The Lenkurt Demodulator

NEWS FROM LENKURT ELECTRIC

VOL. 9 NO. 9 SEPTEMBER, 1960

LOGIC CIRCUITS

in Modern Communications

As communications systems become more elaborate, more and more chores once performed only by humans are being turned over to machines or electronic circuits which seem to "think for themselves." Human operators cannot compete with these single-minded switching systems when it comes to speed or reliability. Furthermore, although humans are exceedingly versatile, we sometimes tend to be finicky, emotional, irritable, and subject to moods and fatigue. This article discusses some of the fundamental ways in which machines—which don't suffer these human difficulties—may perform logical functions in communications systems.

Logic is usually associated with the higher mental processes. Reason and logic are usually believed to occur only as one of the highest functions of human intellect. How, then, can we obtain "logic" from arrangements of lifeless devices? Circuit designers do not mean "intelligent" or "intellectual" when they refer to "circuit" logic. They mean circuits which are designed to give a logical response when presented with certain conditions. Actually, at the most fundamental level, there is probably no difference between the "logic" performed by a man, an animal, a plant, or a circuit. A plant turns its leaves to follow the source of light, and closes up at night. The driver of an automobile starts and stops in response to traffic signals.

An elementary example of machine logic is a thermostatic control system for keeping the interior of a building at a certain temperature. If the temperature begins to drop, the thermostat recognizes this condition and turns on the heating system. As the temperature rises, the thermostat turns off the heater.

If the temperature rises too far, the cooling system is turned on. The thermostat must not turn on the furnace if cooling is desired, nor should it operate both the furnace and the air cooler at the same time. In short, it must perform as a logical device. Man's complex behavior results from very elaborate combinations of simple "logic circuits."

The essence of logic is in recognizing a certain condition and making an appropriate response. At this basic level, the simplest form of logical response is to answer "yes" or "no" to a certain stimulus; that is, to take one of two possible states. Thus, a thermostat responds to the question "Is it warm enough?" by answering "no" (turns the furnace on), or by answering "yes" (turns the furnace off). A similar circuit, making similar decisions, controls the operation of the cooling device.

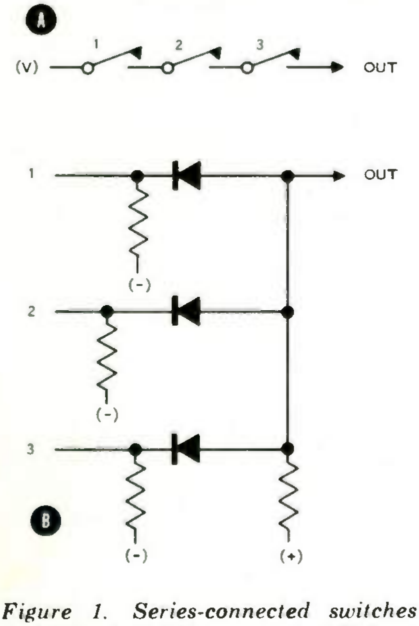

Figure 1. Series-connected switches form simple AND gate in A. All three must close for signal to appear in output. In diode AND gate of B, current flows through all three diodes from (+) to (-) until cut off by positive voltage at input. All three must be cut off by input signals before current flow stops, raising voltage at ouput.

"Logical" may not seem to be an appropriate term for such simple examples. However, a very few basic logical circuits can be arranged to provide devices of vast "reasoning power." The human brain, with its tremendous potential, consists of an arrangement of some four billion basic nerve connections or "switches." Just as levers, wheels, and inclined planes can be built up into typewriters, automobiles, and sewing machines, the many junctions and combinations of simple nerve cells within the brain produce the intellectual performance that has resulted in man's heritage of philosophy and science. It should be pointed out that duplication of the *number* of logical elements involved will not necessarily duplicate the performance. A machine as complicated as the human brain might only achieve the reasoning ability of an elephant, a bird—or a telephone switching system. The *plan* to which the basic elements are assembled makes the ultimate difference in the final performance.

