of diode AND and OR gates is attenuated. Second, diode gates are passive elements and unable to drive a network of gates.

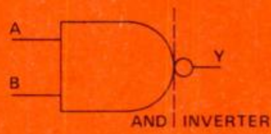
Common emitter transistors have the ability to amplify a signal. By putting a transistor at the output of the diode AND and OR gate circuitry, the attenuated signal is restored to its original level. Because transistors are

OR LOGIC SYMBOL

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

OR TRUTH TABLE

Figure 5.



NAND LOGIC SYMBOL

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

NAND TRUTH TABLE

Figure 6.

active devices, they are capable of driving a network of logic functions.

As well as solving the inherent problems of diode gates, transistors perform the logic function of inversion. Regardless of the input signal state, the transistor output will be inverted (a "1" becomes a "0" and vice versa). Transistors are known therefore, as INVERTERS.

NAND and NOR

The combination of a logic AND gate and a transistor INVERTER is called a logic NAND gate (for NOT–AND) (Figure 6).

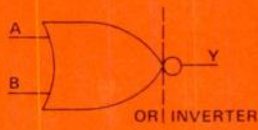
The output from a NAND gate will be negative, if, and only if, A and B are both positive.

A logic NOR gate is the combination of a logic Or and an INVERTER (for NOT–OR) (Figure 7).

If, and only if, both the NOR inputs are negative, the NOR output will be positive.

Integrated circuit technology has made NAND and NOR gates less expensive than the use of discrete components to construct NOT–AND and NOT–OR circuits.

For simplicity, the inputs to the logic gates have been limited to two,



NOR LOGIC SYMBOL

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

NOR TRUTH TABLE

Figure 7.

A	B	C	Y
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	0

NAND TRUTH TABLE
FOR THREE INPUTS

Figure 8.

but in practice, the gates can have more than two. The same logic rules prevail. For a NAND gate, the output will be negative, if, and only if, all the inputs are positive. Similarly, for a NOR gate, the output will be positive, if, and only if, all the inputs are negative. The truth table for a NAND gate with three inputs is shown in Figure 8.

Flip-Flops

One of the most common circuit building blocks formed from groups of logic gates is a flip-flop — widely used for storing a single bit of information. The popularity of flip-flops is due to the following factors:

1. They are available in integrated circuits or can be built from readily available discrete components.
2. They are fast acting — can be made to change states in as little as a few nanoseconds (depending upon the propagation delay of the logic family).
3. They are active devices.

Truth tables rather than circuitry will be used to explain flip-flops. The designer is interested more in what happens to his signal, than how it happens. Having selected his logic modules from the same family (compatible power requirements, etc.), the designer works with a "black box" and its corresponding truth table. The flip-flops discussed are from the 930 DTL (Diode Transistor Logic) family used in the Lenkurt 91A PCM system.

The basic flip-flop is made of two NAND gates. It has two inputs (R and S) which determine what state ("0" or "1") the flip-flop will assume next, and two outputs (Q and $\overline{Q}$) which determine the flip-flop's present state. The Q and $\overline{Q}$ outputs from any flip-flop are always opposite states; if Q is "1", $\overline{Q}$ is "0" and vice versa.

The inputs and resulting outputs for an R–S flip-flop are shown in the truth table for a particular bit time (Figure 9). The output is a function of the flip-flop's outputs and its inputs at the previous bit time.

INPUTS AT BIT TIME t_n		OUTPUTS AT BIT TIME $t_{(n+1)}$	
R	S	Q	$\overline{Q}$
1	0	1	0
0	1	0	1
0	0	?	?
1	1	Q_n	$\overline{Q}_n$

R-S TRUTH TABLE

Figure 9.

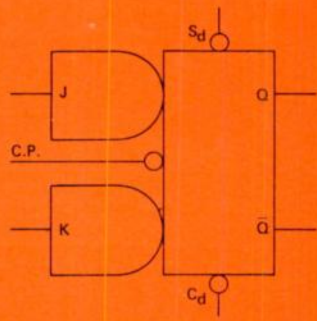
If the R input is "1" and the S input is "0", the Q output will be "1". If the input states are reversed, the output states will also be reversed. If the input states are both "1", the output will be unchanged from what it was at the previous bit time. The "?" in the truth table indicates the output is undesirable, and therefore to be avoided, when the input states are simultaneously "0".

