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Transistors and Cold Fusion - Part 2

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No Permanent Winners, No Manifest Destiny

Part 1 closed with the questions: Was the transistor truly inevitable? Where would we be without it? Is any innovation inevitable and unstoppable? I conclude that fundamental breakthroughs, like the transistor, are not inevitable, but once they are made, contingent, derivative or follow-up breakthroughs like integrated circuits become inevitable. The discovery of cold fusion was not inevitable by any means, and cold fusion technology may never be developed because of technical difficulties or political opposition, but if it is developed and it becomes established, many contingent breakthroughs, like home power generators, will become inevitable.

The book *Crystal Fire* [1] begins with a quote from Bill Gates: “Without the invention of the transistor, I’m quite sure that the PC would not exist as we know it today.” That is the conventional wisdom, and it is probably right. On the other hand, ours may not be the best of all possible worlds, and it is conceivable that something better than the transistor might have been discovered, resulting in better PCs. Furthermore, the transistor itself may not be as important as the integrated circuit, in which transistors, resistors, capacitors and other circuits are fabricated together and miniaturized. Integrated circuits were developed in 1958, but they might have come along sooner, and they might have been easier to manufacture if they had not been made with semiconducting silicon. (As explained below, integration with silicon looked like a bad idea at first.)

By the 1940s, people understood that something better than the vacuum tube amplifier was needed. Vacuum tubes were fragile, bulky, and they consumed thousands of times more power than was necessary for the job. Many people thought that a solid state device would be the best choice, and different solid state devices were developed. AT&T came up with the transistor; Univac developed a solid state “magnetic amplifier,” which worked better and faster in some computer applications than the transistors available in the early 1950s. [2] A replacement for the vacuum tube was inevitable, but it might have been . . . a better vacuum tube. Tubes might have been shrunk down to microscopic dimensions and integrated with other circuits on a chip made from some material cheaper and easier to handle than silicon. Such vacuum tubes were developed as high speed signal processors for special applications. Microscopic, mass produced vacuum tube technology is presently undergoing a renaissance in low power, flat panel, high resolution plasma screens for televisions and computer monitors. I asked a leading researcher in this field, Charles Spindt of SRI, to speculate about this. [3] He responded:

> . . . sure, if solid state never came along, Ken Shoulders’ and Don Geppert’s ideas on integrated micron-sized “vacuum tubes” (Vacuum Microelectronics) from the late 50s and early 60s could be what we would be using today, but it sure wouldn’t have been easy . . . and might not have happened. I expect that even there had been a 20-year head start for micro-vacuum devices, solid state would have become a (or the) major technology eventually.

Technology Is Forever in Flux

When AT&T announced the invention of the transistor, its importance was recognized immediately, but many years and millions of dollars of intense development were needed before the transistor was established as a practical replacement for vacuum tubes in most applications.

Devices invented for one purpose often end up being used for other purposes. Transistors were invented to replace amplifiers, which of course they did, but they were not suited for use in computer circuitry until the mid-1950s, when IBM and others decided they were the wave of the future. AT&T announced the transistor in 1948 and distributed sample devices the same year. Many major U.S. corporations launched large scale, intense research and development projects immediately. IBM held back until 1955, when it began the "Stretch" computer project. "It was . . . obvious that an enormous investment would be required to develop the infant transistor technology." The Stretch used 169,100 transistors. The solid-state devices of that time "were neither fast enough nor had they the current-carrying capabilities to drive the ferrite core memories." Engineers who had been trained to work with vacuum tubes had difficulty adjusting to the new technology. "For a time the laboratory expressly forbade anyone to have a piece of vacuum-tube equipment visible within his work area." In 1956, eight years after the initial breakthrough, IBM still had no transistor manufacturing facilities. It had to buy initial lots of transistors from Texas Instruments. [4]

