INTEGRATED CIRCUITS

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PREFACE

To say that the invention of the Silicon Monolithic Integrated Circuit in the 1960's, since dubbed the chip, was the start of a second industrial revolution would almost be an understatement. Indeed, the chip has changed the inner workings of industry tremendously, shifting the emphasis more severely to higher technology. But to stop looking at the revolutions here, with only industry, would be restricting the sphere of change to only one area of society. To stop looking here would be to look at life with tunnel vision. Not only has industry been effected, but (I would venture to say) every area of life has been touched, if not changed drastically. Just looking at how great an impact computers have had on society in the last five years is only an indication of how huge the changes are that the chip has made.

"It is easy enough to look at the world around us and conclude that the computer has not changed things all that drastically. But one can conclude that the earth is flat, and that the sun circles it every 24 hours."19

With the emergence of the chip, music, cooking, geology, medicine, industry, engineering, mathematics, physics, chemistry, astronomy, space travel, teaching, learning, travel, trade, work, and play have all been effected. With the implementation of the chip, the standard of living and life in general has been enriched.
INTRODUCTION

The chip, it seems trifling, barely the size of a newborn baby's thumbnail and hardly thicker. The puff of air that would extinguish a candle would send it flying. In bright light, it shimmers with a dullness similar to that of a soap bubble. It has a backbone of silicon, an ingredient of beach sand. Even so, it is less durable than a fragile glass sea sponge which is composed largely of the same material. There have been less tangible things that have given their names to an age, and this small silicon chip has more than enough power to create a new one.

At its simplest, the chip is electronic circuitry. In silicon, minuscule switches are joined by "wires" etched from thin films of metal. Under a microscope, the sight would be one of a huge city viewed from the air. The designs and patterns would look like streets, plazas, and buildings. If this isn't extraordinary enough, the low cost, compact electronics, and its ability to contain logic and memory give it the essence of human intellect. Thus, the chip has infinite capability and can alter life drastically.

There is almost no area of life that the chip has not effected. In cash registers the miniature computer on a chip totals bills, posts sales, and updates inventories. In pacemakers it times heartbeats. It sets thermostats, tunes radios, pumps gas, controls car engines, and robots are dependent on it. Scientific instruments such as gene synthesizers also rely on it. Machines do not have to slave harder than humans but can nearly work as flexible and
as intelligently. This surge in productivity may one day be called the second industrial revolution.9

The changes caused by the microelectronics explosion expand too far and in so many directions that it is impossible to take note of each one of them let alone go into detail. For every advance that the chip makes another direction and dimension is created, and so the cycle continues. Today's engineers call it the "crude oil" of electronics, attesting to the fact that world dominance in technology rests substantially on the chip.9

Seeing that the advances caused by chips are almost infinite, one could see a research paper on integrated circuits fill volumes of bindings and these bindings in turn fill numerous shelves at the local library. Since this topic has this quality about it, I have chosen to give only a very general view of chips from today's standpoint. I will barely scratch the surface on the intricacies of the chip so that anyone, no matter what their background, can understand. There is one exception though. There is a section giving a chip example. In this section a limited hardware knowledge is assumed. The first area that will be dealt with will be the history of the chip, from whence thou came. How chips are made will be next in the development of the paper and then we will take a look into the size of the industry.Fourthly, an example of what a chip would look like for various applications will be presented. Then the biggest part of the paper will be explored, Modern Applications, followed by what the future may hold. Finally, after all of this has been examined, some of the social effects of the chip will be looked at. So, let's get started.
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HISTORY: THIS IS YOUR LIFE, MR. CHIP

First, let's look at some history which in retrospect is funny. For example, one hundred years ago the Binary System was discovered. The article follows:

April, 1883: "Professor Eaton Zweiback of Slippery Rock University recently announced the discovery of a new number system called the "Binary System". This system uses only two numerals, 0 and 1, as opposed to the decimal system which uses ten. Professor Zweiback claims that the binary system will have absolutely no practical value and will be used mostly as a mathematical novelty."

A very interesting article to say the least, let's look at another one:

April, 1883: "Harvard anthropologists have discovered the remains of an ancient Arabian city just seventy-five miles north of where ancient Babylon once stood. Little is known about the inhabitants of this city except for the fact that for some unknown reason they wrote the numeral zero with a slash through it. The anthropologists are completely puzzled as to why these people used such a strange symbol."

It's funny how history repeats itself. This next article fits right in with chips.

April, 1883: "Agricultural experts have abandoned efforts to develop farm land in the valley south of San Francisco, California. The experts claim that it is difficult to grow crops in the soil because there is too much silicon. There is so much silicon present that some residents of the valley have started gathering it together and melting it into "chips", which they plan to dump somewhere near Boston, Massachusetts."

The next article shows that the Chinese were ahead of us a hundred years ago instead of the Japanese. (If it's not the Japanese, it's the Chinese.)

April, 1883: "Missionaries near Peking have discovered a very small abacus, which the Chinese call "Mei Kro". This extremely small device, about the size of a postage stamp, is said to be extremely fast for computations. One of its drawbacks, however, is that the operator must use a pair of tweezers to manipulate the beads."
That's the way it was a hundred years ago; but how about fifty years ago? Let's see how far we had advanced in fifty years.

April, 1933: "The International Business Machines Company of Elmira, New York, announced last month that, although it will continue to manufacture typewriters and adding machines, most of its resources will be devoted to the development and sale of fire alarm systems. 'We figure that the most important device in a business office is the fire alarm', said Thomas Inatson, the president of the company. 'After all, if there is a fire, who cares whether you have a typewriter or not. In fact, in future years, when you think of International Business Machines, the first thing that will come to your mind will be fire alarms'."

"In a related item, film star Charlie Chaplin turned down a request by International Business Machines to appear in its promotional literature. 'It's a great company', said the mustachioed comic, 'but frankly the idea of having me promote business machines is one of the most ridiculous things I've ever heard'."

April, 1933: "Things continue to heat up in the adding machine market. Following the introduction last year of the mini-adding machine, rumors have reached us that the Japanese are ready to market a 'micro-adding machine'. This new invention said to employ VLSS (very large-scale smallness) technology has an incredibly light weight of only 47 pounds. To combat the threat of this new small machine, American adding machine manufacturers are said to be at work incorporating deluxe features into their new models. One rumor has it that work is almost complete on a machine that can multiply."

April 1933: "The Acme Calculating Company of Piscataway, New Jersey, has just announced a machine which it calls a 'Disk Storage Device', the machine consists of a disk drive mechanism called a 'turntable' and a series of interchangeable data disks, or 'records'. The disk is read by placing it on a rotating platform located on top of the disk drive. A pin, called a stylus, is inserted into one of dozens of grooves etched on the disk. Under proper conditions a voice-like sound can be heard. This voice can be used to encode all types of data and can even be used to portray music-like sounds. The Acme Calculating Company will market the Disk Storage Device as part of an 'office system' which will include a typewriter, an adding machine, a typist, and someone to crank up the turntable. Also included will be software by N. Jolsen and Rudy Vallee and His Connecticut Yankees.

It is very interesting to see how far we have progressed in the last one hundred years. It seems as if fifty years ago we were still in the "Dark Ages" - as it were. It seems that people a few years ago were shortsighted,
almost dumb. But it must be remembered as Isaac Newton stated it so well in the 17th century.

"If I have seen farther than other men, it is because I stand on the shoulders of giants."

With this background, a more serious approach to history will be taken. We will start with Mr. Edison.

