

Conversation with John Bardeen:

John Bardeen [5] with a little help from his friends absolutely and forever changed our world. He invented the transistor.

One day in the summer of 1987 I was reading about him and realized he was still alive and living in Carbondale, Illinois. On a long shot, I called Carbondale information for his number. It was listed. The phone number of the father of the Electronic Age was listed. The manager of our local Circuit City has an unlisted number.

John's wife answered and said "Yes, he's sitting here at the table," and put him on the phone without asking who was calling. I told him I wanted to talk to him about the invention of the transistor, was it a convenient time? Was he in a comfortable chair? He said fine, so we talked for about an hour. He never asked me who I was or why I wanted to talk.

I had been reading about the situation at Bell Labs during his tenure there. In 1945, on deceptively straightforward theoretical grounds everyone had concluded that a solid state triode device could never be made. Unlike a diode, where you can shove two dissimilar metals together so that they share a common face, three solids can't be fashioned so as to have a finite mutual junction in space. Try it yourself with three pieces of different colored clay. It's not fair to mix the different colors, and remember that finite means bigger than a point.

Thus, despite the problems with vacuum tubes, always blowing, problems well known to baby boomers, not their children, particularly well-known near the end of WWII to radar operators in vibrating planes, despite these problems, compared to the everlasting stability of solid state diodes, and what that promised for solid state triodes, it seemed to the non-Bardeen scientists at Bell Labs, for the reasons illustrated with clay above, a frustrating waste of time to attempt developing solid state triodes. Very visual geometric arguments are often accepted as axiomatic without too many tests. The earth is flat and the sun revolves around it daily would be a good example.

A diode, like the crystal of crystal radios, known to most every boy living at the time [2], could rectify, meaning it could pass a current in only one direction, and by combining it with a few other components, some ear phones, and a long wire antenna strung to a nearby tree, one could hear AM radio broadcasts lying alone in your bed at night, and feel remarkably in touch with the world. But to amplify the sound so as to hear it through a speaker, one would have needed a tolerant mother a source of power, and an amplifier. An amplifier needed three elements, and the three elements needed to be inside of a vacuum tube because the process wouldn't work in air.

One element was a source of free electrons, called a cathode which would be a hot piece of metal inside the tube connected to the negative terminal of a battery through a pin sticking out of the bottom of the tube. Another element was a place for the electrons to flow to after they traveled across the tube. This was the anode and would be a cool strip

of metal some distance away from the cathode with a positive charge on it. The charge was supplied by the positive side of the battery and delivered through another one of the pins on the bottom of the vacuum tube. The third element was a piece of screen wire called a grid somewhere between the other two elements which could, by its charge, regulate the flow of electrons between the cathode and the anode in tune with the music. If the grid was given a positive charge by a power source which was connected to one of the pins coming out of the bottom of the tube, then the electron flow was enhanced (some of the electrons collided with the wires in the grid and were lost, but most of them just flew through the holes and were received at the anode plate. If it were more negative, they were repelled. The signal, or the varying charges on the grid, in the earliest amplified radios, could have come directly from a device resembling a crystal radio. The electrical current from the cathode to the anode that the grid controlled was the power that went to the speaker through the cables. Later it got more complicated. What the whole thing accomplished was that a very weak signal coming out of the air into the antennae was transformed into a much stronger but similar signal by the power from the battery and the ability of the triode to control that power. The triode actually had five pins, because two of them were needed to heat up a filament, like a light bulb, which heated the cathode. Usually when a tube blew, it was the heating element that failed. And they did fail a lot. That's why they had tube testers in every hardware store. But hardware stores were inconvenient to put into airplanes and the tubes in radar did the same things as in a radio and failed very often due to the vibrations.

Solid state diodes hardly ever failed and Bardeen was a stubborn man. He believed in the possibility of a solid state triode in spite of the fact that three solids can't overlap in space. He thought there must be some way that would allow for one of the elements to control the current between the other two, in other words, to act like the grid in a triode vacuum tube.

On the phone that morning, he told me there was one man at Bell Labs, a senior marketing fellow, who could smell the money that a solid state amplifying element would make from the military and wasn't too impressed with the theoretical impossibilities. Perhaps he had never played with clay. And so he alone encouraged John to put a little effort into it in spite of the fact that Bardeen's immediate supervisor, William Shockley, according to Bardeen, thought it was wasted effort. Gordon Moore, founder of Intel and author of Moore's Law, worked with Shockley later in Palo Alto, and gives Shockley a little more credit for realizing the potential of solid state devices. [6] I'd bet on Bardeen's version, but anyway Bell Labs was a loose enough scene in those days that John could work on it without Shockley's permission, and Shockley wasn't there just before Christmas in 1947, when the germinal experiments were done.

