



## **Oral History of Jonathan Titus**

Interviewed by:  
Dag Spicer

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**Spicer:** Okay, perfect. Well, okay, so, it's Wednesday, October 2, 2019. We're here with Jonathan Titus, who is a computing pioneer. And, Jonathan, thanks so much for joining us today.

**Titus:** You're welcome. Happy to be here.

**Spicer:** I wanted to ask you a little bit about your life and where you were born. Tell us a little bit about where you grew up and what kind of things your parents and your family -- what kind of roots they came from.

**Titus:** Sure. I was born in Washington, D.C. in 1945. My dad was in the Service during World War II in the intelligence branch. He was stationed at Arlington Hall Station, where they were doing a lot of code-breaking and deciphering communications. And my mom had moved down to the Washington area to be with Dad and I was born in Walter Reed Army Hospital.

**Spicer:** Oh, my gosh. Sorry, let me interrupt for a second. Was he [your Dad] part of the CSAW Group? Do you know who that is?

**Titus:** I don't know. I know he worked with William Friedman--

**Spicer:** Oh, wow.

**Titus:** --and the group that was at Arlington Hall Station, which then become the Army Security Agency. And he actually left some artifacts when he died that I sent to the National Cryptological Museum at Fort Meade, Maryland. I think that's where it is.

**Spicer:** Oh, wonderful.

**Titus:** And one of them was a couple of copies of an internal newsletter they put out during the war and the museum said they'd never seen it. They'd heard that such a newsletter existed--

**Spicer:** Oh, my gosh.

**Titus:** --and there was also a photograph of a number of people who were involved in the cryptography effort during World War II, that I don't know whether they had it or-- but, anyway, they were happy to get it.

**Spicer:** Oh, that's a great story. Fantastic. So, now, can you tell me a bit about him? Was he an engineer or--?

**Titus:** My dad? No, my dad actually went to Pratt Institute after high school to become an architect, but he got out of school in the middle of the Depression and there was not much need for architects at that time. So, he decided he would go back to law school and went to law school and went to Brooklyn School

of Law, got his law degree and became a practicing attorney in Huntington, New York, which is on Long Island and that's where we lived, I think, from '47 to '54. And then some property came available close to where my maternal grandparents lived. So, we decided-- or my mom and dad decided that they'd like to move there and, since my dad was an architect, he re-designed the building that was on the site to become a better dwelling for a husband, wife, and three kids. So, we grew up in Greenlawn and attended the Harborfields School System and then-- you know, my mom was a school librarian. She was very concerned about a recession that took place in the 50s as the government cut back on military spending. And military spending for a great number of years funded Long Island's economy. It was Grumman and Republic and a couple of other companies out there that played the role of major contractors for those aircraft companies. So, as hard times hit, my mom decided, "You know, I'm going to go back to work and make sure that I can supplement the family's income," because a lot of my dad's work was real estate law.

**Spicer:** Oh, right.

**Titus:** So, my mom went back to Queen's College and got her masters degree in library science and got her teaching certificate in New York State and became an elementary school librarian and did quite nicely. She won an award for the best elementary school library in New York State.

**Spicer:** Oh, wow, that's great.

**Titus:** Yeah, so, we certainly were a bookish family. We had lots of books around. And mom made sure that we read during the summer, too, so we'd have lots of book reports ready to go when we got back to school.

<laughter>

**Spicer:** Oh, that's wonderful. So, that's great. And, so, you went through the-- up to high school in that area in Long Island?

**Titus:** Yeah, there was Harborfields High School in Greenlawn, New York.

**Spicer:** Okay.

**Titus:** That's where I went to high school. And I have two brothers. I have-- both of them younger. My brother Bill is three years younger and my brother Chris is five years younger.

**Spicer:** Okay, great. And what are they doing?

**Titus:** Well, my brother Bill is retired. He has spent his entire career at a museum on Long Island, a small art museum in Huntington, New York. He became the registrar and retired from that position a couple of years ago, now lives in Virginia. My brother--

<overlapping conversation>

**Titus:** I'm sorry: Go ahead, Dag.

**Spicer:** No, please go ahead. I was just saying, yeah. I was just agreeing. Yes.

**Titus:** Okay. My brother Chris and I were interested in many of the same things and he and I did a lot of things together that I'll describe later on as we get into more details, but Chris was one of the scientific brothers. I was very interested in science and technology from an early age. And my paternal grandfather had been an electrical contractor and had his own business. When he was-- I'm trying to remember-- I don't know how old he was, but he encouraged my dad to develop my interest in electricity and gave my dad a lot of these big one and a half volt cell batteries about the size of a drinking glass that they used to call "ignition batteries". Perhaps they were used in cars or whatever. But I had those and wire and knife switches and light bulbs and bells and buzzers and all kinds of different things that I could wire up various circuits with and enjoyed it. I had a lot of fun doing that. So, that kindled my interest in electricity.

**Spicer:** Right. And that's perfect. I was just going to ask you if you had any hobbies as you grew up. So, electricity would have been one. And any others?

**Titus:** Yes. I was very interested in chemistry, too. My dad got some highway flares or railroad flares on July 4th and that was our July 4th celebration, watching these red flares burn. But--

<laughter>

**Titus:** --I wondered for a long time what caused the red flame and my dad said, "Oh, it was the chemicals that were mixed in there." And I thought, "Oh, that's interesting. This chemical business--"

**Spicer:** Right.

**Titus:** "--there might be something to it." So, a couple of friends and I decided that we were going to look into chemistry and the first way we decided to proceed was we took one of those big one and a half-volt batteries down in the basement and took it apart and we decided, "Well, you know, if we can figure out how this battery is made, maybe we can make our own batteries, even bigger and better." But what we did was make a big black stain on the floor in the basement--

<laughter>

**Titus:** --and get stuff all over the place and--

**Spicer:** Yeah!

**Titus:** My dad was not happy that we had done that in the basement and we never did anything more in the basement. And that kind of put a damper on chemistry until I guess I was in-- I guess fifth grade. I

must have been about 10 and I got one of the A.C. Gilbert chemistry sets for Christmas. And that was just fantastic. And then I got a book, I think, maybe the same Christmas. It was by a guy named Alfred Morgan. And I've got it up here on my shelf. It's called "Simple Chemical Experiments". And I don't know what the copyright is on it, but it says in here, "From Mom and Dad, Christmas 1958".

**Spicer:** Oooh.

**Titus:** So, I loved that book and it's still around. And it had a lot of chemistry experiments in there. So, my dad said, "Well, look, you've got your Gilbert chemistry set, why don't you make a list of some of the other chemicals that you think you might need and we'll go into New York City where there's a place that sells small amounts of chemicals to home experimenters."

**Spicer:** Oh, that's fun.

**Titus:** "And we'll get some of these."

**Spicer:** Yeah.

**Titus:** So, I had quite a lab in the basement.

**Spicer:** Oh, that's nice. So, yeah, I'm amazed at how many people got into science because of those chemistry kits.

**Titus:** Oh, yeah!

**Spicer:** It's amazing. So, did you do anything interesting? And by "interesting" I mean-- well, you left a big black stain, which I think everyone who uses those kits has one of those stories--

<laughter>

**Spicer:** --like a big black stain or a horrible smell or--

<overlapping conversation>

**Titus:** Yeah, or \_\_\_\_\_ <00:09:43> rug or something.

<laughter>

<overlapping conversation>

**Spicer:** Yeah, so-- sorry, go ahead. Yeah.

**Titus:** We were pretty careful. We had a small basement under the house, so we had a small spot in the small basement, a small table and some shelves. As I went through high school, I knew the high school chemistry teacher quite well and he let me take small portions of the chemicals in jars home, you know: weigh out 10 grams or 20 grams of it and take it home and put it in my lab. He knew enough about me and he knew my folks, too; so, it was-- he figured he was in safe territory letting me take this stuff home and experiment with it.

**Spicer:** Right. Do you have a thought for what kind of compound you were-- I mean, most boys would try to make something explosive, I'm guessing.

**Titus:** Yeah, well, we did that, too. And then we got to the point ordering chemicals in 5- and 10-pound batches and making fireworks.