In 1883, Thomas Edison was working on the perfection of the lightbulb. In one of his experiments he constructed the first simple vacuum tube. He thought that it was another one of his failures so he put it aside and went on with his work. He noted that the tube had several interesting characteristics, but it just didn't cut it as a lightbulb. The truth of the matter is that Mr. Edison did not know what he had created. Just like several other of his "failures", it took someone else to see how important of a discovery he had made.4

A few years later a British scientist called J. J. Thompson explained what Edison had. By heating this tube with electricity an electric current was produced. The hotter the tube, the more powerful the electric current. After explaining this the era of the vacuum tube was entered. This is oversimplified greatly.

After several years of development the vacuum tube was heralded as one of sciences greatest accomplishments. "No single development in electronics has so aided progress in electronic technology than has the electron tube. From the first crude triode tube of Lee deForest, electronics has grown until it has become a part of almost all other fields. With the decrease in the cost of electron tubes have come increases in the variety and efficiency of tube types." So, this vacuum tube is a not so distant relative of the chip.4
With the development of the vacuum tube it wasn't long before the first computer was built. The first electronic digital computer was built in 1946; its name was ENIAC. Was it big? You decide! It weighed 30 tons. To say that it wasn't very mobile would be a huge understatement. In that 30 tons, ENIAC embodied 100,000 electronic components. It drew the power of a hundred lighthouses, and could perform all of 5,000 calculations a second. Pretty impressive? As the first computer, it is very impressive, but it seems to dim in comparison to today's computers.9

The next step in the approach to the chip was the transistor. It was invented in 1947 by Bell Telephone laboratories to replace the bulky glass tubes that controlled and amplified electric currents in early computers such as ENIAC. The 18,000 vacuum tubes were energy hungry, gave off tremendous amounts of heat in comparison to transistors, and frequently burned out. With the transistor everything was dramatically shrunk in size. But the transistor too had a flaw, it broke off circuit boards, plastic cards embossed with flat, snakelike wires. Transistors were used for quite awhile, and they worked fine, but there was more to come.9

To solve the problem of transistors breaking off, a remedy was found. Two men, Jack Kilby at Texas Instruments and Robert Noyce at Fairchild Semiconductor, found the answer independently: Make the crystal in a transistor serve as its own circuit board. When the snake ate its tail, the integrated circuit, since dubbed the chip, was born. This was the 1950’s.9,10,15

Now let us do a little comparing. ENIAC's successor is the microprocessor, a "computer on a chip". This chip, a quarter inch square on a side, can hold a million electronic components, ten times more than the 30 ton ENIAC. It
draws the power of a nightlight instead of a hundred lighthouses. It performs a million calculations a second, 200 times as many as ENIAC ever could. Just looking at these few facts is mind boggling. In just 50 years we have come from 30 tons to the size of a pea. Every year for more than two decades, engineers have roughly doubled the number of components on a chip, mainly by shrinking them. The vacuum tubes burnt out at about one every seven minutes whereas the chip will last virtually forever.\textsuperscript{9,15}

So, how has this technology effected engineering? The effect is the trend toward greater circuit complexity. In 1964, there were two to four logic circuits on a chip. A year later, six to eight logic gates were marketed. By late 1965, 20 logic gates became practical, and by the end of 1966, small scale integration was a reality. Each year more logic gates were put on the chip. Finally, a problem occurred. A single metallized layer could not satisfy the requirements of interconnecting several circuits on a chip to produce a composite subsystem. The obvious answer was multilevel interconnections. As more complexity arises from more and more logic gates being shrank onto a chip, more problems will arise. But with this problem there will be a solution, and with this solution new worlds will be opened up. With these facts, it is easy to see that this is a testimony to the saying: Bigger is not always better.\textsuperscript{3}
HOW CHIPS ARE MADE

The first step in chip production is design. In reality, this is the most critical stage of chip production. Without proper or efficient design, the usefulness of a chip is diminished. The design process is a time consuming project taking as long as three months to build a microprocessor. The reason that it takes so long is because of the complexity of the chip. For example, a four by eight foot sheet of drafting paper filled edge to edge with thousands of squares and rectangles in different colors is only one section. One section is fifteen hundred microns! One micron equals thirty-nine millionths of an inch, that is the width of 20 hairs from your head! To spread out the rest of the chip's design would take a gymnasium.9

It takes up to 100 calculations to properly place a transistor on a large chip. And some of these chips have as many as two million of them which is entering very large scale integration or VLSI. There is computer aided design (CAD) available which, with chips, "stores diagrams of transistors, rules for connecting them, and data on the intended function of new chips, information that enables the computer to design a chip circuit, display it on a screen, simulate its operations, and report its performance". But as of yet, no computer can calculate, in reasonable time, the optimum way to wire a VLSI chip. Humans must still tediously debug them and with video screens and attached electronic pens reroute connections. So, it is no wonder why the design process takes so long.9
The base of the chip, and earth's most abundant element after oxygen, silicon is refined from quartz rocks. There are two things that make silicon, a semi-conductor, the favored material for chips. Its ability to carry electricity can be precisely altered by ingraining its crystal structure with chemical impurities, or dopants. Secondly, silicon surfaces can be conveniently oxidized into an electrically insulating glaze. The refining process is very exacting. So exacting, in fact, that "if contaminants were redheads, there would be but 15 of them on earth."³

After the silicon has been purified it is grown into crystals. The crystals are then sliced razor thin. These thin slices are called wafers. These crystals can yield wafers that are as large as five inches across. The wafers are then polished mirror smooth, and then are racked according to size. Each of these wafers will become the base of hundreds of chips. Out of these hundreds of chips a few will be bad because of impurities that were not gotten out of the purification stage.⁹

In actuality, chips are sandwiches. Techniques are used that are reminiscent of silk screening that stack and stencil the wafer with layers of insulation and crystal. The crystal is doped with infinitesimal pockets of impurities laid out in some 300 identical chip-scale circuit patterns. These impurities are conducting areas, conducting electrical pulses from top to bottom of a wafer. When it's all over, there will be as many as twelve detailed levels that need interconnecting. This interconnecting is the last step and is completed with an aluminum coating and a final etch that makes the conducting filaments invisible to the naked eye.⁹

In a simplified form, the steps of chip making are as follows. The wafers are insulated with a film of oxide, then coated with light-sensitive
plastic called photoresist. This photoresist is hardened into the wanted outline by masking the wafer with a stencil and flooding it with ultraviolet light. Acids and solvents are then used to strip away unexposed photoresist and oxide. This patterned silicon is left bare to be etched by superhot gases. This is just one technique that is used in etching. More silicon is laid down, masked and stripped as before. Chemical impurities are then implanted, these forming positive and negative conducting zones. These steps are repeated as necessary, building layers linked by connecting "windows". These "windows" have to be filled in order to construct conducting pathways. A metal is used, usually aluminum, to fill these gaps. The metal is condensed onto the wafer completing the leveling. Each chip is diced from the wafer using a diamond saw, then bonded with conventional wires and wired to gold frames and sealed in small ceramic cases with stubby plug-in prongs.9

This whole process is done in "clean rooms". The air is filtered and holds less than a hundred particles of dust or other contaminants per cubic foot. "To a microscopic chip circuit, motes are as menacing as boulders." With two million transistors in a chip, and a goal of ten million by 1990, it is easy to see how a boulder could turn into a mountain. Later in this paper we will see how ten million transistors will be put into a chip.9

This is the basic process that is used in chip manufacturing, but there are different logic circuit families. Each logic circuit family has its own basic electronic circuit. These basic circuits are then used to create more complex circuits and functions. The basic circuit in each family is either a NOR or a NAND (see Appendix A). There have been many different logic families introduced, but there are four basic ones that have been used
extensively. They are:

1). TTL - Transistor-transistor logic,
2). ECL - Emitter-coupled logic,
3). MOS - Metal-oxide semiconductor, and
4). CMOS - Complementary metal-oxide semiconductor.