Although it is possible to design a circuit such that the input states are never simultaneously "0", it is also possible to use a J–K flip-flop which tolerates all possible input combinations (Figure 10).

Regardless of what the output was, it will change to the opposite state, when both inputs are "1". The output will be unchanged, if both J and K are "0".

The J–K flip-flop is essentially two R–S flip-flops in series. The J–K inputs affect the flip-flop only when synchronized with a clock pulse — a steady stream of signals used to allow the input voltages to reach their final value. The direct set and clear inputs (S_d and C_d), on the other hand, operate directly on the output without being synchronized with the clock pulse. The first R–S flip-flop reacts at time "1" as shown in Figure 11; the second R–S flip-flop at time "2"; while the direct set or clear can react at any time.

If a "0" is applied at C_d, the J–K flip-flop is placed in the clear state (Q=0). If a "0" is applied at S_d, the J–K flip-flop is placed in the set state (Q=1). The S_d and C_d inputs dominate the output even if synchronized with the J–K inputs.

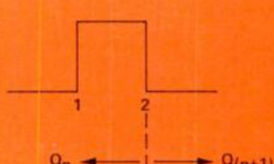


J-K LOGIC SYMBOL

INPUTS AT BIT TIME t_n		OUTPUTS AT BIT TIME $t_{(n+1)}$	
J	K	Q	$\bar{Q}$
1	0	1	0
0	1	0	1
0	0	Q_n	$\bar{Q}_n$
1	1	$\bar{Q}_n$	Q_n

J-K TRUTH TABLE

Figure 10.



CLOCK PULSE FOR J-K FLIP-FLOP

Figure 11.

Logic Modules for PCM Sampling

The sampler at both transmitting and receiving terminals in Lenkurt's 91A PCM system is basically a shift counter. This counter is the heart of the electronic mechanism that sequentially opens and closes the sampling gates for each channel – thereby multiplexing or demultiplexing the signals.

The number of stages in the shift counter is half the number of channels to be sampled; therefore, a 12 stage shift counter is needed to sample 24 channels.

Such a counter can assume 2^{12} = 4096 binary states. Only 24 states are required for sampling – the other 4072 states are undesirable and must be suppressed. The counter is operating properly when these undesirable states have been eliminated and the desired mode 1 operation (Figure 13) is sequentially sending out 24 separate pulses to the gates of 24 separate channels.

Mode 1 operation is accomplished by connecting 12 J–K flip-flops in series – one for each stage (Figure 14).

These flip-flops are driven by a clock pulse. With each clock pulse, the flip-flop state is shifted one stage to the right – the state of stage I at time t_1 will be the state of stage II at time t_2; etc. At stage XII, the Q output is fed back to the K input of stage I and $\bar{Q}$ is fed back to J of stage I. This "crossover" of output to input causes the state to reverse.

In a shift counter, the same state is shifted from one stage to the next with each clock pulse, reversing state when shifting from stage XII to stage I. Mode 1 fits this definition; there-

