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The University, Electrical Engineering and Space Travel

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Doran J. Baker



Utah State University
Faculty Honor Lecture
March 1979

FIFTY-NINTH HONOR LECTURE DELIVERED AT THE UNIVERSITY

A basic objective of the Faculty Association of Utah State University, in the words of its constitution, is:

to encourage intellectual growth and development of its members by sponsoring and arranging for the publication of two annual faculty research lectures in the fields of (1) the biological and exact sciences, including engineering, called the Annual Faculty Honor Lecture in the Natural Sciences; and (2) the humanities and social sciences, including education and business administration, called the Annual Faculty Honor Lecture in the Humanities.

The administration of the University is sympathetic with these aims and shares, through the Scholarly Publications Committee, the costs of publishing and distributing these lectures.

Lectures are chosen by a standing committee of the Faculty Association. Among the factors considered by the committee in choosing lecturers, are in the words of the constitution:

(1) creative activity in the field of the proposed lecture; (2) publication of research through recognized channels in the field of the proposed lecture; (3) outstanding teaching over an extended period of years; (4) personal influence in developing the character of the students.

Doran J. Baker was selected by the committee to deliver the Annual Faculty Honor Lecture in the Sciences. On behalf of the members of the Association we are happy to present Professor Baker's paper.

Committee on Faculty Honor Lecture

**The University, Electrical Engineering
and Space Travel**

Doran J. Baker



INTRODUCTION

In this paper, my purpose is three-fold: First, to tell some of the story of the development of the Engineering College at Utah State University; second, to present selected concepts and applications in the evolution of electrical engineering; third, to relate these concepts and developments to our space venture and to the twenty-first century. My perspective is that of a school teacher, engineer, scientist and historian; superimposed upon this is my imbedment in the system as an administrator of teachers and researchers. I intend to strike a balance between generality and depth, between technology and philosophy, and between perception and speculation.

ENGINEERING COLLEGE

Looking Down From the Hill

The sarcastic putdown by the Wizard of Oz to the Scarecrow with his head of straw was: "I can't give you brains, but I can give you a diploma." We educators must continually ask: Just what is the purpose of this university diploma we are so anxious for our young people to acquire? How shallow or deep is the significance of the diploma?

Borrowing terms from electrical engineering, the university should function both as a **filter** and as a **transformer**.¹

The students must bring the brains and the desire; we provide the filter, namely an enforced standard of performance. Frederick Emmons Terman, former head of the Electrical Engineering Department and later provost at Stanford University, used to say: "If you want a track team to win the high jump, you find one person who can jump seven feet, not seven people who can jump one foot."

On the other hand, the filter must not be used for a false purpose. Any worthwhile achievement requiring discipline and tenacity should be recognized. Quoting from John Gardner:² "The society which scorns excellence in plumbing because plumbing is a humble activity, and tolerates shoddiness in philosophy because it is an exalted activity, will have neither good plumbing nor good philosophy. Neither its pipes nor its theories will hold water."

The university acts as a transformer through both content and method, so that the student may emerge with increased knowledge, experience and confidence. The content of the education should have sufficient depth in selected areas so that the graduate is salable. Nonetheless, the overall university education must remain general because we cannot predict with any surety exactly what knowledge and skills will be needed. One can learn specialties at

work; however, the university interlude is probably the only time when the person will make the effort to systematically approach the principles and concepts of a broad discipline.

Gardner's articulation of the ideal university posture is as follows:

Focused, systematic, responsible, even aggressive concern for the manner in which society is evolving — a concern for its *values*, for the *problems* it faces, and for the *strategies* appropriate to clarify those values and to solve those problems.

The university, in other words, functions as an intellectual **subsystem** of the **suprasystem**. We must suppose that it has survived over the long pull because this subsystem is producing more useful than useless **outputs**.

The origins of the modern university (such as Utah State University) date back to the Middle Ages in Europe. The medieval Latin term *universitas* originally meant community or corporation, but used with *studium generale* implied a center of learning for all. The first European university was the ninth-century medical school at Salerno, Italy, the town now more remembered as a beachhead where the Allies landed to capture Naples during World War II. Hundreds of years later in France the University of Paris grew from a twelfth-century school for the study of dialectic to become the model for the other universities, including Oxford and Cambridge in England. Students came from all over Europe to attend these universities.

Following the traditional pattern set by the English schools, the first American university, Harvard, was founded through religious zeal and philanthropy in colonial Massachusetts in 1636. John Harvard had been a student at Cambridge University. Immediately after American independence, state tax-supported universities began to appear, with the University of North Carolina as the first.

Farmers and Mechanics go to College

In the latter nineteenth century a new kind of school developed in America, namely, colleges of agriculture and mechanical arts for the common people. These new colleges stood in marked contrast to those schools structured for the elite professions — religion, medicine and law. The Land Grant Act, signed by Abraham Lincoln during the Civil War,³ granted thirty thousand acres of public land to each state according to the number of congressmen from that state.⁴ The commonwealth of Massachusetts added most of its appropriation to the endowment of the Massachusetts Institute of Technology (MIT), which opened its doors immediately after the Civil War to become the leading engineering school in this country. From 1865 to 1900, two hundred U.S. colleges were founded, more than doubling the total number in existence. Over sixty of these were land grant schools.

According to the Land Grant Act, the agricultural and mechanical arts

colleges were supposed to have been started by 1874, but Utah Territory did not get its local hassling settled until 1888. In the undignified bartering over the tax-supported institutional spoils of the territory, Salt Lake City already had the University of Deseret,⁵ and the penitentiary as well. Provo had the insane asylum. Ogden claimed both the reform school and the school for the deaf and blind, so Logan had to take what was left over — the agricultural college.

The Lund Act⁶ of March 8, 1888, giving birth to USU, was the response in Utah to the federal Land Grant Act. It specifically called for the Agricultural College of Utah to include civil engineering and also technology in its courses of instruction. Jeremiah Wilson Sanborn, non-Mormon agriculturist and political scientist from Dartmouth and also the University of Missouri, was elected as the first president of the faculty. He set up four distinctive lines of instruction when the college opened its doors in September of 1890: (1) agriculture, (2) domestic arts, (3) mechanic arts and (4) civil engineering.⁷ Carrying out the spirit envisioned by Professor Turner for his "industrial universities" across America, with agriculture as the great basic industry, the Utah Agricultural College charged no tuition. However there was a yearly "entrance fee" of five dollars.

Engineers on the Faculty

President Sanborn in 1890 engaged the services of Jacob M. Scholl, who held a bachelor's degree in mechanical engineering, to teach the engineering courses at the Utah Agricultural College. He was soon joined on the faculty by another instructor of mechanical engineering, and a professor of civil engineering whose specialty was irrigation.⁸ These men, like all of the collegiate level faculty members hired by President Sanborn, were non-Mormons from outside of Utah. The first two engineering graduates from the Utah Agricultural College were given their B.S. diplomas on the first commencement day, May 31, 1894. Completing the four-year course in civil engineering were William Bernard Dougall of Springville and Andrew Bernstoff Larson of Levan. All of the engineering courses were taught in what is now Old Main, until the first phase of the Mechanic Arts Building was erected in 1896, the year Utah became a state. At last the noisy, smoky blacksmith forges could be removed from the basement of the main building.⁹

John Andreas Widtsoe, Jr., of Logan was one of seven young Mormons who ventured east to study at Harvard with Joseph Marion Tanner, president of Brigham Young College of Logan.¹⁰ Tanner's plan was to encourage several bright young men to go to college under his supervision and then return with him to Utah to do more effective educational work. Tanner, in turn, had been a protégé of legendary teacher Dr. Karl Gottfried Maeser at the Brigham Young Academy in Provo.¹¹ After his graduation, Tanner had worked as an engineer in laying out the Denver and Rio Grande Railroad and

then was appointed surveyor for Provo City. When the Republicans took charge of the new State of Utah in 1896, Democrat Joshua Hughes Paul¹² was forced to step down as president of the UAC and Republican Tanner took his place.

In 1901, under the vigorous leadership of President William Kerr,¹³ who was a mathematician and scientist, the remaining three-year programs were done away with and the college changed from the semester to the quarter system. William Duke Beers of Richmond was added to the engineering faculty by President Kerr. An 1899 civil engineering graduate of the UAC, Beers was with the party that surveyed the Kelton to Mackay railroad. He then served as an engineering consultant with the Telluride Power Company. In January of 1902 at the urging of Kerr and Beers, the UAC board of trustees established a course of instruction in **electrical engineering**.

The programs in engineering at the UAC were short-lived, however. Before the electrical engineering program was off the ground, the state legislature passed and the governor, John Christopher Cutler, signed an act (1905) prescribing and limiting courses of instruction: "But the Agricultural College shall not offer courses in engineering, liberal arts, pedagogy, or the profession of law or medicine." At the time of this act, only engineering was being offered.¹⁴ During the seven-year official absence of engineering on the UAC campus, a program of irrigation engineering continued, but it was advertised as being in connection with the University of Utah.¹⁵ The embryo of an electrical engineering program on campus would lie dormant until after World War I.

TIME DIMENSION

Field of View

It is my purpose at this juncture to put electrical engineering into brief historical context. Subsequently, I will deal with some aspects of the spatial context. Perspective is dimensioned in both **time** and **space**. Time is the traditional medium of the historian; space is that of the geographer.

At the university, where our graduates are products for the future, the temporal coordinate extends forward as well as backward. Unlike the historian, we by necessity incorporate both positive and negative time in our **system models**.

To portray the perspective of human concern, I've borrowed and modified the space-time graph of Donella Meadows¹⁶ and her colleagues of the Club of Rome. "The majority of the world's people are concerned with matters that affect only family or friends over a short period of time. Only a very few people have global perspective that extends far into the future."

About Time

The measure of time ranges from the imperceptible "shake" of the hurried

nuclear physicist to the enduring “era” of the patient geologist.¹⁷ More evident in human life is the “year.” More random and less spoken is a **lifetime**. In this section, I will try to place our present coordinate position into relatively recent historical context.

Barring prior catastrophic breakdown of our national life support system, the most likely age at demise of each of us in this audience is four score years — two decennia short of a full century. We will define a **mean lifetime** as eight decades.

The middle-aged 40-year-old, born in World War II, may live to about *anno Domini* 2020. This year’s graduates from our Institution should have productive careers lasting until then and beyond. The life reach of today’s infants, our children, might be 2060 A.D.

Adopting the eighty-year lifespan as a dimension of the time perspective, the post-Columbian existence of our country can be divided rather naturally into five spans. The *first span* was the phase of coastal settlement which began with Jamestown (1607) and Plymouth Plantation (1620) and lasted until about A.D. 1700. The *second span* was the colonial period of growth, consolidation and nationalism which climaxed in the *Declaration of Independence* of 1776. The *third span* was the stage of American nationhood, westward expansion, industrialization and a North-South polarization which culminated in the 1860-1865 Civil War. The *fourth span* was characterized by the maturing of the nation and the growth of international power. The latter was manifest in three wars of escalating scope and violence, the last of which was the 1939-1945 Second World War. The *fifth span* is that in which we are now living. I date it from the World War II “watershed” up until about A.D. 2030, a time which may prove to be even more climactic.

I wish to focus our attention for a moment upon this fifth lifespan. So far this period has been characterized by five very significant **impulses** upon the national (and world) system: (1) *Pearl Harbor — 1941*, (2) *Hiroshima — 1945*, (3) *Sputnik — 1957*, (4) *Kennedy murder — 1963*, (5) *oil embargo — 1973*.

From the perspective of our representative forty-year old, the first two wartime impulses occurred during early childhood. America’s system response to the Japanese attack upon Pearl Harbor was a marshalling of technology, engineering and science to a degree unparalleled in the history of the world. Men and women returned from a concentrated effort to defend a way of life and set about technologically to change that way of life. Assisted by the GI Bill and motivated by uncommonly clear goals, thousands of engineers were graduated from American universities during the first decade after the war. Entrepreneurs used the minds and hands of these men to sweep across the land with a second industrial revolution. The maturing of three solid engineering colleges in Utah is directly attributable to the war-driven impetus.

The world war was stilled by a doublet of nuclear flashes which consumed a hundred-twenty-thousand souls. By a nuclear fission bomb (1945) and its

Promethean offspring, the nuclear fusion bomb (1952), the fire of the Sun had been handed by the Gods to mortal man. Terror of mutual annihilation appeared to limit subsequent "hot" wars. A momentary high prestige of nuclear physicists on campuses deteriorated as the memory of the war context faded, but the spectre of the bomb and its fallout radiation has continued.

When our forty-year-old was a teenager in high school, *Sputnik* metamorphosed the Russian-American "cold war" to a race into space. The NASA-funded part of the space programs at Utah's schools can be directly traced to the impulse on the American system of this Russian satellite appearing in the sky.¹⁸ Shortly, I will comment on the system response to this impulse.