**Spicer:** Oh, wow!

**Titus:** And we, at one point, were putting on fireworks displays with homemade fireworks for the tennis club or beach club that my mom and dad belonged to. So, we were really in the fireworks business for a while. And my brother Chris decided when he was in high school, "Look, you know, we know how to make fireworks and we know the formulas and so on. Let's write them up and sell them." So, we took out a couple of small ads in Popular Science magazine in the Classifieds section that said, "Fireworks Information," or "Buy Fireworks Information," and so on. So, we sold the fireworks formulas, I think, for about a dollar for maybe four or five pages of these things. And it was amazing the number of people who wanted fireworks information. So, we decided, "Okay, if they want information, maybe they'll buy supplies, too." So, we wrote to a company called Ensign Bickford up in Connecticut. They manufactured safety fuses like you'd use with dynamite or fireworks or whatever. And we bought, I don't know, how many thousands of feet of this fuse in big rolls, like you see on the side of the road with telephone wire on them.

**Spicer:** Wow.

**Titus:** And we would spool it off into 50-foot lengths and put it in an envelope and send it to people.

**Spicer:** Oh, my gosh.

**Titus:** And then we decided, "Hey, yeah, let's sell some chemicals, too. So, we found a company in New Jersey that made smoke grenades of the type that the fire department would use in training and such.

**Spicer:** Oh, yes.

**Titus:** So, we wrote to them and we said, "Hey, would you sell us some of the mixed up smoke powder in a can? We'd like to buy 50 pounds or 100 pounds," and they said, "yeah, sure, just send us a check." So--

<laughter>

**Titus:** --we were boxing that up in one pound bags and shipping that in the mail and we did that for a while. And then, one day, some people knocked at the front door and identified themselves as FBI agents.

**Spicer:** Oh!

<laughter>

**Titus:** --you know, the whole fire and--

**Spicer:** Yeah, ATF. Yeah.

**Titus:** And my dad being a lawyer said first, "Well, what's this all about?" And they said, "Well, we want to talk to you about the shipments of smoke powder and fuse," and so on and so forth. And my dad invited them in and they said, "Well, we want to see the laboratory." And my dad said, "No. You can talk to me and that's as far as it's going to go." And, so, they chatted with my dad for a little while and left. But when we took the next shipment down to the post office, the post office said, "No, no, sorry, we can't ship this anymore." So, instead of just giving up, we went to the next town over where they figured that the post office wasn't any the wiser and we mailed it from there. And that was the last shipment of smoke powder we made.

**Spicer:** Oh, wow. Yeah, I was amazed as you were telling that story. I was thinking, "How is this possible?"

**Titus:** Today, you could probably get arrested for who knows what.

**Spicer:** Yeah.

**Titus:** Anyway.

**Spicer:** Oh, my gosh, well, that's a great story. You're obviously showing some entrepreneurial "flare" at an early age as well.

**Titus:** Yeah.

<laughter>

**Spicer:** And it reminds me when you said you put an ad in Popular Science, it's like, "Wow, this is like the radio electronics thing, but 20 years earlier," or whatever it was.

**Titus:** Yeah, it was probably in the early 60-- well, not early '60s. I would say mid-60s, because I know I was in college and Chris was still in high school. So, that's probably about when it was. But, at the same time, we were doing that, my brother Chris and I were very interested in [the] use of relays and switches

to create what today we would think of as logic circuits AND and OR-- although we didn't know about Boolean algebra or De Morgan's theorems or any of those things, to design circuits, but we enjoyed putting together circuits and making them do things. And my senior year in high school I made a binary adder with relays. It was a four-bit adder. So, it was a big deal--

**Spicer:** Oh, wow.

**Titus:** --you could add four <00:14:15> binary bits.

**Spicer:** Yeah.

**Titus:** But it used a number of relays and switches and only later did I realize that the circuit could have been much more simplified if I had known about how to design logic the way an electrical engineer would design it. It could have been so much simpler. But it was kind of a brute force effort and it worked and it did what it was supposed to do. So, I got a science fair award for that. So, I had parallel interests: chemistry and electronics. Electronics pretty much focused on computers, although I did get a ham [amateur radio] license when I was-- I guess after I graduated from high school.

**Spicer:** Oh, great. Did you know about the Simon Computer at the time? That was a relay-based-- it was a kit from--

**Titus:** What was it called?

**Spicer:** Simon. S-I-M-O-N. From Edmund Berkeley.

**Titus:** Oh, no, I didn't. That was in the early 60s also?

**Spicer:** Yeah, even late 50s, we've got one on display at the museum. It's actually a box about the size of a microwave oven, I guess, and it's just dozens of relays as far as you can see.

**Titus:** No, the only thing that was similar to, I guess, that-- without the relays-- I think was called Brainiac.

**Spicer:** Oh, yes, right.

**Titus:** Brainiac was built on what I would call Masonite board with holes drilled in it. And you would wire up these little brass contacts on the board and behind it there'd be wires between them and then there was this circular piece of Masonite that mounted on the front that also had little brass jumpers on it. And you were supposed to be able to make machines or, like, tic-tac-toe machines and some other logical devices with this, but I could never get those contacts to work very well. So, I gave up and moved on to relays; and relay as in "switches."

**Spicer:** Right. Did you ever combine your electricity and chemistry interests?

**Titus:** I did, but that's later on.

**Spicer:** Okay. We can come back to that.

**Titus:** In my career.

**Spicer:** Yeah. So, anything else you want to say up to-- we're up to your high school years now and-- oh, maybe the amateur radio stuff?

**Titus:** I was interested in amateur radio for quite some time, because as a kid one of my friends suggested that he would get a ham radio and stick it in the bedroom of a friend of ours down the street and broadcast at night and try and scare him. And I thought, "Well, that's interesting. Radio. I've never heard about people communicating by radio like that." So, I kind of tucked that in the back of my mind. And when I was a senior in high school there was a younger fellow down the street who had his ham license and I went down to see his station. And he was talking with people all over the place, both with code and also with voice. And he said, "John, why don't you get your ham license?" I had a shortwave radio receiver and I said, "Well, I can build a transmitter kit. They're not too expensive. Why don't I go ahead and get my license?" which I did during the summer between senior year and going off to college. At that time, though, the license, which was called the Novice license was only good for one year. After the year, you were supposed to have upgraded to the next level of license--

**Spicer:** Right.

**Titus:** --or you lost your license. So, okay, I went to college. I had so much on my mind, I didn't think about ham radio and lost my license and I didn't get back on the air until the mid-'70s. But it was an interest and it was always something that fascinated me: communications.

**Spicer:** Did you build any Heathkits when you were growing up?

**Titus:** Oh, many. Yeah, many. And I built kits also from Allied Radio. At the time, they were called Knight Kits, with K-N-I-G-H-T for Knight. I had built a shortwave receiver kit from them--

**Spicer:** Nice.

**Titus:** --and that was fun. Then I did a number of Heathkits. I put together--now, let's see-- what was it? It was a vacuum-tube volt meter kit and--

**Spicer:** Oh, yes.

**Titus:** --they had an oscilloscope kit and then, later on, when I was in graduate school I built a Hi-Fi receiver amplifier that Heathkit put together. And, later on, they had a dual trace oscilloscope, bench scope-type instrument, and I built one of those. So, I really enjoyed the Heathkits very much.

**Spicer:** I always thought their documentation was second to none.

**Titus:** Absolutely right. Absolutely.

**Spicer:** Yeah, it was just beautifully done. Okay, and let's see-- anything happening between-- well, let's talk about the colleges you applied to and how you got in there.

**Titus:** Sure. Okay, I applied to Worcester Polytechnic Institute. I applied to Drexel and I applied to Lowell Tech up in Lowell, Massachusetts. And the day that I came home from the science fair with my binary adder there was a letter there accepting me at WPI. So, I accepted that--

**Spicer:** Ah!

**Titus:** --and went to WPI in Worcester, Massachusetts, with the desire to major in chemistry. I had not seriously considered electrical engineering, because it didn't seem to me at the time that the people doing electrical engineering were doing the kinds of things that I was interested in, the heavy-duty computing, and so on. At least, the electrical engineering department at WPI didn't seem to be involved in that. They did have, I think, some computer equipment, but I never saw anybody use it.

