per second, with a signal-to-noise ratio of 7 db, the expected bit error rate is one in one million. Experiments indicate that satisfactory operation at 1,000 bits per second may be expected without phase equalization and at 1,000 bits per second with phase equalized lines and no special noise elimination treatment.

At 2,400 bits per second with the present experimental system, satisfactory service on private lines can only be established on lines with a noise peak distribution 6 db lower than shown in Fig. 5. Also, at the present time, such services could only be established on synchronous carrier lines and radio circuits.

The long-distance carrier network by itself does not appear to represent a serious problem for high-speed data transmission with respect to phase distortion. Excessive phase distortion for higher speed services is usually introduced, with loaded cables serving as a link between customer premises and the toll exchanges. In many cases phase correction does not represent an insurmountable problem and can be achieved with simple means and without excessive testing procedures.

References


Bibliography

ON-OFF MODULATION OR DOUBLE-SIDEBAND AM SYSTEMS


FREQUENCY MODULATION SYSTEMS


VESTIGIAL SIDEBAND ON-OFF SCHEMES


PHASE MODULATION AND SYNCHRONOUS DETECTION


The Impending Revolution in Computer Technology

R. RICE

WEBSTER gives one definition of a revolution as follows: "A total or radical change." The following discussions are concerned with a radical change in the technology which provides components for use in digital data processing systems. At the onset of a revolution it is not clear what the outcome may be. Technological revolutions, as opposed to political revolutions, however, tend to have a common characteristic of inducing major changes regardless of whether or not the revolution is completely successful. The papers presented in this session consider various aspects of what is being anticipated as a technological revolution.

Disjointed papers dealing with individual aspects of the new technology, such as components, circuits, logical design, and programming have been presented in several conferences. But the full impact of the drastic reduction in logical device size and cost is somewhat difficult to grasp if these subjects are considered separately. This session is presented to unite the various aspects of the total picture. The papers are co-ordinated and each author will discuss anticipated changes in the particular field with which he is primarily concerned.

The authors are presenting their own views. In all fairness to them, it should be said that at this point in time, and with as little experience as engineers have had in this new technology, it is extremely difficult to predict exactly the future.

Rice—The Impending Revolution in Computer Technology

From the collection of the Computer History Museum (www.computerhistory.org)
Fig. 1. Relay logic

Fig. 2. Tube logic

Fig. 3. Transistor logic

From the collection of the Computer History Museum (www.computerhistory.org)
in the back panel picture to the right.

In systems utilizing relay logic, speeds below 1,000 logical decisions per element per second are about the best that can be obtained.

**TUBE LOGIC**

Fig. 2 illustrates tube logic. With the introduction of filament-type electron tubes, a radical increase in speed was achieved. Speeds above 4,000,000 logical decisions per element per second are possible. Note that the volume occupied and the interconnections involved show only minor improvements over relay systems. Note also that additional types of "passive" components are included in the circuits used. These passive elements increase the total number of interconnections required to perform equivalent logical operations.

**TRANSISTOR LOGIC**

Improvements in the speed achieved and in the space occupied are obtained with the use of transistors. This type of logic is shown in Fig. 3. Speeds above 40,000,000 logical decisions per element per second are reasonable. As in the case where electron tubes are used, additional passive elements and their interconnections are introduced. No significant reduction in lead lengths for interconnections has occurred despite the introduction of printed- and etched-circuit wiring techniques at about the same time. Advantages of these latter techniques are in areas other than those under consideration here.

Parallel with the change in components from relays to tubes and then to transistors, there has been an increasing demand for more complex logic, more storage, and the greatest possible speed economically obtainable. This is a result of applying machine systems to larger and more complicated problems.

The physical volume occupied by the electronic logic in machine systems has been increasing. This is a result of several factors. First, increased speed has been obtained by using faster circuits which, generally speaking, require more components. Second, speed increases have been obtained by paralleling of operations. This also requires more components. Third, as previously mentioned, larger systems to solve more complex problems increase physical volume. As a result, the average interconnection length has increased.

**SWITCHING TIME**

The bar graph, Fig. 4, illustrates the relative switching times for tube and transistor circuits. Relay switching times are completely off scale and are omitted. The ordinate represents switching time in milliseconds, and the abscissa, chronological time, in years, of approximate developments dates. The fastest tube and diode machine with which the author is familiar has a 4-megacycle clock rate producing circuit switching times of 250 millimicroseconds. Transistor machines presently being developed in universities and elsewhere are approximately an order of magnitude faster and switch in about 25 millimicroseconds. Devices which are now in research promise switching speeds greater by another order of magnitude. This yields switching times of 2.5 millimicroseconds.