Before the space contest was decided, the assassination of a charismatic American president unleashed a decade of social chaos. Our forty-year-old completed a college education and began a family and a career while the TV news bespoke a bewildering succession of disturbing events: Dallas, Harlem, Watts, Newark, Detroit, Memphis, Washington, Los Angeles, Kent State, Attica, Wounded Knee and Watergate. While the political system was in shock, Kennedy's successor strove to assuage the frustrated expectations of some of our minorities; his approach was massive social welfare. At the same time, but in furtive manner, he sent crusaders to the far Orient in misdefense of American honor and security.

A major impact of all of this on the university scene was a severe deterioration of academic standards, a symptom of which is grade inflation. Giving students priority is admirable, but we are doing neither them nor society any favors by watering down their education to make it easier to get a diploma.

Today during the middle age of our contemporary human lifetime, an unstable economic situation is compounded by the recent oil embargo imposed from a world-wide cartel. In the news media, the word "energy," long familiar to engineers and scientists, suddenly is popular. The ecology movement, spawned from a youthful need to rediscover the basics, may yet be trampled by the gluttonous thirst for energy.

We can expect more impulses upon the suprasystem. A food crisis awaits its turn. From a systems standpoint, I will speculate on this briefly at the end of the paper.

ELECTRICAL ENERGY

Engineering with Electricity

The great discoveries of electricity came in lifespan three, as we have delineated the time since the European settlement of America. Electricity was put to use in lifespan four. We will consider first the development of electrical energy, and then look at the use of electricity in handling information.

Information and energy are transferred and transformed to serve the needs of mankind. This is the essence of electrical engineering. This double

dualism in the field has persisted since the invention of the electromagnet.

On August 29, 1831, Michael Faraday made one of the greatest discoveries of all time — that electricity can be produced **magnetically**.¹⁹ Faraday, the son of an English blacksmith, was at the time a scientist employed by the Royal Institution in London. Within the year, across the ocean and working independently, an obscure thirty-four-year-old American professor, by the name of Joseph Henry,²⁰ made the same discovery by likewise building an **electric generator**. Furthermore, that same year, Henry also engineered not only the first successful **electric motor** but also the first **electromagnetic telegraph**.

Joseph Henry was also the first to study currents induced in a distant circuit by the **electromagnetic waves** from an electrical spark. Electrical energy could be transmitted from one circuit to another with no wires between! Samuel Finley Breese Morse, who had promoted the first commercial telegraph line based upon Henry's principle, quite by accident also discovered **electric induction**. About 1842 he was experimenting with a signal cable laid across a river when a ship came along and snapped his wire. To his astonishment, he could still very weakly receive the signals even though the wire was broken.

Satisfactory explanation of propagation of electricity through space awaited the next lifespan, number five since American settlement as we delineated them earlier, and the growing to manhood of a genius, James Clerk Maxwell. He was born the same year that Faraday and Henry made their discoveries.²¹ The two-volume work, *Electricity and Magnetism* published in 1873 by Professor Maxwell of Cambridge University, stands a century later as one of the most splendid monuments ever raised by the genius of a single individual. It is the foundation of electrical engineering.

Two questions remained to be answered. The first: Is **light** an electromagnetic wave? Maxwell showed in his theory that electromagnetic waves would necessarily have to travel at a speed determined by the ratio of the force between **electric charges**, and the force between **electric currents**. He next devised a method of making the measurement, upon which his electromagnetic theory of light would stand or fall. The best measurement of the velocity of light in his day was 298,000 km/s. His measurement came out 288,000 km/s. This was convincing evidence that, yes, light is electromagnetic.

The second question to be answered is whether electricity is a flow of tiny particles. The realization that the atom was not nature's ultimate small particle was long in coming. Experiments on the chemical action of electric currents sowed the seeds of doubt at the beginning of the nineteenth century, but it was forty years before the **ion**, Faraday's name for the electrified atom, could be accepted. It was ninety years before the **electron**, the basic particle of electricity, was finally identified. Just before the turn of the twentieth century, Cambridge University professor Joseph John Thomson used an evacuated glass bottle, closely akin to what today is a TV tube, to prove the

existence of electrified particles that are two thousand times lighter than atoms.²²

Power and Light

Electricity is the magic by which man has extended his muscles and his senses beyond belief. It transports our stuff, does our work, lights our way and helps us think. Four great primary areas of electrical engineering can be traced directly to (1) the dynamo, (2) the arc light, (3) the telegraph and (4) the calculator. The dynamo and the electric light concern energy; the telegraph and the calculator concern information.

Within two years of Henry's creation of the electric motor, Mortiz Herman von Jacobi at the University of Dorpat in Russia built a large machine. It so intrigued the Tsar that he had Jacobi build an electromagnetic motor to power a paddlewheel launch that would carry a dozen passengers four miles an hour for a whole day. **Electrical power** was born.²³

The idea of using electricity for lighting purposes dates back to Sir Humphry Davy of Cornwall in 1802. He discovered that he could form a bright arc flame by touching carbon rods, each connected to the terminals of a battery, and then drawing them apart. By mid-century, arc lamps were coming into use for lighting streets and railway stations. Much later, Philadelphia high school professor Elihu Thomson used the arc to heat and melt metals for **welding**.²⁴

Heating a wire by electricity until it becomes red or white hot seemed to be the way to make a light for homes. But for forty years after the invention of the electric generator, a succession of men tried without real success to make a practical, small **electric light**. Finally, Thomas Alva Edison, the inventor of the phonograph, by sheer tenacity of trial and error put together a combination of old elements to produce a new thing: an electric light bulb consisting of a carbon filament supported by platinum wires enclosed at all points by glass, and evacuated to a high vacuum. Edison's electric light would burn for over forty hours without darkening the bulb.²⁵ He put on a dazzling display of his success at Menlo Park, New Jersey, at Christmastime in 1879.

Right away, Edison constructed a public supply station in New York, using dynamos driven by high-speed steam engines, to provide electricity for the incandescent lamps which he had just invented.²⁶ Financially and emotionally, Edison was committed to his **direct current (DC)** power and light system. But the DC system was destined to be a local enterprise because with DC there was no practical way to **transform** his 110 volts to high voltage for more efficient transmission over wires.²⁷

Unlike Edison, Civil War naval engineer George Westinghouse wasn't "hung up" on DC. In fact, he had already been fooling around with an **alternating-current (AC)** system to power arc lamps. He was keenly interested in hearing what a thirty-two-year-old Austro-Hungarian immigrant, Nikola Tesla, had to say about AC before the American Institute of Electrical

Engineers (AIEE) in New York City in 1888.²⁸ Tesla talked about the single-phase, two-phase and three-phase AC power generation and distribution systems that he had conceived, built, tested, and patented — complete with dynamos, transformers, distribution systems, and motors.²⁹

After the talk, Westinghouse approached Tesla with a direct offer. "I will give you one million dollars cash for your alternating current patents, plus royalty."

Tesla replied "If you will make the royalty one dollar per horsepower, I will accept the offer."

"A million cash, a dollar horsepower royalty," Westinghouse repeated.

"That is acceptable."

"Sold."

Tesla went to Pittsburgh to consult for Westinghouse. Accustomed to working for himself, it was a struggle for him to accept any changes by the Westinghouse engineers. One thing he was adamant about was his choice of 60 cycles per second for the frequency, instead of the 133 cps the company men wanted. Westinghouse built ten great dynamos at the Niagara waterfalls to start putting the country and then the world on an AC basis for electrical energy. The first, a fifteen-thousand horsepower generator went into operation in 1896.³⁰ To compete, Edison merged his company with that of Elihu Thomson to form the General Electric Company. Tesla set out, using the power generated at Niagara, to try to perfect his "world wireless system."³¹

High tension lines strung on poles soon criss-crossed the American landscape; they ran from water-powered dynamos into factories and towns. One of the first high-voltage lines was that run in 1897 from Provo to the Mercur mills; it carried electrical energy at 40,000 volts. Electricity became a powerful impetus to the three-dimensional growth of huge cities.

Power on the Hill

Of local electrical engineering interest is the University's AC dynamo at the first dam on the Logan river just upstream from USU's Utah Water Research Laboratory. It was built in 1912 and is still in operation. This is the brief story of how it came to be.

Dr. John Andreas Widtsoe, Jr., became the fifth president of the UAC in 1907. He was recalled to the college after his agricultural program at Provo threatened to eclipse that at Logan from which he had been discharged only two years earlier.³² Widtsoe, along with outspoken Professor Lewis Alford Merrill, had been dismissed from the UAC because of the internal "row" over whether President Kerr was pushing engineering and other fields at the expense of agriculture.

Shortly after Dr. Widtsoe returned to the UAC, he had to solve a very pertinent electrical engineering problem for the school. Mr. E.P. Bacon, the district manager of the Telluride Power Company of Colorado, called on President Widtsoe and informed him that the charges to the college for light

and power from their plant at the mouth of Logan Canyon would be doubled.³³ Sharp words ensued. Immediately after the visitor departed, Widtsoe and his engineering assistants, including Franklin Stewart Harris, surveyed a site for a small power plant further up the Logan river (the first dam). The next morning as soon as the statehouse in Salt Lake City opened, Widtsoe's assistant filed upon the site. Fifteen minutes later, a power company representative showed up to make the same filing, but he was too late. Later on, a diesel-powered electrical plant was also built. It was located adjacent to the Mechanic Arts Building.

President Widtsoe next determined that he would solve the scrap between the University of Utah and the UAC concerning duplicate engineering schools in the state. He went down to Salt Lake City to call in person on Joseph Thomas Kingsbury, the U of U president. Kingsbury invited his dean of the School of Mines and Engineering, Dr. Joseph Francis Merrill to join in the discussion.³⁴ Engineering roles for each school were agreed upon; the central theme of that at the UAC would be irrigation, that at the U of U was mining.

Armed with the U of U support, President Widtsoe was successful in having the restrictions on engineering partially removed by the legislature. Accordingly, the School of Agricultural Engineering and Mechanic Arts was established in 1912 and Franklin Stewart Harris was selected by Widtsoe as its director.

Frank Harris, was born on August 24, 1884, in the small farming community of Benjamin, a few miles southwest of Provo. He attended BYA for a year before going to Chihuahua in Old Mexico to teach, as his father had done before him. He returned to Provo as an undergraduate assistant to Dr. Widtsoe, who at that time was director of the BYA School of Agriculture. Harris joined Widtsoe in the 1907 move to Logan. After a year, Frank Harris went to Ithaca to get his Ph.D. in agronomy at Cornell University and then returned to Logan to join the faculty. In 1912 he was President Widtsoe's choice as the first UAC engineering "dean."³⁵

INFORMATION AND COMMUNICATIONS

Information Explosion

We will look next at the second great area of electrical engineering, namely, the transformation and transfer of information. The growth of communications by telegraph, telephone and radio during lifespan five — the period between the Civil War and World War II — was phenomenal. However, the synergism of telecommunications and the computer now taking place may be looked at by future historians as a second industrial revolution.

Communications

Soon after Joseph Henry's invention of the electromagnetic telegraph, electrical telecommunications spread quickly. Within the year, a system was inaugurated in Germany. In America, Samuel Morse had created his code and began to promote telegraphy. Morse was a good landscape and portrait painter, but he was a terrible technician and an even worse engineer. He wound his first electromagnet with bare wires directly on an iron bar, ignorant that the wire must be insulated. A friend, Leonard Dummell Gale, took over to adapt Joseph Henry's engineering while Morse did the promoting. Morse convinced Congress to pay for his telegraph line between Washington and Baltimore.³⁶ After consolidation with many small companies, Morse's telegraph system became Western Union.

The **telephone** was the logical extension of the telegraph, and may be considered as the last of the great, simple, electric inventions. In Germany at the time of the American Civil War, Professor Johann Phillip Reis experimented with a telephone that transmitted by musical tones.³⁷ Unknown to each other in 1876, Professor Alexander Graham Bell of Boston University and Elisha Gray, an Ohio electrician, on the very same day filed at the U.S. Patent Office for patents on a telephone.³⁸ Bell promoted his system at the centennial exposition, and soon a colossal telecommunications network sprung up. By 1900, the Bell Telephone Company alone had a million subscribers talking over a million miles of wire.

Via Wireless

The urge to destroy or avoid being destroyed has from the outset been the motivation for evolution of the machine. The Second World War literally revolutionized electrical engineering — "electrical" became "electronic." The war stimulus accelerated the miniaturization and refinement of electronic parts for **radio** and for **radar**.

Just before the turn of the century, Professor Heinrich Rudolf Hertz of Karlsruhe Polytechnic Institute experimentally established with certainty the electromagnetic waves predicted by Maxwell. The high-frequency oscillations inherent in spark discharges indeed projected waves off into space and the waves traveled at the speed of light. Dr. Hertz's receiving antenna was a brass ring, broken to form a tiny gap. Each time a strong arc was made to jump in the **transmitter** circuit some distance away, a tiny spark instantly showed between the gaps in the brass ring **receiver**. He showed that the waves produced could be reflected by metal objects, and also exhibited refraction and polarization as does light. The length between peaks of these electromagnetic waves was about five meters.³⁹

The problem in using the Hertzian waves for wireless telegraphy, however, was the difficulty of detecting the received signal. Searching for tiny sparks just would not do for practical communication. On New Year's Day, 1894, Hertz died of chronic blood poisoning. In the prime of life, this brilliant man was only thirty-six. Professor Oliver Joseph Lodge of University College, Liverpool, kept the work going by assembling a wireless system using a glass bulb filled with loose nickel filings as the detector.⁴⁰ He also used a coil and capacitance tuning system. Two years later, Guglielmo Marconi came from Italy to England, took out the first patents granted for wireless telegraphy, and put together the first commercial system using longer wavelengths than did Hertz. In 1901 in Newfoundland Marconi picked up the three dots of the Morse code "S" broadcast across the Atlantic from his transmitter in Cornwall on the first try. He soon had ship-to-shore wireless systems in operation; each shipboard wireless operator was appropriately nicknamed "Sparks."

