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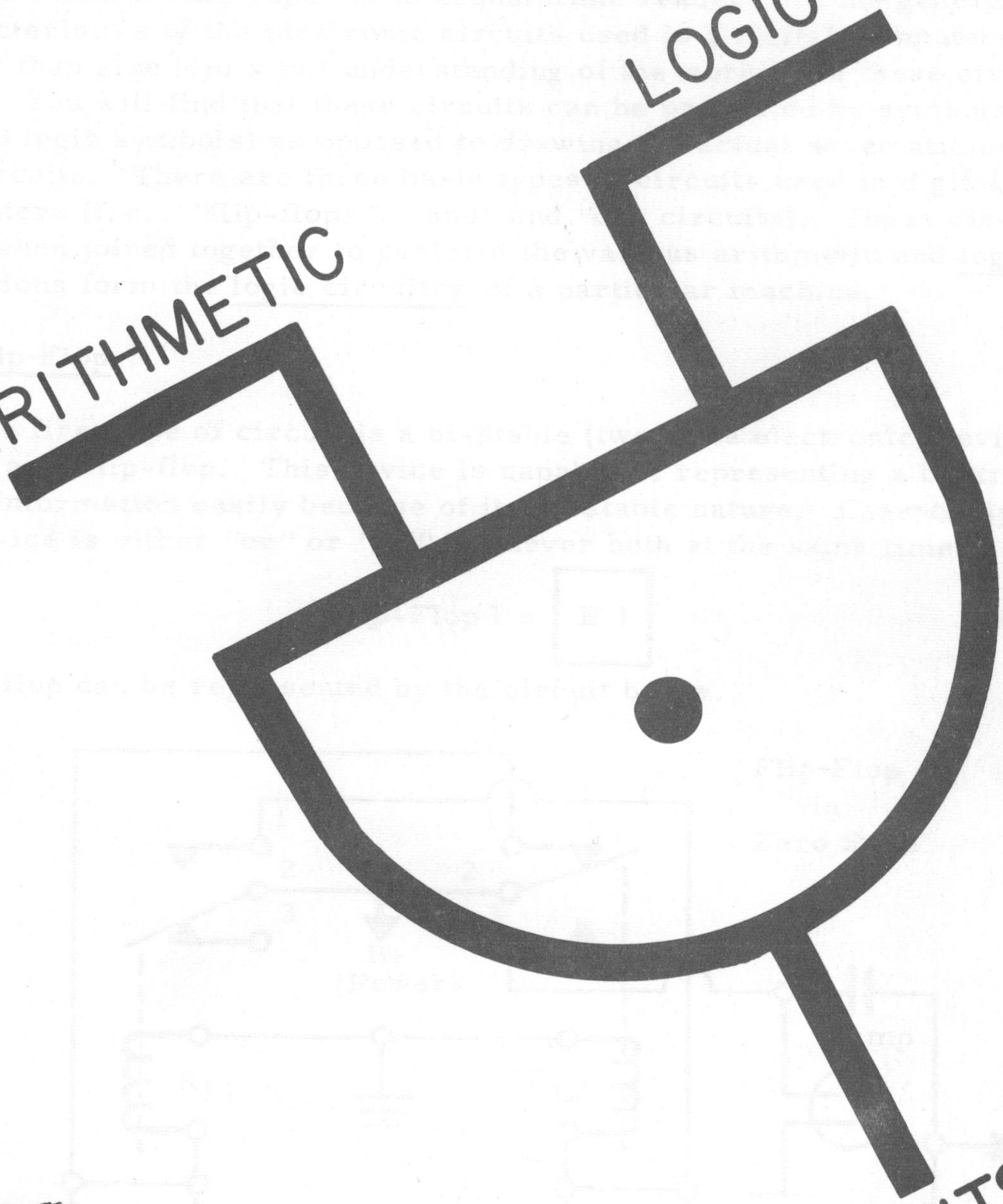
ARITHMETIC LOGIC UNITS



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ARITHMETIC AND LOGIC UNITS

1. INTRODUCTION

The intent of this paper is to acquaint the reader with the general characteristics of the electronic circuits used in a digital computer rather than give him a full understanding of the working of these circuits. You will find that these circuits can be presented by symbols (called logic symbols) as opposed to drawing the actual schematic of the circuits. There are three basic types of circuits used in digital computers (i.e., "flip-flops", "and" and "or" circuits). These circuits when joined together to perform the various arithmetic and logic operations form the logic circuitry of a particular machine.