**Spicer:** Right.

**Titus:** So, I figured-- I liked chemistry. I really enjoyed chemistry and got my chemistry degree from WPI.

**Spicer:** Oh, great. All right. And how was your college experience?

**Titus:** It was a good experience. I enjoyed it very much. There were some subjects I didn't enjoy very much, but for the most part it was a good education and I was lucky to get some good professors in the chemistry department and good physics professors, too. I enjoyed physics and chemistry. I wasn't that great in economics and I wasn't that great in calculus, but you take the courses you have to. The thing with calculus was that I don't think I used it very much after I graduated from WPI.

**Spicer:** Right, yeah, that's a very common observation, I must say. But, so, let's see: When you were at the college did you-- anything interesting happen to you in your social life while you were there? You were there for four years?

**Titus:** No. You know, it's interesting. I had dated a couple of girls in high school, not seriously, but just to go to a movie and things. And when I got to WPI I realized I was surrounded by a lot of people smarter than I was, so I was going to put my nose to the grindstone and get through WPI and not get into any kind of relationship with a young lady that would detract from studies. I just had to put my nose to the wheel and--

**Spicer:** Right.

**Titus:** --plug ahead. So, not much on the social scene. I did-- I was still interested very much in electronics and approached the electrical engineering department about having access to their labs. But they said since I was not an electrical engineering major I couldn't have access to their labs. I [sic] said, "Why don't you go over to the physics department?" So, I found some professor in the physics department who said, "Yeah, sure, you can use my lab and anything that's in there. Just let me know."

**Spicer:** Oh.

**Titus:** So, I was able to do some electronics experiments in his lab, which was great. I didn't have a lot of time to do it, but it was nice that somebody said, "Yeah, you can do what you want to do and go down to the physics shop and they'll do whatever they can for you." So, no hesitation about sharing resources between the physics department and the chemistry department.

**Spicer:** Well, that's nice. Now, tell us a bit about your experience there. What kind of systems are we talking about? A mainframe, I take it?

**Titus:** Yeah. Sure. General Electric put out a manual, you know, about neon bulbs. I've got one here on my shelf. Let me grab it. It's called "The Glow Lamp Manual" from General Electric. And it talked about how people could use these little neon bulbs that they put out. And they put out many different types and varieties, those little glow bulbs that you find in night lights and you used to find in pilot lights for various radios and TVs and so on.

**Spicer:** I remember the NE-2.

**Titus:** That's right! The NE-2. That's right. And they had an NE-2H, which was the high-intensity model. And in that book General Electric shows circuits for the basic gates of a NAND gate and an OR gate and so on. So, I thought, "Hey, that is really cool, because it's really electrical. It's not a lot of electronics." So, I wired up some of these circuits and had a difficult time getting them to work properly and discovered later on that the characteristics of those NE-2 lamps vary considerably from one to the other. They serve their purposes of pilot light, but if you want to use them in logic circuits, you have to match them carefully. And that takes a lot of work to do. So, out of all of them, you might get five that all match.

**Spicer:** Okay.

**Titus:** And that was a bit discouraging, but I continued to work with them and make little relaxation oscillators and some other things, but I never got to do any computer circuits. The closest thing that I got to a computer circuit in a school like WPI was that I was in a fraternity, Beta Chi, and a couple of us decided that wouldn't it be nice to have an intercom between rooms? And I thought, "Okay, I could solve that problem."

**Spicer:** Right.

**Titus:** And I made, basically, a dial telephone system--

**Spicer:** Oh, fun!

**Titus:** --that was strung between a number of the different rooms. You could-- it didn't have a dial on it. It had a push button, but you could push the number of times for an extension. So, if you wanted to talk to somebody on extension three, you pushed the button three times.

**Spicer:** Oh, wow.

**Titus:** It would connect you and it would give a ring tone at the other end. And then when a person hung up, it would reset itself.

**Spicer:** Wow.

**Titus:** So, that was a lot of fun. Okay, that was a good-- I think it was over Christmas vacation.

**Spicer:** Well, that's an interesting project. As you know, with telephony there's a lot of sort of tricky stuff--

**Titus:** It is.

**Spicer:** --to keep in mind, like the levels from the central office-- or, sorry, in this case, I guess there's no central office. <laughs>

**Titus:** Yeah.

**Spicer:** But, still, to provide ring back and dial tone and all that stuff is tricky.

**Titus:** Yeah. I never got involved with the phone hacking that was of interest to a lot of experimenters at the time where you could get free long distance calls or--

**Spicer:** Oh, yeah.

**Titus:** --that sort of thing. You know, the Captain Crunch and the whistle that was in the cereal boxes that you could use--

**Spicer:** Right.

**Titus:** --never got into that at all. In fact, I probably didn't even know a lot about it at the time.

**Spicer:** Now, what year did you graduate from W--

**Titus:** I graduated in '67.

**Spicer:** Okay, that's with the bachelor's in chemistry, right?

**Titus:** Right, right.

**Spicer:** Right.

**Titus:** And while I was at WPI, this was from '63 to '67, the Vietnam War was well underway and I did-- while I was there, I would go through the four-year ROTC program to graduate as an officer in the Army. I found myself thinking, "I'd better go in the Army as an officer rather than get drafted," and who knows what happens to you. So, I did and I got my commission at the end of the WPI four years.

**Spicer:** Wow.

**Titus:** The Army said, "We will give you two years for graduate school if you want to go to graduate school." So, I decided, yes, I did. I was going to go and get a master's. In fact, my advisor at WPI in the chemistry department suggested I get a master's degree. He basically said, "Look, you've got a good foundation of basic chemistry here, but if you want to be a professional chemist, you really need more education, you need to be experiencing other types of chemistry and just broaden your horizon." So, I decided, "Okay, I'll consider that." And I applied to Rensselaer and I might have applied to a couple of other schools. I just can't remember, but I decided to attend Rensselaer and I was there for two years.

**Spicer:** Oh, terrific. So, from WPI to RPI.

**Titus:** Yes--

**Spicer:** Yep.

**Titus:** --and the nice thing about RPI was that they offered an "Electronics for Scientists" course.

**Spicer:** Oooh.

**Titus:** So, the first year I was there-- and this was a package that was, I think, sold by Heathkit at the time. That's what I remember anyway. A lab station-- had instruments and power supplies and various modules. We learned about vacuum tubes and operational amplifiers and that type of thing. It was an interesting course. And, also, I had worked with my thesis advisor on a couple of organic chemistry projects that just didn't work out. So, he suggested that I talk to one of the other professors in the chemistry department about getting a master's degree with him instead. And he said, "Okay, we're going to do some electrochemistry."

Well, that was right up my alley: chemistry and electronics. So, I got to do electrochemistry, where we put chemicals in solution, we broke them down, we added reagents to make new chemicals and characterized them. It was quite an interesting process, because it was so clean instead, of heating a lot of chemicals and boiling them and distilling them and so on. This was fairly easy. Things just precipitated out of solution-- and just beautiful results. It was very interesting, too, because it gave me an opportunity to look at operational amplifiers and how those operational amplifiers could be used as feedback

elements in a circuit to control the potential across these solutions so that they're not wildly all over the place. They're kept within a specific range so you're not screwing up the experiment. So, you would do some tests to give you that information about voltages and then apply it and make these new chemicals. It was really interesting. I really learned a lot.

**Spicer:** Were you interfacing the op amps to a digital system in any way?

**Titus:** No. We weren't. We were just using the operational amplifiers in something that was called a potentiostat--

**Spicer:** Oh!

**Titus:** --which simply means that you're keeping the same voltage across the cell with something in solution. And we used the operational amplifiers as voltage devices and the output at the end was used to drive a Hewlett Packard power amplifier that provided the high current to break the compounds apart and then add them--

**Spicer:** Ah, now I see.

**Titus:** --add things to the solution and make the new chemicals. So, we had to have additional power and the professor said, "Look, why don't you just buy this programmable amplifier from HP?" which we did. And we put the low voltage in and we got the same voltage output at a much higher current.