The breakthrough to a suitable detector for wireless telegraphy came when John Ambrose Fleming, professor of electrical engineering at University College, London, adapted for Marconi the thermionic valve, or vacuum diode. While he was a consultant to the Edison Electric Light Company, Fleming had learned about the "Edison effect" of one-way electrical conduction from a light filament to another element in the bulb.⁴¹

In America Dr. Lee De Forest, graduate of Yale and early employee of the Western Electric Company, in 1906 interposed a fine screen between the plate and the filament of the Fleming vacuum diode. A minute negative charge on this grid could change or even shut off the current through the diode. This new device, which De Forest called an "audion," could be used either as an amplifier or as an all-electronic relay. It was the basic invention that gave birth to modern electronics.⁴²

After the success of Marconi, it was quickly realized that the transmission of the human voice via the wireless was feasible. A steady, high-frequency wireless wave could be impressed or **modulated** with a telephone signal to transmit actual sound. The same year De Forest invented his audion, Reginald Aubrey Fessenden used a modulated spark generator to broadcast music and a Bible reading. It was heard by several startled radiotelegraph listeners up and down the Atlantic Coast of America.⁴³

During and immediately after World War I, De Forest's tube began to be used in radiotelegraphs and radiotelephones — shortened to **radio**⁴⁴ — to detect and amplify the signals. Thousands of young men emerged from the war with training in the exciting new field of radio. Many became amateur radio "hams."⁴⁵ It was these hams who launched radio broadcasting. In 1920, five American stations began regular service.

Sidney Richard Stock from Fish Haven, Idaho, was one of the young servicemen of World War I.⁴⁶ He interrupted his studies in mechanic arts at the Utah Agricultural College to enlist in the Army Air Corps. After his discharge, he returned to the UAC, finished his B.S. degree, and was appointed as an assistant professor to teach auto ignition. His dream, however,

was of aviation. Soon, automotive and aeronautical electricity were his specialty in the Mechanic Arts program.

In 1929, the same year that the name of the school was changed to the Utah State Agricultural College, Professor Stock brought Larry Snow Cole of Logan to campus as an instructor for the first radio courses taught on campus. While still a teenager, Cole had been one of the first hams in Cache Valley. Then in 1925 he had started the first commercial broadcast station in northern Utah. Since very few people had radios, the station was ahead of its time and soon folded.⁴⁷

In 1936, Ray Benedict West, who had himself succeeded Franklin Harris as the dean of the School of Agricultural Engineering, unexpectedly died of pneumonia. George Dewey Clyde, later governor of Utah, became dean.⁴⁸ Dean Clyde set up a department of radio, aviation and automotive electricity under Professor Stock in the mechanic arts division of the engineering school.⁴⁹ Two years later, Ronald G. Bowen was added to the staff to teach radio and to assist the U.S. Forest Service in the operation and maintenance of their radio and telephone units. Professor Clayton Clark joined the faculty in 1937, replacing Professor Bowen.⁵⁰

Pictures Through Space

A Scotsman, Robert Alexander Watson-Watt, is considered to be the father of radar — the use of reflected radio waves to detect objects.⁵¹ He took out his first radar patent in 1919 while he was still an assistant at the University College in Dundee.

During the decade of the twenties when radio was in its exciting days of adolescence, Doctors Gregory Breit and Merle Antony Tuve of the Carnegie Institution of Washington attempted and succeeded in using radio pulses to measure the height of the ionosphere.⁵² With the backdrop of gathering war, crash programs in the development of radar were carried out in Britain and Germany to detect and locate enemy airplanes and ships. The early radars were like the radio pulse ranging equipment used by Breit and Tuve.

By 1938, practical radar equipment based upon the system of Watson-Watt was operational in Britain. The early radar sets played a decisive role in winning the battle of Britain and in losing the battle of Pearl Harbor.⁵³ On Hawaii, the advancing Japanese planes were detected by accident when an experimental radar unit was being operated by a soldier as an early Sunday morning punishment. The information was not acted upon.

The offensive application of radar in World War II greatly hastened the development of miniaturized electronics. The war also produced another technical change: conscription of talent. Scientists provided the “know-why”; engineers and technologists provided the “know-how.” To develop radar in America, engineering and physics talent was assembled into the Radiation Laboratory at the Massachusetts Institute of Technology in Cambridge, Massachusetts. The laboratory was staffed by professors from a number of

universities who were placed under the overall direction of Dr. Lee Alvin Dubridge of the University of Rochester.⁵⁴ Dispersed over the nation after the war and no longer forced to work in secret, the Radiation Lab engineers made a major impact upon sophisticated postwar electronics.

It was a simple step to make the postwar adaptation from radar pictures to wireless television pictures.⁵⁵ Practical television awaited the development of an all-electronic camera pickup device. It came in 1929 from a Russian immigrant working for the Westinghouse Corporation, Dr. Vladimir Kosma Zworykin, who the same year left Westinghouse and went to work for the Radio Corporation of America.⁵⁶ A decade later TV programs were being regularly broadcast in some of the large cities on the east coast. The first commercial TV station in Utah was KDYL-TV, which began regularly scheduled programs in 1948, the year TV came to some fifty cities across the U.S. The first transcontinental TV relay system was completed three years later to give live nationwide programming.

Information

Shortly after World War II, from the same place and at the same time came two developments that precipitated the second revolution in electrical engineering. It took place in lifespan five.⁵⁷ The place was the Bell Telephone Laboratories; the year was 1948. The developments were (1) the invention of the transistor and (2) the formulation of **information-communication theory**. Together, they made possible the seemingly unlimited possibilities of the **computer-telecommunications system**.

The transistor was invented by Doctors John Bardeen, William Bradford Shockley, and Walter Houser Brattain. This solid-state **semiconductor** device was the logical outgrowth of the crystal detector, just as De Forest's "audion" was the follow-on of Fleming's valve forty years earlier.⁵⁸

Within a few years after the invention of the transistor, several investigators saw that the characteristics of semiconductors, such as doped silicon and germanium, might be further exploited. The body resistance of the semiconductor itself and the capacitance between the junctions of its positive and negative regions might be combined with the transistor action to create a tiny complete circuit of resistors, capacitors and amplifiers. In 1953, Harwick Johnson of RCA patented such an **integrated circuit**. **Microelectronics** had arrived on the scene.⁵⁹

Today, an integrated circuit on a single quarter-inch chip can embrace more electronic elements than the most complex piece of electronic equipment that could be built at the beginning of the 1950s. For example, the pocket calculator contains about a hundred times as many transistors as a TV receiver.

The use of microelectronics, based upon the integrated circuit, has precipitated the third revolution in electrical engineering.⁶⁰ The use of

IC's has increased ten-fold every five years since 1960.

I wish next to turn to the synergy of microelectronics with perhaps its most profound application.

There was a scientist who asked a giant computer: "Is there a God?"

The machine whirred and then answered: "There is now."

With the passage of time, the national consciousness more and more tends to remember microelectronics as created because of the computer. It was the opposite.⁶¹ The missile and satellite programs called for complex electronic systems with severe restraints on size, weight, power, and reliability. The microelectronics development was promoted and paid for largely by the military and space agencies.

The first significant electronic computer was built by the University of Pennsylvania in 1946 to perform ballistics calculations for the U.S. Army Ordnance.⁶² This computer used a myriad of vacuum tubes. When transistors became available the large computer became practical, but it was fussy about its air conditioning.

The computer was a necessary precedent to the space age. Orbit determination and inflight corrections would have been impossible without the computer.

The other development from the Bell Laboratories in 1948, that I want to comment briefly about, is Dr. Claude Elwood Shannon's conceptual formulation of the underlying principles of communication systems. His work is the foundation of information-communication theory.⁶³

Shannon made it possible for communication engineers to distinguish between what is possible and what is not possible. He gave them a quantitative measure of the effectiveness of their systems. He accomplished this by showing how to (1) measure the **information rate** of a message source — such as the output from a microphone or a TV camera — and (2) how to measure the **capacity** of a communication channel — such as a telephone line or a microwave relay.

Shannon also showed that it was possible to attain error-free transmission over noisy communication channels. Hitherto, this was thought to be impossible. He discovered that for random noise, the interference can be reduced by **statistical processing** without a corresponding reduction in signal level.⁶⁴

The year after Shannon's publication, Dr. Warren Weaver of the Rockefeller Foundation extended Shannon's work in a joint publication. Weaver divided the problem of communication into three levels.⁶⁵ These are: (1) The **technical** — How accurately can the symbols of communication be received? (2) The **semantic** — How well do the received symbols convey the desired meaning? (3) The **effective** — How effectively does the received meaning affect conduct in the desired way?

As an example of Weaver's division of the problems of communication, in this paper I have some confidence of success at the technical level of communication. Wayne Kraft⁶⁶ says at this shallowest level of information transfer that **patterns** are the primary concern. What is most important is the

language, namely, the appropriate grouping and sequencing upon each page of symbols taken from the Roman alphabet and from the Arabic numerals. Add to this proper grammar and faithful typography.

Less certain am I of communication at the semantic level, where meaning is of prime consequence. Quite apart from the symbolic or phonetic details of the paper, does it convey *knowledge*? What interpretation will my reader give to my meaning?

Finally, at the deepest level of communication theory, namely, the effective plane, changing behavior is the primary focus. Here, every author embarks with a mix of audacity and trepidation. From Kraft: "Every message ever sent by anybody is presumably sent with the *ultimate purpose* of affecting, modifying, or influencing behavior of the recipient in one way or another." We logically conclude that the ideal content of communication at the effective level would be *wisdom*.⁶⁷

SPACE DIMENSION

Upper Air

One of the physicists at the MIT Radiation Laboratory in Cambridge, Massachusetts, was Dr. Leon Blood Linford of Logan.⁶⁸ He had graduated from the UAC in 1924 and then stayed on for two additional years of graduate study in physics prior to going to the University of California where he obtained his Ph.D. in 1930.

After the Radiation Laboratory was disbanded at the end of World War II, Dr. Linford returned to Utah to become head of the Physics Department at the University of Utah. There in 1947 with Dr. J. Irvin Swigart of his staff and Professor Obed Crosby Haycock of electrical engineering, he started a project of radar pulse soundings of the ionosphere using V-2 rockets.⁶⁹ He obtained funding from some of his former Radiation Laboratory colleagues who joined in the formation of the Geophysics Research Directorate, one of several research units located in Cambridge and Boston which the government coalesced into the Air Force Cambridge Research Center. By 1951-52, Dr. Linford's Upper Air Research Laboratory at the University of Utah had contracts from the Air Materiel Command exceeding a hundred thousand dollars.

The rockets and electronics marriage contract between Utah's universities and the U.S. Air Force is now entering its fourth decade. A thousand students are the fruitful pride of this wedding.

Outer Space

Man's modern challenge to the "outer" spatial dimension⁷⁰ began in earnest with the rocket experiments of Dr. Robert Hutchings Goddard, physics professor at Clark University in Massachusetts.⁷¹ As a post graduate student at Princeton University before World War I, Goddard had demonstrated that rocket propulsion would work in a vacuum. He obtained a five-thousand-dollar grant from the Smithsonian Institution during World War I to experiment with rockets. On March 16, 1926, he successfully launched the first liquid-fueled rocket, an event comparable in significance with the first aeroplane flight of the Wright brothers from Kittyhawk in 1903. Unwanted in the Commonwealth of Massachusetts and unfathomed by the federal bureaucracy — but armed with a five-thousand-dollar Daniel and Florence Guggenheim Foundation grant — Goddard moved his work into the empty deserts of southern New Mexico.⁷² Charles Augustus Lindbergh, who had just flown an aircraft solo across the Atlantic, helped Goddard get the grant.

On the opposite side of the world, another school teacher also dreamed of space travel: Konstantin Eduardovich Tsiolkovsky, the Russian father of space flight. Using only his imagination and his mathematics, he had determined that the way into space was with multistage rockets powered by reaction engines. He also had the foresight to realize that high air-friction temperatures would be encountered. Fridrikh Tsander and Valentin Glushko led a team of men who set out to fulfill Tsiolkovsky's dream. By 1936, they had flown a two-hundred-pound rocket three and a half miles into the air.