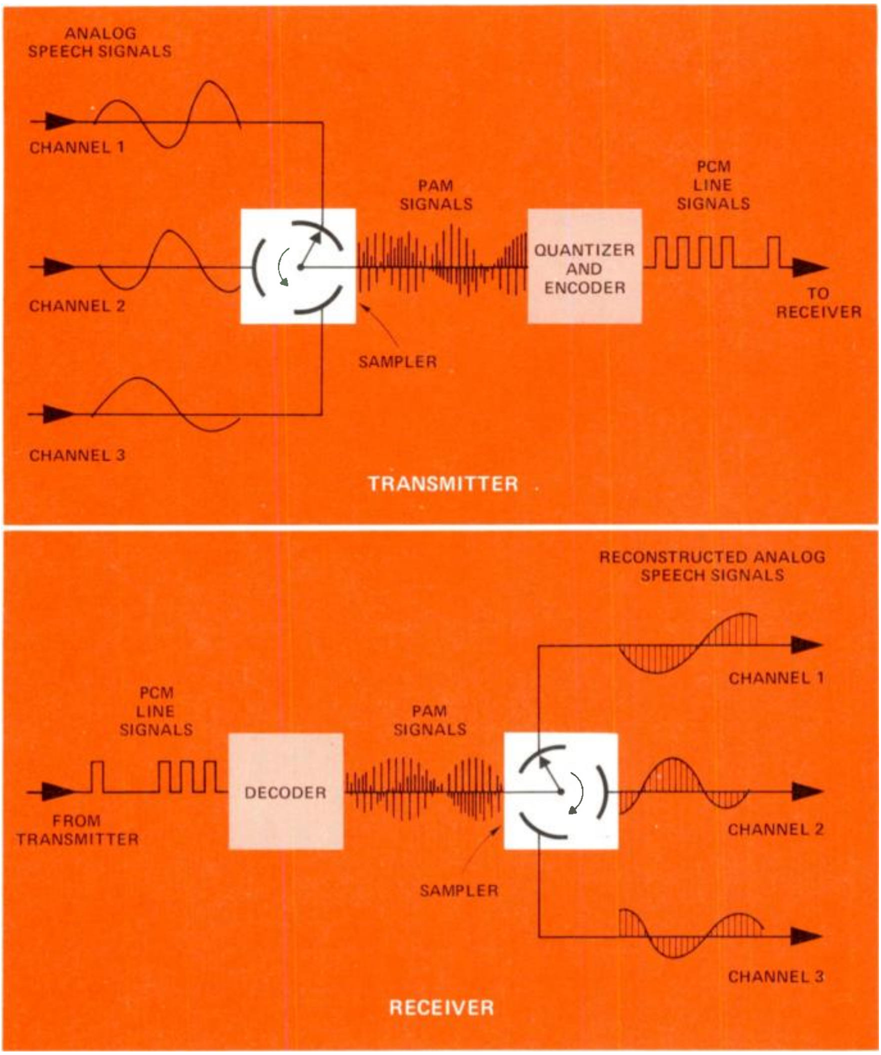


Figure 12. Simplified PCM system (only 3 of the 91A's 24 channels are shown).

fore, once the register assumes a mode I pattern, the counter will begin to cycle within this mode.

Applying power to the counter, the register may contain any one of the 4096 possible binary states (110001110000, for example). It is necessary to add either gate "X" *or* gate "Y", to suppress the undesirable states in the shift counter (Figure 14).

Gate "X" is actuated when both stage I and stage XII are in state "1", setting all the internal stages (II – XI) to "1". On the following clock pulse,

Q OUTPUTS FOR STAGES

BIT TIMES	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0	0	0	0	0
4	1	1	1	0	0	0	0	0	0	0	0	0
5	1	1	1	1	0	0	0	0	0	0	0	0
6	1	1	1	1	1	0	0	0	0	0	0	0
7	1	1	1	1	1	1	0	0	0	0	0	0
8	1	1	1	1	1	1	1	0	0	0	0	0
9	1	1	1	1	1	1	1	1	0	0	0	0
10	1	1	1	1	1	1	1	1	1	0	0	0
11	1	1	1	1	1	1	1	1	1	1	0	0
12	1	1	1	1	1	1	1	1	1	1	1	0
13	1	1	1	1	1	1	1	1	1	1	1	1
14	0	1	1	1	1	1	1	1	1	1	1	1
15	0	0	1	1	1	1	1	1	1	1	1	1
16	0	0	0	1	1	1	1	1	1	1	1	1
17	0	0	0	0	1	1	1	1	1	1	1	1
18	0	0	0	0	0	1	1	1	1	1	1	1
19	0	0	0	0	0	0	1	1	1	1	1	1
20	0	0	0	0	0	0	0	1	1	1	1	1
21	0	0	0	0	0	0	0	0	1	1	1	1
22	0	0	0	0	0	0	0	0	0	1	1	1
23	0	0	0	0	0	0	0	0	0	0	1	1
24	0	0	0	0	0	0	0	0	0	0	0	1

Figure 13. The 24 possible register patterns for mode 1.

stage I goes to "0" and all other stages are "1" as required for mode 1 operation. Figure 15 shows a sequence of patterns which starts with an arbitrary display when the power is applied and continues until the display matches mode 1.