**Spicer:** Wow. Now, were there particular reagents and chemicals you were using--

**Titus:** Yeah.

**Spicer:** --geared towards industrial applications or--

**Titus:** No.

**Spicer:** --not so much.

**Titus:** I think it was geared more at looking at how this could possibly be used for synthetic chemistry. That is, you're making new compounds or a different way to make other compounds. And the one that we started with was called hexamethylbenzene. And it meant that benzene with a methyl group off of each of the carbons in a six-membered ring--

**Spicer:** Right.

**Titus:** --and we could pull a hydrogen off that and, once we did, we could add something to the solution that would extend that molecular chain beyond that benzene ring. For example, if you put water into the active electrical solution, you would attach an -OH group on the end and you'd have an alcohol. If you

added an alcohol to it, you would get an ether. And there were a lot of different things you could add to get different compounds. And if you jacked up the voltage, you could cause two of the hydrogens to split off of this hexamethylbenzene and add two different components to it. So, it was pretty interesting chemistry. And the thing I liked about it was, it combined electronics and synthetic organic chemistry and it gave some clean reactions. I didn't have this tarry material that had to be worked up in multiple stages to give us something that we could look at and analyze.

**Spicer:** I like that. Yeah. So, maybe less alchemy and more clean electronics.

**Titus:** Yeah. Absolutely.

**Spicer:** Yes. Right. Well, that's fantastic. So, you finished your master's, I guess.

**Titus:** I did. In two years. And, at that point, I had interviewed before with DuPont and DuPont said, "Well, look, we don't have a job for you right now, but when you finish graduate school, why don't you give us a call?" And one of their recruiters was on campus, so I just kind of went over and had an informal conversation with him and DuPont offered me a job down at their Eastern Laboratory, which no longer exists. It was in Gibbstown, New Jersey right on the Delaware River. And they had a big industrial plant there that made precursors for plastics. They also had the Eastern Laboratory there where there was a small lab. But they did some specialized work and I got assigned to make a particular compound that they thought might be useful in fabrics and also in the belt in the-- what was it?-- the tubeless tires, I guess, at that time.

**Spicer:** Oh, yeah! The inner tube.

**Titus:** Yeah, we didn't want inner tubes. We had the tubeless tires--

**Spicer:** Oh!

**Titus:** --and they wanted to make them strong.

**Spicer:** Right.

**Titus:** So, they had a number of different fibers, Nylon, of course, and Rayon, and they were looking for another one. And the compound that they wanted to use was difficult to make. So, they said to me, "Okay, here's your test. Try and figure out a way to do this." Well, I didn't get very far. I was only there for the summer when I got orders to report to active duty in the Army for two years. But it was enjoyable. It was a good lab experience. I enjoyed working for DuPont and I enjoyed having their chemistry library available to me on weekends, too. I didn't go in the lab on weekends. You weren't supposed to work alone, but I had access to the library and I learned a lot there. I learned a lot about working with other people, working with groups, reporting to a boss, and how to keep a good lab notebook, and so on. So, it was a good experience.

**Spicer:** Yeah, that's-- I mean, if you were into chemistry, DuPont has got to be one of the top-- it's like going to IBM.

**Titus:** Yeah, they were! Yeah, absolutely.

**Spicer:** If you're not into computers. So, did you have any idea about your future at this point? What kind of career-- I mean you were, I guess, sorry, you were in the military. So, that's your career.

**Titus:** No, no, that's okay. I knew and DuPont knew that I was going to spend a couple of years in the Army and when I left DuPont said, "Well, look, you know, when you come back, let us know and we'll have a job here for you."

**Spicer:** Oh! Good.

**Titus:** So, I said, "Well, that's great. Once I get out of the Army, I can write to my boss and move right back to New Jersey." Well, that sounded particularly good because as soon as I finished at RPI, I got engaged.

**Spicer:** Oh! Wonderful.

**Titus:** I had been on summer vacations for quite a few years on a lake in Canada and, through that, met a young lady up there. And we were good friends for a couple of years and then started dating and decided, "You know, we really love each other. It's just not friendship anymore. It's blossomed beyond that."

**Spicer:** Ah.. That's-- yeah.

**Titus:** So, we got engaged and we had set our marriage for October of 1970. So, we decided, "Okay, we'll get married." I had been in the Army for a little while and we got married. So, I knew that the marriage was coming and it seemed to be a good idea to have some stability; that is, a job to go back to at DuPont.

**Spicer:** Yeah.

**Titus:** And I thought that after the Army I would certainly go back to DuPont.

**Spicer:** Right. And how was your stint in the military? Did you go abroad or stay--

**Titus:** No, I didn't actually. I got assigned to a base that a lot of people don't know about. It was at the time called Sandia Base--

**Spicer:** Oh.

**Titus:** --and it was in Albuquerque, New Mexico. It's now part of, I think, Kirtland Air Force Base, which is to the south of Albuquerque. And I was assigned to become a member of what was called a nuclear emergency team.

**Spicer:** Oh, wow.

**Titus:** And that team was trained to go out if there were any nuclear accidents, military nuclear accidents-- we were trained, eventually, to go out and decontaminate the site--

and scoop up the radiation and do whatever had to be done. Thankfully, we didn't have to do that. The military didn't have any radioactive material accidents. But we also trained other people to do that. And I think training was probably the most important thing that we did. We would have people come in from various military groups-- Air Force, Navy, and Army-- come through and get trained in the basics of decontamination and how to suit up and how to avoid contaminating yourself with radiation.

**Titus:** So, it was an interesting job. We were supposed to be on rotating 24-hour alerts to go pretty much anywhere in the world. So, the military sent us off to various schools. We went to an arctic survival school in Alaska. We went to mountain climbing school at Fort Parson, Colorado.

We did Air Force wilderness survival training. And I was on my honeymoon, but a group of guys went down to Panama for jungle training. So, the group was trained to go pretty much anywhere. and we had bags with all our gear in it ready to go. I remember walking around at our first married Christmas, I had a radio and kind of a lunch pail, those old Motorola two-way radios--

**Spicer:** Oh, yeah.

**Titus:** --while we were Christmas shopping in case we got the call and we had to go some place--

<overlapping conversation>

**Spicer:** Oh, gosh.

**Titus:** Thankfully, we never got the call. We just trained people and kept our own training skills up-to-date. So, that was interesting. But the nice thing about being in the military right there was that I was stationed right next to the Sandia Corporation. And Sandia Corporation ran lunchtime courses in everything from accounting and English as a second language up to how to use integrated circuits. And, of course, integrated circuits were fairly new and I thought, "Well, I've got lunch times free. I'm going to go over." And I took a course in digital integrated circuits and I took another course in linear or analog integrated circuits. And I thought, you know, "These are kind of interesting devices. I bet I could use them."

So, I got myself one of these solderless bread boards and I called the local Texas Instruments and other semiconductor company representatives and said, "Hey, I need some samples of these devices," and

bought integrated circuits and wired them up and got NAND gates and flip-flops and various other chips to work. So, I was teaching myself based on my own experiments, but, at that time, a fellow named Don Lancaster was writing extensively for *Popular Electronics* magazine and he had digital clocks and digital counters and all kinds of things. And I found I was able to adapt what he had done in his circuits to do things in the circuits that I wanted them to do something in. So, with that knowledge, I was able to design and build an automatic phone dialer. So, I had-- I could program the numbers in with a matrix of diodes and then whoever was using it could select the phone number and push a button and it would automatically dial it. At that time it wasn't tone dialing. It was just the on-off as if you were using a rotary dial.

**Spicer:** Right.

**Titus:** It was just a relay pulsing the phone line. But it was kind of cool. I think I had four or five numbers in there that you just press a button and off you go. Your call is already made, you didn't have to remember phone numbers.

**Spicer:** Did they have-- at that time, I know there was a Mostek chip, the MK5082, I think, the DTMF chip--

**Titus:** They didn't have DTMF on the phone system at that time.

**Spicer:** Oh, okay. This was an on-base phone system.

**Titus:** Oh, wow. So, it probably lagged technology at the time. And I just used standard TTL 7400 series devices.

**Spicer:** Right. So, now was Don's-- Mr. Lancaster, was his TTL and CMOS cookbook out yet at this time?

**Titus:** I didn't-- yeah, I didn't have those books. I just had the information that he provided in the articles.

**Spicer:** Right.

**Titus:** And based on that information I could duplicate some of his circuits and learn what to do by making mistakes and correcting them and figuring out how to get things to work together. For example, I was experimenting with one chip and I just couldn't get anything out of it. And then by reading the datasheet, I discovered, "Oh, this has what are called open collector outputs."