However, it was the Germans who set the pace in rocketry. Inspired by the space travel writings of Hermann Oberth and funded by the Nazi war machine, Captain Walter Dornberger led the engineering research team. He held a doctorate of engineering; his young engineering graduate student was Werner von Braun. In 1939, they flew a rocket to a height of seven and a half miles. Three years later, they sent a scaled-up version to an astonishing altitude of fifty miles. It flew outside the earth's atmosphere and came down 120 miles distant.⁷³ It was true, the reaction engine didn't need air "to push against." In Deutsch, Dornberger said to von Braun: "Do you realize what we accomplished today? Today the space ship was born." The rocket became known as the V-2; forty-three hundred were operationally launched by the Germans.⁷⁴

In early 1945, the German defenses crumbled before the Russian forces advancing upon the Peenemünde rocket base. The key German engineering personnel, including von Braun, gathered up their papers and plans and with their families hurried to the underground rocket assembly site in the Harz Mountains near Nordhausen where they were then held by their own SS troops. The U.S. 3rd Armored Division overran this area in April to capture both the V-2 factory and the key personnel. The underground factory was a former salt mine a thousand feet underground — a twelve-mile labyrinth.

The V-2 parts were scattered about the huge tunnel factory where slave labor had been used for assembly. Since the area would be in the Russian zone, railroad bridges were quickly rebuilt, trains rounded up with German trainmen and three hundred boxcars of components for a hundred V-2's and thirty-two tons of engineering documentation were hauled to the dock at Antwerp where they were loaded on sixteen liberty ships and taken to America under the direction of Holger Nelson Toftoy.⁷⁵ By permission of the State, Commerce and War Departments, Toftoy was allowed to select a hundred of von Braun's "prisoners of peace" to bring to the U.S. Beginning in December of 1945, a total of a hundred and twenty-seven came and were housed in an army hospital within a fenced enclosure at Fort Bliss near El Paso, Texas.

The Army Ordnance Proving Ground at White Sands, between Las Cruces and Alamogordo, was selected to be the rocket testing range.⁷⁶ Here, the German engineers began to assemble the V-2 rockets under the direction of American army officers. The General Electric Company was given a contract by Army Ordnance to provide technicians to support the launches.

Instead of explosive warheads, the warhead compartments were used to house observing and recording instruments for the measurement of the upper atmosphere. These instruments were provided by agencies of both the Army and the Navy, and also by the Air Force after it was split off from the Army.⁷⁷ Six universities participated in the upper-atmospheric studies using the V-2 rockets. One of these was the research team set up at the University of Utah by Dr. Leon Linford.⁷⁸

By the early fifties the supply of a hundred German V-2's was exhausted. Anticipating this, the Applied Physics Laboratory at John Hopkins University was given a contract by the Navy to develop a fin-stabilized, upper-atmosphere research rocket. The result was the *Aerobee*. This workhorse rocket for upper atmospheric research, manufactured in quantity by Aerojet General Corporation of California, is still being used.⁷⁹ Numerous radar pulse transmitters and receivers were flown by the University of Utah engineers aboard these "sounding" rockets to ascertain the nature and structure of the ionosphere.

Aerojet was a company spun off by Dr. Theodore von Karman, wartime director of the Jet Propulsion Laboratory at the California Institute of Technology. This school was California's answer to MIT, and as soon as the MIT Radiation Laboratory was closed at the end of World War II they hired its Director, Lee DuBridge to be its president.

Another company that came to work closely with Caltech's JPL, was Thiokol Chemical Corporation. JPL ordered five gallons of their liquid synthetic rubber called "thiokol." The name was taken from the Greek words *thio* for sulfur and *kol* for glue. The concoction looked like molasses and smelled like rotten eggs. This synthetic rubber was accidentally discovered by Dr. Joseph C. Patrick in 1926 and was manufactured in Kansas City. The neighbors didn't like the stench and so asked the company to leave.

The JPL engineers found that a form of the synthetic rubber with solid perchlorate and aluminum particles could be used as a solid fuel for rockets. The "rubber" could be easily casebonded into the rocket motor, leaving a star-shaped opening for a burning surface. The Army agencies funding JPL asked Thiokol to go into business manufacturing the solid-propellant motors. Joseph W. Crosby, the president of Thiokol, hired Harold W. Ritchen and others to set up their plant at the Army's Redstone Arsenal near Huntsville, Alabama.⁸⁰

As a coincidence, three days after *Sputnik* was launched in 1957, Ritchen established for Thiokol its solid propellant research and production facility on a fourteen-thousand-acre tract of land northeast of the Great Salt Lake. They turned out the solid propellant engines for the *Minuteman* and for the space shuttle. Its peak employment reached about five thousand persons.

The United States suffered a technological shock when the Russians orbited *Sputnik II*, which weighed half a ton and carried a live dog. America, accustomed to thinking of itself as the most advanced and most powerful nation on Earth, was stunned.

Von Braun's team, then at the Redstone Arsenal, was released from foolish political constraint, and within ninety days put a satellite into orbit. The great space race was underway. Charged to restore America's prestige, NASA was hastily formed and copiously funded. The first steps were not long in coming; late in the year 1958, the U.S. sent a probe out to a distance of nearly ten Earth diameters. Man's machines had at last truly ventured to outer space. "How high" lost its meaning to technical jargon: "apogee" and "perigee."

For a solid decade it was Russo-American leapfrog. A blurry Russian picture was obtained of the never-before-seen backside of the Moon. Then she was touched by one of man's machines; the twisted wreckage of a *Lunik* forever testifies to her violation. Soon, one of the orbiting space ships had a man in it; he spoke the tongue of Mother Russia. In turn, American robot ships flew past Venus and then Mars. When the Russians crashed a probe onto Venus in 1966, man's machines had touched the planets.

The flight of the American space probe, called *Mariner II*, in August of 1962 did not yield scientific results that can be described as revolutionary. Radio astronomy had shown six years earlier that the planet's surface was very hot. However, the engineering results were spectacular. The demonstrated ability to take instruments by remote control to within twenty-one thousand miles of Venus, to make measurements, and then to transmit the results to the Earth (which was thirty-five million miles away at the time) is a spectacular achievement. The significance of this "first" has passed into history largely unnoticed, even by mechanical and electrical engineers. While it was visiting Venus, the power of the signal received on Earth from the transmitter on *Mariner II* was only 10^{-18} watt. The electrical power of the transmitter on the space ship was only three watts.

The instruments and transmitter aboard the probe to Venus were provided

electrical energy from a panel of ten-thousand silicon solar cells. This solar battery, which produces electricity directly from sunlight, will become even more important as a future clean source of electrical energy.⁸¹

While these first phases of space research were being carried out, American engineers designed and built a rocket system the likes of which may never be seen again. Their creation stood higher than a thirty-five story building. If it had been possible to weigh it, the scales would have pointed to three thousand tons. It could fly faster than the “magical” twenty-five thousand miles per hour needed to leave the Earth without further energy. They called it *Saturn*.

Using this “humongous” spaceship, American explorers were able to fly to the Moon. Reconnoitering on Christmas Eve a decade ago, they sent home to TV onlookers images of both the Moon and the Moon’s “moon” — Earth. On the next trip it was time to land; July 20, 1969, aeronautical engineer Neil Alden Armstrong and his companion Dr. Edwin Eugene Aldrin, Jr., stepped out of their space machine and walked upon the Moon.

Discovering Earth

By leaving footprints in the Moondust, America restored her technological prestige. The venture had shown that the fear of bullet-like meteors was unfounded and that the perils of radiation, vacuum and weightlessness could be overcome.

Behind all the international hubub, though, was the fanciful wish to see what form extraterrestrial life would take. The fear of ridicule as a crackpot, as happened to planetary astronomer Percival Lowell,⁸² was enough to make most scientists and engineers keep their space-life anticipations to themselves. Sure enough, the Moon was dull, silent and devoid of life. But despite the fanciful Moon stories of Jules Verne a century ago, it was the planets (and most especially Mars and Venus) which were imagined as the habitats of strange creatures. People expected to find life on the planets.

In 1924, scientist Maynard Shipley answered the question: Are the planets inhabited? “Changes in the canals (of Mars) and other dark markings require vegetation for their satisfactory explanation. If Mars possesses plant life, then we cannot it seems, logically exclude animal life.”

Mr. Reginald Ryves, a British authority, found it difficult to believe that the canal system is not a feat of Martian engineering.

Willy Ley, the German paleontologist, said: “We are justified in believing in life on Mars. As of 1949: the canals of Mars do exist.”

The space probes revealed beclouded Venus to be a boiling cauldron. Polar-capped Mars turned out to be a pockmarked, rockstrewn, lifeless desert. The mystique of the red planet was forever stripped away. We were suddenly left with facing up to an, at best, dim prospect of finding any other life within our physical solar system.⁸³

Life on the far distant worlds of the other stars? Will we go there to find out? Good news and bad news in this regard. The good news: the *Saturn* can

boost its forty-five ton payload fast enough for a coasting escape from the gravity of both the Earth and the Sun and thus reach the nearest star: object alpha in constellation Centauri. But the bad news is that it would take half a million years to get there. Rocket speeds of tens of millions of miles per hour may be achieved in the twenty-first century when exotic nuclear, ion and photon motors are engineered. But even then, flight to the nearest stars will still take half a millenium.

In looking into outer space, we have rediscovered the priceless uniqueness to us of our inner space. Here on Earth, life teems in countless exotic forms for us to see and enjoy. The suprasystem must care for wildlife as well as humanlife, it looks like it's all we will ever have.⁸⁴

Space Research at Utah State

Dr. Leon Linford died of cancer late in the year 1956, and Professor Obed Haycock became director of the Upper Air Research Laboratory at the University of Utah. To assist in some of the ground instrumentation, Haycock gave a modest subcontract to Professor Larry Cole, head of the electrical engineering department at the USAC.⁸⁵ The same year that Professor Cole and some of his students began participating in *Aerobee* rocket experiments at the Holloman Air Force Base near the White Sands Proving Ground, Professor Clayton Clark returned from obtaining his Ph.D. at Stanford University. He immediately started a graduate program in electrical engineering based upon ionospheric and antenna research.

In 1958, while on the way to and from the nuclear tests at Eniwetok atoll, Professor Cole asked me to look over the campus of Utah State University and the program planned under Dean Freeman Peterson, Jr., which included a new building for engineering.⁸⁶ I decided to join his electrical engineering faculty the next spring. My purpose was to teach and to develop a graduate research program combining electromagnetics and space research.⁸⁷

During the summer of 1970, the space research program made a significant advance when Dr. Kay D. Baker moved his research program from the University of Utah to Utah State University. Upon coming to USU the Upper Air Research Laboratory was renamed the Space Measurements Laboratory, and was administered under the Center for Research in Aeronomy, itself founded in the year previously to give USU scientific balance to complement the already strong engineering expertise in the Electro-Dynamics Laboratories.⁸⁸

A third major addition to the USU space program occurred in 1975 when Dr. Peter M. Banks similarly brought his research team to USU. Under his leadership, grants have been obtained from NASA to put USU experiments aboard the Space Shuttle. The first NASA shuttle is scheduled for launch into orbit around the Earth in late 1979 or early 1980.⁸⁹

SYSTEMS

System Dynamics

In this concluding section, I wish to tie some of the previously discussed observations into a bigger picture — the suprasystem. My approach is to consider some of the aspects of system theory, another branch of electrical engineering that evolved out of the secret research of World War II.

Nobody is happy with any definition of the word “system,” but everybody keeps using it. Probably, if we define it too precisely we will kill its utility.⁹⁰ At least we can wisecrack about it:

Waldo’s observation is: “One man’s red tape is another man’s system.”

Shaw’s principle says: “Build a system that even a fool can use, and only a fool will want to use it.”

The one I like best is Zymurgy’s first law of evolving system dynamics: “Once you open a can of worms, the only way to recan them is to use a larger can.”

Modern systems are becoming increasingly larger and more complex. Today, a typical large electrical engineering system consists of (1) control, (2) computer, and (3) communication subsystems, functioning in a highly integrated and interdependent manner. Before talking about the composite system, it is necessary to consider some of the principles of control.

Feedback

In the first half of the third century B.C. there lived in Alexandria a barber named Ktesibios. The balmy Hellenistic city on the Mediterranean near the mouth of the Nile was flourishing with the scholars of the world: Aristarchus, Euclid, Archimedes, and Eratosthenes. In the account given by Otto Mayr,⁹¹ Ktesibios, while engaged in crafting a great water clock, invented the float valve. His gadget is regarded as the oldest known **feedback control system**.

Constant water level systems were subsequently contrived by Philon of Byzantium a generation later and then by Heron of Alexandria in the first century A.D. These men were delighted with the pure principle of the invention; “They were able to think in terms of **closed causal loops**.”

The float valve regulator, as is used in automobile carburetors, and other feedback control systems all have the following common characteristics:

(1) A given entity is **automatically maintained** at a desired value despite external circumstances.

(2) It operates as a closed loop with **negative feedback**.

(3) It includes a **sensing element** and a **comparator**.

Feedback is a method of controlling a system by reinserting into it the results of what it is already doing. For comparison, the feedback signal is transmitted from the output side back to the input side of the system. The

algebraic sign of the feedback is negative because you want the correction signal to be the *difference* between what the system is actually doing and what you want it to be doing.