If gate "Y" is used instead of gate "X", all the internal stages (II – XI) are set to "0" when stages I and XII are both "0".

For each of the 24 desirable states of the shift counter there is a readout gate made up of a two-input NAND

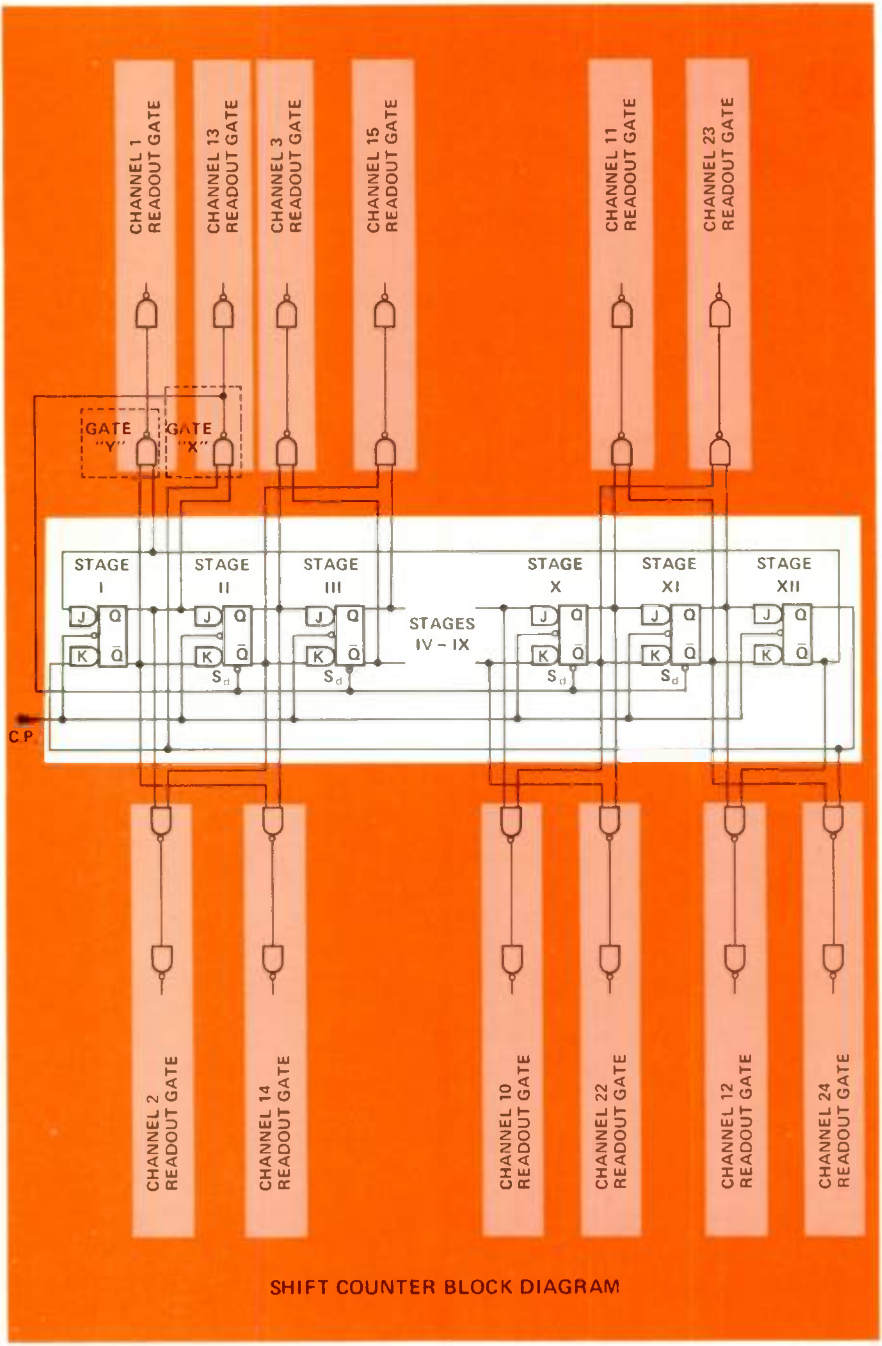

CHANNEL 1 READOUT GATE
CHANNEL 13 READOUT GATE
CHANNEL 3 READOUT GATE
CHANNEL 15 READOUT GATE
CHANNEL 11 READOUT GATE
CHANNEL 23 READOUT GATE
GATE "Y"
GATE "X"
STAGE I
STAGE II
STAGE III
STAGES IV – IX
STAGE X
STAGE XI
STAGE XII
CP
CHANNEL 2 READOUT GATE
CHANNEL 14 READOUT GATE
CHANNEL 10 READOUT GATE
CHANNEL 22 READOUT GATE
CHANNEL 12 READOUT GATE
CHANNEL 24 READOUT GATE
SHIFT COUNTER BLOCK DIAGRAM

Figure 14.

BIT TIME	STAGE I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
POWER ON	1	1	0	0	0	1	1	1	0	0	0	0
1	1	1	1	0	0	0	1	1	1	0	0	0
2	1	1	1	1	0	0	0	1	1	1	0	0
3	1	1	1	1	1	0	0	0	1	1	1	0
4	1	1	1	1	1	1	0	0	0	1	1	1
GATE "X" REACTS	1	1	1	1	1	1	1	1	1	1	1	1
5	0	1	1	1	1	1	1	1	1	1	1	1
6	0	0	1	1	1	1	1	1	1	1	1	1
7	CONTINUES TO CYCLE IN MODE 1											

Figure 15.

gate followed by a single input NAND gate. (Figure 14)

The register state can be determined by knowing where there is a transition from "0" to "1" or vice versa, or by knowing that there is no transition (all "0's" or all "1's"). By comparing the outputs of adjacent stages (white areas in Figure 13), the register transition points can be determined. This comparison is done with the readout gate. For each bit time only one readout gate will be in state "1" – indicating the position of the transition point or the lack of any transition.