The basic circuit for the TTL logic family is the NAND gate. From this logic family, as in most others, there are several versions. There are low-power, high-speed, standard, and a combination of the previous three versions. Each of these versions comes in one of three output configurations referred to as: 1) Open-collector output, 2) Totem-pole output, and 3) Tri-state output (see Appendix B). The open-collector gate needs an external resistor to work properly and is connected to the integrated circuit (IC) package externally. The totem-pole output is the standard output and is specifically designed to reduce propagation delay (see Appendix C). The tri-state output exhibits three output conditions. Two states are the normal binary states of 0 and 1, and the third is a high-impedence state. This allows the formation of a bus where the gate having access to the bus will be enabled, while all other gates connected to this bus will be disabled. 17

The basic circuit in the ECL logic family is the NOR gate, but many ECL ICs provide an OR output (see Appendix B). Two outputs or more of ECL gates can be connected externally to form a wire OR function. There are also several versions for the ECL logic family. The MOS logic family is a unipolar transistor that depends upon the flow of only one type of electronic carrier. This carrier may be electrons (N-channel) or holes (P-channel). This is different from TTL and ECL gates in that they are bipolar and both carriers exist during normal operation. A P-channel MOS (PMOS) requires negative voltages for operation while a N-channel MOS (NMOS) requires positive voltage to operate. Complementary MOS (CMOS) is another MOS version and it uses one PMOS and one NMOS transistor connected complementary
with positive voltage required. (For a comparison of the different circuit logic families, see Appendix D.)

After a chip is made it is given certain distinguishing numbers. From these numbers it can be determined what kind of chip it is. The chips are usually identified by five major designations: 1) the logic circuit family type, 2) circuit function name (memory, register), 3) circuit complexity, 4) type of package and number of pins, and 5) IC identification number and name of vendor. The first two have been mentioned, and the fifth one is assigned by the manufacturer. Circuit complexity deals with the number of gates. Small-scale integration (SSI) has ten gates or less. Medium-scale integration (MSI) has between ten and one hundred gates. Large-scale integration (LSI) has more than one hundred gates. Very large-scale integration (VLSI) has thousands of gates. All this information is usually kept in a service catalog so that when maintenance is needed, a replacement part can be found.
SIZE OF THE INDUSTRY

To look at the size of the chip industry is one approach to getting insight on how extensively used the chip is. In 1982, the world market was estimated to be 10 billion dollars for chips alone. This is not including the reasons why chips are so much in demand. Some of these reasons are robotics, home computers, watches, cars, planes, and calculators, for starters. In fact, the industry is so big that in Japan so many new factories have opened on Kyushu in the past few years that this southernmost island has been name Silicon Island.°,1°

Japan's growth is second only to America's. In California, a valley has gotten the name Silicon Valley. Fifty years ago it was cultivated for prunes, and it supplied half the world. Through the sixties it was used for plums, pears, apricots, and cherries, and it was one of the nation's most bountiful growing regions. Today there are only 13,000 acres of orchards left out of the original 100,000. In the late 1960's buildings that embodied many semiconductor companies were beginning to fill the region from Palo Alto to San Jose. The population of San Jose has grown from 95,000 to 660,000 in thirty years.°,1°

Another indication is how fast companies have grown. One company, Siltec, produces the silicon wafers from which chips are made. They started at scratch and have reached 50 million with a new goal of 150 million in a few years. Apple Computer stock is worth 100 million dollars after the first Apple was built in 1976 in a garage. These are just two companies
out of the eighty chip manufacturers in Silicon Valley, and who knows how many computer companies that are grossing mass amounts of money. Going along with corporate profits are standards of living. At $24,000 a year, per family income ranks the highest in the nation. How about bonuses? One company (AMD) gave a Christmas party. Some party - all 350,000 dollars worth in San Francisco's Civic Auditorium. Another company wanted to change someone's life so they offered a 240,000 dollar company drawing. I think those are the kind of bonuses that anyone could appreciate.9, 10

Hand in hand with huge money making projects and profits is theft. In computer software, it was Hitachi and Mitsubishi, Japan's industrial giants, that tried to steal IBM secrets. In computer chips, it was the 1981 Thanksgiving weekend that was the big score, 3.5 million dollars in chips from Monolithic Memories were stolen. The problem? Greed. Since chips are so small, someone can walk out with a fortune in his fist. In 1980, 11,000 memory chips were stolen from Synertex. It is organized crime, and it is not just on a small scale. It is international industrial sabotage.9, 10

Finally, when corporations start buying into other corporations there has to be money involved. The business agreement being talked about these days is the deal IBM made with Intel, the pioneering Silicon Valley semiconductor manufacturer. IBM agreed to pay 250 million dollars for 12 percent of Intel. This is a big change in IBM policy for in the past they have shied away from buying a piece of another company. So, why did they? IBM was concerned about the continued good health of a major U.S. supplier of chips with technological prowess. They buy 100 million dollars worth of semiconductor components from Intel. I can see why IBM would be interested in keeping Intel healthy.8
A CHIP EXAMPLE

Now that the history of the chip, how it is made, and the size of the industry has been looked at, it would be good to see how chips are actually used. The first example of how a chip is used is very common, a digital watch. Every one has seen a digital watch, but how does it work? A simplified block diagram of such a watch is shown in Figure 1 and consists of a time base, pulse counter, and display devices. The manner in which these basic components function to indicate time is as follows. First, the block labeled time base is an electronic oscillator and is assumed to deliver exactly $f$ pulses per second. Elapsed time is then determined by simply counting output pulses from the oscillator and arranging to display the count in seconds, minutes, and hours. The accuracy of the watch is determined by how exact the $f$ pulses are each second.¹

To generate the display, the time base is followed in sequence by counters that are arranged to give outputs each time the time base has delivered $f$, $60f$, and $3,600f$ pulses. The outputs then correspond to second, minutes, and hours. To be more specific, the first counter is wired to give one output pulse for every $f$ input pulses. It then returns to the zero state and starts to count input pulses again. This will be referred to as a divide by $f$ or $\div f$ counter. The pin that provides the single-pulse output is called the terminal-count pin.¹

Since the terminal output of the $\div f$ counter consists of 1 pulse per second, the $\div f$ counter is followed by a $\div 60$ counter which gives a terminal output pulse once every minute. Since the internal state of this $\div 60$ counter records the passage of seconds in each minute, a seconds display is obtained
by the use of other outputs of the counter which is hooked to a display as shown in Figure 1. Another 60 counter is then connected to give a terminal count in hours. The internal state of this counter records the passage of minutes.

In watches a crystal is used for the pulses. These pulses have the frequency maintained very accurately at 60-Hz (60 cycles per second). This is a very convenient time base for a digital watch. Counters, decoders, and display devices can then be arranged in the manner shown in detail in Figure 2 to produce a highly accurate and a very practical digital watch.

The basic signal-processing operations that are performed in the clock are as follows. First, the 60-Hz pure sine wave is fed to a circuit that produces a standard output pulse that starts each time the 60-Hz sine wave passes through zero in the positive going direction and lasts for the duration the sine wave is positive. The part of the chip that would do this is called a voltage comparator. The output of the voltage comparator is a sequence of 60 pulses per second (60pps), each pulse having a standard size that can be used to drive a counter. As is shown in Figure 2, the first counter is wired to divide by 6, so its output is 10 pps, or 1 pulse every tenth of a second.