**Spicer:** Oh, yeah.

**Titus:** And, "Okay, how do you handle open collector outputs?"

You have to put a pull-up resistor on them. "Oh, okay!" So, once I got a pull-up resistor on them, everything worked fine. But it was kind of self-education.

**Spicer:** Yes! Well, that's-- yeah, exactly. And I think you're on almost the same level as professional engineers, because it was new to them, too. And some of the vacuum tube knowledge that they had was not really transportable over to transistors. They don't really work the same way.

**Titus:** Right, right. Exactly.

**Spicer:** Yeah. So, there was another engineer, too, Forrest Mims. Does that name ring a bell?

**Titus:** I'm sorry?

**Spicer:** There was another engineer called Forrest Mims? Does that name ring a bell?

**Titus:** Oh, I knew of him, but I don't remember at what time.

**Spicer:** Oh, yeah. So, he was sort of the same--

<overlapping conversation>

**Spicer:** --kind of idea as John Lancaster, except he wrote a series of books for Radio Shack, which were very popular. I remember using those.

**Titus:** Yes.

**Spicer:** And you may have used those, too. They were kind of cookbooks.

**Titus:** I probably did, because I remember building some of the things I think he wrote. He, at one point, had some circuits for people interested in model rockets, a little transmitter--

**Spicer:** Exactly. Yeah.

**Titus:** --on "The Citizen \_\_\_\_\_ <00:44:29> and so on. Yes. Though I do recognize his name, absolutely.

**Spicer:** Yeah, and, in fact, I think, was it him-- I want to get this right, but that's how MITS got founded? Forrest Mims was with--

<overlapping conversation>

**Titus:** No, I don't know whether he was involved at MITS. They were in Albuquerque pretty much the same time I was there.

**Spicer:** Okay.

**Titus:** But they were making-- I think MITS stands for Micro [sic] Instrumentation and Telemetry System--

**Spicer:** Exactly.

**Titus:** --and they focused a lot on just what I said: transmitters and things for model rockets. Or maybe model aircraft as well. But that's how they got their start.

**Spicer:** Right. So, okay, now you're out of the service...

**Titus:** Yes, well, before I got out of the service, I wrote to DuPont again and I said, "Okay, I'm ready to come back. Tell me what I have to do." And I got a nice letter back, just said, "Well, we've closed that laboratory. And those jobs have disappeared, but we can take you back on a 90-day-- for a 90-day period and during that time you can look around at DuPont and see if you can find another job." And I said, "Well, I'm not going to move my wife and my stuff to New Jersey or to Delaware for 90 days to look for a job that might or might not be there." So, I started sending resumes out and got absolutely nowhere. At the time, there were very few jobs for chemists. I'm not sure I can remember why, but a friend of mine who was in the Service with me, also stationed in Albuquerque, he must have sent out hundreds of resumes before he got a job.

**Spicer:** Wow.

**Titus:** And it was just very, very difficult for chemists and maybe for other physical scientists also. So, I was happening to look through a magazine called "Chemical and Engineering News" from the American Chemical Society and I saw a little advertisement in there that said, "Get your PhD in chemical instrumentation." And I thought, "Oh, man, this is great! This would be great for me, because--"

"--I'm very much interested in electronics and instrumentation, but I also have a chemistry background."

**Spicer:** Sounds perfect for you.

**Titus:** So, I wrote to the chemistry department at Virginia Tech and said, "Hey, here I am. I'm an ideal candidate for you," and I got an offer to join their PhD program. So instead of going back to Dupont, I went to Virginia Tech and started a PhD program in the chemistry department.

**Spicer:** Wow. That's very serious.

**Titus:** These things seem to mesh perfectly at times. It's just amazing. You look back and you think boy that was just phenomenal luck that that came at exactly the right time, and I looked in the magazine [laughs] at exactly the right time. You do wonder sometimes.

**Spicer:** I know exactly what you mean. Yep. That's happens so often in life. Well tell us about your PhD, what your topic was and how long it took, did you have fun doing it and those kind of things.

**Titus:** Well I had a lot of different things. Fun was one of them. I started along with everybody else, but since I had a master's degree it put me a little bit ahead in some areas although I still had to take some of the basic courses they expected from all PhD students, and the first year it was a good introduction. I'd been out of chemistry for two years in the military, so it was good to get back in it, and we did a course in quantum mechanics, there was a biochemistry, an organic chemistry and the usual stuff that you would expect to get as you go back to graduate school, and they had those seminars that students gave and so on and so forth, but my main interest was in an instrument that was called a rapid scan spectrometer, and the rapid scan spectrometer would monitor 128 different wavelengths of visible light at the same time. It's much like a linear slice out of these charged couple devices that are used in cell phone cameras. Instead of being a two-dimensional array it was a one-dimensional array, and it was made by a company called Reticon, R-E-T-I-C-O-N.

**Spicer:** I remember it well. Yeah.

**Titus:** Okay. Yeah. Then they made a number of other circuits as well, but Reticon made this linear array, and I took that and along with another PhD student we created a rapid scan spectrometer. So we would have something attached to it called a stop flow apparatus, and a stop flow unit had two syringes with a different reactant in each one. We used pneumatic plungers to push down on those syringes and mix the two solutions together in an optical chamber, very small optical chamber, so the reaction would take place very quickly. We would shine white light through that chamber so that we could see the changes in absorption as the reaction went to completion in a couple of milliseconds or so, and then the spectrum would be spread out along that linear array, and we would take maybe a thousand spectra a second and it was all the way from violet to red.

So we could monitor any wavelength we wanted for a thousand spectra a millisecond apart, and we could see peaks rise and peaks fall, and it was interesting. One of the most interesting parts was the design of the instrumentation and the design of the optics which the other fellow took care of. I was involved with, okay, once we've got the information out of this linear photo detector how do we get it into a [DEC] PDP-8 minicomputer, and how do we process it? Well we had to something called DMA or direct memory access, and that took a lot of figuring out how to do. I did make one prototype that just did not work, and eventually completely redesigned it so that it would use First In First Out memories and absorb all the information very quickly, and then at a different rate dump it into the PDP-8, and that worked quite well and we got some preliminary results out of it.

I was in the PhD program from '71 up until '74. In '74 I had a draft thesis ready to go, and my advisor said, "No, you know, I just can't accept this," and so I said, "Okay I'm out of here." I don't care whether I get a PhD at this point or not, I've got other things to do. My brother Chris and I had formed a company, and we had done consulting and designing equipment for a number of companies. We did work for Dart Drug up in New Jersey, for the National Institutes of Health, and we had taught courses on computers in a lot of different places too. So I had to be out there making money, not sticking around doing stuff over that my research advisor thought I should do. So I bailed out of the PhD program, and we started these businesses. Eventually in '77 about the time our daughter was born, our second child, the people in the chemistry department said, "Hey, you know, you ought to give some thought to coming back and finishing

up your degree.” So I did. I went back nights and weekends and finished in a year and wrapped everything up and got my PhD.

**Spicer:** Good going. That’s awesome.

**Titus:** But I was working at the same time too, so it was this stretch, a new baby--

**Spicer:** Oh my. I can imagine.

**Titus:** -- working and going back to school. So on weekends my wife would often pack a lunch and bring the kids over to the park across the street from the chemistry building, and we’d sit there and have lunch, and they’d go home, and I’d go back to work.

**Spicer:** That’s wonderful.

**Titus:** The interesting thing about that was though that when I went back I could not easily resurrect all of the electronics, so I completely redesigned it and I used a microprocessor to handle the data. So I got rid of the PDP-8 minicomputer pretty much.

**Spicer:** Now when do we talk about the Mark 8? Must be just before '77, right?

**Titus:** Well yes. Intel came out with the 4004 microprocessor chip, and I looked at that and decided that 4 bits just was not going to be enough bits to do something useful with. So I kept my eye open, and when Intel came out with the 8008-- 8 bits-- okay, you can fit ASCII characters in 8 bits, you can do some decent things with 8 bits. That really got me going. I thought okay, fine, and I got one of Intel’s data books and I looked at what we call a reference design today but it was just a basic design that they had put in one of their manuals so that engineers could understand how things worked, and it was this schematic diagram for one of their development boards. I forget what it was, but it must have been about 10 inches by 10 inches, big board, and I looked at that I remember on vacation, and looking at that and saying there’s a better way to do this and there were simpler ways to do this because the design Intel had used the proms-- the programmable read only memories-- to bootstrap things up.