2. Flip-Flop

The first type of circuit is a bi-stable (two state electronic) device known as a flip-flop. This device is capable of representing a binary bit of information easily because of its bi-stable nature. Essentially the device is either "on" or "off" but never both at the same time.

Flip-Flop 1 = | FF 1 |

A flip-flop can be represented by the circuit below.

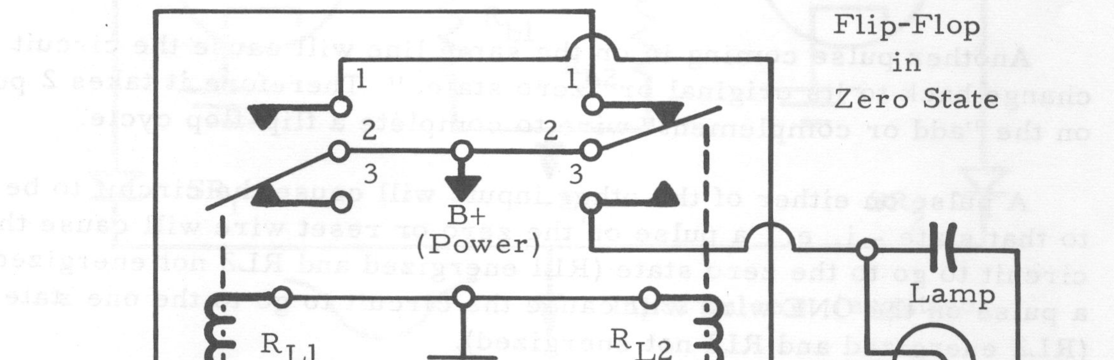


Figure 1

RL1, and RL2 are relays - devices which have a spring loaded armature that moves toward an iron core coil when the coil is energized In Fig. 1, RL1 is energized and RL2 is not. Thus, position 2 is connected to position 3 on the contacts of RL1, and position 2 is connected to position 1 on RL2. Position 2 is then called the "common" position, position 1 is the "normally open" position, and position 3, the "normally closed" position.

RL1 is "closed" or energized, because its coil receives power through the closed circuit of contacts 1-2 of RL2. This flip-flop has three possible inputs. The first one to be discussed will be the Add or Complement pulser. A pulse travelling into this input can take two paths (through SR2 or SR3). SR2 and SR3 are diodes, and will pass current only when their cathode (labeled K) is at a lower voltage potential than their plate (labeled P). Since (Figure 1) the cathode of SR2 is tied to B+ through contacts 1-2 of RL2, current will not pass through SR2. This is because the incoming pulse is of slightly lower potential than B+. This leaves the path through SR3. Since there is zero potential at the cathode of SR3, the pulse will energize the coil of RL2, and pull down the armature (contact 2). This will now open contacts 1-2 of RL2 and cut off power to the coil of RL1. When this occurs contact will be made between positions 1 and 2 of RL1 and the coil of RL2 will receive power through these contacts. At this point contact is made between positions 2 and 3 of RL2 and the lamp is energized, showing that the circuit has switched to the "one" or on state.

Another pulse coming in on the same line will cause the circuit to change back to its original or "zero state." Therefore it takes 2 pulses on the "add or complement" wire to complete a flip-flop cycle.

A pulse on either of the other inputs will cause the circuit to be set to that state - i. e., a pulse on the zero or reset wire will cause the circuit to go to the zero state (RL1 energized and RL2 not energized); a pulse on the ONE wire will cause the circuit to go to the one state (RL2 energized and RL1 not energized).

In practice, relays are not often used in computers due to their lack of switching speed (inherent because of their mechanical nature). Vacuum tubes or transistors are most often used because of their fast (electronic) switching speeds. However, the relay circuit offers a good analogy of what happens in the electronic flip-flop.

Before attempting a discussion of the electronic (Eccles-Jordan) flip-flop, it is wise to review some of the so-called "on-off" properties of these electronic devices. Since the analogy between vacuum tubes and transistors is similar, only a discussion of the former will be undertaken at this point.