Basic Circuits

The most basic logic element is a simple two-terminal switch capable of being either on or off. Whether the switch is electrical, mechanical, or hydraulic has no bearing on the principles involved. The same general logical principles used in computers and switching systems often appear in mechanical devices.

Three basic circuits exist from which the most elaborate logical function may be built up. These three circuits are AND *gates*, OR *gates*, and *inverters*. The term *gate* refers to the circuit's function of either blocking or transmitting

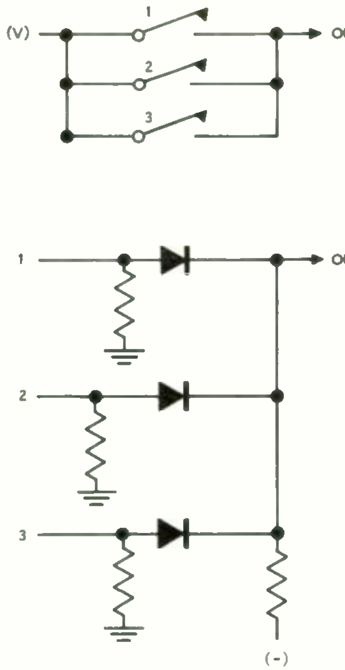

Figure 2. Parallel switches comprise OR gate. Closing any switch produces output signal. In diode equivalent, positive input signal appears across output resistor, but cannot be shunted to ground through parallel branches because of diode polarity.

the output signal or response which it controls.

The AND gate is a circuit having several inputs, all of which must have a signal present for a signal to appear at the output. Figure 1 shows an AND gate made up of several switches in series. All three switches must be closed before a signal can appear at the output. The designation "AND" refers to the requirement that a signal is needed at input 1 AND input 2 AND input 3 to obtain an output signal.

An OR gate also has two or more inputs, but requires an input signal to appear on only one of them in order to obtain a signal at the output. As shown in Figure 2, a signal applied to input 1 OR input 2 OR input 3, OR any combination of these will cause a signal to p-pear at the output.

The last basic logic circuit i the *inverter*. This circuit reverses the *meaning* of any signal applied to its input. Thus, a **1** at the input of the inverter is converted to a **O** at its output. The absence of input signal results in output signal, and vice versa. Special types of inverter may be used in practical circuits. One of these is the *inhibitor* function. In this arrangement, an output signal is *prevented,* regardless of the state of the input circuits, so long as a signal is applied to the inhibitor input.

A practical example of a simple inhibitor is the electrical interlock between the heating and cooling thermostat switches in the example given earlier. This interconnection prevents either the heating system or the cooling system from operating if the other system is already on.

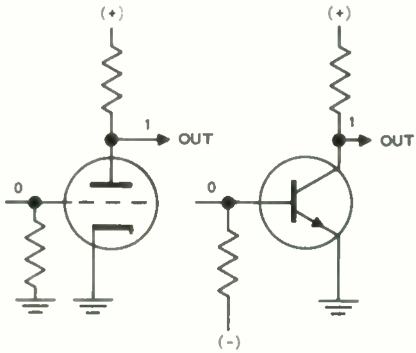

*Figure 3. Typical electron tube and transistor inverters. Input signals are shifted 180° in phase so that **O** becomes **I**, and **I** becomes **O**.*

One way that the inhibitor function may be achieved is by using an inverter in one of the inputs to an AND circuit, as shown in Figure 4A. If each input to an AND circuit is inverted, each becomes an inhibitor and the circuit might be dubbed a NOR circuit (output signifies that neither A NOR B NOR C . . . have a signal). An OR circuit followed by an inverter also yields a NOR circuit. Many other such combinations will appear in actual circuits. Although each of the basic logical functions may be achieved separately, it may be more efficient and economical in practical computers and switching systems, to design simple circuits which combine several functions. Figure 4 shows examples of various combinations of basic functions.