And they worked. Bardeen and Walter Brattain demonstrated using a germanium diode that a signal applied to a tiny lead at the junction of the diode could control the current through the diode.

He had lots of solid state diodes, which are two dissimilar metals pushed together tightly so that they share a common surface, and they act like vacuum tube diodes because they

allow electrons to pass through in one direction and not the other. The reason this worked in a vacuum tube diode (and the reason I say “worked” is that they are now collectors items—they still work, but we don’t use them anymore) was that one side of the circuit, the cathode, was heated by a filament and therefore had a cloud of electrons buzzing around in the surrounding vacuum, kind of like a pot of boiling water on a stove has a bunch of steam around it, and the anode was relatively cold and did not have a cloud of free electrons around it. So the electrons could flow to the anode but not away from it, like steam can land on an ice cube but can’t escape from it. In a solid state diode the situation is a little more complicated, but it works the same way. One side has some loosely bound electrons and the other doesn’t. Bardeen was looking for a way to regulate the flow rate of electrons from the anode to the cathode with a relatively small signal current, and thus make an amplifier. Since a third solid element could not be crammed into the junction of the metallic anode and cathode, he sneaked in a teeny little wire, which he described as a “cat whisker” on the phone. Little thin wires called “cat whiskers” had been used by hard core crystal radio enthusiasts to find the “sweet spots” on their galena crystals. In 1947 he carefully placed a whisker right at the junction of a diode and measured the current of electrons flowing across it to see if it could be effected by a tiny current flowing in from the “cat whisker.” It was a tricky measurement to make because micromanipulators hadn’t been developed and, well you must know about cats and their whiskers. But it did work. It was amazing that it worked. But it did. It wasn’t something you could make two million copies of with good quality control right away, but the cat whisker was out of the bag so to speak, and after Shockley figured out how to do something very similar, but without the inconvenience of extremely thin precisely directed wires, they started making the things by the billions,. Bardeen , Walter Brattain, and Shockley got the Nobel Prize in 1956 [1], and the scientists at Bell Labs who had thought it was impossible, had to eventually buy transistor radios for their kids. Shockley was later thought to be downright weird particularly for his social concepts. I never talked to him myself, and being an excellent judge of weirdness due to an intimate familiarity with the subject, I hate to rely on lesser judges.

That day on the phone I told John Bardeen that I was sitting at my kitchen window looking out on the beach in La Jolla, and that there about ten transistor radios within sight with hundreds of transistors in them, and scantily clad college girls who had brought them from Arizona for the week-end, and in my house I was surrounded by at least a million more in my electronic equipment. I could have said a billion, and it would have probably been right, but I didn’t know for sure. And what did he think about that? Did he have any idea back there in New Jersey what was going to happen?

“Well no,” and I’ll have to paraphrase here because I can’t remember his exact words, but I remember what he meant, “I was thinking they would be useful for radar of course, because of the vibrations in an airplane, that’s what got me into it, and I thought maybe they might be useful for hearing aids.”

“Did you envision little radios that people would carry around?”

“No I didn’t see why anybody would want to carry around a radio.”

I pictured my own grandfather sitting peacefully and deeply inside his ancient red upholstered chair beneath his completely mechanical grandfather clock on the mantle, beside his cabinet size Magnavox, oblivious to any cares and especially of his wife calling from the kitchen. He was listening to Benny Goodman and maybe if he had owned a portable radio he might have carried it down to the barn to listen to the farm report while he was doing the early milking, but it probably would have frightened the cows and anyhow, what about his big red chair. He couldn't very well carry that down to the barn. I have to agree with John, I don't see why anybody would want to carry around a radio.

“Did you realize that John von Neumann [4] was about thirty miles up the road at the Institute for Advanced Studies in Princeton working on one of the first electronic computers. They say it had ten thousand triodes, and made a lot of heat. The tubes were always blowing out. They could have really used transistors.”

“Yes, they could've. I didn't know who he was or what they were working on. There's more communication today”

“Probably because of you, John. Nice talking to you.”

I'm glad I called him. He was a real gentleman, and he not only changed our lives in ways that become more unbelievable every day, it was such a momentous thing that they did, it may well have changed our souls, whatever those are.

1. <http://www.nobel.se/physics/educational/transistor/function/firsttransistor.html>
2. <http://www.midnightscience.com/project.html>
3. <http://hyperphysics.phy-astr.gsu.edu/hbase/solids/bcs.html>
4. <http://ei.cs.vt.edu/~history/VonNeumann.html>
5. <http://www.physics.uiuc.edu/people/jbardeen.html>