Vacuum tubes can be made to act as controlled on-off devices. Essentially they can be made to conduct current fully (acting as a short circuit),or not at all (acting as an open circuit). They can be made to do this by placing small controlling voltages on their control element which is called a grid. The plate and cathode are tied to positive and ground potentials respectively. If the grid is hit with a positive pulse of sufficient size, the tube will conduct. If hit with a negative pulse, it will cut-off (allow no current to pass). Thus, the grid can act as a trigger for the tube and turn the tube on or off depending on the nature of the voltage applied to the grid. Thus, if it could be arranged that a single input pulse could trigger the circuit like the relay circuit above, then we would have a vacuum tube device which is bi-stable in nature.

Such a circuit is shown below (Figure 2).

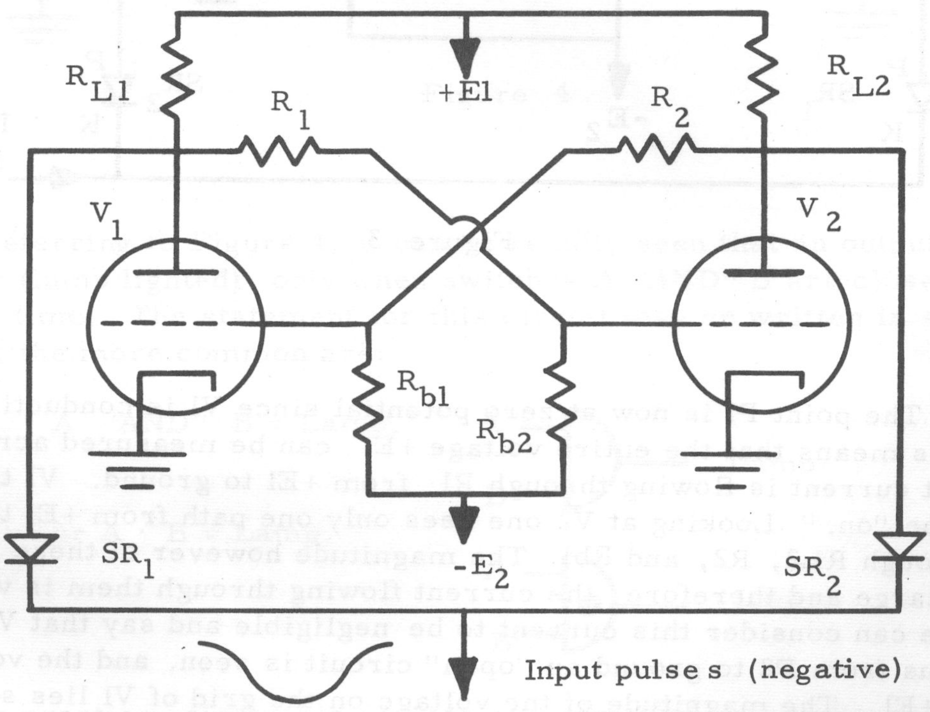


Figure 2

Assuming Vl is conducting and V2 not conducting, the circuit can be shown as below (Figure 3).