Such basic logic circuits can be built up into combinations capable of making extremely complex decisions where many possible choices or combinations of variables are involved. If some means are provided for storing partial answers for further use, computers can be devised which can solve extremely difficult and complicated problems.

Logic in Communications

Although most of the interest in circuit logic stems from the development of high speed electronic computers in recent years, the basic principles have been known and used much longer in the design of telephone switching systems. Many telephone system switching devices, such as crossbar switches, various relay arrangements, and trunking equipment, are logic elements and incorporate one or more of the basic AND, OR, or inverter functions. Semiconductor devices, such as diodes and transistors, are particularly suitable for elaborate combinations of logic circuits, and great progress has been made in producing computers and switching circuits that use only semiconductor devices.

An excellent example of the importance of logic circuits in communications is provided by a recently developed microwave path protection system which reduces the standby microwave equipment required to provide reliable communication in high-density systems. Microwave transmissions are subject to

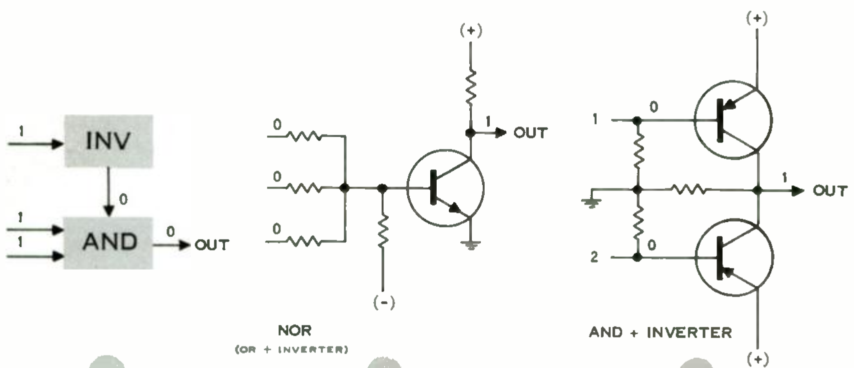

Figure 4. Several typical logic circuit arrangements. Inhibitor in A combines inverter and AND. Positive signal to inverter is reversed, prevents completion of AND function. Inverter is sometimes called NOT circuit. OR gate plus inverter yields NOR. Output signal is possible only in absence of signal on all inputs.

