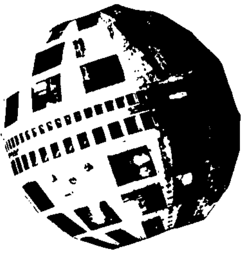

LOOKING BACKWARD AND LOOKING FORWARD: RIGHT OR WRONG

John R. Pierce

The future doesn't shape itself to fit prophesies. Rather, it follows a path paved by the successful work of those with a yen for more.

Lively engineers are never satisfied with what is already done. They want to get on to something bigger or smaller, but certainly better. Thus, they all spend a part of their time imagining that which they are sure will come. I've always been full of the future. Sometimes I've been right; sometimes I've been wrong.

The future doesn't shape itself to fit prophesies. Rather, it follows a path paved by the successful work of those with a yen for more. Even unsuccessful endeavors may lead to good things—if an idea inspires work on which new things can be built.

Many years ago, shortly after I went to Bell Laboratories in 1936, I became intrigued with electron multipliers and saw them as a wave of the future. As a first step, I wanted to make a good electrostatically focused photomultiplier. Bill Shockley came to my rescue with a wonderful sheet of stretched rubber on which electrodes at different potentials were represented by level supports at different heights. Electrons were steel balls that we rolled down the slopes between electrodes. With this device I easily found a staggered pattern of electrodes that focused the secondary electrons emitted from one electrode onto that at the next highest potential. Jan Rajchman did just the same thing at RCA at about the same time—and quite independently.

Well, electron multipliers *have* been important, but photomultipliers weren't important to Bell Laboratories. High transconductance, low capacitance tubes for negative-feedback amplifiers for a new coaxial cable system were. Why not put the electron output current of a tetrode through an electron multiplier and so increase the transconductance? Others did, but such tubes were of passing interest.

I was more ambitious. In a tetrode the thermal velocities of electrons limit transconductance per milliampere. Even with electron multiplication, high transconductance would be coupled to high current. That wasn't what I wanted. Bill Shockley taught me about Liouville's theorem, and I found that there should be no limit to transconductance per unit current in a tube in which a finely focused electron beam is swept past a sharp edge. This led me to work on such deflection tubes.

But I didn't know how to get a well focused beam at low voltage. So I invented what has been called the Pierce gun. Instead of trying to calculate where electrons would go in an electron gun of more or less arbitrary design, I found how to form electrodes that would make the electrons in a wedge-shaped or conical beam think they were traveling between concentric cylinders or spheres. And we already knew how the voltage varied with distance for such electron flow.

The change I worked was like that between night and day. Before, it was hard to get a good electron beam with a small current. After, one could get well focused beams of tens of milliamperes in klystrons and traveling-wave tubes, and, at higher voltages, currents of tens of amperes.

In klystrons and traveling-wave tubes? What happened to the deflection tube and the electron multiplier? The combination was no good because in negative-feedback amplifiers long electron transit time is as

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deleterious as low transconductance or high output capacitance.

My vision of the future had at first been that of good photomultipliers without focusing magnets. Well, they were important, but not to Bell Laboratories. Next, I wanted to use electron multipliers to make better tubes for broad-band negative-feedback amplifiers. But that didn't and couldn't work out. In the course of this work I invented an electron gun that is still of great use in microwave tubes.

My long-defunct deflection tube played an important part in this invention. Later, I found that a near and dear friend, Liss Peterson, had entered in his notebook the very idea of designing an electron gun as I had. He had not worked out the electrode shapes, let alone building a gun. He felt no clear need for such an electron gun. I did, even if my need proved illusory.

I haven't told this story idly. It has various morals. Unless something is carried through, unless it becomes a part of technology, it's of no use. A clear need, a need such as that for better tubes for negative-feedback amplifiers for coaxial cable systems, can lead an engineer to do new things. What is done, what is made, may or may not be of value. If it is of value, the value may lie beyond what the engineer sees at the time. I doubt if the Wright brothers thought of the airplane as replacing railroads and ships for long-distance passenger travel.

I have given an example of a real but unattained goal that led to something realizable with current technology. During World War II the Pierce gun was essential in the low-voltage reflex klystrons used in American radar receivers, the 707A (10 cm), the 723A (3 cm), and the 2K29 (7.5 cm). After the war it was essential in the traveling-wave tube, invented by Rudi Kompfner during the war and improved by me in various ways, including adding loss to the circuit and the use of periodic permanent-magnet focusing. The traveling-wave tube is still of use in communication satellites.

