Oral History of James Spilker

Interviewed by:
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Recorded August 30, 2018
Palo Alto, CA

CHM Reference number: X8783.2019

Rino: It's September 6, 2018. We're in the office of Professor Jim Spilker. Professor Spilker is the architect of what we call the GPS CA signal, which is the gateway to GPS for all its users, both military and civilian, and it's estimated now that there're over four billion users of GPS. So Professor Spilker, can you tell us something about your early life and how you came to Stanford University?

Spilker: Well, you wouldn't expect anything significant ever to have come from a tiny, sickly little kid who is legally blind without glasses, and often had a temperature of 105 degrees. I was raised by a mom who was a wonderful lady, but she had to raise us with no money to speak of, and she had to work by getting up at 5:00 A.M. to catch a bus to her job as a secretary in San Francisco. When I graduated from high school I was not even five feet tall, and I did not even apply to a university because we had no money. I went to community college because that was just a few blocks away, and it was very much very low-cost to get into College of Marin, San Francisco, near San Francisco, in California. Fortunately, two of the professors at the community college, in Physics and Chemistry, were impressed with me because I had already had my own internal chemistry lab. My mom was able to provide me with glassware so I could have a chemistry lab and also study science and engineering books and Scientific American. So when I got to the College of Marin and talked to these two professors, they said I was, the smartest young student that they had ever come across. So when they found out about my chemistry background, they said I need not even take the first-year chemistry class in the community college, because I already knew all that topic. So they would give me a special series of experiments to do by myself, and they both said that they would try their best to get me a scholarship to Stanford University. So these were really wonderful, wonderful gifts that I was granted by the community college, and indeed I submitted an application to Stanford University and took the exam for to enter Stanford as a junior and when we got the exam results, they found that I scored in mathematics at the 99.99 percent level. The very top.

Rino: This was in 1955 now?

Spilker: Let's see, '53, 1953. So when I entered Stanford, I found out that the classes that I took at the community college were designed for California Berkeley University, and so then I would have to make up at least two full quarters, if not more, in order to graduate in two years with the rest of the class. So that was indeed a very difficult task because I had to take at least 21 units or more every quarter to graduate on time. I was able to do that, fortunately, by taking a very heavy load of classes, and I had to work part-time in order to pay for the room and board, and indeed, I was able to get awarded the Deans Honors for my senior year at Stanford. So I was really gifted to have those wonderful professors.

Rino: And what was the course of study?

Spilker: This is the bachelor's degree in Electrical Engineering, and I was able to not only take this extremely high load of classes but to get awarded the Deans Honors for the School of Engineering. So I'm indeed, very grateful to be able to accomplish that, and I was allowed to enter Stanford from a master's degree without any further exams, and after finishing the master's degree in Electrical Engineering, I passed the PhD examination, and those exams, and I was able to complete my PhD in 1958 at the age of 23, and, a wonderful beginning to my engineering career.

Rino: What was your PhD thesis?

Spilker: My PhD, was on transistor electronics. At Stanford, we had a close relationship with the Bell Telephone Laboratories, so we were able to get transistors for transistor amplifiers and other technology free of charge so that we could do some very interesting research. I also had been studying communication theory, so I had a strong background in both communication theory and transistor electronics.

Rino: So that takes us up to your graduation from Stanford University. Did you have any inkling or any association of, any idea, of what GPS was about a that time or did that come later?

Spilker: The work on GPS and navigation came several years later. That really got its main start in 1973. So the progress towards satellite navigation really didn't make an awful lot of progress until the 1973 era.

Rino: —Okay.

Spilker: So my first job after getting my PhD at Stanford was at the Lockheed Research Labs in Palo Alto, California, and there I was working primarily in communication theory, and I invented the, a very special optimal tracking receiver. The tracking receiver I called the delay-lock loop, and that was published in the 1961 proceedings of the IRE, the Institute for Radio Engineers, the predecessor of the now well-known Institute of Electrical and Electronic Engineering, the IEEE.

Rino: It occurred to me that 1958 was the year that Sputnik was launched, so your timing was excellent.