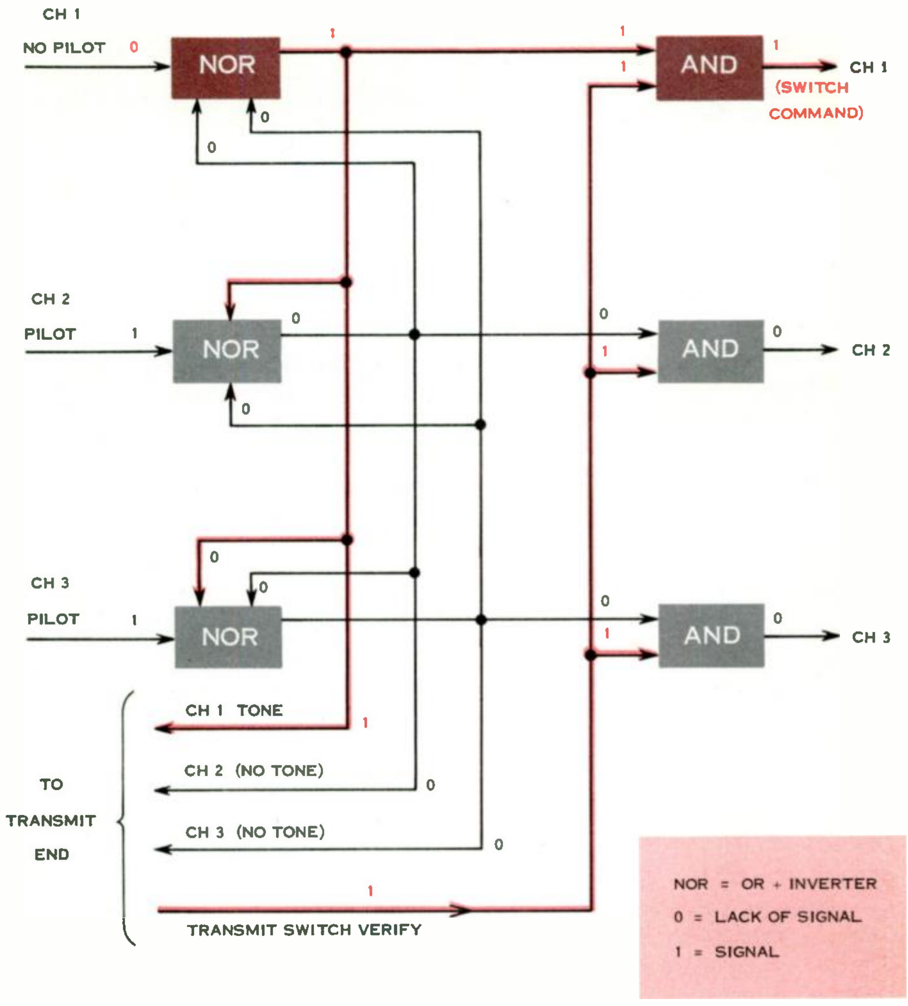

Figure 5. Logical functions at receiving end of 57A Microwave Path Protection System. Pilot tone from each channel appears as one input to individual NOR circuits. Pilot failure causes output from NOR circuit. NOR output is applied to other NOR inputs, preventing their response if other pilots fail. This lockout prevents "competition" between channels should more than one fail. Output from NOR is applied to AND circuit which controls channel switching, and to a tone oscillator which notifies transmitting end to transfer channel 1 baseband to stand-by microwave channel. Transmitting end verifies switchover by transmitting a tone which is applied to all three AND circuits at receiving end. Only channel 1 AND circuit responds because of signal from NOR. Other two channels cannot respond because of lockout.

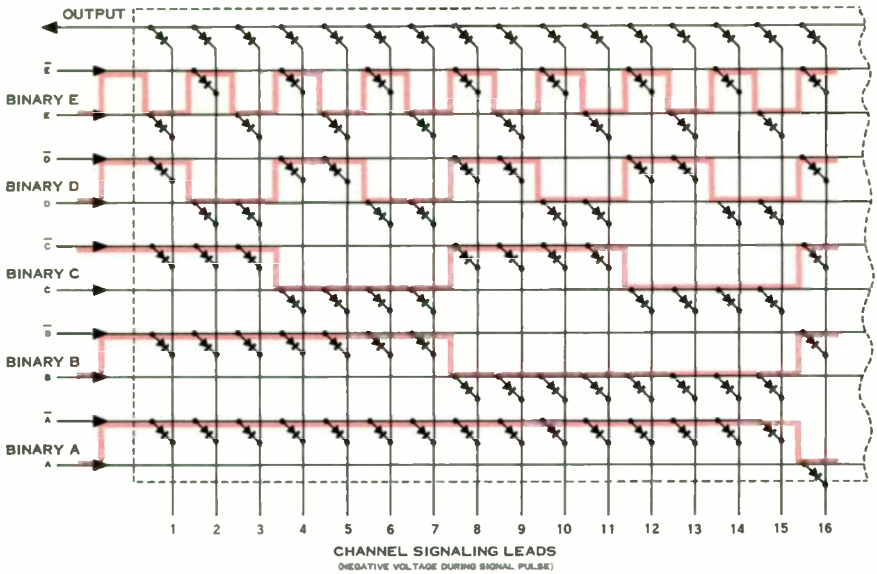

Figure 6. Time-division signaling system uses logic circuits to sample 24 channels in proper sequence. Loop signals (such as dial pulses) apear on vertical lines. Red waveforms represent synchronized pulse trains generated by "flip-flop" circuits in external clock-pulse generator. Diodes are connected so that each vertical connection becomes an AND gate controlled by the pulse combinations existing at each sampling moment. Signal pulses appear on output line only when all five diodes are non-conductive and loop signal is present.