People have a false sense that our way of life is permanent and our tools have been with us for a long time. We think of computer random access memory (RAM) as the main use of transistors, but until 1970 most RAM was made of ferrite core. Transistors remained difficult to manufacture and expensive. In 1966, after 18 years of massive, worldwide research and development, semiconductor computer RAM memory cost roughly $1 per bit compared to $0.10 for magnetic core or film, or $0.01 for slow ferrite core. [5] Ferrite core memory is used in the Space Shuttle, which was designed from 1972 to 1978. RAM was also made of thin films, plated wire, and in early computers, rotating magnetic drums like today's hard disks. Semiconductor RAM was too expensive for primary storage. It was used for fast, CPU scratch pad memory. [6] Magnetic ferrite core dominated for 15 years, semiconductors replaced it for 30 years, and if recent developments pan out, magnetic memory may soon make a comeback, replacing semiconductors again. Magnetic RAM remains attractive because it is fast and it holds data without consuming power even when the computer is turned off. [7] New kinds of memory may replace semiconductors. Exotic, three dimensional, holographic RAM might be perfected. A holographic memory chip would hold terabytes (a million times more than today's RAM) and it would operate thousands of times faster. [8] In handheld computers and digital cameras, tiny fast hard disks may soon replace semiconductor memory -- a revival of the magnetic drum. Since 1986, the cost and data density of hard disks have been improving faster than semiconductors, confounding industry predictions. [9]

Competing solutions to the same problem -- like magnetic versus semiconductor RAM -- often race neck and neck for years. Sometimes they end up converging, when someone finds a way to combine the best features of both. A good example is the competition between propellers and jet engines. The Wright brothers invented the pusher propeller mounted on the back of the wings, which kept the air stirred by the propellers from affecting flight performance. This was followed by tractor propellers mounted on the front of the airframe or on the wings. The propeller works best at speeds below 400 miles per hour, and it does not work at all above 500 mph, when the blade edges exceed the speed of sound. The "pure" jet, or turbine engine, was invented in the 1940s. It works well at or above the speed of sound, but it is inefficient at slower speeds. The turboprop engine -- a jet driving a conventional propeller -- came next. It has excellent flying qualities, fuel economy and reliability, but it cannot go above the 400 mph propeller speed limit. Finally, the propeller was placed inside the engine cowling to make the fan-jet, which is the biggest and most efficient engine yet. It is a hybrid, combining the advantages of propellers and jets. General Electric occasionally advertises a futuristic looking jet engine with an unducted fan at the back of an engine which is mounted on the rear of the airframe -- bringing us back to the Wright brothers pusher propeller design.

> . . . the commercial development of the turbine passed through some paradoxical stages before arriving at the present big jet era. Contrary to one standard illusion, modern technology does not advance with breathtaking speed along a predictable linear track. Progress goes hesitantly much of the time, sometimes encountering long fallow periods and often doubling back unpredictably upon its path. [10]

A Piaggio P180 Avanti. The company claims, "The Avanti was developed by discarding conventional aeronautical thinking!" - http://www.piaggioamerica.com/, but ironically this design is reminiscent of history's first airplanes, the 1903 – 1909 Wright Flyers, with a canard wing forward and twin pusher propellers mounted on the wings. Photo by J. Rothwell

In the mid 1960s, people did not know that semiconductors would soon become the dominant form of RAM, and they continued to pour money into commercially successful but obsolescent alternatives like magnetic cores, thin films and plated wire. In 1966 RCA advertised that it was developing superconducting cryoelectric computer memories which "offer far greater potential bit-packing density in computer memory elements than does any current state-of-the-art system . . . and at a far lower cost per bit." The advertisement boasted that a 3-cm square memory plane "might well contain as many as one million bits!" This was ten times better than the best ferrite-core memory plane then available. [11]

Research and development is risky; companies lost fortunes backing the wrong kind of transistor, or the right kind at the wrong time. An engineer who worked on the 1955 Univac LARC supercomputer wrote:

> The development of a 4 µsec memory was a great technical challenge (otherwise known as a headache). The biggest problem without apparent solution was that there wasn't a transistor available that was capable of driving heavy currents that could switch fast enough. If only the memory could have been designed two years later, the problem would have disappeared. The problem was resolved but in a brute force, expensive manner. . . .
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> . . . all problems were solved, but at great expense and delay to the program. LARC is an example of the price that must be paid for pushing the state of the art before it wants to be pushed. [12]

When a technology is just beginning, people do not have a sense of how the machine should look or what the best use for it will be. In the early days of automobiles, airplanes, RAM memory and personal computers inventors created a wonderful effusion of picturesque and improbable designs. Transistors were first made of germanium, then later silicon. Competition was hot from the start. Soon after Bell Labs invented grown junction devices, General Electric announced the alloy junction, which was easier to manufacture. RCA licensed GE's design and soon began mass production. In a recent interview, Jack Kilby recalled: [13]

> The semiconductor technology, in general, changed very rapidly in the 1950s. We went through, I think, six completely different types of transistor structures in that period from point contact to grown junction, alloyed junction, surface barrier, diffused base, and planar. This could be done in part, because the equipment was very inexpensive. Not much money was involved in tooling so that basic changes of that type could be accomplished.