Spilker: Yes, and at that point we were, the United States was looking at being a country that was behind the Russians in space technology and Lockheed was one of the leaders in space technology and so this new electronic tracking system was, with the delay-lock loop, was the optimal tracking system for any arbitrary signal, and it was optimal in the sense that it produced the finest accuracy and that technology and variance thereof has been in use for GPS for many, many, many years. Yeah, it generalizes to the receiver design that works for any arbitrary signal. So it's a very powerful technology that works for not only pseudo-noise code-division multiple access signals, but as a special case of the phase-lock loop that works with periodic satellite signals. So this signal processing system, the scalar delay-lock loop, tracks one signal at a time and is still the optimal processing cell and uses the differentiated version of that signal as a reference to create the optimal tracking network.

Rino: So from Lockheed, then you went to Ford Aerospace? How did that transition occur?

Spilker: Yes. Ford Aerospace was in the satellite communications business with on the ground side more so than the Lockheed, which was building the satellites. However, at Ford Aerospace they had a project that was very important in response to the Russians' satellites in that Ford Aerospace was getting a contract with the North Atlantic Treaty Organization, NATO, to build the world's first military satellite communications system using several satellites, mainly about seven or eight of those satellites, which they launched seven at a time. My job was to design and implement the military communications payload for those satellites. I was promoted to Director of Information Systems.

Rino: What frequency were those communication systems running?

Spilker: The military satellite communication systems and these at NATO were the first ever. They operate in the band of about eight gigahertz, so-called X band. The satellites were X band, and they worked with ground stations that were fairly large, 40 to 60-foot broad band antennas, but these were the world's first military satellite communication systems.

Rino: Now, there was one aspect of your early days overcoming some of those challenges you had. We know that you're very athletic. You're a competitive weight lifter. When did you start that kind of activity? Was that in at Stanford or earlier?

Spilker: At high school and grammar school and at Stanford, I was just a tiny sickly little kid, and it really wasn't until much later when I was about 40 years of age that I was able to have my health at a reasonable state and was able to wear glasses that were not these big, heavy things but use glasses that were just a small plastic that fits over the eye, and I was able to be a more normal height and weight and one of the activities that I picked up on was with a French professor who was doing hundred-meter sprints and training for a hundred-meter sprints competition. Fortunately, I was able to join him in that activity at Stanford University at Angel Field. And so this was a big, a big effort for me and one of my favorite activities was training for running hundred-meter sprints on a small track at Stanford.

Rino: Okay. So we come back to Philco-Ford, working now on communication systems and communication satellites. How did that work go forward and where did it lead you?

Spilker: So at that point I had, also taken on a small activity for Stanford teaching a class in satellite communications, and that class was in 1970 and as a result of the class, I decided to create a textbook on "Digital Communications by Satellite" for Prentice-Hall, and that book went through 10 printings. It's a well-known textbook at universities not only in the U.S. but other countries as well, and that book, with the 10 printings, it even created a paperback version of the book. So that gave me some visibility not only in the U.S. but in other countries as well.

Rino: So where did you connect with Francis Natali? Was that right; it was Francis?

Spilker: Fran Natali was somebody that I ran across when I was at Ford Aerospace, and I hired him and we've been friends ever since then and still right now. My close friend.

Rino: So we're at Ford Aerospace still, and took on writing a textbook on communications and what from there?

Spilker: So the textbook on satellite communications gave me interaction with other students and PhD's at MIT and at MIT Lincoln Labs, and at other universities as well, including being selected to be on the

Stanford University Advisory Board for the School of Engineering and on the University of Southern California Information Systems Center and participating with them as well as at Stanford. So at that point then I had been in contact with some other senior engineers at the Ford Aerospace and two of them and I got together to form a new company, which we named Stanford Telecommunications, Incorporated.

That company got off to a very slow start because the original ideas from my friends and senior executive engineers, Marshall Fitzgerald and John Browning, who had come from a Division of Ford Aerospace called Sierra, a company engaged with commercial telecommunications, those ideas didn't really pan out, so we didn't really get any venture capital financing, so we were kind of left without really a fine example to start the company. Fortunately, at the Air Force, Colonel Bradford Parkinson was given the task of starting a satellite navigation system, which was to be called GPS, but had kind of stalled with the lack of progress until Colonel Parkinson joined the scene and brought in a few highly competent Air Force officers. He tasked me with the contract to devise the civil signals and the other signals for GPS. I took on that responsibility with a couple of other people at this new startup company, and with some real help from Stanford University computers I was able to devise the optimal civil signals for this new GPS civil satellite navigation system, and the task was made much more difficult than a similar one for Code Division Multiple Access (CDMA) cell phones because of the very high Doppler shift caused by high velocities of the satellites and high velocities of the user equipment.