The output of the + 6 counter, labeled C1 in Figure 2, is fed onto a + 10 counter, labeled C2, whose terminal output is then 1 pps or 60 pulses per minute (60 ppm). In addition to the terminal-count output, the counter labeled C2 has four status outputs shown coming out from the bottom of C2 in Figure 2a. These status outputs are used to determine the internal state of the counter at any time. If the counter is first set to read zero and then five input pulses are fed into it, a combination of low and high voltages will appear on the four status outputs to indicate that exactly
five pulses have entered the counter.¹

Four status-output pins (rather than 10) are used because the counting is done in the binary or base 2 system, rather than the base 10 which we are used to using. Thus, the five output pulses would be represented by the binary number 0101. These digits represent the sum of 0 eights, 1 four, 0 twos, and 1 one; for more about the binary system see Appendix E. A low level on an output terminal corresponds to a binary 0, while a high level corresponds to a binary 1. The need for four status outputs follows directly from the fact that any decimal number 0 to 9 can be represented as a four digit binary number.¹

Because the binary number system is used to count, but we want output to be in the base 10 system, we have to connect a special decoding circuit between the status outputs of the counter and the device that we are using to display the decimal state of the counter. Suppose that we wish to use for each decimal number a seven-segment numerical display as shown in Figure 3. This special circuit is then called a BCD-to-seven segment decoder where BCD stands for binary coded decimal. The display device has seven segments that can be independently lighted to give any number from 0 to 9. In summary, the second counter in Figure 2a, labeled C2, is a 10 counter that does its counting in the binary number system with internal connections that cause it to produce one terminal output pulse after 10 input pulses. Status outputs are provided to "read" the state of the counter C2 in the binary number system, this state serving as the input to a BCD-to-seven-segment decoder. The BCD-to-seven-segment decoder in turn drives a seven-segment display device to indicate the appropriate integer in a base 10 system.¹

The remainder of the clock in Figure 2a can now be seen to consist simply of a set of counters with appropriately connected decoder and display
units attached. For example, C3 is a ± 10 counter with an output in seconds. It accumulates the information needed to construct the digit of the seconds display, and its output drives a ± 6 counter (C4) which accumulates the information necessary to construct the tens of seconds display. Additional counters, decoders, and seven-segment display devices are connected to read minutes, tens of minutes, hours, and tens of hours. For this 24-h watch, the display with its maximum value is shown in Figure 2b. Some logic operations are performed on the hours readout to reset the hours display to zero at the time it would read 24 hours. In particular, the logic circuit labeled G1 in Figure 2 functions so that when the decimal content of C7 is 4 and that of C3 is 2, the output of G1 drives the input terminals labeled MR which will reset the counters C7 and C8 to the zero state.1

At this point it may seem that a large number of circuits are used to make a digital watch. This is true, but it is also clear that really only four basic circuit types are used repeatedly: We need three ± 6 counters, four ± 10 counters, and seven BCD-to-seven-segment decoders which drive the seven-segment display devices. This is the best characteristic of digital circuits in general: A few basic circuit blocks are used repeatedly to develop a given circuit function.

Through this description on the digital watch internal wiring has been referred to. What is internal wiring? With this question, it is now time to go deeper into the block diagram in Figure 2. First, a ± 6 counter will be looked at. Figure 4 shows how the ± 6 counter could be constructed. (See Appendix F). Figure 4 is just a 4-bit binary counter, with CP being the clock pulse or, in correlation with our example, the time base. The logic 1 input is the terminal output of the previous counter. Since the decimal system is different from the binary system the counters won't
FIGURE 3.
BCD/7 segment decoder.
reset to the zero state at the correct time unless a clear input is used. The clear input, when zero, will cause the counter to be reset to the zero state. This happens when a pulse is sent to the next counter. For example, suppose that the number of pulses that have reached the \( \pm 6 \) counter is 5 represented by the binary number 0101. At the next pulse, the \( \pm 6 \) counter becomes 0110. At this time a pulse is sent to the next counter or in our case a 1. This 1 is inverted to 0 and input to the clear terminal. This causes the counter to be reset to the zero state. The first \( \pm 6 \) counter is different from the others in that there is no display device connected to it (Figure 5).\footnote{17}

The \( \pm 10 \) counters work the same way as the \( \pm 6 \) counters do (Figure 6) and can be constructed the same way as the \( \pm 6 \) counters except for the inputs to the terminal output and gate. The counter is cleared when the binary representation is 1010 which is decimal ten. Like the \( \pm 6 \) counters, the four outputs control the BCD-to-seven-segment decoder.\footnote{17}

The easiest way to construct the BCD-to-seven-segment decoder is shown in Figure 6.\footnote{7} A four by sixteen ROM is used and is seen in more detail in Figure 8, which only shows ten output possibilities instead of sixteen. Since there are only ten numbers (0 thru 9) in the decimal system the other six output possibilities are not needed, so they are left out. The decoder in the ROM is shown in more detail in Figure 9. An explanation of how the segment decoder works follows. First, a 4-bit number will be transmitted to the decoder. These four bits will be representing a number between 0 and 9 inclusive. From these four bits a row of memory cells will be chosen. If the number is zero, the first row will be chosen. If the number is one, the second row will be chosen. This continues down to row ten which will be selected by the binary number nine (1001). When a row of memory cells are
chosen, the number that is in each of these cells (either a 0 or 1) is transmitted to the seven-segment display device. The table showing how these segments are lit for each segment is shown in Figure 10 and corresponds to Figure 8.17

All of these gates are put onto a chip. The gates are composed of transistors that determine what kind of gate it will be. For an AND gate the electrical circuitry including transistors are different than an OR gate. Each gate as shown in Appendix A has a different transistor configuration. On the average it takes about 5,000 transistors to make a chip for a digital watch.1

More modern digital watches use the basic idea and structure of the previous example. Instead of the mechanical devices for the power supply, a digital watch uses a battery. The time base is a quartz crystal which oscillates at a frequency of 32,768 pulses per second. Circuits, like those already discussed, halve the pulses 15 times to arrive at intervals of one second. In the stop watch mode, found on many digital watches today, the fifth circuit divides the frequency of 1,024 by ten to approximate 10ths and 100ths of a second. The chip also controls the digital display. There are millions of microscopic liquid crystals floating between a grid work of electrodes that can form all numbers. When the electrodes are charged, creating an electric field, the crystals line up in opposition to the surface polarizing film to produce a display for a watch.9

This is just one example of the millions of uses that the chip can be used for. Although this example might have seemed complex, it is very trivial when an actual computer is thought about. A digital watch chip has 5,000 transistors, a pocket calculator has 20,000 transistors, and a small
FIGURE 7. Block diagram of a 16x7 ROM.

FIGURE 8. Detail of a 16x7 ROM.

Outputs go to a BCD/7 segment decoder.
FIGURE 9.
Detail of a 4x16 decoder.

FIGURE 10a.

FIGURE 10b. Truth table.
computer has 100,000 transistors. This small computer is equal to older ones that were as large as rooms. So it is easy to see that chips can become far more complex than just a chip that is used in a digital watch.
MODERN CHIP APPLICATIONS

One of the most fascinating things about chips is how they are actually used. We have just seen one example of how they are used, but this is very trivial compared to what chips can be used for. Everything from digital watches to pocket calculators to robots to computers depend upon this small slice of silicon called the chip. In cash registers, pacemakers, thermostats, radios, gas pumps, and car engines, the chip has found one application or another. The most recent phenomenon that the chip powers is the home computer. The chip's most amazing potential lies in what it can do for people. Unperfected but promising is a chip implanted beneath the scalp that can restore very rudimentary sight and hearing to some of the blind and deaf. Robots and computers can talk, heed speech, and read to a limited degree. All of this seems (and is) pretty amazing, so let's take a horizon expanding look into where chips are.2,9

In cash registers, the miniature computer on a chip totals bills, posts sales, and updates inventories. In pacemakers it times heartbeats. Radios are fine tuned, and car engines' carburetors are adjusted. Also in cars recently is a navigational aid. By Honda, this navigator enables drivers to negotiate complex cities like Tokyo with the help of a cursor that traces the course on a map. Now in police cars are computer terminals. In seven seconds police in Vancouver, British Columbia, can query Ottawa with names and license plates for readouts about fugitives and stolen vehicles.2,9
Other applications with the actual engine will be the voltage regulator. Electronic fuel control and ignition systems have already been used. Engine revolution counters and road speedometers combined with an electronic gasoline-metering system to give gasoline consumption in miles per gallon are in use. Automobile safety functions such as antiskid control, speed regulation, vehicle proximity indication, improved headlight dimming, safety interlocks, and faulty-indicator systems will also be incorporated into future cars.