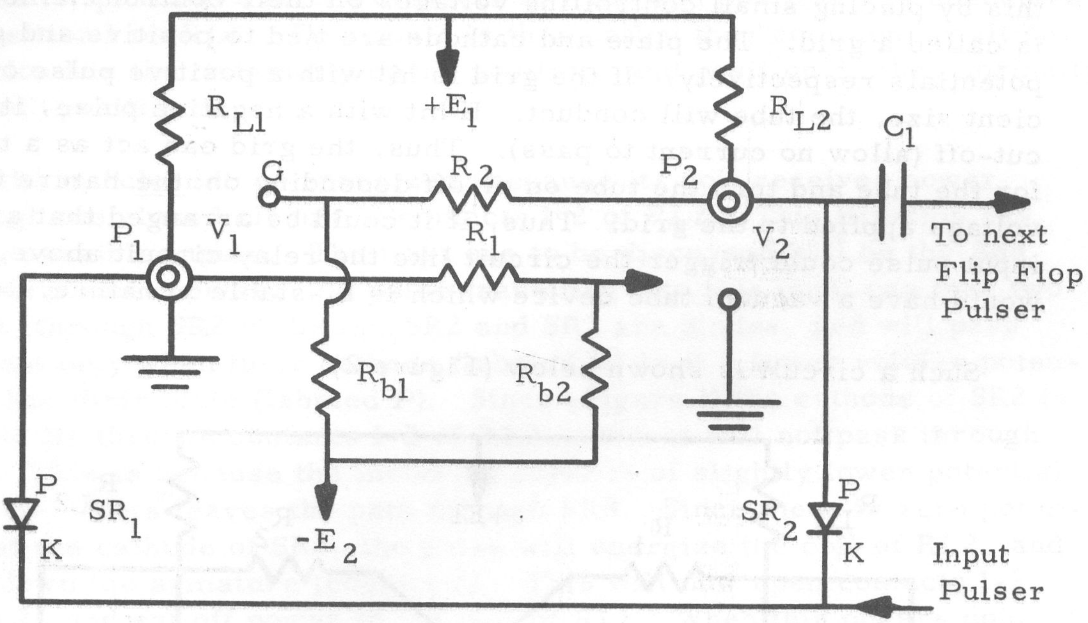


Figure 3

The point Pl is now at zero potential since Vl is conducting fully. This means that the entire voltage +El can be measured across Rl, and that current is flowing through Rl from +El to ground. Vl then, is said to be "on." Looking at V2 one sees only one path from +El to ground - through RL2, R2, and Rbl. The magnitude however of these resistances is large and therefore the current flowing through them is very small. One can consider this current to be negligible and say that V2 is "off". Thus from P2 to ground an "open" circuit is seen, and the voltage at P2 is +El. The magnitude of the voltage on the grid of Vl lies somewhere between +El and -E2, but is of sufficient positive magnitude to keep Vl conducting. The magnitude of the voltage on the grid of V2 lies between 0 and -E2 and is of sufficient negative magnitude to keep V2 cut-off. A negative pulse on the input pulser will be directed toward P2 (P2 is more positive than Pl which is at zero volts). This negative pulse will affect the grid of Vl since R2 forms a path from P2 to the grid. This negative pulse will cause Vl to cut off, thereby raising Pl to a potential of +El. This rise will now be transmitted through Rl to the grid of V2, sending V2 to the conducting state and causing the voltage of P2 to drop to zero. It takes two input pulses to complete the flip-flop cycle.

3. <u>"AND" Circuit</u>

The second circuit to be discussed is the "AND" circuit. It is one of the most often used (along with the "OR" circuit) circuits in logical design. An elementary "AND" circuit can be thought of as a series circuit composed of switches, each of which must be closed in order to produce an output (Figure 4).

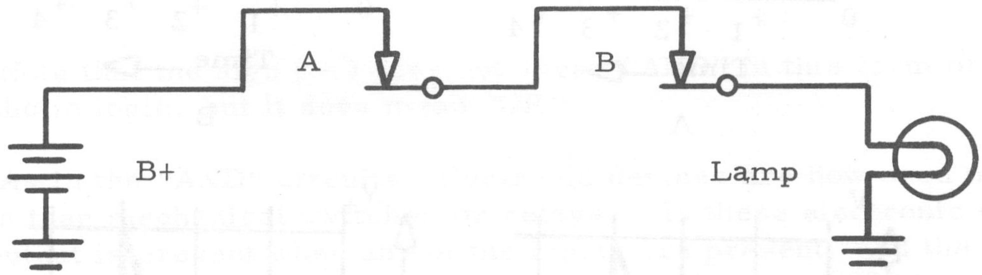
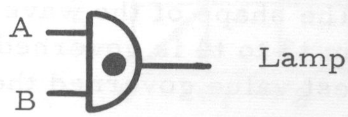


Figure 4

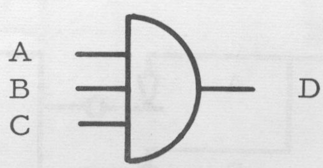
Referring to Figure 4, it can be readily seen that an output will occur (lamp lighted) only when switches A "AND" B are closed at the same time. The statement for this circuit may be written in several ways; the more common are:

A "AND" B = Lamp,

or A · B = Lamp,



In practice, electronic devices are now used more often than switches or relays. In these devices, an output is present only when all of the inputs are present, and the output is proportional to the smallest input. Thus, if an "AND" circuit with inputs A, B, and C (as shown below) was examined at the output, the curve of D, Fig 5 would be expected.