The first (1620) feedback control system invented in modern Europe was Cornelius Drebbel's constant temperature chicken egg incubator and chemical furnace. The feedback device that attracted the attention of the general engineering community, however, was the centrifugal governor James Watt used in 1788 to control the speed of his steam engine.⁹² Perhaps the most familiar contemporary feedback control is the thermostatic system in each of our homes. Starting with the humble temperature regulator, the Honeywell Heating Specialties Company built itself into a corporate giant.

Control engineering blossomed during the Second World War. Problems of gun aiming, bombsights, radar, autopilots and guided missiles were solved by electrical and mechanical engineers unable to reveal what they were doing. When the veil of secrecy was lifted, the concept of feedback control had already passed through adolescence and was ready to spread from engineering into other disciplines. Its utility was discovered by biologists, economists and sociologists.⁹³

An incisive, rigorous development of system control theory was formulated by Dr. Norbert Wiener, professor of mathematics at MIT. He published his work in that same pivotal year, 1948, that both Shannon's communication theory and the Bell Laboratories transistor came forth.⁹⁴

It was feedback control that brought success to Goddard out in the dust of New Mexico. He had long been plagued by his rocket tipping over soon after launch. The key is to use a gyroscope to sense any change in the vertical orientation of the rocket. An electrical departure signal is generated and used to drive two pairs of movable vanes located aft of the exhaust nozzle. The vanes in the discharge stream deflect the escaping gases in the direction needed to counter any tendency of the rocket to tip over.⁹⁵

Professor Wiener's perception was so broad that he envisioned that a new field was being born. He christened the new field "cybernetics"; he adopted the Greek word for "steersman" which he found by searching the etymology of the word "governor." André Marie Ampère, for whom the electrical current unit is named, had conducted the same search in 1843 for a different reason. He proposed cybernetics to mean the science of government.⁹⁶

Wiener referred to the prime concept which he expounded by the physiological term **homeostasis**, the function of an organism so as to self-correct for adverse disturbances — in other words, negative feedback system control. He observed that too much negative feedback can lead to system **instability**, as can the absence of feedback or the presence of **positive** feedback. Wiener's cybernetics is a general overview of the relationships between certain concepts and man and his world — the suprasystem. His homeostasis is a specific concept within cybernetics.

Analysis of the stability of systems has been advanced by many persons. Two that come to mind are Drs. Harry Nyquist and John Robinson Pierce, additional bright electrical engineers of the golden age of the Bell Telephone

Laboratories.⁹⁷ Control theory has developed to the state that a very general and flexible tool now is available for **system optimization**. However, before concluding with some optimal system concepts and speculations, it is important to address briefly what can happen when the feedback is positive instead of negative.

Linear Perception by Nonlinear Beings

A closed feedback loop without the reversal of sign is **unstable** — it can be a “vicious circle.” **Positive feedback** leads to explosive growth. However, such constructive feedback can be exploited to our benefit, as the following example illustrates. Even though we engineers are so familiar with the effect, it still startles us. Our senses are physiologically nonlinear, but at first blush we seem to think of things as being linear.

Open a savings account for your daughter today by depositing a thousand dollars at simple ten percent interest. After one lifespan — 80 years — she will have eight thousand dollars interest plus the original thousand: a total of **\$9,000**. This is **linear growth**. Double the time, double the increase.

Compare this with depositing each interest amount as it is earned and adding it to the bank balance. This positive feedback technique is, of course, called “**compound interest**.” What will the total be after one lifespan? If the interest is compounded daily, the eighty-year accumulation will be **\$2,980,076**.

In comparison, if your daughter withdraws the money at middle age (40) she will receive but fifty-five thousand dollars. The growth is highly **nonlinear**: Divide the eighty-year total by the forty-year amount and note that double the time gives fifty-five times the increase!

The formula for computing the compound interest growth is

$$\$1000(1 + \frac{10\%}{365})^t$$

where t is the number of days since the thousand dollars was deposited. Time appears as an exponent. Thus, the feedbackwards of output to reinforce input has caused **exponential growth**. Exponential growth can just as easily be disastrous as it can be beneficial. One person's interest credit is another person's interest debt. Inflation is today's prime example. Ten percent yearly inflation, compounded daily, can raise the price tag on today's thousand-dollar-a-month household bill to three million dollars a month in our children's lifetime.⁹⁸

Unchecked, positive feedback growth will “go critical” like the chain reaction in a nuclear bomb and explode to its limit. In its infancy, however, the exponential regeneration “demon” masquerades itself as innocent **linear progress**. And so it is that the false assurance of a past remembered, can deceive us into neglecting the coming future.

Implosion

Any exponential growth, whether a voltage in an electrical circuit or the size of a corporation, must eventually reach a limit. If the constraints that determine the limit of the exponential growth are properly engineered, at the appropriate time the feedback in the system is changed from positive to negative to achieve a steady state at the desired level.

Without intrinsic constraints, the growth will continue until resources are exhausted and/or a system component has been stressed beyond its limit. If many interactive components blow out, the failure of the system will be catastrophic.

Our suprasystem — the world — is ultimately limited by space as well as resources. Our ecosystem is inside a closed box. If uncontrolled, positive feedback drives things into explosive saturation, the explosion is directed inwardly back upon itself. The suprasystem will **implode**.

Once parameters start to decrease in a system with positive feedback, the decrease is reinforced whereas previously it was the increase that was reinforced. This leads to **exponential shrink**.

Our suprasystem seems to have evolved, at least since the days of the great plagues, in a general state of positive feedback. All five basic factors of the suprasystem — (1) *population*, (2) *industrial production*, (3) *agricultural production*, (4) *material resource consumption*, and (5) *pollution* — are rising exponentially. To an electrical engineer, circuit voltages and currents increasing exponentially is a familiar scenario: smoke, panic, hit the switch. Invariably, it's too late. The circuit had to be made "idiot-proof" in the first place. The great question we all face is: What will be the system response when one or more of the above system factors reach saturation?

Feedforward

Paul Ehrlich's rule about intelligent re-engineering is: "Save all the parts."

We are rushing toward a world of almost unmanageable technical complexity.⁹⁹ The piecemeal, cut-and-try design approach, with redesign and patching, isn't good enough anymore. Although our technology can be blamed for many of our problems, it is also our technology — supported by our engineering and science — that comes to the rescue by providing us with advanced tools to deal with the situation.

The evolutionary approach to system design, which allows for changing needs, proceeds as follows: (1) Formulate the design problem, (2) visualize the overall framework and outline the system functions, (3) define and analyze the subsystems and their interrelationships, (4) decide the implementation sequence, (5) perform detailed subsystem design, (6) re-examine the system requirements and feedback the design results, and (7) continue the design cycle. The approach used by the system engineer is often a formalistic one using

models — replica or symbolic. However, other approaches may be adopted, particularly for social organizations, such as the heuristic, the operating unit, and the *ad hoc*.¹⁰⁰

To conclude, let's speculate from today's perspective at the meridian of the fifth lifespan since the English settlement of America. What's to be expected during the second half of this lifetime, keeping in mind Fiedler's enunciation of the scientists' credo: "Forecasting is very difficult, especially if it's about the future."

Decade of the 1980's. This will be the time of grandparenthood for a person born at the time of World War II. There will be crises of financing and faculty morale in the nation's universities. President Jerome Wiesner of MIT has given a most relevant articulation of the accelerating problem.¹⁰¹ The crisis is precipitated by inflation and computerized "bean counting," and is exacerbated in engineering schools by the country's extreme shortage of engineers. The Malthusian population increase will continue, and the demand for energy will increase even faster than the population. The energy base will still be fossil fuels, primarily oil. The demand for electrical energy will increase faster than the total demand for energy. Communications will grow faster than population due to positive feedback of knowledge. The most rapidly growing telecommunication links will be for data access; however, mass-produced logic microcircuits will lead to localization of data processing. Numbers of amateur computer "hams" will appear on the scene. Mobile and portable telephones will proliferate. Picture-phones will become common, lessening the need for mandatory travel. Wall-sized, high-fidelity color TV via coaxial cable will substantially replace present low-resolution sets in the home. Cartridge libraries will become common. Space activity will primarily be near-Earth using the Space Shuttle, except for several unmanned "grand tours" of the outer planets which will report no evidence of extraterrestrial life.

Decade of the 1990's. At the universities there will be a crisis in management due to accelerating size and complexity; grinding day-to-day pressure of details will threaten even more to turn remaining leaders into mere custodians of their offices. The shortage of oil will grow more acute, and the demand for electrical energy will lead to the crash development of electrical power plants fired by coal, nuclear fission, nuclear fusion, and solar energy. With the development of powerful minibatteries, electrically-powered motors will begin replacing gasoline engines. A telecommunications capacity crisis will lead to the building of helical waveguide transmission networks operating at millimeter wavelengths. Dozens of synchronous communication satellites will be launched into orbit, and modulated-laser-beam telecommunication relays will be developed. Microcomputer-controls applied at home, at work and in the car will become necessities. Microelectronic engineering can be expected to be applied to molecular biology with revolutionary results.

Decades of the 2000's. Land that existed in great abundance all through

history suddenly will become scarce. Oil will be in short supply. Metals will become scarce. There will be pollution crises and food crises.¹⁰²

To the engineer the problems have never looked tougher, but at the same time the possibilities have never been greater.¹⁰³ Forces should come into play to counter the Homeostatic exponential growths. The steady state of the suprasystem we seek to reinforce will probably not be DC, but will be oscillatory like the AC, born from the genius of Maxwell and Tesla, that electrically directs and powers the modern world.

¹In order to give emphasis, words that have technical meaning are presented bold face where they first appear in context.

²John W. Gardner, *No Easy Victories*, Harper and Row, N.Y.; 1968.

³The Land Grant Act was signed July 2, 1862, two months before the battle at Antietam, the bloodiest day of the war between the states.

⁴The Land Grant Act of 1862 is often called the Morrill Act, after Representative Justin Smith Morrill from Vermont. The real father of the concept of a federally-sponsored university for farmers and mechanics in each state was Jonathan Baldwin Turner, professor at Illinois College of Jacksonville in President Lincoln's home state.

⁵The name of the University of Deseret, originally founded in 1850, was changed to the University of Utah by Legislative Assembly act of 1892.

⁶Antho[n] Henrik Lund, was the delegate to the House from Ephraim who introduced the bill.

⁷The first semester's work began on September 2, 1890. There were nine faculty members and 139 students. Everyone had to attend chapel exercises every day. Each class missed was five demerits; a hundred demerits meant dismissal from college. The south wing of the main building was started in 1889. The north wing was added in 1894, and the front portion was added in 1901.

⁸These men were G. M. Orrock (1892) and Samuel Fortier (1893), respectively.

⁹The Mechanic Arts building was destroyed by fire in 1905; it was rebuilt the following academic year.

¹⁰This Mormon college closed its doors in 1926 after 48 years of operation, and seven of its faculty members joined the UAC faculty. The college was Brigham Young's answer to the land grant system. He set aside 10,000 acres which extended west from the original 1855 Elkhorn Ranch site, for support and location of a church college. Part of this area is today still known as "Church Ward" and "College Ward", although the BYC was built at the present site of Logan High School.

¹¹In 1903, the name was changed to Brigham Young University; Tanner was a member of the first BYA graduating class in 1878.

¹²Paul, who like Tanner had been president of the BYC, was a sociologist from Illinois Wesleyan University. He succeeded Sanborn as president of the UAC in 1894.

¹³In 1900, President Tanner resigned because of the opposition of non-Mormons to having a polygamist at the head of a state educational institution. Ironically, his successor, Democrat William Jasper Kerr from Smithfield, was also a polygamist, but at least he wasn't a Republican.

¹⁴Earlier in the legislative session, the college barely escaped from being consolidated with the University of Utah. Since consolidation required a constitutional amendment, a two-thirds majority was necessary in the state senate; fortunately, the attempted consolidation bill of 1905 failed — the margin was only two votes. Kerr had served as a delegate from Cache County in the 1895 Constitutional Convention. At that time, he had favored consolidation, joining those who said the small state of Utah could only afford one tax-supported college. As president of the UAC, however, he angered both the U of U administration and the agriculturists at the UAC by planning schools of engineering and mining.

¹⁵The UAC billed herself as Utah's industrial school, with agriculture being the basic industry. Her ads touted the land grant college goal; "In the twentieth century no young man or woman need be uneducated."

¹⁶D. H. Meadows et al., *Limits to Growth*, Universe Books, N.Y.; 1972.

¹⁷The shake is the equal of 10^{-24} seconds. The Pre-Cambrian Era was 4×10^9 years; as an aside, this tells us that Dublin Professor James Ussher's traditional age of the world (4,0004) is off by six zeros.

¹⁸The National Aeronautics and Space Administration was organized by Congress on October 1, 1958.

¹⁹Prior to the invention of the dynamo small amounts of continuous electrical current were derived from the battery, invented in 1796 by Count Alessandro Giuseppe Antonio Anastasio Volta, professor at the University of Pavia in Italy. The unit for electric potential, in other words voltage, is named in his honor. Earlier, it was found that static electricity could literally be stored in a bottle; the capacitor, called the "Leyden phial", was discovered by Professor Pieter van Musschenbroek in 1745 at Leyden, Holland.