Other amazing advances in applications is with the chip itself. They can never make things fast enough or small enough or powerful enough. The Japanese have unveiled a new generation of memory chip with four times the capacity of 64K RAMS. What use to take a squad of engineers 18 months to design, a microprocessor, university students from the California Institute of Technology and Lynn Conway of Xerox Corporation are doing in far less time. At an IBM plant in eastern New York, beams of electrons transfer chip designs directly from computers to wafers. The accuracy with which they do it is comparable to a skipper holding his ship within 525 feet of its course throughout a voyage from New York to New Orleans. These beams have unmatched potential to pattern wafers with fine circuits. At the National Research and Resource Facility for Submicron Structures at Cornell University, Dr. Michael Kacson has carved into salt crystals letters so tiny that a 30-volume encyclopedia could be written on a chip, the size of a half-dollar. Other scientists try building chip circuits, atom by atom, of chemicals beamed on wafers. The goal of such "molecular beam epitaxy" is more transistors on chips, packed in three dimensional rather than flat arrays. This process also sheets wafers with layers of gallium and arsenic compounds that will
conduct electricity ten times as fast as silicon.²,⁹

The electronic mail is already here. Through this each subscriber can choose what he wants to look at. It is a little expensive, but in a few years with the dropping costs of hardware, it will be very affordable. AT&T has already tested an electronic edition of the Yellow Pages. Following this is a combination telephone and computer terminal, with a compact keyboard and screen. The desk top device logs appointments, finds phone numbers, makes calls, sends and receives memos, and displays files. Though experimental, Bell's teleterminal exemplifies the chip's power to alter the way we work, or even where we work. In 20 years many people will work at home, not just craftsmen or entrepreneurs.

One of the latest crazes is video games. Though many people see them as a waste, there are advantages to many of them. One advantage is hand-eye coordination. This could be disputed, but to those people out there who will push in 300 million quarters this year there must be some fascination. This is one of chips' funnest if not biggest money makers. Pac-Man alone could gross 200 million dollars this year. All of the graphics, sounds, and movements are programmed in a chip. This chip contains a single video game program. Intellivision, Atari, Mattel, and Odyssey are the big names in home computer video games with several other manufacturers fighting to get a hold on a piece of the market.⁹

What is good enough for society is good enough for the military it seems. The U.S. Army tank gun crews toy with the chip, built into training simulators modeled on a video game. Like that diversion, the simulators stir aggressive impulses, and troops gladly practice more without the peril and expense of real tank maneuvers. The chip also makes possible the guidance of intercontinental missiles, and the exploration of space. It has changed the way
wars are fought, as the Exocet missiles proved in the South Atlantic and Israel's electronically sophisticated forces did in Lebanon. Through chips, friend or foe recognition radar systems are being built. These radars send out a beam that bounces back with the "signature" of the surface of the planes or other objects they encounter. The most spectacular use of the chip is another military mission, the missile that can be given new instructions in flight. Though not perfected, this is the way it works. A fighter pilot fires two missiles at an enemy plane, the first missile destroys the target, so the pilot sends out a signal that redirects the second missile to a different target. What happens if the target redirects your own missile at you? Possible but not probable. The complexity would be too great for such code cracking.2,5,9,15

Still another use for the chip is data collection. There are many types including bar-coding, optical character recognition (OCR), and magnetic strips to name the most popular. Everyone has seen bar-coding, but if asked what it is, they would look and feel perplexed, then they would guess. On all grocery items somewhere on the package there are familiar little black and white stripes, usually printed black on white. These adorn billions of retail products from cans of food to boxes of breakfast cereal, and even magazines. These stripes are easily read and decoded by computers and are used to make computers more efficient. This applies to OCR and magnetic stripe technology also. A type of wand is used to "read" the code and this information is translated into binary digits to be transmitted to the computer. From here the information is processed or just stored for future use.7

Robots, although not used extensively, are starting to be used quite effectively. The most recent robots are BOB (Brains on Board) from Androbot, Inc. and HERO (Heath Educational Robot) from Heath Company. Although very
limited in use, these robots are a start. Both robots can "talk", "walk", and "see" to certain degrees. They can also understand a limited vocabulary. HERO has an arm that he can pick up objects with. He can be programmed to pour drinks, deliver mail, and even walk the dog. These are personal robots, but the most widely used robots are used by industry and the military. In the military, robot soldiers have no place in Pentagon planning, and cosmetically, robots are light years behind the sleek androids of science fiction. However, the Army will soon test a robot ammunition handler with chips for a "brain". With a mechanical arm flexing hydraulic "muscles" and a pneumatic gripper "hand", it will hoist and arm 200 pound howitzer shells, a duty that now fatigues and endangers four GIs.9,16

Robots in the automobile industry are being used more extensively now than ever before. The reason? The chip. The chip has made the cost affordable as well as the size manageable. With its reprogrammable abilities, the chip has been put to use on the assembly line. Improving productivity is the main thrust as they tirelessly paint cars, weld ships, feed forges, and more. These hulking "steel collar workers" toiling in such jobs resemble counter balanced beams set on boxes full of electronics. Other smaller robot arms have shoulder, elbow, and wrist joints nimble enough to assemble electric motors or jiggle dainty light bulbs into automobile instrument panels. Some machines have more finesse, but none match the versatility of a robot. All it needs to switch jobs is a new tool at the end of its arm and a new program in its chips.9

In one Chrysler plant where once 30 men sweated to weld 60 cars an hour, the faster robots now handle as many as 100. Robots are more consistent also. If they weld right the first time, they weld right every time, Mondays and
Fridays included. At a General Motors plant in Ohio the praise for robots was greater. Robots work overtime without extra pay, cut defects and waste, and never strike. Robots now measure openings with lazer "eyes", one of many additions such as tactile sensors, TV cameras, and infrared probes, making robots increasingly productive. By 1990, General Motors hopes to be using ten times the 1,600 robots that it has today.9

These applications mentioned so far are all amazing, but when the chip advances into the area of the human body like it has, I stand totally amazed. In an indirect way a blood analyzer helps humans. As tests for detecting diseases become ever more sensitive, the data stored in the analyzer have to be brought up to date constantly. The chip has made this product much more flexible. With a reprogrammable chip, the new information can be written onto the chip very easily. More directly effecting the human body, chips at Stanford University are being used to help those people with hearing problems. Implanted behind the ear, the "bioear" promises rudimentary hearing for the profoundly deaf.9

The most amazing application of the chip is in the advent of inexpensive computer power. Nowhere has that power made such dramatic contributions as it has in the world of the physically handicapped. Today, paraplegics, quadraplegics, amputees, and cerebral palsy victims are using computers to perform tasks that once seemed beyond their capabilities. A quadraplegic, Rob Marince, lies in his bedroom at the heart of one of the most sophisticated computer control and communications centers in the United States. It is a patchwork of off-the-shelf electronic parts including a desktop computer, remote-control video recorder, a scattering of video games and pinball machines, a conference type telephone system, and a backyard antenna big
enough to broadcast network quality television signals. All of this has been pieced together during the past five years by Rob's brother, Gary, and a friend, Ted.\textsuperscript{14}