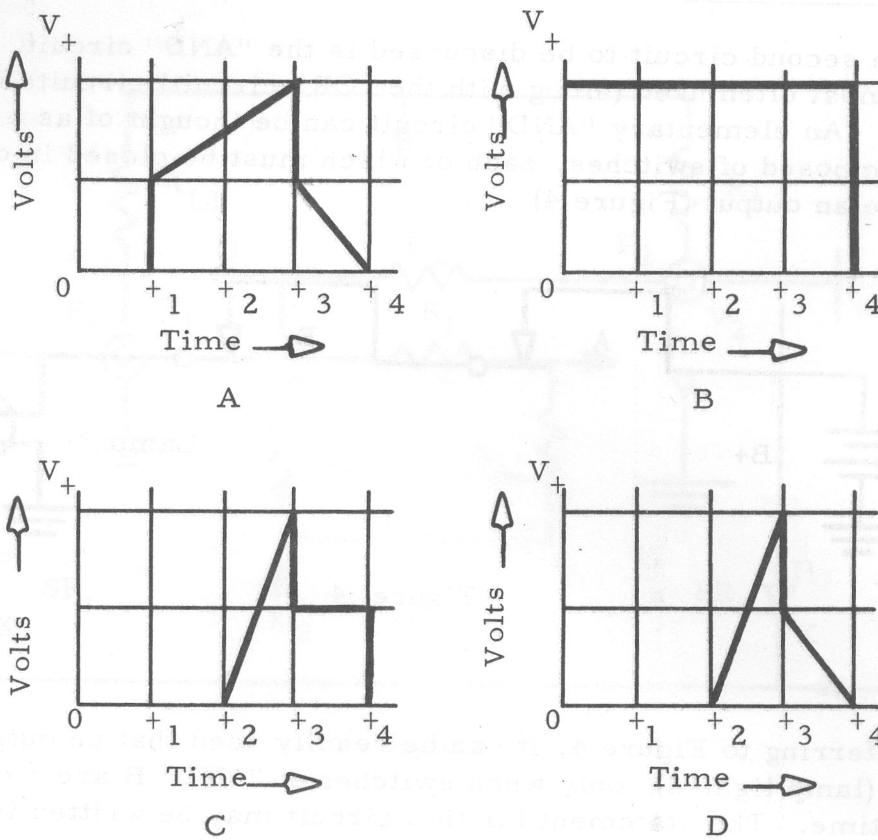


Figure 5

Notice that although B is on from 0 to t4, the only output is between t2 and t4. The shape of the wave (in D) from t2 to t3 is governed by C, and that from t3 to t4 is governed by A. In each case, it will be noted that the lowest value governed the total output.

4. "OR" Circuit

The third basic circuit to be discussed is known as an "OR" Circuit. An elementary "OR" circuit can be thought of as a parallel circuit composed of switches, any of which may be closed in order to produce an output (Figure 6).

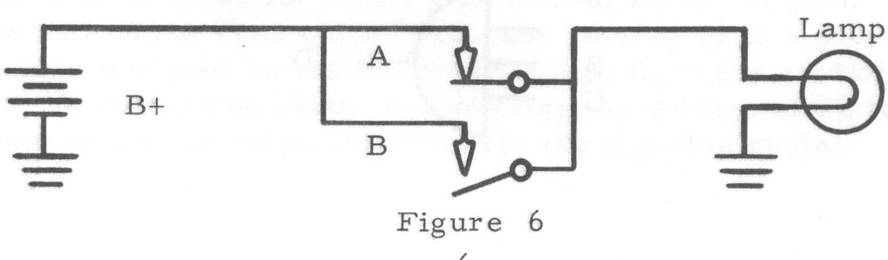
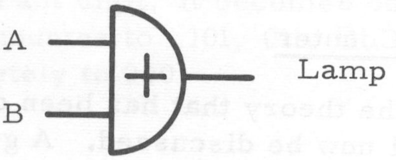


Figure 6

It can be seen from Figure 6 that if switch A "OR" switch B is closed (or both), the lamp will light. The statement for this circuit may be written in several ways:

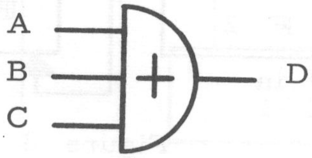
A or B = Lamp

A + B = Lamp



Note that the sign (+) does not mean "AND" in this form of symbolic logic, but it does mean "OR".