Many different cold fusion devices have been developed, using palladium, nickel, and superconducting materials. Loading has been achieved with electrolysis, electromigration, deuteron beams, and various other methods. Critics say this effusion of techniques means that scientists are floundering around. They are floundering, but this is a healthy, normal part of dynamic, early stage, free-form discovery.

Integrated Circuits Looked like a Bad Idea

After transistors became practical, other inventions were needed to make them ubiquitous. To start with, engineers could not pluck out triode vacuum tubes and install transistors instead; they had to redesign products from scratch and reeducate themselves in the process, like the IBM engineers working on the Stretch computer. Conventional heaters and motors will likewise have to be redesigned to utilize cold fusion power.

Transistor innovation did not end when AT&T was granted a patent. Transistors required a tremendous amount of research. They underwent many changes, growing faster and more powerful as new types were introduced, and as fabrication equipment and materials improved. Improvements continue to the present day, and will continue for as long as transistors are used. The most important innovation in transistor design was the integrated circuit, invented independently in 1958 by Robert Noyce and Jack Kilby. An integrated circuit consists of two or more transistors, resistors, capacitors and other circuits, including the wires connecting them, fabricated together on a single piece of silicon. At first glance, integration seemed like a peculiar idea because, as Kilby explained, “Nobody would have made these components out of semiconductor material then. It didn’t make very good resistors or capacitors, and semiconductor materials were incredibly expensive.” [14] It turned out to be a great idea because it reduced labor and errors and it allowed circuits to be miniaturized. Today, millions of circuits occupy the space formerly taken by one. In a sense, integration and miniaturization were more beneficial than the discovery of the transistor itself.

Integration became inevitable after a printing technique, photolithography, was successfully applied to fabricating transistors. (This is a good example of an old technology used for a new purpose.) Robert Noyce explained that with photolithography, Fairchild produced hundreds of transistors on one piece of silicon, “But then people cut these beautifully arranged things into little pieces and had girls hunt for them with tweezers in order to put leads on them and wire them all back together again . . . Then we would sell them to our customers, who would plug all these separate packages into a printed circuit board.” This was a waste of time, effort, and money. Even though silicon was expensive, it was worth making resistors and capacitors out of it to eliminate this step. Noyce concluded that integration was inevitable: “There is no doubt in my mind that if the invention hadn’t arisen at Fairchild, it would have arisen elsewhere in the very near future. It was an idea whose time had come, where the technology had developed to the point where it was viable.” [15]

Integration, like zone refining (a purification technique developed at Bell Labs; see Part 1), is not directly related to transistors, but it was developed in response to the transistor boom. Integration would have been valuable even if transistors had not come along. In fact, it might have delayed or prevented transistors if it had come first, because, as explained above, it works well with vacuum tubes, and it might have been used to make millions of tiny tubes or magnetic core memories.

Transistors Never Became Easy to Reproduce

In Part 1, I said that one of the myths spread by cold fusion opponents is that soon after things are discovered, they become easy to reproduce. Transistors never became easy to reproduce. Integrated circuits are even worse. In the 1980s, after three decades of the most intense high-tech R&D in history more than 50% of factory die yields had to be scrapped. Today 10 to 20% fails. This is mainly because circuit density keeps increasing; if manufacturers were still producing 64 K RAM chips the yield would be high. But it is also because of fundamental limitations in knowledge and know-how. Reproducibility problems were gradually overcome not by simplifying the problem or finding a general principle which allows 'any scientist' to reproduce a transistor easily -- as the skeptics seem to believe -- but by a combination of heroic measures and "a plethora of small continuous improvements," as an Intel plant manager put it. Heroic measures, or brute force solutions, means building clean rooms, dressing technicians in gore-tex astronaut suits and goggles, and other extreme measures to exclude contamination. Intel maintains such tight control over the machinery in its clean rooms that when an equipment supplier wishes to use a different kind of screw to hold the faceplate onto the equipment cabinet, the supplier must first inform Intel and go through a complex approval process. Such measures would not be needed if this were an exact science. Intel would simply spell out the specifications for screws, telling its vendors what parts to use and what parts to avoid. [16]

The Advantages of Open Development

A few cold fusion scientists claim they have viable heat producing cells. They are apparently sitting on these devices, trying to perfect the technology by themselves, presumably so that they will get a larger share of the scientific credit or royalties. Others, like CETI, talk about establishing a "coordinated" research program with a small number of "research partners." These strategies will not work. Cold fusion is too big to be developed by any single company, or with a planned program of coordination and cooperation. Even AT&T was not big enough to handle the transistor. When one person, one company, or the DoE is in charge of development, even if it only "coordinates" research, the decision makers will probably make a wrong turn and ruin everyone's prospects. AT&T soon went astray in transistors, ignoring the development of integrated circuits for several years.