The result of getting 60,000 dollars worth of free components and teaching themselves everything from computer programming to the arcana of pinball relays is a system that permits Rob to roam the heavens by voice control. With a vocabulary of 280 words, which the computer recognizes, Rob can search the ring of satellites that orbit the earth and pick up more than 150 television channels. He can also dial the telephone, adjust the angle of his bed, dim the lights, dictate letters, play video games, and write programs on the Carnegie-Mellon University computer network in nearby Pittsburgh. Next January he will start taking college level courses by satellite. Because of the chip's complexity, systems like these are getting easier and cheaper to build. In the past few years there has been a tremendous increase of individuals and small groups that develop special aids for the disabled.\textsuperscript{19}

Another paraplegic, Nan Davis, using a computer based locomotion system stood in front of television news cameras and took half a dozen halting strides. She was paralyzed from the ribcage down in a car accident in 1970. She was supported by a parachute harness that supported a third of her weight, and she gripped a pair of parallel bars. The achievement marked the "marriage of 200 year old electrical stimulation techniques to today's high speed computers". Dr. Jerrold Petrofsky taped some 30 electrodes and sensors over the major muscle groups in her legs. Then he programmed a desk top computer to five successive bursts of electricity, carefully orchestrated to trigger the right muscles at the proper time. A feedback system monitored the movements of Davis' ankles, knees, and hips, making corrections as necessary. The
movements were crude and jerky, and extending the program so that Nan can turn, sit, squat, or climb steps will pose enormous difficulties.

So how does the chip relate to this? At present, the 200,000 dollar system can only direct one foot in front of the other. Before the system can be practical the 150 pound device must be streamlined and miniaturized. This is where the chip comes in. When it is perfected the system will be implanted pacemaker style. The question arises, "What next?". There seems to be no end to the chip's application. At the University of Utah, medical prosthetics designers are making advances with circuitry often as small as nerves and neurons. Ken South, a victim of a powerline accident that claimed both arms and shoulders, tries out electronic limbs, activated by motion sensors and electrical signals from the skin. 9

Although there seems to be no end to what chips can be used for, there are already ideas on how to use them more effectively and efficiently. Not only are uses being explored, but the improvement of the chip is being researched. It is amazing to see all the areas in which the chip is being used. It is almost impossible to believe that chips actually do the things they do. The next section is going to explore what direction the chip is going to take in the future. As was stated earlier, for every advance that the chip makes another direction and dimension is created.
FUTURE APPLICATIONS

When future applications are talked about, sometimes dreams become involved, but then what is wrong with dreaming? Eventually, one billion transistors, or electronic switches, may crowd a single chip, 1,000 times more than possible today. A memory chip this complex could store 200 long novels. By 1990 engineers expect to squeeze ten million transistors on the chip by enlarging it slightly and making it as complex as a city nearly 1,000 miles square. How do you build a megalopolis almost twice the size of Alaska? From Bell Telephone Laboratories, scientist Andrew Bobeck has come the magnetic bubble memory. Bubble-shaped magnetic areas in a film of garnet crystal will store such computerized messages as "We're sorry, but the number you have reached has been changed to...". One day a bubble chip the size of a postage stamp will hold the contents of a small phone book.

Chips refrigerated in ultracold liquid helium make feasible a supercomputer more powerful than any yet built, with a central core as compact as a grapefruit. Researchers at Bell Labs, IBM, and elsewhere are refining Josephson junctions, electronic switches made of metals that lose all resistance to electric current when chilled to near absolute zero. These chips can switch signals in seven-trillionths of a second, presaging ultrafast telephone switching equipment, or a refrigerated supercomputer. Its chilled circuits cutting traveling time for signals enable the machine to carry out 60 million instructions a second, ten times more than any modern high performance computer. IBM hopes to build a prototype in a few years.
Naval scientists envision semi-intelligent and autonomous robots that can pilot ships to evade enemy fire as well as rescue sailors and recover sensitive code books from sunken submarines.

Borrowing techniques from drug manufacturers, chemists now want to grow, not build, future computer circuits. The drive to cram more components on the chip may end in a test tube. Dr. Forrest Carter of the United States Naval Research Laboratory in Washington, D.C. thinks that relatively soon molecule size computer switches will be synthesized from inorganic chemicals, like some drugs. Then, within 30 years, a cubic centimeter could be jammed with a million billion molecular switches, more than all transistors ever made.

Unbelievable? After looking at what has been done, who could doubt that these things are possible? Right now parallel processors are used in computers to do all steps of a task simultaneously. Chips may be designed to simplify construction of these parallel processors. Supercomputers operate somewhat like this now. In hours they run calculations, long range weather forecasts for example, that other computers take days to finish. This speed is expensive, costing ten million dollars for a supercomputer. Dr. Carver of the California Institute of Technology, however, believes that with the new chip designs, supercomputers could be built small and cheap enough to give one to every child. "The consequences would be awesome", he predicts. "Kids could simulate with utter realism what it is like to pilot a jet, fly by the rings of Saturn, or be jostled by the atoms banging around in a fluid. Think how kids raised with such computers would transform society. There is nothing they wouldn't believe they could handle."
These might seem a little futuristic, so let's look at something that also seems futuristic but in actuality is not that far away, probably the 1990's. A thinking computer is one such item. The Japanese are earnestly working on this. What are their goals? Ease of use is their biggest goal. By recognizing natural speech and written language, it will translate and type documents automatically. All you will have to do is speak a command, and if the machine does not understand, it will talk back to you. This computer will draw inference and make its own judgements, based on knowledge of meanings as well as numbers. It will also learn by recalling and studying its errors. Artificial intelligence, machines acting in ways humans regard as intelligent, is as much art as science.  

"Knowledge engineers" obtain from human experts factual knowledge and the sometimes unrecognized rules of thumb they use to apply it. This information is then encoded into programs. Genetic experiments are planned, then structure of molecules are deduced, and diseases are diagnosed with this encoded information. Future "expert systems" may advise chip designers, soldiers who must troubleshoot complex weapons, and even plant lovers, as the programs become everyday consultants.  

At the University of Pittsburgh, Nobelist Herbert A. Simon teaches that computers reason with a program that seeks orderly patterns in irregular data and thereby hits on predictable laws of nature. Approximating the intuitive thinking of human scientists, the program has independently rediscovered laws of planetary motion and electrical resistance, as well as the concept of atomic weight. Could Bacon (the program) discover an unknown natural law? "Maybe, but the main goal is learning how the mind works", Dr. Simon says. "I grew up in a computerless world amid vague
ideas about thought and the brain. Computers, when you try to program them
to act like us, shed great light on such things", he said. Could a computer
win the Nobel prize? "The Nobel Committee may yet have to think about that."9

Still another example of chip know-how that is within two years of use
is the automobile industry. Chrysler has replaced the electromechanical
odometers in the Imperial with chips because they are more reliable. The
automobile offers one of the most promising settings for the new chip.
Detroit hopes to be manufacturing self-adapting engines made possible by the
chip. The chip's performance grows with function. It learns the details
of what has happened to the unit in which it is used, and it matures. The
chip's memory responds to signals from sensors and adjusts quickly to change,
both inside the engine and outside the car. On the chip's orders, the engine
will regulate fuel injection, combustion rate, and other functions to cope
with the changing altitude on a trip from Los Angeles to Denver. 5

The engine will also make allowances for its own deterioration. If the
engine has a clogged air filter the chip will send a message to tell it
to compensate in the fuel mixture. If worn spark plugs are the problem it
will compensate in the spark gap. The chip could also be used in drilling
and cutting tools. The machine would be able to adjust its blade to the
hardness of the metal it was cutting as well as its own wear. In an
automobile engine the chip will keep a record that is constantly updated.
When the car can no longer cope and is taken in for repairs, the mechanic
can hook up a diagnostic instrument to the chip; "the chip will spill out all
the car's woes". 5

Also in the future is the totally automated factory. There is some
automation in today's factories, but the push for automation has just started
in the last five years. The factories would make computer designed goods
with mass production economy and the distinction of custom detail. The
Boeing Commercial Airplane Company is heading that direction now because of the chip's cheap computing power. Boeing fills orders for ten jets, each with unique seating, but builds them together with computer customized blueprints. It is easy because a robot like device drills holes wherever wanted with just a change in a program, dictated by a design computer.