But sometimes a "good" idea has to wait a long time before it is really good for anything. That was the case with PCM. Copies of technical memoranda tell me that I was thinking about PCM encoders and sending material to the Bell Laboratories Patent Department in October of 1943. I was led in this direction by Claude Shannon, and the idea appealed to me greatly. Bill Goodall was also full of enthusiasm. Barney Oliver caught fire. It was Barney's missionary zeal that led to a joint publication in the PROCEEDINGS OF THE IRE in 1948, "The Philosophy of PCM," by B. M. Oliver, J. R. Pierce, and C. E. Shannon.

PCM was used in a classified war-time communication system. In peace time it seemed to have everything—everything except commercial feasibility with the technology at hand. Despite a spirited development program by C. B. H. Feldman, narrow-deviation FM won out in the experimental TD-X microwave link installed between New York and Boston in 1947 and in the TD-2 system which spanned the continent in 1951. Indeed, only now are communication satellites going digital.

PCM triumphed because of the invention of the transistor in 1948. At Walter Brattain's request, I named the transistor, but I had nothing to do with its invention and development. The transistor made possible the 24-channel short-haul T1 system, introduced in 1962. T1 was a fire that swept all alternative approaches away.

Even earlier than T1, some of us, including Barney Oliver, just knew that switching ought to be time-division PCM switching instead of space-division switching. After a reorganization in 1956, I found switching research in my division at Bell Laboratories. W. D. Lewis, Director of Switching Research, and Earle Vaughan were working on an experimental all-electronic

J. R. Pierce with 1946 traveling-wave tube. (Photo taken late 1940's.)

local office, ESSEX, which had everything, including sex. Conversion between voice and PCM was to be at pole-mounted concentrators. T1 lines would carry signals to and from several interconnected all-electronic switching offices of modest size. My one contribution to PCM switching was to stop some parallel research toward an all-electronic space-division system.

But that was a day before LSI. Bits were stored in ingenious magnetostrictive delay lines, or on drums.

ESSEX was a landmark of research, but the first Bell System electronic switching system, ESS No. 1, put in service in 1963, was an electronically controlled space-division switching system using electromechanical switches.

In 1956, Deming Lewis and I became convinced that data communication over phone lines would soon invade all offices.

PCM time-division switching did not triumph in the Bell System until the ESS No. 4 toll switching system was first installed in 1976. Who developed ESS No. 4? H. E. Vaughan, the Earle of ESSEX. So, the inspiration of ESSEX and the research of Earle Vaughan were not lost, after all. They just had to wait for suitable technology.

At about the time of ESSEX (1956), Deming Lewis and I became convinced that data communication via telephone line could economically replace a lot of business mail, and what a wonderful thing to have business files in machine-readable form so that they could be processed by computers!

This led to experimental cassettes on which text could be recorded at slow speed and later transmitted over telephone lines at high speed. It led to work by others toward a clumsy, impractical, and allegedly "universal" digital interface with telephone lines. But nothing came of this then. Partly, the digital art was too primitive. Perhaps we needed LSI. But we needed something else much more.

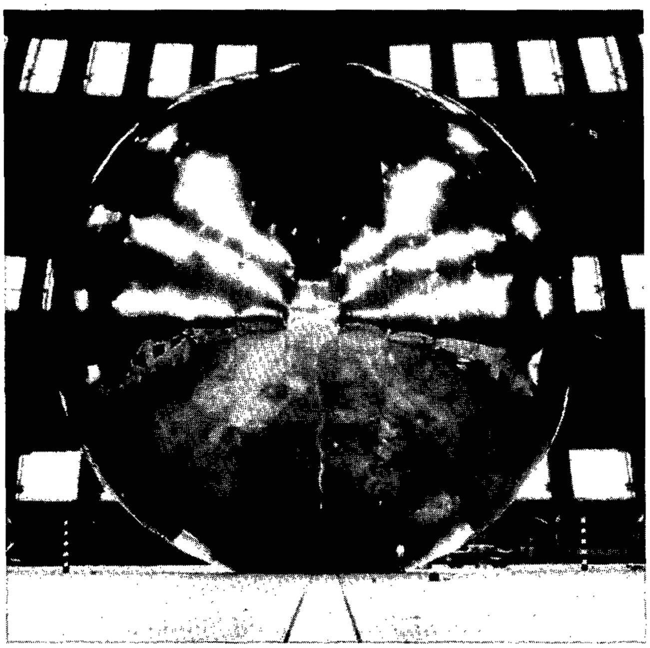
In those days the only way to digitize a full character set (teletypewriters were upper case only) was a clanking piece of junk called the Flexowriter, which cost around $5000. Invaluable as the Flexowriter was, it was no device for a secretary's office, either in cost or performance.