When a readout gate is in state "1", it opens the corresponding channel sampling gate. The cycling of the 24 readout gates for the shift counter successively opens and closes the sampling gates of each of the 24 multiplexed channels in the 91A PCM system.

Figure 14 shows that the "X" and "Y" gates used for mode suppression of the counter are required for readout – allowing the mode suppression without additional logic modules.

Binary logic and the 930 DTL modules are also utilized in the quantizing and coding equipment for Lenkurt's 91A PCM system.

Framework for Expansion

PCM has achieved its present state in the communications industry because of efficient application of binary logic and the timely development of reliable, low cost logic modules.

Binary logic provides the framework for PCM's future expansion.

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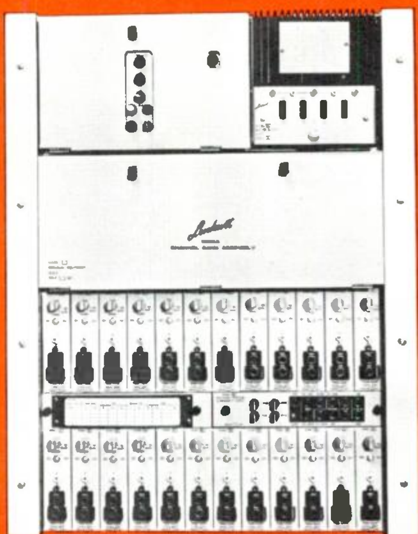

Lenkurt's 91A PCM Cable Carrier System economically fills the need for low-cost exchange, EAS, and toll connecting trunk services on cable spans extending up to 50 miles or more. The system adds 24 toll-quality channels on two cable pairs — featuring complete end-to-end compatibility with the Western Electric T1 system. For additional information, write Lenkurt, Department C134.

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