The most advanced factories of this type may be in Japan. In the Fanuc, Ltd. plant near Mount Fuji, "unattended carts glide to automatic storage racks, accept metal blocks, and then roll to robots; they loaded the metal into unmanned drill presses and lathes to be shaped into parts for more computerized tools and robots". On a shop floor bigger than a football field there could be only 15 human workers. Japan has roughly half of the world's 25,000 robots. Because of this, Dr. James S. Albus, a robotics expert at the United States National Bureau of Standards says, "Japan has given us another Sputnik". Japan is ahead, but as we have seen earlier, American factories are racing to the fore to catch up.

There are literally thousands of ideas that are being worked on as far as chip application. The scope of the chip influence is too big to give even a reasonable overview. Even though there are so many possible areas of application, there is one basic goal that every area is trying to attain. This goal, more of a trend actually, is greater circuit complexity. From a single logic circuit to today's three-dimensional circuits, the complexity has increased dramatically. Multiple function chips, or multifunction chips, are chips that have two or more distinctly separate and self-contained circuits. This is another level of complexity. Large scale array chips are a modified form of multiple function chips. However, the basic circuit is repeated many times on the chip. This gives large scale
array chips two worthwhile properties. The first property is a 100 percent yield of good circuits on any one chip is not necessary. Faulty or marginal chips can be bypassed to produce a higher overall yield of usable complete chips. Second, by using a different second level interconnecting pattern, different subsystem functions can be obtained from the same basic chip. For example, by using a certain metallization pattern several logic gates on a chip could be interconnected to give a shift register, with a different pattern the same gates could be connected to provide a full-adder.

Still advancing toward this goal, self-repairing systems would add another level of complexity. Long-term missions impose severe demands on reliability. Certain missions require some provision for on-board maintenance, and since some of these missions will be unmanned, some method of self-maintenance will be necessary. This is accomplished by having a spare bank of spare circuits or subsystems on the same chip. When a malfunction is detected a spare subsystem can be switched in.

With all of these changes, it is hard not to ask how this chip is going to effect society. Is it going to better society? Is it going to worsen society? Is it going to broaden the gap between the haves and the have nots? Is privacy being challenged? These are some of the questions that will be looked at in the next section.
SOCIAL CONSEQUENCES OF THE CHIP

In the shadow of all the uses and dreams about the chip, there is a very serious question to be asked. "What effect will the chip have on society?" It has been estimated that by 1990 1.5 million programmers, more than three times as many as today, will be needed to write instructions for computers that issue paychecks, run factories, and target nuclear missiles. So what will happen to all these programmers as the chip keeps changing things so drastically? All too often they are washed up by the time they are 35 or 40, and new ones take their place. The younger engineers are sharper than the older engineers. Each year 10,000, or five percent, of the nation's electrical engineers transfer out of their field because they feel useless or technologically obsolescent. By 1985 the United States is expected to suffer a shortage of more than 100,000 engineers. Plans have been started to correct this. Through alliances of industry and academe, the engineer will spend as much as ten percent of his working time continuing his education.

Continuing with education is the fear of unequal access to knowledge. The chip is changing this into a world where information is literally wealth. "Without equal skill in using computers to get and employ information, people may divide into 'knows' and 'know nots' and suffer or prosper accordingly." Things bring up another interesting question. "Will the rich get smarter while the poor play video games?" A survey found that
60 percent of the country's 2,000 largest and richest public high schools have access to at least one micro, while 60 percent of the 2,000 poorest schools have none. "If computers are the wave of the future, a lot of American is being washed out." This brings a panic situation in to play. It is thought that where computers were a luxury a year ago, they are a necessity now.⁹,¹³

Although educators worry about the tilt of technology, they agree that a computer is a powerful motivator of a school age child. Students with access to a micro spend more time studying and solving problems. The ones who write at their keyboards compose more freely and revise their work more thoroughly. The profoundest effect of computers on children may be to make them reflect on how they think, but the kids who don't get indoctrinated to computers by the seventh grade are not going to develop the same proficiency. Contrary to others, some observers think that in the long run all children will have computers. These people see computers as an equalizer instead of a divider.⁹,¹³

Another effect that chips are having, and will have to a greater extent in the future, is in the job market. With robots and chips, this technology affects offices as well as factories. It could create an economic vise where one side shoves people from the plant, and the other limits their shift to white collar jobs. Without some type of retraining program and new jobs, a severe economic dislocation could occur. In the long run, jobs will be created as more workers are needed in the robotics industry. Then new job markets will be opened up by the chip. Examples are deep sea mining and repair of home robots.⁹
We see that jobs will be affected in type, but they will also be affected in area. It has been estimated that in 20 years many people will be working at home, using computers and dealing with our office by electronic mail. This may be one way to attract or keep workers who dislike commuting, have small children, or are homebound by handicaps. Some banks and insurance companies already use this form of working to a limited extent. This may change society drastically in the way it thinks about the nine to five workday. Sick leave, vacation, and pension policies will change as well as the separation of work and family and the concept of leisure time, what to do with it, and when.

This sounds exciting, but could the world become Orwellian in nature. With the chip, such a concept is conceivable. "Word processors and computer terminals can keep us under surveillance. A boss can know how many keystrokes a secretary makes in a minute, hour, or day. At insensitive companies, new technology may be an opportunity to grip workers totally." This creates a challenge to our privacy in this decade. "With personal computers and two-way television we will create a wealth of personal information and scarcely notice it leaving the house. We'll bank at home, hook up to electronic security systems, and connect to automatic climate controllers. The television will know what x-rated movies we watch. There will be tremendous incentive to record this information for market research or sale."9

Problem. While some ponder how to shield sensitive information lodged in the chip, others try to tap it. For revenge, for fun, and for profit are three motives that have figured in computer crimes. Computers are easily corruptible. Files can be altered, unauthorized commands can be added to
programs, and legitimate ones misused, often without discovery. No great skill is needed either. Amateurs have broken the defenses of even classified military computers. These have been estimated to run with price tags anywhere between 100 million to 6.5 billion dollars annually, and this is only the reported loses. "The potential for plundering is sobering: Daily now, banks transfer more than 500 billion dollars around the United States by computer."

In the future, as personal computers multiply, electronic lawbreakers may hit harder and more frequently. Teenagers have wrought long-distance havoc with their keyboards. Using telephone lines as a link, two California boys tampered with racehorse and greyhound pedigrees stored in a computer in Kentucky. Files in a Canadian corporation were an open book to youngsters at school in Manhattan for some time. "Children of their time, you may lament, making mischief in a fashion ushered in with incredible rapidity by the chip. With such swiftness that you may conclude a revolution in our lives is well under way." The surprising thing is that it has hardly begun. "In decades to come the technology of this age of the chip will surely seem minor, gradually dwarfed by its sweeping social effects."9

Some of the social changes will come as the chip is put to new uses. One such new use is implanting microcircuits in our heads to augment our intelligence. How do we deal with this? How do we deal with all of these changes that are taking place? These are questions that will have to be answered in the not so distant future.
CONCLUSION

In less than 50 years we have come from a computer that weighed 30 tons to a cubic centimeter of silicon that can do almost 100 times the work on one ten-thousandth of the power. The chip has entered the atomic cosmos as well as the deep frontiers of space. It has changed the way people think. It has brought new possibilities where there were none before. It has given hope to people who had no hope. It has made dreams come true for those who dared to dream. It has given power to ideas, and it has opened up areas that only the boldest dare to challenge. It has added new dimensions to old social issues. It has altered our self-image. To think was thought to be human, but apes that master sign language and use tools have already shaken this idea. Now this view will even decline further if machines too begin thinking. Such overwhelming adjustments seem to be the unavoidable and unsettling price to pay to live in the age of the chip. "But not too great a price, for in saying it we stand to gain the benefit of exercising some of our best virtues: patience, flexibility, wisdom."
BIBLIOGRAPHY


APPENDIX C

1. Fan-out - specifies the number of standard loads that the output of a standard gate can drive without impairing its normal operation. A standard load is usually defined to be the load needed by an input of another similar standard gate.