There was no way to enter data except load it into one of these PROM devices, plug it in the board and if it didn't work, good luck trying to troubleshoot it. You'd have to make changes in the program, erase the PROM, and then go through this cycle maybe a dozen times before you got something to work, and I thought you know if it had lights on it, one of the PDP-8 minicomputers so you could see what's going on both the address information and the data, and if it had switches on it so that you could enter data and easily change it or take data out and update different instructions and try things it would be much easier to use. So that's what I did.

I took Intel’s design and adapted it to make it a lot easier for people to use, and I put together a prototype and I took it into Virginia Tech and I showed it to my thesis advisor and some other people, and I think they were just kind of flabbergasted that I had done this [laughs], and I remember sitting at my workbench

in an apartment and late at night I decided okay I'd checked out the circuits and everything was working, now came the big time to plug in the 8008 chip, and it worked. I was absolutely amazed. I didn't have to do any troubleshooting. I had been very careful with color-coded wires and checked the wiring very carefully. I was just astounded. I could hardly sleep, so I got up early at 6:00 and I went over to Virginia Tech and set it up and I think it was just amazing, amazing to me. So I thought if \*I\* did this, there are probably other people who are interested in having their own computer too.

So I sent letters to the editor Larry Steckler [ph?] at Radio Electronics, and also to Les Solomon and-- who's the other fellow at Popular Electronics-- there were two of them at Popular Electronics, and I never heard from Popular Electronics, but Larry Steckler called me up and he said, "You really have a computer?" I explained to him yes, and I used an Intel chip. He said, "I'm going to fly down." He was in New York, and I was down in Blackburg [ph?], Virginia. He said, "I'm coming down. I'm going to get to Roanoke at such and such a time. Pick me up. I want to see it." So I went to Roanoke and picked up Larry and brought him back and showed him the computer and he was just awed. He just couldn't believe it. He said, "How fast can you get this into shape for an article in a magazine, and also boards that people can put together?" We're talking about I guess it was around Thanksgiving or Christmas. I know it was cold. I said, "I can probably do it by March," and he said, "That's great." So I did. I made up the boards that people now have that are the Mark 8 boards, and I found a case that was left over from another project that I did.

So I had a case, a metal case that I had used one of, I'd bought two, one of for another project, and so that became the Mark 8 case. I wanted to put a red lens on the front for the very small LEDs to make them easier to see, and I didn't have any red plexiglass so I found some dye and a piece of clear plexiglass and made the front panel and laid the switches and where the labels and such would go, and then I called Larry and I said, "I'm ready to go," and I took it up to New York I'm pretty sure it was in March of '74 for photographs, and then I went to the chemistry department and used their Selectric typewriter to type up a draft of the article and send it to Larry, and he sent me back an edited copy and checked it over and they went to press with it in the July issue in '74.

**Spicer:** That's amazing. Wow. What an amazing story.

**Titus:** Well to me it was amazing that I actually got something to work in the first place because that circuit that Intel had could be simplified even from what I did, and I'm sure other people figured that out, but you just look at that circuit and you say boy this is just terribly complicated, but it was easy for me to see because I had a background in the PDP-8 computer to know how the data would flow and what control signals had to happen at what times, and Intel provided a tremendous amount of information.

Now at that time Intel was selling those 8008 chips for \$120, so I wrote to Bill Davidow at Intel, I think it was Bill, and said here's what I'm interested in doing, any chance I can get a couple of samples, and when I got back from vacation I had three samples that had arrived while I was gone, and I imagine they were out of temperature specific or timing specific or something, but yeah, he gave me three of those 8008 chips. I still got a couple of them in an envelope around here someplace.

**Spicer:** That's amazing. So they kind of knew what you were up to.

**Titus:** I think they might have. After that I did go out and talk to a couple of people at Intel. I was out there with a friend of mine, Dave Larson, and we decided oh well let's go down to Intel and made an appointment with one of the fellows down there, and they were interested. They were more interested in some ideas we had for educational computers.

**Spicer:** Oh yes. Like a computer in the classroom.

**Titus:** Yes, but more I think about teaching engineers about how to use, microprocessors.

**Spicer:** Oh. I see. That makes more sense for them.

**Titus:** Yeah.

**Spicer:** Well that's amazing. So no direct feedback from Intel about the article or the kit or anything like that? No?

**Titus:** No. I didn't hear from anybody at Intel. I heard from a lot of people who were interested in buying a kit, and I had to tell them well I'm a graduate student, I don't have a lot of money to put into an inventory of kit parts.

**Spicer:** A aside from Intel, what about all the hundreds of people who did write you and get in touch? Tell me a bit about them. That sounds fun.

**Titus:** Sure. A lot of them had purchased the booklet that Radio Electronics produced because they couldn't fit everything into one magazine article. So they put together the whole article that I had written rather than just a short portion of it, and I'm sure they sold many thousands of those. I would say maybe 5,000 or 6,000. I don't recollect anything more than that, and they sold them for \$5.00, and I got a small royalty from that which was nice, and also *Radio Electronics*-- Larry Steckler told me that there was a company called Techniques in New Jersey that would make the printed circuit boards and that *Radio Electronics* would publish their name and address and order information in the article so people could buy a set of boards, and they also paid me a small royalty on the sale of a board, so I had enough money to buy a decent IBM Selectric typewriter so that I could write without having to go in and borrow somebody's typewriter.

**Spicer:** Oh that's great.

**Titus:** So that was a big achievement for the Mark 8.

**Spicer:** You did the circuit board layout as well, right?

**Titus:** Yes I did. I had done some circuit board layout, but not very well, and when I started the Mark-8 layout I did it two to one scale. At the time there was a company called Bishop Graphics, and Bishop Graphics is now part of Chart Pack. Bishop Graphics used to make these stick-on layouts of pads for integrated circuits and components, and I used those and the-- I guess it's almost like black crepe tape that you can put down on clear mylar or clear plastic, and laid it out by hand, based on drawings I had done and based on large schematics that I had drawn too.

**Spicer:** Wow. That's good.

**Titus:** Now two things that people ask me is why didn't I use plated through holes, and the situation was plated through holes would cost extra money, and Technique said okay, we're going to charge I think \$49.95 or \$49.00 for the set of boards, and I said you know that's probably what the experimenters can spend. They don't want to spend \$75.00 and have plated through boards, and they don't want to spend that much money and maybe more to have gold-plated fingers on the boards because then we have to make a motherboard. So I decided, okay, no plated through holes, people could solder wires on both sides of the board if necessarily, and I'm not going to put gold plated fingers on this, I don't want to create a motherboard that's going to take more time [and] it's going to cost more money, the connectors that would go on it, the female connectors, would be expensive, and it's just going to price it out of the ballpark for a lot of hobbyists and experimenters who are building their first computer. First you're spending a lot of money on the chips and everything else, so some people complained about that but not many. They got their Mark 8-s to work, and that's the other thing I will say. I never had anybody write, never, and say that their Mark-8 didn't work.

**Spicer:** That's great.

**Titus:** They wanted to know how am I going to expand it, how am I going to do this, do I have to do this, do I have to do that, but there was no troubleshooting. I made sure that I stayed true to Intel's circuit and just wanted to make it simple for people to put together and make sure that it worked the first time.

**Spicer:** How about some applications from these people. Did anybody tell you what they were using their Mark-8 to do?

**Titus:** It's interesting. At first people said oh yeah you can use them to run your model railroads. Well I don't know too many people that have model railroads that they want to run with a computer. They certainly do that now, but back then they didn't. I think they just liked to experiment with it and get it do stuff that they wanted to do whether it was turn on the LEDs or lights or whatever. The problem was there wasn't much out there in the way of things that you could connect to a computer at the time, and I tell people it's kind of like inventing chalk and everybody says oh this is great stuff but what are we going to do with it, nobody's invented the blackboard yet.

**Spicer:** Right. That's great. And can you think of one that maybe stands out in your mind at all like a--

**Titus:** I can't. I looked through some communications, but there were a number of people who decided that they would expand it. There's a fellow whose name is Bob Suding. Do you know Bob?