Well, 23 years later we aren't all that much better off. You can buy some sort of recreational computer with keyboard and cathode-ray display for around $600. But a lousy line printer costs $1200. If you want a satisfactory text editor with a good line printer, something that will enable the secretary to put text satisfactorily into machine-readable form, you'll have to pay around $10 000. That's too steep for most office managers.

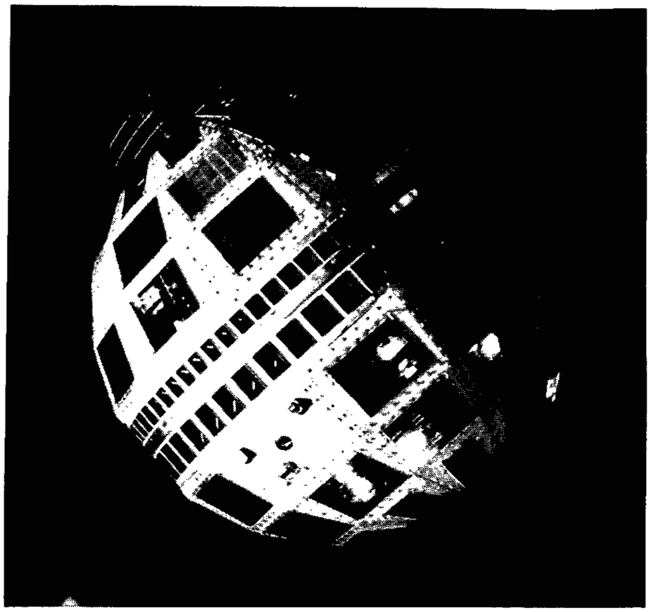
Transistors led to the triumph of digits in telephone transmission in 1962. Integrated circuits led to the triumph of digits in switching in 1976. But when will digits triumph in the office? It isn't the cost of logic or memory that is holding us up. Even keyboards have become cheap. It's the cost of display, and even more, the cost of getting good hard copy. Printers may not clank anymore, but they stink—and are offensively expensive.

Usually I've been too optimistic. In 1936 I thought that electron multipliers might provide amplification with a boundless figure of merit. All I accomplished was to invent an electrostatically focused electron multiplier and an electron gun. Amplifiers of boundless figure of merit came after the invention of the transistor—and a good many years after. In 1944, when I first heard of Rudi Kompfner's traveling-wave tube, I felt sure that it would lead to communication systems with bandwidths of hundreds or thousands of megahertz. Well, that isn't how things went, although we now have tubes with that bandwidth. In 1943 I felt that PCM would sweep communications, and by 1948 Barney Oliver, Claude Shannon, and I were convinced of it. The first clean sweep of PCM came with the T1 carrier system in 1962, 14 years later. In 1956 Deming Lewis, Earle Vaughan, and I felt that the PCM takeover of switching was imminent. That didn't start until ESS No. 4 went into service in 1976, 20 years later. And in 1956 Deming and I felt that digital files and digital transmission over phone lines would soon invade all offices. That still hasn't happened, 23 years later. When will it happen? When technology is ready, and I hope that will be soon. I want a text editor *myself*.

Sometimes, however, I've been unduly pessimistic. The Echo passive balloon satellite, launched in 1960, was my idea. Why didn't I opt for an active satellite? I was worried about the survival of electronics in space.



Plastic sphere 100 ft in diameter with aluminized surface to reflect microwaves, of type used in Project Echo.



Model of Telstar II against artificial background (1962).

I wanted something to happen that would show the world that satellite communication could really work, as I was sure that it could. And Echo did work. Who remembers project SCORE, a very limited low orbit communication satellite for recorded voice whose batteries failed after 12 days? Who remembers a successor, Courier, launched three months after Echo, a satellite which didn't last long or do much? Failures don't accomplish anything, and they don't attract attention unless they kill people.

At least Echo was better than Advent, a very elaborate active military satellite program initiated by ARPA in 1960. The sin of Advent was that it couldn't be done with the day's technology. Advent was never built or launched. It cost the country around $170 million and delayed military satellite communication for many years. Advent made it impossible to get the more modest Echo launched by the military, but NASA was more realistic. On August 12, 1960 Echo went into orbit, carried voice across the continent, made the front page of *The New York Times*, and convinced the management of AT&T that there really was something in satellite communication.