As in the "AND" circuits, electronic devices are now used more often than mechanical switches or relays. In these electronic devices an output is present when any of the inputs are present, and the output is proportional to the highest input voltage. Thus, if an "OR" circuit with inputs A, B, and C was examined at the output, the curve of D, Fig 7 would be expected.



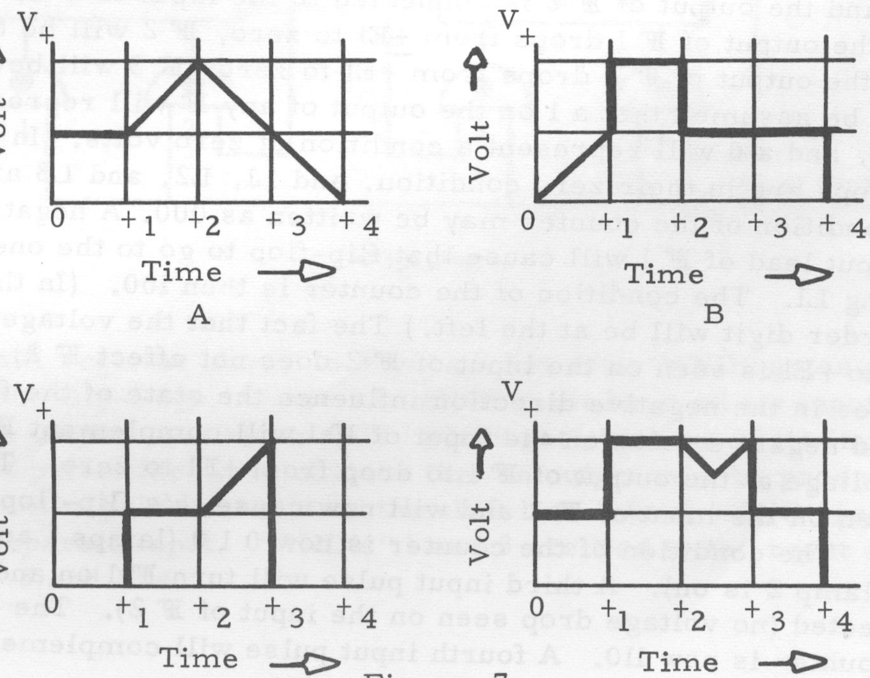


Figure 7

If the curve of D is analyzed it can be seen that input A governs the signal from 0 to tl; B from tl to t2; A and C from t2 to t3; and B from t3 to t4. Here it is a case of the largest voltage governing the output.

5. Serial Counter

Using the theory that has been developed, the subject of serial adders will now be discussed. A group of three flip-flops will be used to show counting up to seven. Assume that the flip-flops shown below (Figure 8) can only be complemented with a pulse that goes in the negative direction. Such a pulse is one which can be obtained when the voltage on the output of a flip-flop drops from +El to zero.