**Spicer:** No.

**Titus:** Oh Bob Suding, he is in Colorado someplace. I don't think I have his contact information, but he put together a whole series of notes on the Mark-8 on ways to expand it and to change the bus and simplify things, and he did quite a nice job for the Mark-8 community in providing additional information.

**Spicer:** Okay. Well thank you. I'll make a note of that.

**Titus:** Yeah. I'll see what I've got. Let me just make a note here. Bob Suding was one of the people who was behind the Digital Group.

**Spicer:** Oh yes. Okay. Now is this the right time to talk about that?

**Titus:** About what?

**Spicer:** The Digital Group.

**Titus:** Oh I don't know much about the Digital Group. I did have one of their computers, but I did not use it. I was given it by a friend.

**Spicer:** It's interesting because they were also in Blacksburg, Virginia, weren't they?

**Titus:** No. I don't think so. I think they were in Colorado someplace.

**Spicer:** Am I getting that wrong? Okay. Great. What about-- so the Mark 8, that would have been 1974.

**Titus:** Yes, then in the July issue. That's right, and at the same time I wrote an article for EDN Magazine which was one of the top electrical engineering publications on how to use the 8008 for a traffic light controller.

And it was just a fairly simple example. It just, again, aimed at engineers to show, "hey look, here's how you can use these microprocessor chips and how you would program them," and explained the program I think with a flowchart, and then had the code there for them too and that was-- I don't know whether that was in July '74 or August of '74, but that's about the same time.

**Spicer:** Okay. I'll try to look that up. That's really interesting because of course that was one of the canonical arguments Intel itself used all the time for their micros, right? Which is their use in industrial controls, traffic lights, scales, those kind of things.

**Titus:** Yeah. The interesting thing is that a couple of years ago I was going to teach a course here for kids, and I made a traffic light with red, green, yellow bulbs, and I used an Arduino Nano or an Aruino Mini, and some relays that would turn the lights on and off in various switches, various sequences. I had switches on there that would go through flashing red and yellow and the regular red, yellow, green sequence and so on, and when I took it in the kids could hear the relays clicking and they wondered if that was the computer, and I said no, those are just the switches, here's the computer this tiny little black speck on the board, that's what's actually controlling the traffic light. I've still got it. I'm helping with a robotics class in a local junior high school. I'm going to take it in to show the kids once they start getting into the computer-based control.

**Spicer:** Oh wow. Lucky kids. That's amazing.

**Titus:** Yeah. I enjoy it. I told the teacher I paid it to me in there with the kids.

**Spicer:** That's lovely.

**Titus:** Lot of fun.

**Spicer:** So what happened after the Mark-8? That was quite a while ago.

**Titus:** Yeah. After the Mark-8 my brother and I and two people at Virginia Tech, we designed a computer called the Mark-80, and the Mark-80 it wasn't a great design. It was okay. It was marketed by a company called E&L Instruments up in Derby, Connecticut, and it was aimed specifically at the education market. It was a series of boards that plugged into a motherboard. It used an 8080 chip, and it had a front panel very similar to the front panel on the Mark-8, and they sold that into schools and probably to companies that wanted to educate their people into what microprocessors could do. It wasn't great because the form it was put in was cumbersome and it wasn't terribly easy to use, so it didn't last on the market for very long, but then my brother Chris and I realized that we really did need kind of a single board computer with a small keyboard, as well as a specific dedicated breadboard area and some memory and an expansion connector on it so that if somebody does want to do something more with it they can, and so we brought out the MMD-1 or the Mini Micro Designer 1 which E&L Instruments also licensed from us, they paid us a royalty on it, and they did a nice engineering job on it, put it in a nice box and had a power supply with it. It turned out to be expensive, but it lasted on the market for a long, long time. A lot of schools were very interested in using it.

The nice thing about that was that we had started writing books about microprocessors and we came out with a series that we called the Bugbooks books, and there were four of us who were involved with that. I was involved with it, my brother Chris was involved with it, Dr. Peter Roney [ph?] at Virginia Tech in the chemical engineering department was involved with us. Sadly Peter died recently, otherwise you could have interviewed him, and David Larson who was in the chemistry department and did a lot of instrumentation work, in fact Dave and Peter on campus offered a digital electronics for scientists course, and showed the young people how to use integrated circuits and what they did and how they worked, and the chemistry department also offered a computer for scientists I guess, and then they had the PDP-8

computers that they had students on writing some simple programming and programs and doing some simple interfacing and measurements. So the chemistry department and chemical engineering departments at Virginia Tech at the time were real hotbeds of this computerization, data acquisition, and data analysis.

**Spicer:** That's very forward looking for that era definitely. Well tell us about the Bugbooks because you know in a lot of cases the thing that determines success is actually the documentation -- yeah?

**Titus:** It is, and we realized that pretty quickly our fortune was not going to be made in building computer systems. Anybody could build computer systems, but we could write good educational material and instructional material about how to use these devices, how to program them, what they could do, about the analog and digital converters to be used with them, about the other types of devices you could control with the them. So the Bugbooks were started by Peter Roney and Dave Larson. They wrote a two-volume series that we called Bugbook One and Bugbook 2 on how to use basic digital integrated circuits, and then I collaborated with Dave and Peter on what we called Bugbook 3, which was really about the 8008 microprocessor chip and how to use that, and those books were very successful. We got a lot of good reviews, and people really enjoyed them. I still hear from people once in a while that say you guys changed my life because I was I didn't know quite what I was going to do but I got my hands on these books and I got a pretty good understanding of what was going on and decided that I wanted to go into electrical engineering, I made electrical engineering my career, and it--

**Spicer:** Well let me add my voice to that because that's exactly what happened to me, and Bugbooks...-- I'm from Canada, so there wasn't a lot of information up there, but I could get Bugbooks and thought that was awesome, and then I remember the Mark-8 came out. Anyway, this interview is not about me but since you bring it up, I am one of the many who were deeply impacted by your work -- so thank you.

**Titus:** Well we were great believers in basically giving away a lot of information to the people. We also wrote at the time columns for a number of publications in the U.S. and overseas as well. We had the Bugbooks translated into-- I know they were translated into Italian, and I think I've got one around here that was in Japanese, oh and Italian, a lot of Italian books, there was a company over there, Electronica Oggi that published the--

**Spicer:** That ["oggi"] means "today" in Italian.

**Titus:** Yeah, and it was-- oh, okay, that's good. So it was very nice for us to hear from people like that. We had other outside authors who contributed books too. We had a guy in Australia who was writing for us. We had some other people at Virginia Tech. We wrote about the TRS-80. My brother Chris wrote about software for the 8080 and the 8085, active filters, the 555 timer, all kinds of different things because we really thought it was important to have good practical information for people and experiments that people could do to see okay, "now I understand how this works or I have some basis to do my own experiments to better understand what I'm interested in exploring."

**Spicer:** Right. How did you handle the software aspect? Were there any tools for people or were they kind of starting from scratch or...

**Titus:** My brother Chris was very big into software, and he wrote a debugger for the 8080, and he wrote an editor and an assembler for the 8080 and the 8085.

We sold that book or Howard W. Sams eventually took over publishing of the book-- we wrote, and they published and distributed-- we sold that at the time on paper tape or on a set of EPROMS that people could buy, and it was sold at reasonable prices. We weren't trying to make a killing off of it. There were also people-- because we provided the listings-- they could go in and enter that byte, byte, byte if they wanted to, and that is in fact how we found that there was an error in one of the listings that had gotten published, not because we had not given them the right information, but apparently part of a letter got scratched off on the printing plates, so I don't know whether a b looked like an f or just something happened like that, and we did eventually correct that, but it was interesting at the time that people were actually using that listing to enter the data, that's how we learned that there was an error.

**Spicer:** Okay. Well let's see. Are we at like up to 1980 at this point or...

**Titus:** Yeah. I would say probably about then, and we were enjoying writing. We did do courses. We taught some courses in Blacksburg, had people come in. One course that we ran [in which] people actually built their own computer. They used a template and a perf board and wire wrap, and as they designed and followed the lectures, we would test their board to make sure things were working up to that point, then we'd give a lecture on some other portion of the computer design and how to use the computer, and they would work on their computer, and at the end they had a working computer that they could hook up to a terminal, and it was loaded with all of the necessary software like the debugger and I forget what else was in it, but that was very successful too. People enjoyed coming and building and learning at the same time they were building.