"fades" due to changing propagation conditions. One of the best ways of providing protection against fades and equipment failures, where frequency allocations permit, is to use *frequency diversity* transmission. Two complete transmitters and receivers are used for each direction of transmission, each pair operating on a different frequency. Since fades rarely occur simultaneously on two well-spaced frequencies, a good signal is usually present. In cases of failure of one set of equipment, the other takes over. The disadvantage of this method is that twice as much microwave equipment is required.

If so many channels are transmitted over one route as to require several parallel microwave links, great savings result if one microwave channel can be used to provide protection for two or more radio channels, instead of the one-for-one normally required. When this is done, it is important to prevent "competition" between the protected channels for the protection channel. Also, it is necessary that both transmitting and receiving ends transfer promptly to the same channel, and that normal service be restored rapidly and in an orderly fashion when transmission improves. The problem was solved by using a combination of logic circuits at both the transmitting and receiving ends of the common microwave path. Figure 5 diagrams the logical control circuits used at the receiving end of an installation where one microwave circuit provides protection for three others.

Logic circuits are used in the time-division signaling of the 81A Exchange Trunk Carrier system (see DEMODULATOR, *August*, 1960). In this system, 24 voice channels share a common signaling channel, with time division providing the separation between channels. The signaling leads from all 24 channels are connected into a diode matrix or network consisting of 24 AND gates. Five synchronized timing pulses from a "clock" pulse generator are also applied to the matrix so that the diode switches in the matrix "open" and "close" in a regular pattern. The AND gates for all telephone loops are opened in sequence except where no loop signal is present.

Note that all the "switches" used in the matrix are semiconductor diodes. Diodes have an indefinite life, no moving parts, and very low power requirements. Since diodes have a very high resistance in one direction and a much lower resistance in the other direction, diode switches are "open" (non-conductive) when the back bias is greater than the forward bias. The switch is "closed" by applying a signal to the input that is greater than the back bias voltage.

Almost every type of switching now used in telephone systems can be achieved with semiconductor diodes or transistors, usually with great savings in space, power consumption, and required maintenance. However, the improved performance of semiconductor devices suggests even better arrangements that promise great improvements in transmission quality and switching speed.

Logical Developments

Using extensions of the basic logic techniques described above, very advanced computers have been designed which change their own programming to meet new conditions; that is, they "learn" by experience. Other devices have been designed which troubleshoot themselves, disabling circuits which are malfunctioning, and substituting reserve circuits. The entire Number 4 Toll Crossbar system, by which most telephones across the United States can dial any other telephone in the country without the aid of an operator, can be considered a single logical machine. It has been called the most complicated machine on earth.

Perhaps as these various devices are refined and extended, we shall some day have a single communications complex that repairs itself, increases service to areas of heavy traffic, and re-assigns idle facilities within its web to areas in temporary need. Such an entity would perform all of its own accounting, of course, billing customers directly, and notifying its human masters of its needs. Many of the elements of such a system are in commission today, and most of the remainder are already in sight. •

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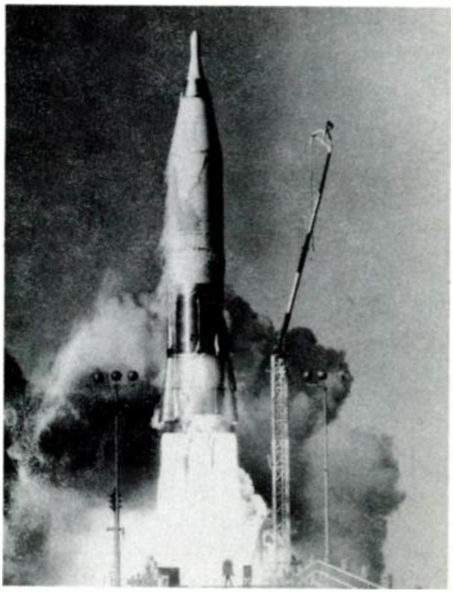

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