Telstar, which first carried TV and voice across the Atlantic in 1962, surely grew from the success of Echo, but it was the product of the development area of Bell Laboratories and was fabricated by Western Electric. I think that my conservatism, and that of Rudi Kompfner, Chap Cutler, Roy Tillotson, and many other colleagues in the research area of Bell Laboratories showed in the nature and design of Telstar. Telstar was not launched into synchronous orbit like Syncom, built by Harold Rosen and his colleagues at Hughes and launched by NASA about a year after Telstar. Telstar was a much more conservative and therefore a less forward-looking satellite than Syncom. But Telstar worked on first launch, somewhat to the surprise of skeptics in the group of notables here and abroad who gathered courageously at the time of launch to witness a demonstration of Telstar's capabilities during its first circle around the globe.

Although I wrote of active synchronous satellites in my first paper on satellite communication, which was published in 1955, I didn't know whether the first commercial satellites would be attitude-controlled and in synchronous orbit. Others at Bell Laboratories thought a system with low-altitude nonsynchronous satellites could be put into service earlier than a synchronous satellite system, and Ken McKay so testified to a Congressional committee in 1962. We were not experts in aerospace matters, and we somewhat underestimated the resources of the space art. Some have seen the Bell System, and me, I suppose, as conservative and obstructionist in not opting for synchronous satellites from the very first, as ARPA did in initiating the Advent program.

Well, Telstar worked. In her Christmas message of 1962, Queen Elizabeth referred to it as "the invisible focus of a million eyes." Telstar confirmed Echo and went beyond it. It showed the Congress of the United States what a powerful plum satellite communication could be, and on August 31, 1962 the Congress legislated the Bell System out of international satellite communication by passing the Communication Satellite Act of 1962 and creating Comsat.

Satellite communication is something that has gone faster and much farther than I expected it would. So, as a prophet, I'm either too optimistic or too conservative. I expected digital transmission, switching, and officeware to go much faster than they have. I expected that communication satellites would go slower than they did. Those are my credentials as a prophet as I look toward the future.

In the long run, satellites cannot compete with fibers for carrying digital traffic between large cities in the United States or between the U.S. and Europe.

Certainly, communication satellites will continue to play a large part in communication. They're our only way of providing economical communication to very distant locations with little traffic. They're the only way to provide some indispensible sorts of mobile communication.

At the moment, communication satellites seem to me to be off on a wrong technical track. For one thing, *traveling-wave tubes must go*. Solid-state devices *are* the wave of the future, at microwaves as well as at baseband—cheaper, longer life, efficient enough—and, perhaps lower power?

What of that? If we escape from ironmongery to electronics and use electronically steerable arrays instead of super-accurate dishes, we can go to higher and higher frequencies without the penalities of tighter attitude control or more and more accurate dishes and feeds. And we can get more and more effective radiated power simply by bolting together more and more simple standard array elements, each with its solid-state integrated-circuit microwave transmitter, receiver, and phase shifters. I owe these ideas to Doug Reudink of Bell Laboratories.

We will have full duplex to homes and offices eventually, at 64 kbits/s and ultimately, via fibers, at many Mbits/s.

What about small and mobile terminals, ground or air? Why not use self-steering phased arrays for them? This harks back to the STAR arrays of Cutler, Kompfner, and Tillotson. But today we have microprocessors and microwave integrated circuits that could provide an approach better in detail if not in spirit.

I'm sold on the future of satellites, but not for everything everywhere. They don't have the potentiality of bringing broad-band switched digital channels to every office and eventually to every home, as light-wave communication via optical fibers does. I don't think that in the long run satellites can compete with fibers for carrying digital traffic between large cities in the United States, or for carrying digital traffic between the United States and Europe. I expect fibers to go far, very far indeed, but not as fast as satellites. Satellites go up in a hurry. It takes longer to install a more capable and ultimately more economical communication path by laying, or hanging, or sinking a cable made up of tens, hundreds, or thousands of fibers, each able to carry a digital stream at rates approaching a gigabit a second.

Long before fibers become universal, or even very common, all *new* telecommunication, whether transmission, switching, voice, or video, will have gone digital. We'll have bit streams into and out of offices at a rate far greater than necessary for data alone. All the communication world will be streams of bits, and no one can know whether these represent voice, video, mail, or computer traffic without tracing them to their destination.

Even there it may be difficult because office and home terminals will mix voice and data and pictures, or digital instructions for drawing pictures, in communicating, or in using the same lines for talking, transacting digital business, and playing computerized games with other people or with distant computers. In the future a communication network will be many links with many nodes, and there will be digital processing of some sort at every node.

There are technological barriers that have not been overcome. One is to get 64 kbit full duplex bit streams (the standard set by the T1 carrier) into any office at a cost comparable to, or perhaps no greater than, that of the familiar voice-grade subscriber loop. New buildings could easily be wired up 4-wire, with two thin pairs rather than one thick pair constituting a subscriber loop. And 64 kbits full duplex *can* be sent over existing subscriber loops.