**Spicer:** That's wonderful. Yes. I think wire wrap is not used enough because building your own little system like that, knowing that every single connection you personally made, is really important to you. It certainly builds your confidence when you turn it on, and it works. That's pretty amazing.

**Titus:** It does.

**Spicer:** Okay. So you're writing and teaching courses in Blacksburg with your brother.

**Titus:** Yes. I'm just trying to think. Well we got to a point where the publishing companies, I would say the early 80s, around '82, '83, said "look you know we've got a glut of computer books out here, and we don't know whether the IBM PC junior or the Coleco Adam or the VIC-20 or the Commodore 64 is going to rule the world, so we just got to cool it on these books and we don't want too many more books."

But we had a number that we were writing, and we finished those, and then we looked at each other and we said you know, "okay, if people don't want these books that we've been spending time on, what are

we going to do?" We decided that we had three choices. We could continue doing what we're doing and hope for the best, we could hire somebody as almost a company president executive to tell us what to do and what direction to go in consulting, or we could say look, we had fun for 10 years working together as a group and writing these books, what else do we have in life. Well one of the fellows decided he'd go and concentrate on teaching, another fellow decided okay, he had some real estate interests, he said you know I'd really like to spend more time with my real estate and other things, and my brother Chris and I said you know okay let's find some things to do. My brother Chris stayed in Blacksburg for about a year and wrapped the business up and did some other things. I applied for a position at *EDN* magazine as a technical editor and went up for an interview and got the job as an associate editor, and so that worked out quite nicely for me. I could continue to write about things that I was interested in, and when I went in to have an interview with the chief editor he said you know I have to tell you I learned programming from your Bugbooks 3 about the 80s, so he and I chatted most of the time about programming, and a year later I got promoted to senior editor, and a year after that I got promoted to the chief editor of *EDN* Magazine.

**Spicer:** Oh my gosh. How did I not know that? Okay.

**Titus:** Yeah. I don't know. The fellow who was my boss said you know I have to tell you as soon as I interviewed you I knew you were going to be the chief editor because he was getting tired of the job, and *EDN* typically hired engineers to write, but a lot of the engineers didn't have any kind of management or business experience. So he said you know you've got all these different aspects to your career, I think you would do just fine in here.

So I was at *EDN* between 1984 and 1993 I think, '92 or '93, and then at that point my boss, a different boss who was the publisher, said look I'm going to go down the hall here and take over another magazine called *Test and Measurement World* and they need a chief editor, do you want to come down there with me, and I said yeah, okay, it's a smaller magazine, I'm not managing a staff of 20 or 25 people, I'm going to manage a staff of 7 or 8, okay, that sounds good to me. So I was at *Test and Measurement World* magazine from '92 or '93 until 2002, and the publishing company had been taken over by a Dutch and British conglomerate, and they were cutting staff, so I said to my boss who was a good friend, I said "Roy they're going to lay these people off, I'm happy to take the golden handshake. My kids are in college or out of college, if somebody has to go it can be me because each of those two other guys on the staff have kids, one who's in high school and the other one was coming up a little kid, and I said you know they've got kids to raise, they've got families, and my kids are done and gone and my wife is working, so if you lay somebody off I'm happy to go." So I took the golden handshake and did freelance writing from 2002 to January 1, 2014 when I retired.

**Spicer:** Oh. Great. What kind of publications were you doing freelance for?

**Titus:** I was doing freelance for *Design News* magazine which was owned by the company that I had left. I wrote regularly for a tabloid publication called *ECN*. They were I think at one time called *Electronic Component News*. I did a lot of work for them, and I even continued to write a bit for *Test and Measurement World*, even though I had left there, and also I did some work for companies. They said, "look we want to put a white paper out on such and such a topic," and I would interview their people and

talk with them and learn more about the technology and write up an-- what is it-- unattributed white paper for them.

**Spicer:** Right. Oh. That's great.

**Titus:** And I enjoyed it, but I got to the point where-- let's see, what was I in 2013, I guess I was 68, and I just decided who knows what's going to happen, I'll just go ahead and retire, and I have written recently for *Nuts and Volts* magazine publication, and I did a couple of construction articles for them, and I think I have one more that they have in their queue. So that's about all I've got that I've done. I've been active in volunteering here as I mentioned. I work now with a junior high school, it's part of a charter school, I'm on their board of trustees and when I heard they were doing this robotic course I said oh boy, let me in on that, I'm happy to come in and help.

**Spicer:** Right. Now in your role as an industry observer, this is after Mark-8 and covering your years on the various magazines, are there any patterns you can see> There's obviously Moore's Law, but any other patterns you see about how the industry has changed over that 30-year-period?

**Titus:** I think things have changed a lot faster than most people would think they did, and I think a lot of people didn't think big enough. They were thinking two years out rather than ten years out, and I'll give you an example. The class that I'm assisting with is off tomorrow on a field trip to see an automated dairy, and this is not a dairy that anybody has to go in except maybe once in a while to check on the cows, but the cows themselves decide when they want to get milked and they walk into this machine and it uses robotics to clean the udder and then it decides where the nipples are, and it has a vacuum device that fits on, it cleans the nipple, it cleans itself, it does all this and it gets more milk out of it than they would out of just put the suction device on the nipple, and it can test for disease, it can do all these kinds of things, it's just absolutely fantastic, and I said to the teacher you know look at this device and think about 50 years from now. 50 years from now this will be really old technology so far out of date because 50 years ago from today there was no microprocessor, there were no electronic calculators like we have today, no cell phones, automobiles you had to drive it, you couldn't let a computer drive it. All these things that we didn't expect and couldn't project happened in 50 years. So you can imagine 50 years but you're going to be completely wrong. You'll get to that 50-year point faster than you think.

**Spicer:** Yes. Oh that's great. That's a wonderful observation. That's also a great example what you might call the AI-driven dairy.

**Titus:** Yeah. They showed a video of what the kids were going to see, and they told the kids you take your lab notebook because I'm going to give you a test on some of the aspects of this, and it was just amazing to watch these machines, and this is where people have a dairy that has a hundred of these machines running it, and they have I don't know how many cows they have but it's absolutely amazing how they get the milk from these cows and how they take care of the cows in this automated system.

**Spicer:** So is the increase in output due because the cows can just get milked whenever they want?

**Titus:** I think so. And it may be other things too, but I think that's one of the things. The cows realize hey look I'm heavy with milk, and the cows wear some kind of wireless unit around their neck so that they can monitor the output by cow, and they can detect which cow it is that might be sick or have a bacteria or have some kind of problem, and it's just unbelievable. I saw this video and it was like I thought they were going to talk about basic automation of delivering food to the cows or something, not that the machines would actually milk the cows. That was just fantastic. [laughs]

**Spicer:** That really is pretty incredible. Yeah. I'm going to probably use that as an example when I talk about AI.

**Titus:** It's a good one.

**Spicer:** Yeah, it really is because I think the connection to something living really makes it quite compelling.

**Titus:** That's right. Yeah. Absolutely. And the cows seem to be contented maybe because they know they can get in the machine and get milked and you're not driving the cows into the barn to force them to be milked. They called it something like milking on demand or I don't remember, it was--

**Spicer:** I'm sure the acronym is MOO.

**Titus:** Yeah. Maybe. [laughs]

**Spicer:** Well Jonathan, this has been great. Is there anything else you'd like to close or to tell us today?

**Titus:** I don't think so. I just had a marvelous career, and I had good parents who let me kind of run loose, and my brother Chris run loose. I'm sorry to say that my brother Chris was injured in an automobile accident in '85 and disabled from doing anything beyond that, but he and I were just glued at the hip at times and enjoyed working together, and I just had a lot of fun. Yeah, life has its ups and downs, but I would say lots of ups and lots of fun, and it's always good to hear from people that say, "hey you know your book helped me or the article you wrote was helpful." It's very nice.

**Spicer:** Exactly. Like Steve Jobs said, you made a dent in the universe.

**Titus:** Yeah.

**Spicer:** That's an awesome way to end it I think. Yeah.

**Spicer:** Okay. Thanks so much, Jonathan. This has really been great.

**Titus:** Oh you're welcome. Nice chatting with you. Take care.

**Spicer:** Likewise. Take care.

**Titus:** Bye.

END OF THE INTERVIEW