²⁰Prior to his appointment to Albany Academy, Henry had worked as a civil engineer surveying a road from West Point to Lake Erie. Having aspired to be an actor, he was an entertaining teacher. He built electromagnets more powerful than anyone had ever seen before; some could lift a ton.

²¹Maxwell reported his revolutionary approach in "A Dynamical Theory of the Electromagnetic Field," published in *Phil. Trans.* Vol. 155; 1865. He predicted, theoretically, that it was possible for the effects of

electricity to be radiated in the form of waves, similar to light waves and traveling at the same speed, but with a much longer wave length.

²¹The charge of the electron, the smallest unit of electrification known, was not measured until 1910, when graduate student Harvey Fletcher, from Utah, and his professor at the University of Chicago, Robert Andrews Millikan, made the achievement using an oil drop experiment. Fletcher, the father of recent NASA director James Chipman Fletcher, later served on the staff of the Bell Telephone Laboratories where he invented the stereophonic sound system. He later served as dean of science and engineering at the BYU. The term "electron" is derived from the Greek word, *elektra*, for amber. The name "electron" was first suggested by the Irishman George Johnstone Stoney in 1891, although the word was first used in another sense by Homer in 900 B.C. Some historians have credited the discovery of the electron to the Prussian, Johann Wilhelm Hittorf. (See E. Whittaker, *A History of the Theories of Aether and Electricity*, Harper, N.Y.; 1951.)

²²The first commercially successful electric motor was demonstrated by the American blacksmith, Thomas Davenport, in 1837. As early as 1841 at King's College, London, Professor Charles Wheatstone, of resistance bridge fame, followed up the Faraday-Henry induction discoveries with a generator using revolving permanent magnets that gave essentially continuous electrical current. In 1863, Englishman Henry Wilde invented a generator using electromagnets instead of ordinary permanent magnets, which Dr. Werner Siemens modified by putting the field coils in series with the armature coils so the machine supplied its own current for the electromagnets. Siemens called his machine a dynamo.

²³The arc welder was invented in 1886; Thompson later merged his company with Edison's to form GE.

²⁴Pioneers along the way were Frederick de Moleyns (1841), J.W. Starr (1845), and Joseph Wilson Swan (1848). (See E.T. Canby, *A History of Electricity*, Hawthorne, N.Y.; 1963.)

²⁵This DC power plant was built in 1881. (See R. Calder, *The Evolution of the Machine*, Van Nostrand, N.Y.; 1968.)

²⁶The heating loss in a wire varies as the square of the current but is independent of the voltage. Therefore, since the power transmitted is the product of the current and the power, the most efficient power lines are operated at high voltage. Edison's argument was that high voltage AC would be too dangerous.

²⁷A baby was born exactly at midnight July 9-10, 1856, at Smiljan in what is today Yugoslavia, to begin a strange experiment with life that comprises the story of Nikola Tesla — creator of the modern electrical era. After studying EE at Gratz and then Prague, he came to America in 1884 to work for Edison, with four cents in his pocket. Edison jokingly told Tesla he'd pay fifty thousand dollars if defects could be designed out of his DC dynamos. After Tesla accomplished the redesign, he learned the joke was on him. Finding Edison not interested in AC, Tesla left to become a ditch digger by day and an experimenter by night.

²⁸This was five and a half years after Tesla had invented a rotary magnetic field AC dynamo. In February, 1882, he was in Budapest recovering from an illness which had caused him acutely amplified sensory effects. One evening as he was watching a beautiful sunset over the Danube, the rotary field concept in all its elegance came to him. When Tesla applied for a single patent on his whole AC system, the U.S. Patent Office bureaucracy couldn't stand for that kind of simplicity and instead spread it out into seven separate patents. The Westinghouse-Tesla negotiation is quoted in John J. O'Neill's *Prodigal Genius*, Ives Washburn, Inc., N.Y.; 1944.

²⁹When Westinghouse got into financial troubles, his backers insisted that Tesla's one dollar a horsepower royalty be discontinued as a condition of their bailing him out. Tesla said, "The benefits that will come to civilization from my polyphase system mean more to me than the money involved," and then voluntarily tore up his Westinghouse contract worth untold millions. Tesla died alone, nearly unnoticed, in a New York flat on January 7, 1953, with an unpaid hotel bill. Following up a report that Tesla had a secret invention that might be used in the war, the FBI came and opened his safe and took all his papers.

³⁰Tesla claimed that he could transmit communication signals over interplanetary distances, and that he had engineered wireless transmission of energies involving thousands of horsepower which could in the wrong hands be used as a death ray. He said his energy ray had a voltage of fifty million and it had a two-hundred-mile range, but only because of line-of-sight limitations. Tesla's world wireless system died with him. Others have tried without success to duplicate his claimed success, including a Utah man who recently set up an experimental wireless-power test laboratory near Wendover.

³¹Widtsoe's fortunes changed suddenly after his departure from Logan. In 1907, John Christopher Cutler, who had replaced Heber Manning Wells as governor, reconstituted the Board of Trustees of the UAC. The new board immediately, by a vote of five to four, demanded the resignation of Kerr and selected Widtsoe as the new president. The USU presidents have been: (1) Jeremiah Wilson Sanborn (1890-1894), (2) Joshua Hughes Paul (1894-1896), (3) Joseph Marion Tanner (1896-1900), (4) William Jasper Kerr (1900-1907); (5) John Andreas Widtsoe, Jr., (1907-1916), (6) Elmer George Peterson (1916-1945), (7) Franklin Stewart Harris (1945-1950), (8) Louis Linden Madsen (1950-1953), (9) Henry Aldous Dixon (1953-1954), (10) Daryl Chase (1954-1968), and Glen L. Taggart (1968-1979). (See Joel Edward Ricks, *The Utah State Agricultural College, A History of Fifty Years*, Deseret News Press, SLC; 1938.)

³²In 1912, the Utah Power and Light Company acquired the Telluride Power Plant and its distribution system. The Telluride Power Company was the successor (1905) to the Logan Power Company, which in turn was the successor (1903) of the original Hercules Power Company. Logan City built (1904) its own power plant further up the canyon beyond the private power company's dam (the second dam) and intake. Water for the private company was piped from the second dam over the hill down to the mouth of the canyon. This plant has since been dismantled. An interesting power war developed between the private company and Logan City. The former added five feet to its dam to flood out the city's power plant then under construction. The federal government, upon the city's protest, ordered the private company to stop interfering. (See Leon Fonesbeck, *The Logan City Light Plant*, The Caxton Printers, Caldwell; 1944.)

³⁴Doctors Widsoe and Merrill later served together for many years on the Mormon Council of Twelve Apostles. The engineering program at the U of U was started by Professor Richard Roswell Lyman beginning about 1896, the year he joined the faculty as a civil engineer. He did his undergraduate work at the BYA in Provo, the BYC in Logan, and at the University of Michigan. He obtained his Ph.D. from Cornell in 1905. Dr. Lyman resigned in 1922 to become an apostle. Professor Merrill, who first joined the U of U faculty in 1893, introduced a class of applied electricity as part of the mining engineering program in 1908. This quickly grew into a four-year electrical engineering course. Merrill had obtained his bachelor's degree from the University of Deseret in chemistry and physics in 1889, then like Professor Lyman studied at Michigan, Cornell and Chicago. He obtained a Ph.D. in physics and electrical engineering from Johns Hopkins University in 1899. In 1916 he became director of the School of Mines and Engineering. He left in 1928 to become superintendent of the LDS school system and civil engineer Richard Bird Ketchum was named dean and A. LeRoy Taylor became director of physics and electrical engineering. Upon Ketchum's retirement in 1939, Taylor was chosen as dean, and stayed on also as head of the EE department which was now separate from physics.

³⁵After 1922, the heads of the schools were called deans instead of directors. The UAC listed five schools: Agriculture, Commerce, Home Economics, Agricultural Engineering and Mechanic Arts, and General Science. Dr. Harris in 1921 was named as the fourth president of BYU, then in 1945 returned to Logan to become the seventh president of Utah State. The six deans at USU were as follows: Franklin Stewart Harris (1912-1916), Ray Benedict West (1916-1936), who died in office, George Dewey Clyde (1936-1946), Jerald Emmett Christiansen (1946-1957), Dean Freeman Peterson, Jr. (1957-1974), and Eddie Joe Middlebrooks (1974-).

³⁶The first message carried in 1844 was not "WHAT HATH GOD WROUGHT." In fact, the results of Henry Clay's nomination at Baltimore for president reached Washington over the telegraph line at least a week before these promotional words were dispatched. Telegraphy had come a long way since Karl Friedrich Gauss and his cohort Wilhelm Eduard Weber strung wires over the rooftops of the German university town of Göttingen in 1834.

³⁷This was a distorted anticipation of the TOUCH TONE® system by a full century.

³⁸In the resulting patent litigation, Bell won out in the U.S. Supreme Court. Gray organized the Western Electric Company, which was subsequently acquired (1882) as the equipment manufacturing subsidiary by the Bell system conglomerate called the American Telephone and Telegraph Company. Bell was a Scotch immigrant who was a teacher for the deaf.

³⁹The wavelength is equal to the velocity divided by the frequency. Hertz's waves had a frequency of oscillation of about sixty million cycles per second, today's VHF (very-high frequency) range used for broadcasting radio and television. He later extended the frequency to five hundred million cycles per second, (UHF, ultra-high frequency). Not liking the lack of rigor by everyone's dropping of the "per second," the standards committee of the Institute for Radio Engineers (IRE) in 1965 renamed the cycle per second the "hertz" in Heinrich's honor. In the ten years after Hertz's work the capability of generating coherent electric waves was extended up to 75,000 megahertz ($\lambda = 0.4$ cm), the so-called microwave range. But the extension down to 0.2 mm took another thirty years; Ernest Fox Nichols and James DeGraff Tear finally succeeded in closing the gap between electric waves and the optical infrared.

⁴⁰Developed by Edouard Branley of the Catholic Institute in Paris, the filings tended to cling together when high-frequency oscillations were present, thus increasing the current in a local battery circuit. This detector was therefore called a "coherer." The discoverer of the coherer phenomenon was the Anglo-American electrician David Edward Hughes, who thus invented the variable resistance microphone. Seven years before Hertz made his famous 1888 experiments, Hughes used his coherer microphone to detect electromagnetic signals from a spark transmitter 500 yards away. Scientists wrongly told him he was seeing results of near-field induction rather than far-field electromagnetic waves. If Hughes had known what he had chanced upon, the cycle per second today may have been called "the Hughes" instead of the Hertz.

⁴¹Dr. Heinrich Geissler set up a shop in Bonn, Germany, for scientific instruments. He built a "Geissler tube" consisting of a glass bulb enclosing two electrodes in a low-pressure gas. His tube was used as a coherer for wireless detection. This was the forerunner of the neon light. Fleming first made use of his evacuated two-electrode valve in 1904 as a detector of wireless circuits. The discovery that an evacuated tube with a hot and a cold electrode showed unilateral conductivity was discovered and patented by Edison in 1887, his one scientific discovery among thousands of patented inventions. In 1889, Julius Elster and Hans Friedrich Geitel in Germany demonstrated the same effect.

⁴²De Forest didn't fathom the real potential of his invention. He sold his vacuum triode to the telephone company for \$50,000. The device has also been called a "thermionic valve" or a "radiotron."

⁴³As expected, the fidelity of the "receivers" was pretty poor indeed. The resonant arc generator for fast oscillations was invented by Valdmor Poulsen, the Danish electrical engineer who is more famous as the 1898 inventor of the magnetic wire recorder. Poulsen also suggested using metallic dust on paper to make a tape recorder; this was finally accomplished by the Germans around the start of World War II.

⁴⁴The father of the modern radio set was Professor Edwin Howard Armstrong of Columbia University. This obscure radio genius was only 22 years old when he invented the regenerative-feedback radio circuit in 1912; six years later he invented the superheterodyne receiver which is the basic circuit still used today in amplitude-modulated (AM) radios. He developed the superregenerative circuit in 1920 and then in 1933 invented the more noise-free frequency-modulated (FM) systems. He left PCM (pulse code modulation), which is still better noisewise, to the telemetry boys! The year before he died in 1954, he succeeded in broadcasting multiplex FM programs.

⁴⁴"Ham" was the monicker given to inexperienced telegraph operators.

⁴⁵Sidney R. Stock was born in Fish Haven, Idaho, on May 18, 1895. He completed his high school work at the LDS Academy in Salt Lake City in 1915. Stock left the USAC just before Pearl Harbor (October, 1941) to accept a direct commission as commander in the U.S. Navy. He set up a 5,600-student navy electronics school at Corpus Christi, Texas. Then he returned to Logan to oversee a navy electronics school he had recommended for the USAC. He retired from the navy in 1956, and passed away on June 20, 1969. The USU department heads of electrical engineering have been: (1) Sidney Richard Stock (1922-1941), (2) Larry Snow Cole (1941-1968), (3) Bruce O. Watkins (1968-1973), (4) Kay D. Baker (1973-1977), (5) Ronald L. Thurgood (1977-1978), and (6) Doran J. Baker (1978-).