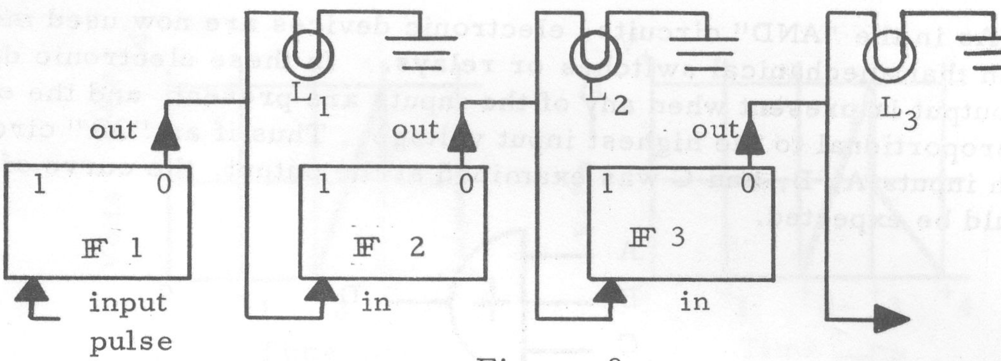


Figure 8

Notice (Figure 8) that the output of FF 1 is connected to the input of FF 2, and the output of FF 2 is connected to the input of FF 3. Therefore, when the output of FF 1 drops from $\pm$El to zero, FF 2 will be triggered. When the output of FF 2 drops from +El to zero, FF 3 will be triggered. It will be assumed that a 1 on the output of any FF will represent a voltage of +El, and a 0 will represent a condition of zero volts. In Figure 8, all flip-flops are in their zero condition, and Ll, L2, and L3 are not lit. The condition of the counter may be written as 000. A negative pulse on the input lead of FF 1 will cause that flip-flop to go to the one state, lighting Ll. The condition of the counter is then 100. (In this case, the low order digit will be at the left.) The fact that the voltage rise from zero to +El is seen on the input of FF 2 does not affect FF 2, since only changes in the negative direction influence the state of the flip-flops. A second negative pulse on the input of FF 1 will complement FF 1, causing the voltage at the output of FF 1 to drop from +El to zero. This drop will be seen on the input of FF 2 and will now cause this flip-flop to complement. The condition of the counter is now 0 1 0 (lamps 1 and 3 are off - lamp 2 is on). A third input pulse will turn FF 1 on and leave FF 2 unaffected (no voltage drop seen on the input of FF 2). The condition of the counter is now 110. A fourth input pulse will complement FF 1, which in turn will complement FF 2. Since there is also a voltage drop seen at the input of FF 3 (output of FF 2 dropped from +E1 to zero), this flip-flop will also be complemented, and the condition of the counter will be 001. The 1 will be the most significant digit. It becomes obvious that succeeding pulses will change the counter to 101, 011, 111. The eighth pulse will reset the counter completely to 000.

6. Parallel Shift Register

In computer applications, it is desirous to have the ability to shift information from one part of the computer to another. This information is held in a device called a register and may then be shifted to another register. In the circuit below (Figure 9), information may be shifted from the A register (FF 1 and FF 2) to the B register (FF 3 and FF 4). Since each flip-flop can hold one bit of information, we can shift "two bits" of information, and in the words of a well known contemporary humorist, "You can't hardly get much for two-bits anymore."

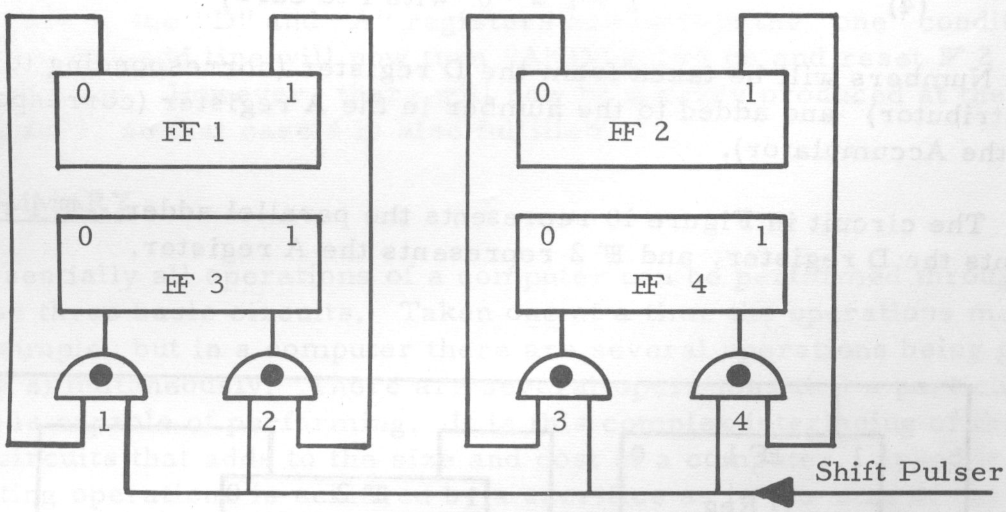


Figure 9

The shift register shown in Figure 9 has four "AND" gates associated with the flip-flops. Since an "AND" must have all its inputs on to produce an output, and since each "AND" gate has one of its inputs tied to the shift pulse line, it is obvious that an output may be produced only when there is a pulse present on the shift line. Each "AND" gate is tied to a separate input. "AND's" 1 and 3 are tied to the reset or "zero" lines of FF 3 and FF 4.

In Figure 9, a 1 condition existes on the output lines of FF 1 and FF 2 which are connected to "AND" gates 2 and 4 respectively. The zero condition lines are tied to "AND" gates 1 and 3 respectively. When a pulse is placed on the shift line, "AND" gates 2 and 4 are turned on and sets FF3 and FF 4 to the "one" condition. Thus the two bits of information that were in the A register are shifted to the B register.