2. Power-dissipation - is the power consumed by the gate which must be available from the power supply.

3. Propagation delay - is the average transition delay time for the signal to propagate from input to output when the binary signals change in value. The operating speed is inversely proportional to the propagation delay.

4. Noise margin - is the minimum noise voltage that causes an undesirable change in the circuit output.

The characteristics of digit logic families are compared by analyzing the circuit of the basic gate in each family. These are the most important parameters.
### APPENDIX D

<table>
<thead>
<tr>
<th>Logic Family</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>TTL</td>
<td>Wide Variety of Functions, Most Popular</td>
<td></td>
</tr>
<tr>
<td>ECL</td>
<td>Very High Speed Variety of Functions</td>
<td>High Power Consumption, Low Noise Margin</td>
</tr>
<tr>
<td>MOS</td>
<td>Unipolar, High Packing Density, Simpler Processing Techniques, Low Power Consumption</td>
<td></td>
</tr>
<tr>
<td>CMOS</td>
<td>Same as MOS, Wide Variety of Functions</td>
<td></td>
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Although the logic circuit families have advantages and disadvantages to them, ICs in general have several advantages regardless of logic family.

They are:

1. Substantial reduction in size,
2. Substantial reduction in cost,
3. Reduction in power requirements,
4. Higher reliability against failures,
5. Increase in operation speed, and
6. Reduction of externally wired connections.
APPENDIX E

The binary system is a number system that works with only two digits, 0 and 1, whereas the decimal system uses 10 digits, 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. Just like the decimal system, addition, subtraction, multiplication, and division can be performed in the binary system. Because we are not used to the binary system, the operations are not always easy. The easiest way to think of the binary system is to think of an odometer with only two digits, 0 and 1.

Addition example:  
\[
\begin{array}{c}
100110 \\
+ 110111 \\
\hline
1011101
\end{array}
\]

Because a string of 1s and 0s can become quite confusing, two other number systems are also used. These are the octal and the hexadecimal systems. The octal system works with only eight digits, 0, 1, 2, 3, 4, 5, 6, and 7, and the hexadecimal system works with sixteen digits, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F. The conversion from binary to octal or binary to hexadecimal or vice versa is quite simple.

Conversion example:

<table>
<thead>
<tr>
<th>Binary: 10011010011</th>
<th>Binary: 10011010011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octal: 4 6 4 7</td>
<td>Hexadecimal: 9 A 7</td>
</tr>
</tbody>
</table>

The conversion from binary to decimal is not too difficult either. For example, take the decimal number 243. This can be represented as 
\[2 \times 100 + 4 \times 10 + 3.\] It can also be expressed as \[2 \times 10^2 + 4 \times 10^1 + 3 \times 10^0.\] Likewise, the binary number 101011 can be represented as...
\[ 1 \times 2^5 + 0 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0. \]

Adding this number up, we get the decimal number 43. Now, for the more difficult part, decimal to binary. Take the decimal number 12. There are two ways that you can find the binary equivalent.

The first method is to find highest power of 2 that will go into 12. In this case it is 8 or \(2^3\). Now we know that there are 4 digits in this binary number. So put a 1 in the leftmost position (a). Now subtract 8 from 12; 4 is left. Now do the same thing. Find the highest power of 2 that will go into 4. In this case it is 4 or \(2^2\). So put a 1 in the next leftmost position (b). Since the remainder is 0, there are no other powers of 2 that will work. This means that the rest of the positions are 0s. Try this for the number 15. (See d for answer.)

The second method is to divide the number 12 by 2. This leaves a remainder of 0 (e). Put 0 in the rightmost position (we do not know how many positions there are in this method). 6 is the number that is left; divide 6 by 2 (f). 0 is the remainder so put that in the next position (work your way to the left). 3 is left, so divide 3 by 2 (g). The remainder is 1 so put the 1 to the left of your last digit. The number that is left is 1 so divide 1 by 2. The remainder is 1 so put 1 to the left of your last digit. The number left is 0 so we are done. This method is easier than the numbers get larger. Try to do 27 (answer is 11011). You can always check your answer by expanding the binary number as we did before.

\[ \begin{align*}
a) & \quad \begin{array}{c|c}
1 & 6 \\
1 & \hline
\end{array} \\
b) & \quad \begin{array}{c|c}
1 & 12 \\
1 & \hline
0 & \hline
\end{array} \\
c) & \quad \begin{array}{c|c}
1 & 100 \\
1 & \hline
0 & \hline
\end{array} \\
d) & \quad \begin{array}{c|c}
1 & 1111 \\
2 & \hline
0 & \hline
\end{array} \\
e) & \quad \begin{array}{c|c}
2 & 12 \\
1 & \hline
2 & \hline
\end{array} \\
f) & \quad \begin{array}{c|c}
3 & 6 \\
2 & \hline
6 & \hline
\end{array} \\
g) & \quad \begin{array}{c|c}
2 & 3 \\
1 & \hline
2 & \hline
\end{array} \\
h) & \quad \begin{array}{c|c}
2 & 1 \\
1 & \hline
0 & \hline
\end{array} \\
i) & \quad \begin{array}{c|c}
1 & 0 \\
1 & \hline
0 & \hline
\end{array} \\
j) & \quad \begin{array}{c|c}
1 & 1100 \\
1 & \hline
0 & \hline
\end{array} \\
k) & \quad \begin{array}{c|c}
2 & 11 \\
1 & \hline
2 & \hline
\end{array} \\
l) & \quad \begin{array}{c|c}
2 & 10 \\
1 & \hline
2 & \hline
\end{array} \\
m) & \quad \begin{array}{c|c}
2 & 11 \\
1 & \hline
2 & \hline
\end{array} \\
n) & \quad \begin{array}{c|c}
2 & 10 \\
1 & \hline
2 & \hline
\end{array} \\
o) & \quad \begin{array}{c|c}
2 & 11 \\
1 & \hline
2 & \hline
\end{array} \\
p) & \quad \begin{array}{c|c}
2 & 10 \\
1 & \hline
2 & \hline
\end{array} \\
q) & \quad \begin{array}{c|c}
2 & 11 \\
1 & \hline
2 & \hline
\end{array} \\
r) & \quad \begin{array}{c|c}
2 & 10 \\
1 & \hline
2 & \hline
\end{array} \\
s) & \quad \begin{array}{c|c}
2 & 11 \\
1 & \hline
2 & \hline
\end{array} \\
t) & \quad \begin{array}{c|c}
2 & 10 \\
1 & \hline
2 & \hline
\end{array} \\
u) & \quad \begin{array}{c|c}
2 & 11 \\
1 & \hline
2 & \hline
\end{array} \\
v) & \quad \begin{array}{c|c}
2 & 10 \\
1 & \hline
2 & \hline
\end{array} \\
w) & \quad \begin{array}{c|c}
2 & 11 \\
1 & \hline
2 & \hline
\end{array} \\
x) & \quad \begin{array}{c|c}
2 & 10 \\
1 & \hline
2 & \hline
\end{array} \\
y) & \quad \begin{array}{c|c}
2 & 11 \\
1 & \hline
2 & \hline
\end{array} \\
z) & \quad \begin{array}{c|c}
2 & 10 \\
1 & \hline
2 & \hline
\end{array} \\
\end{align*} \]