⁴⁷The station started by Cole and his partner, Winston Jones, used the call letters KFXD and operated at about 1230 kilocycles per second. It was located upstairs in the Packard Motor Company building immediately west of the telephone building (presently Hall Mortuary). The closest station was KLO in Ogden, which started in 1924. The first station in Utah, KZN (now KSL) started broadcasting May 6, 1922, from the top of the *Deseret News* building in Salt Lake City, with Harry Wilson as the engineer. Professor Cole, the creator of the USU electrical engineering department, was born August 31, 1906, in Logan. Cole obtained his B.S. degree from the U of U in 1940, his M.S. from the USAC in 1945 and a D.E. in 1950 from Stanford.

⁴⁸Utah State's second (1916) engineering "dean," Ray West, was born in Ogden, on October 21, 1882. He graduated from the UAC in 1904 with a B.S. in civil engineering. West then laid out electrical power plants and railroads and taught at the BYC briefly before hiring on the UAC faculty in 1912 to become professor of agricultural engineering. West engineered both the railroad line from Silver City, Utah, the Colorado mine, and the line to the base of Mount Hood from Dee, Oregon. He was the older brother of Franklin Lorenzo West, the first dean of the faculty. Clyde, whose father was a pioneer Utah irrigation farmer, was the UAC valedictorian of the class of 1921 and as a senior was president of the student association of engineers on the UAC campus. Born in Mapleton, Utah County, on July 21, 1898, he received the Bachelor's degree in agricultural engineering from the UAC in 1921 and then went to the University of California where he studied hydraulics and irrigation engineering and earned an M.S. degree in civil engineering. He joined the faculty in 1923 and rose to the rank of professor while becoming well known for his snow survey work. After serving with the federal government, he became governor of Utah in 1956.

⁴⁹In 1938, the automotive electricity classes were removed from the department and added to the auto mechanics department. In 1942, the departmental name was changed to Radio Department when aviator Stock left and was succeeded by Professor Cole as department head. Cole had been a regular faculty member since 1940.

⁵⁰Professor Clayton Clark helped install the first KVNU transmitter in a small shack. "The voice of northern Utah" started broadcasting in January of 1938 with a power of less than 250 watts at a frequency of 1230 kilocycles per second. It was thought that the high water table at the swampy location of the station would make a good ground plane for the vertical antenna tower. Herschel Bullen bought the station from the original owners within about a year.

⁵¹Radar is an acronym for "radio detection and ranging."

⁵²The experimental proof of the existence of an ionosphere, which reflected radio waves, was established in 1925 by Professor Edward Victor Appleton of King's College in London and Dr. Samuel Jackson Barnett of the Carnegie Institute. Continued ionospheric research was the theme of the first electrical engineering graduate research program at USU in 1957.

⁵³The wavelength of these early radars was about 10 meters.

⁵⁴Dubridge held a 1926 Ph.D. from the University of Wisconsin. The MIT Radiation Laboratory opened its doors in November, 1940, with specific purpose of developing microwave radar as suggested by a special British radar mission which brought along a sample cavity magnetron. This ultra-high-frequency oscillation device was invented by Dr. Albert Wallace Hull in 1921 who left teaching to do research for the General Electric Company. When perfected in 1940, the magnetron made it possible to create short wavelength radars. By early 1944, the microwave radar was operational at a wavelength of 10 cm and was highly successful. The staff of the Radiation Laboratory rose to a peak of 4,000 people in 1945 and then was discontinued at the end of 1945. The present MIT Lincoln Laboratory at Bedford, Massachusetts, is a direct descendant.

⁵⁵Charles Francis Jenkins, who was a lecturer at Johns Hopkins University, invented the telephoto for transmitting over telephone lines in 1922. With the advent of cable TV, the system has gone full cycle. The **cathode ray tube** (oscilloscope tube) so extensively used in radar and TV, was invented in 1897 by Dr. Karl Ferdinand Braun, a German technical high school teacher.

⁵⁶Zworykin had begun to develop his idea while working on his Ph.D. at the University of Pittsburgh in 1923-1926. He introduced a system of color TV in 1957. In 1928, a totally different type of pickup tube, the **image dissector**, was invented by Philo Taylor Farnsworth from Beaver, Utah. Farnsworth left Beaver and went to work in radio at Salt Lake City at the age of 18. In 1934 he put on a public demonstration of TV at the Franklin Institute in Philadelphia. (See S.G. Ellsworth, *Utah's Heritage*, Peregrine Smith, SLC; 1972.) His tube didn't have internal storage capability and so was less sensitive. The Farnsworth Television Company was absorbed into the International Telephone and Telegraph Company. In 1962, Allan Steed and I resurrected the Farnsworth image dissector and used it to build a fast-scanning optical spectrometer. (See D.J. Baker and A.J. Steed, *Applied Optics*, Vol. 7; 1968.) Although the Farnsworth TV camera was less sensitive than that of Zworykin, it could scan much faster. In 1929, the British Broadcasting Corporation (BBC) began a TV service

using the mechanical scanner of John Logie Baird. This remarkable Englishman invented a night vision device ("noctovisor") using infrared light in 1926. He demonstrated a mechanical color TV in 1939.

³⁷As we discussed, the first revolution took place in lifespan four and was precipitated by the discovery of electromagnetic waves and the invention of the radio tube.

³⁸The silicon detector was invented by Greenleaf Whittier Pickard, an engineer for AT and T in 1906, the same year De Forest invented the vacuum triode. Also the same year, General H.N.C. Dunwoody discovered that carborundum would also act as a rectifier. Bardeen was a Ph.D. from Princeton University; after the invention he left the Bell Laboratories to become an electrical engineering professor at the University of Illinois. Shockley set up the Shockley Transistor Corporation at Santa Clara, California, in 1958. The success of this company and its spin-offs created today's "silicon valley" semiconductor industry. Only Brattain stayed with Bell Labs. The name "transistor" was a contraction of "transfer" and "resistor."

³⁹The technological process of making integrated circuits (IC's) is that of slicing thin semiconductor wafers, thin film depositing, and photoengraving. Internal IC circuit design has of necessity been forced into standardization. Johnson's first IC was a phase-shift oscillator. Other IC pioneers were G.W.A. Dummer of the English Royal Radar Establishment, Jack S. Kilby of Texas Instruments and Jay W. Lathrop of the Diamond Ordnance Fuze Laboratories. One of the leading IC manufacturers, Fairchild Semiconductor, was spun out of Shockley Transistor in 1957. Intel Corporation, in turn, was spun out of Fairchild in 1968. It is interesting to note that of the ten leading U.S. producers of vacuum tubes in 1955, only two are among today's top ten semiconductor companies. Recently, even memory elements and A/D and D/A (analog-to-digital and vice versa) converters have been included on IC chips. "Circuit component" has changed since Jesuit high school teacher George Simon Ohm, in Cologne, "invented" the resistor in 1827.

⁴⁰In summary, the four inventive impulses that caused the revolutionary stages of electrical engineering were: (1) the electromagnetic generator-1831, (2) the vacuum tube amplifier -1906, (3) the transistor-1948, and (4) the integrated circuit-1953. The breathless tempo of change is increasing faster than one can keep up.

⁴¹It has been my observation that, similarly, science is usually driven by engineering rather than the reverse as is commonly thought or, at least, said to be the case.

⁴²This computer was dubbed *ENIAC* for "Electronic Numerical Integrator and Computer." In 1939-1944, Professor Howard Hathaway Aiken and his colleagues at Harvard University built the *Mark I* computer. This first large electrical computer, called an automatic sequence-controlled calculator, is generally considered as the invention of the computer. Professor Charles Babbage at Cambridge University labored for a long time devising the basic principles of the computer, but was frustrated by the limitations of the mechanical components available to him in the nineteenth century. Hungarian-born Professor John von Neumann of Berlin University, who came to Princeton University as a visiting professor, brilliantly extended computer theory and design the decade after World War II.

⁴³Shannon accomplished this by replacing a deterministic source with a probabilistic one and fed it over a noisy channel. His paper, which created a broad and lasting stir, was published in the *Bell System Technical Journal*, Vol. 27; 1948. In 1956, Shannon left the Bell Laboratories to become a professor at MIT.

⁴⁴Random, or *stochastic*, noise in the ultimate limit since nonrandom noise (called "pickup") can usually be effectively eliminated by proper design and layout. "Stochastic" is from the Greek word relating to "target aiming skill." Shannon's work showed how to approach taking into account *a priori* information about the message and inspired the formulation of error-correcting codes. The basic unit of measure of information is the *bit*—a contraction of "binary digit." It is the uncertainty between "yes" and "no" (or "on" and "off") when each are equally likely to occur. The channel capacity of a telephone wire is about 60,000 bits/second, that of a coaxial cable relay system is nearly 650 million bits/second.

⁴⁵See W. Weaver, *Scientific American*, Vol. 204; 1949, J.R. Pierce, *Scientific American*, Vol. 227; 1972, and J.R. Pierce, *Symbols, Signals and Noise*, Harper and Row, N.Y.; 1961.

⁴⁶W. Kraft, *Symbols, Systems, Science and Survival*, Vantage Press, N.Y.; 1975.

⁴⁷The potency of communication at the motivational level is contemporarily well demonstrated by the mushrooming of the disco, a direct result of playwright Norman Wexler's cinema, *Saturday Night Fever*. There is also danger: Vance Packard warned that many persuaders are hidden (*Hidden Persuaders*, published in 1957).

⁴⁸Linford, born July 8, 1904, was the son of James Henry Linford, long-time director of the innovative UAC summer school program. Leon's brother, Maurice, who was a botany instructor at the UAC, was the 1923 discoverer of the 2,700-year-old juniper tree up Logan Canyon.

⁴⁹Swigart obtained his B.S. degree from Illinois Wesleyan University in 1929; two years later he joined the University of Utah faculty. He obtained his Ph.D. in 1938 at Indiana University. Upon seeing the similarity to the mother-baby connection, Swigart first coined the words "umbilical cord" for the pull-away cable connecting a rocket to its blockhouse ground control. Haycock (born Oct. 5, 1901, at Panguitch), who started radio station KLGW in Logan in 1954 (now KBLW), graduated from the U of U in 1925 and then was hired by Dean Joseph F. Merrill as an electrical engineering faculty member. Haycock did his graduate work at Purdue University. Haycock, who had served as associate director of the Upper Air Research Laboratory since its inception in 1947, became director when Linford died of cancer in 1956. The Upper Air Research Laboratory was housed on the top floor of the Engineering Building (constructed in 1930) to provide easy access to a rocket antenna range on the roof of the building. Other early members of the Upper Air Research Laboratory staff were MacElwin van Valkenburg, later head of the electrical engineering department at Princeton University, and Drs. Charles L. Alley and Clay D. Westlund of the U of U electrical engineering faculty.

⁷⁰The dimensions of the spatial concept range from the "angstrom" of the spectroscopist to the "parsec" of the astronomer, 10^{-10} to 3×10^{13} meters, respectively. Our most common geographic dimension has been the "mile," soon to be replaced by the kilometer. This vintage distance unit has been handed down from ancient Rome where *mille* meant "a thousand paces." The diameter of our Earth is eight thousand miles. The distance around it is twenty-five thousand miles — 25 million human steps. Until A.D. 1958, man and his machines were confined to the near-surface of the planet. The deepest ocean (Marianas Trench, 7 mi) and the highest mountain (Everest, 5 1/2 mi) are less than a percent of the Earth diameter. Even the highest arc of rocket or shell was well under a tenth of the terrestrial dimension — shorter than the earthfast Great Wall of China.

⁷¹Goddard obtained his Ph.D. at Clark University in Worcester, Massachusetts, in 1911.

⁷²Goddard's rocket range was at the Mescalero Ranch near Roswell. His first rocket flew 184 feet in 2 1/2 seconds, compared with the Wright brothers' first aeroplane flight of 120 feet in 12 seconds. By 1935, Goddard had flown a hundred-pound rocket to a height of a mile and a half. It stood 15 feet high.

⁷³Von Braun obtained his Ph.D. from the University of Berlin in 1934; his dissertation was on rockets. Their A-4 rocket, flown on October 3, 1942, was 46 feet high, weighed fourteen tons and reached a speed of 3500 mph. It was a sight to behold with its smooth torpedo shape, standing tiptoe on four swept cruciform fins.

⁷⁴The letter "V" in both the V-1 jet buzz bomb and the V-2 rocket stood for *Vergeltungswaffen* — vengeance weapon. The German engineers preferred their own name: A-4, for "aggregate", fourth version (prototype). The Allies discovered the existence of the V-2 when in June, 1944, one went out of control from the German development base at Peenemünde on the Baltic and fell in Sweden. (See Walter Dornberger, *V-1*, Viking Press, N.Y.; 1958.)