Be sure of one thing. We *will* have full duplex to homes and offices eventually, at 64 kbits/s and ultimately, via fibers, at many Megabits/second.

Cheap terminals are a greater problem. Simple digital terminals now cost far more than 10 times the (internal Bell) price of a telephone set, and good terminals cost over 100 times as much. It will be no simple matter to bring the cost of useful digital terminals down. But a great deal would follow a reduction of cost to that of an electric typewriter or a TV set. I'm sure that the obstacle of terminals can be overcome somehow.

Alas, technical obstacles aren't the only obstacles on the way to the future. A few years ago the FCC tried to hack communication up into a part that didn't involve data processing, and which could be offered by the Bell System, and into parts that did involve data processing and hence must be supplied by others. Technology has undermined any such division. It now seems clear that in a world of all-digital communication there will be some sort of data processing at every node.

But how, then, to control the Bell System, and Bell Laboratories? The Antitrust Division of the Department of Justice proposes a handy remedy. Separate the operating telephone companies of the Bell System, whose revenues support research at Bell Laboratories, from Western Electric and Bell Laboratories. Separate the toll transmission or long lines function of AT&T from Western Electric and Bell Laboratories. Cut everything to pieces, none large enough to support a long-range program of research and development.

One will then have a number of interconnecting telephone companies, a completely separate long-distance network (at the very digital time in which toll and local switching and transmission are becoming

J. R. Pierce in 1965 discussing satellite communications.

I'd hate to see Bell Laboratories destroyed and the Bell System, of which it is an integral part, dismantled.

inextricably mingled), and one more independent manufacturing company. As to Bell Laboratories? Well, under such a reorganization, or disorganization, it would necessarily vanish in anything but name.

As a long-time Bell Laboratories employee (1936–1971) the prospect saddens me. Not entirely because it is silly, which it is. But also because it would mean that in the future no one could have the opportunities I had. Although Bell Laboratories is a smaller part of electronics than it once was, it is unique. Its close tie to telephony led me to work on electron multipliers as a means for improving coaxial cable systems—and so to the invention of the Pierce gun. Where else would I have felt such an impetus? Where could others have had the endurance and resources actually to realize PCM transmission and time-division PCM switching? Where else would an employee find himself in an organization that would, at its own expense, build and launch a satellite such as Telstar—because that employee was free to get his immediate colleagues and friends and bosses to pursue that crazy Echo satellite?

Bell Laboratories has been a good place for a lot of my friends. Seven people I have known became Nobel Laureates while working at Bell Laboratories. I'd hate to see Bell Laboratories destroyed and the Bell System, of which it is an integral part, dismantled. I am sure that this would be bad for communications and bad for the United States.

In the role of prophet, I must consider the possibility that the Bell System may be dismantled and Bell Laboratories destroyed. Such dismantling and destruction could have a powerful and adverse effect on communication in these United States. Such destruction and dismantling would follow if the Department of Justice got its way in the present antitrust suit. Such dismantling and destruction would follow from some proposed legislation.

Will this happen? As the reader can see, I've been sometimes too optimistic, sometimes too pessimistic. I can't tell. I just don't know.

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John R. Pierce received his Ph.D. degree in 1936 from California Institute of Technology and then joined Bell Laboratories where he remained until returning in 1971 to Caltech as Professor of Engineering.

As Executive Director, Research Communications Sciences Division at Bell Laboratories, Dr. Pierce was in charge of work on mathematics and statistics, speech and hearing, behavioral science, electronics, radio and guided waves. His chief work was in electron devices, especially traveling-wave tubes, microwaves, and various aspects of communication. He proposed unmanned passive and active communication satellites in 1954. The Echo I satellite embodied his ideas; he was instrumental in initiating the Echo program and the East-Coast ground station was constructed in his department. Telstar resulted from satellite work he had initiated. At Caltech he has been concerned with energy consumption in personal transportation, auditory perception, satellite systems, synthetic aperture radar, and problems in the general area of communication.

Dr. Pierce has published many technical books and numerous technical papers, articles on popular science, and short stories. He has received many awards including the IEEE Medal of Honor in 1975 and, most recently, the Founders Award of the National Academy of Engineering, in 1977 (see *IEEE Communications Society Magazine*, September 1978). His many professional responsibilities have included serving on the President's Science Advisory Committee.

WHAT'S YOUR REACTION?

Now that you hear what John Pierce has to say, what do you have to say? Praise, criticism, corrections; disagreements, and other comments are always welcome and appreciated. (Please indicate if your remarks may be published in the Packets to the Editor column).