**PRESENT TECHNOLOGY LIMITS**

Fig. 5 includes the relative switching times as previously given in Fig. 4. The portion of the chart representing current research efforts is magnified in the insert. The ratio \( R \) of the propagation time of a signal down an interconnection of length one foot to the circuit switching time is introduced. A signal propagating with the velocity of light requires about one millimicrosecond to travel one foot. Propagation in a terminated cable is approximately 1.7 millimicroseconds per foot.

In tube systems the ratio \( R \) is 0.007, and may be ignored. For transistor circuits in development \( R \) is 0.07, and consequently lead length must be given some consideration. For the switching speed range of transistors currently in research, lead length becomes critical. The enlarged portion of the chart shows the relative importance of delay in interconnections to delay in switching circuits. If one is to achieve another order of magnitude in speed, a drastic reduction in lead length must be obtained.

As previously mentioned, the requirements for more complex logic and greater speed tend to increase the total volume occupied and consequently increases the average interconnection length. One may ask the following question. If volume requirements are greater and the speed desired is greater, how may these demands be met when one is faced with the interconnection problem? An adequate answer to this question is, perhaps, what determines a revolution in computer technology.
A Revolutionary Technology

Fig. 6 illustrates and characterizes what is believed will be a revolutionary technology. Cryogenic elements have been chosen for purposes of presentation, but several different types of devices under consideration by research groups would have served equally well. The small squares in the illustration represent logical elements. For easy visualization all the elements shown in Fig. 6 have been magnified. The expanded picture of one element shows as an example, a trigger circuit with its interconnections. The overall dimensions of this trigger are less than one eighth inch by one eighth inch.

Reasoning from this example, the impending revolution in computer technology will be based on:

1. Microminiaturization. Extremely small, active, passive, and interconnecting elements allowing dense packing to meet logical complexity and speed requirements.

2. Batch-bulk processes. As characterized by Professor Buck, it is anticipated that systems will be manufactured by producing interconnected batches of circuits from bulk raw materials in automatically controlled continuous processes.

This revolution will have far reaching implications in all phases of the computer field, starting with research and proceeding through system design, manufacturing, including the user. It is the purpose of this meeting to bring attention to the impending changes and to provoke discussion.

Computer Design from the Programmer's Viewpoint

W. F. BAUER

Mr. Rice has introduced the subject from the designer end of the spectrum; this paper will make some further remarks about introduction along the lines of the user's viewpoint and then further develop ideas of what the user expects in the way of computer design.

From the standpoint of the user the principal implication of the impending revolution in computer technology is that information processing will cost less; the advances in computer fabrication and in computer system design will mean that a given amount of information processing will cost less or, alternatively, for a given amount of money more information processing can be purchased. This in turn implies a greater sophistication made possible by the machines of more advanced design. In the United States today, a condition of insufficient manpower to program computers efficiently is rapidly being approached; if adequate strides of progress in programming are not made, more and more people with less qualification will be brought into programming, and the costs will rise rapidly as a consequence.

The author believes that the limiting factor in computers today is not the switching times of logical circuits nor the access times of memory units. Rather, the limiting factor is the lack of capability, on the part of machine and on the part of the user, for advanced programming and advanced application.

Attempts have been made to pin down the idea of the productivity of the programmer and to determine how this productivity has changed through the years since 1950. One such "programmer productivity index" would be the ratio of programming cost to computer cost. Another such index would be the ratio of the size of computation staffs to the speed of the computer. Any such definition shows a very great growth in programmer productivity since 1950 and, more specifically, shows a growth factor of at least five, and very possibly as much as 25, depending on the definition used and the assumptions accepted. This increase in programmer productivity is due mainly to the computer design improvements which, from the programmer's standpoint, make possible ease of coding, especially through automatic programming techniques. The importance of the computer design from the programmer's point of view is obviously great in the case of the general purpose computer or data processor. It is only somewhat less true in the case of the stored program computer designed for more specific application.

For present purposes some of the factors of modern computer design will be discussed and what may be considered to be the "ultimate" in computer design from the standpoint of the user will be described.

Design Features

There has been much discussion over the past years on trends in instruction repertoires of stored program computers. Here again the subject can be discussed in terms of a spectrum of design possibilities. On the one extreme is the micro-instruction which is not powerful but is universal in character; it provides a small unit building block for the computer program. On the other extreme is the macro-instruction which is more powerful but also more restricted in application.

As instruction repertoires become more "problem-oriented" they become less universal in character and more special purpose. Computer instructions more problem-oriented in nature can be synthesized through automatic programming—or, commands in the user's terminology are translated to the conventional machine instruction. To illustrate how the more problem-oriented machine instruc-

Bauer—Computer Design from the Programmer's Viewpoint

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