7. Parallel Adder

Since all arithmetic operations performed in a computer are done through some form of addition,it is well to review the operation of a parallel adder. In binary addition, only four numerical combinations will be considered:

	D A	
(1)	0 + 0 =	0
(2)	0 + 1 =	1
(3)	1 + 0 =	1
(4)	1 + 1 =	0 with 1 to carry

Numbers will be taken from the D register (corresponding to the distributor) and added to the number in the A register (corresponding to the Accumulator).

The circuit in Figure 10 represents the parallel adder. FF 1 represents the D register, and FF 2 represents the A register.

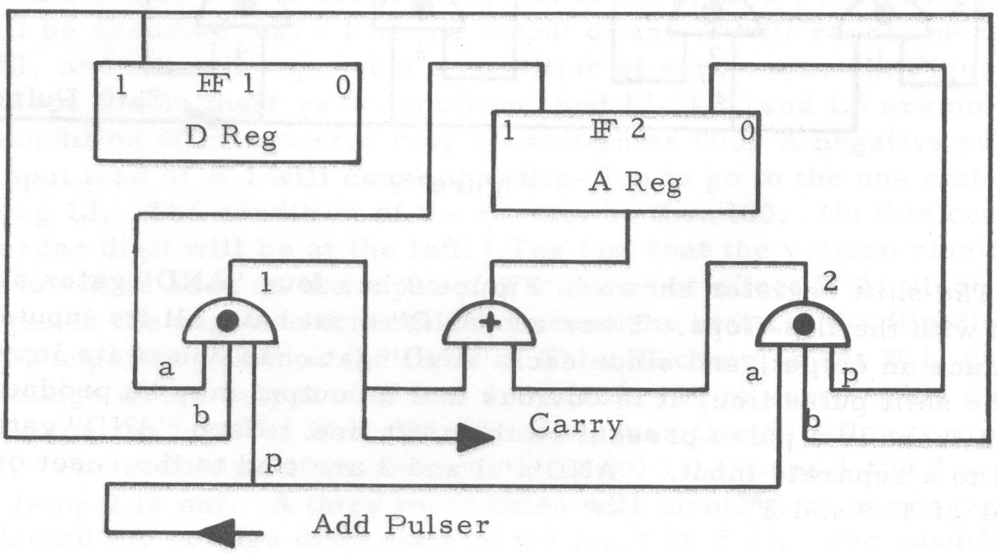


Figure 10

The input to FF 2 is a complement pulse. Assume that the left side of each FF must be +El for a "one" condition to exist. Examining case one (D and A registers both "zero"), a zero voltage would exist on lines a, b, c of "AND" gate 1, and on lines a and b of "AND" gate 2. A pulse on the Add line would change line c of both "AND" gates to a +El condition; however there would still be no output on either "AND" gate due to the remaining zero inputs.

In case 2, the "D" register is "zero" and the "A" register in a "one" condition. A pulse on the add line will still leave line b on both "AND" gates in a zero condition and "A" register will remain a one.

In case 3, the "D" register is "one", and the "A" register is in a zero position. With a pulse on the add line, "AND" gate 2 will be on (the right side of FF 2 shows a +El potential), and FF 2 will receive a complementing pulse through the "OR" circuit. This will flip FF 2 so that a potential of +El will be seen on its left side.

In case 4, the "D" and "A" registers are both in the "one" condition. A pulse on the add line will now turn "AND" gate 1 on and reset FF 2 to the zero condition. However, there will now be a carry produced at the output of gate 1, so that case 4 is also fulfilled.

8. SUMMARY

Essentially all operations of a computer can be performed through use of these three basic circuits. Taken one at a time the operations may seem simple, but in a computer there are several operations being performed simultaneously. There are several operations that a particular device is capable of performing. It is this complex interlacing of the three circuits that adds to the size and cost of a computer. Speed in computing operations is achieved by a sacrifice as to the size of the equipment, i.e., as the speed increases so does the size and hence the cost. It should be noted at this point that although we referred to the components of a flip-flop as tubes, this is not necessarily the case. They could also be transistors or any other suitable device capable of remembering information so that operations could be performed.

END