⁷⁵The Russians took four thousand German technicians and entire assembly plants for the V-2 rockets. The U.S. lucked into the cream of the crop. The army project under Toftoy to make off with the German rocket know-how was called *Operation Paperclip*. The initial interrogation of the Germans was conducted at a schoolhouse at Witzenhausen. One German general testily said that if Hitler hadn't been so pig-headed the Germans would be ordering American engineers around. The U.S. Navy wanted no part of the haughty Germans, no matter how talented they were. The selected personnel were initially brought to the Army's Wright Field near Dayton, Ohio. Their families remained at Landshut, Germany, for a year before at last they too were allowed to come to America to join their husbands and fathers. (See Dieter K. Huzel, *Peenemünde to Canaveral*, Prentice Hall, Englewood Cliffs; 1962.) The V-2 development started at Kammersdorf West near Berlin. A new base, Peenemünde at the mouth of the Peene river on the Baltic north of Berlin was built in 1936. There, von Braun became technical director of the program. The underground V-2 factory was at Niedersachswerfen near Nordhausen in central Germany.

⁷⁶The *Trinity site* where the first nuclear explosion was detonated on July 16, 1945, is at the northern part of the rocket range. The White Sands are the wind-blown remnant of an ancient lake bed and the salts are "plaster of Paris." Fortunately, before he was tragically taken by throat cancer on August 10, 1945, Goddard was able to see one of the German V-2 rockets. A total of 47 captured V-2's were launched at White Sands between April 16, 1946, and the fall of 1952. The first one rotated so fast it spun off a tail fin and crashed; the second try in May was more successful.

⁷⁷The U.S. Air Force was created by the Armed Services Unification Act of July 26, 1947. The nearest base to the Air Force Cambridge Research Center in Boston was Lawrence G. Hanscomb Field, at Bedford.

⁷⁸The other universities were the Johns Hopkins University, University of Michigan, California Institute of Technology, University of Maryland, and Oklahoma State Agricultural College.

⁷⁹Aerojet was founded along with others by Dr. Theodore von Karman, director of the Jet Propulsion Laboratory of the California Institute of Technology. His colleague in rocket work at Cal Tech was Dr. Louis G. Dunn. Their students were the genesis of the companies which blossomed in the rocket propulsion field: Aerojet, Thiokol, Rocketdyne. The name Jet Propulsion Laboratory was adopted in 1943; the laboratory was previously named the Guggenheim Aeronautical Laboratory. The National Science Foundation, founded in May, 1950, helped fund the *Aerobee* rocket development project. The first large U.S. built rocket ever to be launched was the *Redstone*, fired from Cape Canaveral on August 20, 1953. The larger *Atlas* rocket (ICBM) was first successfully launched on December 17, 1957 (See also J.G. Vaeth *200 Miles Up*, Ronald Press, N.Y.; 1956).

⁸⁰Harold Ritchey grew up on a farm near Kokomo, Indiana. He left the farm to obtain a Bachelor's degree in chemical engineering from Purdue in 1934. Two years later, he obtained his Ph.D. in physical chemistry from the same school. Joining Thiokol in 1949, Ritchey is the father of that company's rocket program. A year and a half later, the Army also moved von Braun and his German liquid-propellant rocketeers to the Redstone Arsenal. (See Shirley Thomas *Men of Space*, Chilton Co., Philadelphia; 1961.)

⁸¹The solar cell was invented by Gerald Leonard Pearson and his colleagues (Chapin and Fuller) at the Bell Laboratories in 1954. Made up of a junction of negative and positive types of boron-doped silicon, each cell can by a photovoltaic conversion generate a half a volt between layers. The photoelectric effect was first discovered by Dr. William Ludwig Franz Hallwachs in Germany in 1888.

⁸²Lowell was a nonresident professor of astronomy at MIT. Some jibed that the observatory at Flagstaff, Arizona, was for the purpose of establishing that Martians exist.

⁸³Closeup pictures of Mercury revealed it also to be an airless, pockmarked "moon." The cold outer planets, Jupiter and Saturn, appear to be fluid with atmospheres of ammonia and methane. Temperatures on Uranus, Neptune and Pluto are below that of liquid nitrogen. For a while there was hope that the larger moons such as Ganymede of Jupiter and Titan of Saturn, which are about the size of Mercury, had sufficient atmospheres to

support life. But the atmospheres turned out, like that of Mercury, to be very dilute. (See M. Shipley, *Are the Planets Inhabited?*, Haldeman-Julius Co., Girard, Kansas; 1924, and Willy Ley, *Rockets, The Future of Travel Beyond the Stratosphere*, Viking Press, N.Y.; 1944, and Willy Ley, *The Conquest of Space*, Viking Press, N.Y.; 1951.)

⁸⁴Already in America a hundred species are officially designated as "endangered" by the U.S. Interior Department.

⁸⁵In 1951, the state legislature removed the restrictions on the electrical program at the USAC; the Radio Department accordingly was renamed the Department of Electrical Engineering with Larry Cole as Head. Dean of Engineering Jerald Emmett Christiansen, with the support of USAC President Louis Linden Madsen who succeeded President Harris in 1958, met with the Professional Engineering Council of Utah to plead the case for a broader engineering program at Logan. Dean A. LeRoy Taylor, his counterpart at the U of U, argued against the case saying that electrical engineering at the USAC would be duplication. The Engineering Council voted 4 to 3 in favor of Christiansen's proposal to substitute the simple word "engineering" instead of "civil and agricultural engineering" in the state program authorization statement for the USAC. With the support of the Engineering Council, the bill (written up by Professor Wendell Anderson) passed the legislature. Dean Christiansen was born in Hyrum on April 9, 1905. He obtained his B.S. degree from the UAC in 1927 and obtained graduate degrees from the University of California in 1928 and 1935. He joined the USAC faculty in 1946 and became dean after the departure of George D. Clyde to government service that year. In 1947 a new technology building was started and in 1950 the first Ph.D.'s were awarded (Al Gita and Magi Kodir from Baghdad).

⁸⁶Professor Cole and I first met while I was overseeing AFRCR rocket launches as a lieutenant with the U.S. Air Force. I had been involved with the rocket experiments since 1952, first as an undergraduate and then as a graduate student at the University of Utah (Ph.D., 1956). Dr. Peterson had been named in 1957 by President Daryl Chase to succeed Professor Christiansen as the dean of engineering, the same year that the legislature changed the name of Utah State Agricultural College to Utah State University of Agriculture and Applied Science. Dean "Pete" was developing an expansive program of research in his college. The first phase of the new engineering building, housing electrical engineering, was completed in January, 1960.

⁸⁷On June 1, 1959, with the support of Professor Cole, I started the Electro-Dynamics Laboratories in the USU Electrical Engineering Department. On July 13, 1959, I received my first Air Force contract in the amount of \$59,710. That fall Clair Leon Wyatt became my first graduate student. Over the next two decades our program was able to sustain its funding at the level of an average of a million dollars per year. The thrust of the program has been infrared-electronic engineering to measure aerospace scientific and defensive systems phenomena. My sponsors and collaborators at the Air Force Geophysics Laboratory (formerly AFRCR and AFCLR) have been Dr. Alva Taylor Stair, Jr., and Mr. James C. Ulwick. On July 1, 1978, I was named head of the Electrical Engineering Department and Dr. Allan J. Steed succeeded me as Director of EDL.

⁸⁸The Center for Research in Aeronomy was established in 1969 with Dr. Clayton Clark named as its first director. At the instigation of Dr. Farrell Edwards and myself we were able to add Dr. L. Rex Megill, of the National Bureau of Standards, to the staff that year. Kay Baker received his Ph.D. from the U of U in 1966. He became director of the Upper Air Research Laboratory when Professor Haycock retired in July of 1969. In 1973, Kay Baker was named head of the Electrical Engineering Department at USU, succeeding Dr. Bruce O. Watkins, who had served since Professor Cole left to serve as Acting Dean of the College of Engineering in 1968.

⁸⁹Peter M. Banks and his staff, including electrical engineering Professor Joe R. Doupnik, came to USU from the University of California at San Diego. The first M.S. degrees were awarded in the EE Department in 1959. The first Ph.D.'s were awarded in 1967 to Mark C. Austin, Richard W. Harris and Scott P. Stewart, Jr. Dr. Stewart's degree was awarded posthumously. He died of cancer in 1966, after serving for five years as supervisor of a laboratory of EDL established in Concord, Massachusetts, on January 1, 1961. The laboratory, since relocated to Bedford, was renamed the Stewart Radiance Laboratory in his honor. (See L.S. Cole, *Electrical Engineering at USU*, 1972.)

⁹⁰Webster's dictionary (Merriam-Webster, Third Ed., unabridged) takes half a column to define 13 different major meanings and 21 submeanings of the word "system."

⁹¹Otto Mayr, *The Origins of Feedback Control*, MIT Press, Cambridge; 1970, and Otto Mayr, *Feedback Mechanisms*, Smithsonian Institution Press, Washington; 1971.

⁹²James Clerk Maxwell developed a mathematical analysis of the mechanical feedback system on Scotsman Watt's 18th century steam engine.

⁹³The feedback control principle hides under a different set of words in each discipline, tending to make the disciples of each field think it is their discovery and possession. Words that come to mind include "operations research," "regeneration," "servomechanism," "governor," "homeostasis," "cybernetics," and "operational amplifier." This latter negative-feedback amplifier, commonly used today in electronics, was invented by Harold Stephen Black of the Bell Laboratories on August 2, 1927. The flash came to him while he was crossing the Hudson River on the *Lackawanna Ferry*. (See *IEEE Spectrum*, Vol. 14; 1977.)

⁹⁴Norbert Wiener, *Cybernetics, or Control and Communication in the Animal and the Machine*, The MIT Press, Cambridge; 1948.

⁹⁵Failure of the feedback system was sometimes dramatic. At White Sands, a V-2 rocket rose several thousand feet and suddenly flipped over and headed away. It lit in the cemetery of Ciudad Juarez across the Rio Grande in Old Mexico.

⁹⁶Ampère was a professor of physics at the Collège de France. He showed that parallel current-carrying wires attract and repel.

⁹⁷J. R. Pierce, *Scientific American*, Vol. 227; 1972.

⁹⁸The base of the natural logarithms of Scotsman John Napier (1614), namely, the irrational number $e = 2.71828\dots$, derives from taking the time interval for compounding interest (in our example, one day) and shrinking it closer and closer to zero.

⁹⁹These systems have a myriad of inputs and outputs, the subsystems change with time and interact with one another, they may be linear or nonlinear, the processes may be continuous or discrete as well as deterministic or random, or any combination of these types. (See S.M. Shinnars, *Techniques of System Engineering*, McGraw-Hill Book Co., N.Y.; 1967, and C.W. Churchman, *The Systems Approach*, Dell Publishing Co., N.Y.; 1968.) To the modern engineer falls the task of designing large, complex systems which are optimum in some sense. **Systems optimization** is the process of obtaining the best system result for a given set of conditions.

¹⁰⁰Donald McDonald in 1950 first developed the concepts of optimal control theory. To apply his concepts of optimal control, a unified theory using the so-called **state variable method** based upon matrix algebra was developed with numerous contributors. There are some potent aspects of this general method of system optimization such as **dynamic programming**, originally developed by R. Bellman, and the **maximum principle** of Lev Semenovich Pontryagin. (See also Robert Boguslaw, *The New Utopians, A Study of System Design and Social Change*, Prentice-Hall, Englewood Cliffs; 1965, and D.P. Eckman, *Systems; Research and Design*, John Wiley, N.Y.; 1961.)

¹⁰¹His message was given in a letter to Congress and news release from MIT, Cambridge, at the beginning of the 1978 sessions.

¹⁰²Gregg observed that: "The world has cancer and the cancer is man." (See *Science*, Vol. 121; 1955, and M. Mesarovic and E. Pestel, *Mankind at the Turning Point*, E.P. Dutton, N.Y.; 1974.) The most famous principle of Thomas Robert Malthus is that unchecked human breeding causes population to grow geometrically while the food supply grows arithmetically; he felt that the only natural checks on population growth were war, famine, disease and continence. He published his "An Essay on the Principle of Population as it Affects the Future Improvement of Society" in 1798. (See R. Freedman and B. Berelson, *Scientific American*, Vol. 231; Sep., 1974.) These will be the critical years of mankind's *iatrogenic illness* — sickness caused by the medicine itself (medicine lowering death rate, technology causing pollution, etc.) The contest between expansion and environment will be decided. Of all the *anthomeostatic* factors in society, control of the sources of energy and the means of communication will be the most effective and most important.

¹⁰³Simon Ramo of the TRW Corporation predicts: "We can expect that systems which will relieve man of routine mental effort will become the greatest growth industry of the coming generation, making it possible to reserve man for the highest intellectual tasks to which he is uniquely suited." Ramo, from Salt Lake City, was a 1933 electrical engineering graduate from the U of U. He received his Ph.D. from Cal Tech in 1936, founded the Thompson-Ramo-Woolridge Corporation, and was scientific director for the USAF development of the *Atlas*, *Titan* and *Thor* rockets. (See also James Martin, *Future Developments in Telecommunications*, Prentice-Hall Inc., Englewood Cliffs, 1971.)