In 1948, soon after AT&T filed for a patent for transistors, they began shipping sample devices to leading U.S. laboratories including the Army Signal Corps, Los Alamos, the Naval Research Laboratory, General Electric, Motorola, RCA, Westinghouse and others. In 1951 AT&T and the Joint Chiefs of Staff argued over whether the transistor should be classified. AT&T prevailed, but it did agree "to guard the special manufacturing processes so essential to the success of transistor development." AT&T wanted to reveal full details. This was partly in response to pressure from Justice Department antitrust lawyers, but it was also because AT&T managers understood that even AT&T was not big enough to tackle transistors on its own.

In September 1951, seven busloads of the nation's top scientists and engineers were invited to a Bell Labs laboratory for a five-day symposium on transistor performance and applications. Manufacturing processes were not revealed. In April 1952 another nine-day hands-on training seminar was held for companies that had paid the patent licensing fees. This time, AT&T revealed everything. Mark Shepherd, a Texas Instruments engineer, recalled: "they worked the dickens out of us. They did a very good job; it was very open and really very helpful." [17]

Other companies soon began manufacturing transistors and paying AT&T royalties. Texas Instruments and others soon made better transistors than AT&T for some applications. AT&T purchased them and saved money in their telephone network. Long distance direct dial service began in 1951, just as the first transistors were being installed in the network. It led to a huge increase in long distance telephone calls and profits. AT&T might have given transistor technology to other companies for free instead of licensing it, yet it still would have benefited tremendously.

Footnotes

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1. M. Riordan, L. Hoddeson, *Crystal Fire, the Birth of the Information Age*, (Norton, 1997)

2. R. Glass, *Computing Catastrophes*, (Computing Trends, 1983), p. 100

3. Spindt's research is described at http://www.essd.sri.com/apsl/vacuum.html

4. R. Glass, *ibid.*, p. 94, quoting the director of the Stretch project, Stephen Dunwell.

5. These numbers are suspect. They come from D. Evans, "Computer Logic and Memory," *Scientific American*, September 1966, p. 82, but the cost of transistors is quoted as $10 per bit, whereas other sources from the mid 1960s, like Sanders or Glass, say it was ~$0.50 per bit. At $0.50 per bit, the 32 MB of RAM in today's typical personal computer would cost $144 million.

6. D. Sanders, *Computers in Business*, (McGraw-Hill, 1968), p. 271

7. W. Gibbs, "The Magnetic Attraction," *Scientific American*, May 1999

8. R. Stein, "Terabyte Memories with the Speed of Light," *Byte*, March 1992, p. 168

9. J. Markoff, "In the Data Storage Race, Disks Are Outpacing Chips," *New York Times*, February 23, 1998, p. C1

10. P. Eddy, E. Potter, B. Page, *Destination Disaster, From the Tri-Motor to the DC-10: The Risk of Flying*, (Quadrangle, The New York Times Book Co., 1976)

11. RCA advertisement, *Scientific American*, September 1966, p. 42

12. R. Glass, *ibid*., pp. 101, 102. The LARC supercomputer when fully expanded had 97,500 words of main memory, and 6 million words of disk space (12 megabytes) on 24 disks. It cost $6 million for a basic system, according to the U.S. Army Ordinance Corps, http://ftp.arl.mil/~mike/comphist/61ordnance/app7.html

13. An Interview with Jack Kilby, Texas Instruments Inc., 1997, http://www.ti.com/corp/docs/kilbyctr/interview.htm

14. M. Riordan, L. Hoddeson, *ibid.*, p. 259

15. M. Riordan, L. Hoddeson, *ibid.*, pp. 264, 265

16. S. Lohr, "Suiting Up for America's High-Tech Future," *New York Times*, December 3, 1995

17. Riordan and Hoddeson, *ibid*., p. 196 - 197