Rino: Could you back up just a little bit and say something about what was driving, I mean, the objectives of GPS system?

Spilker: The objectives of GPS, had both commercial as well as military applications. The funding was coming from the military, so that was given a high priority, but we all recognized that the ultimate main market for this type of technology was not military, it was commercial. So the signal that I was trying to optimize was something that had to be this commercial objective, which we now know is servicing something like four billion users, and the objective was to have a navigation system unlike anything ever available to have a very precision navigation system that could make measurements for earthquake measurements in the sub-centimeter basis. Sub-centimeter accuracy level, and to perform other navigation system signal accuracy with that was worldwide and can serve an unlimited number of users, meaning that it was going to be transmitting signals that users would just receive.

They wouldn't have to transmit anything, so they would be, could be, very, very simple, not having to transmit anything, just receive and process the signals coming down from satellites. So this system, so-called GPS, had to be something that would operate worldwide in all continents, at a tremendous accuracy down in the centimeter level, and could even service satellites in orbit that are not on the earth. So you had to be able to track and measure the orbit and position of satellites that were in orbit and even moving towards the moon. Or for lunar travel. So this was a system that had to work in all weather conditions. In storms, fog, and all types of weather and be able to do this even in the event of other perturbations that might come from the ionosphere, from relativity effects, and from trees and whatever that people might encounter in hiking or other types of travel.

Of course, a key obvious advantage is to have something that would operate with high accuracy and security for airplanes and airliners that would be traveling over mountains where you had to make sure that you never hit a mountaintop and if it would make more efficient air travel possible because you might be able to travel more efficient air traveling paths. So avoiding storms and lightning effects and so on. So this is a truly revolutionary system that we were discussing how we would implement, and indeed we over the years was able to accomplish just that, and we have created something that indeed has aided humanity in all, and created those aids to humanity on every single continent of the earth.

Rino: And cost was a big factor. It still had anticipated the development of technology that would make these systems for users affordable.

Spilker: Yes. So I published the book with my recommendation for the civil signal in April of 1974. That indeed was not the end of the story. In 1978, Colonel Parkinson had retired and would be replaced with a new colonel, Colonel Don Henderson, later Major General Don Henderson, and he had been contacted by a group of really excellent engineers who said that he had an emergency on his hands, namely that the GPS CDMA signal that I had devised and the Air Force had accepted, was a disaster because the receivers to implement and work with that rather complex signal was going to be too complex and costly to ever be successful, and that this signal had to be replaced so that the civil community could benefit from GPS, which it could not, they claimed, with the complexity that I had selected with the code-division multiple access signal, So, Colonel Don Henderson called me into his office to say, “This is a tremendous problem that we have on our hands. What can I do?” I responded that I had a strong background in not only communication theory but also transistor electronics. I was from Silicon Valley, and Moore’s Law had been proposed and accepted. It said that the transistor density on transistor chips could increase by two to one every two years. You could have more than twice as many transistors on a given semiconductor chip every two years, and that translates into the idea of Moore’s Law that only the transistor density could increase that way in a really marvelous manner. But the cost would correspondingly go to divide by two. The cost would decrease by a factor of two every two years. So, if you went out just a few years, the cost of implementing a receiver for my CDMA signal, which is admittedly is complicated and costly as of today, 1978 time frame, that in just a few years from 1978, the cost would dramatically be reduced, and that the cost of implementing my CDMA signal would indeed not be a threat to the civil implementation of GPS, but indeed would be something very efficient and have a low-cost implementation. And indeed, if we were standing back at 1978 and looking forward by magic to what the cost is today, you’d see a cost of implementing the chip a few cents, just a few cents. And if you were standing back in 1978 and looked at this year 2018 receiver, and you looked at that physical embodiment of a GPS receiver a la 2018, you’d say one word. The one word would be magic, magic. And indeed, that’s what we have done, magic.

Rino: So, you were thinking about cellphones in those days, but was anybody thinking magic ahead enough to GPS and a cellphone coming together?

Spilker: The key for the cellphone was how you implement something that adds almost nothing to the cost of the cellphone. And indeed, when you can implement the GPS receiver in total, you have something that is affordable because you’ve implemented the whole GPS receiver function on a very low-cost chip costing only a number of pennies.

Rino: But you have to get to radio there too.

Spilker: Yes, but all of that comes down in tremendous cost reduction. So, this is something that is really tremendous. And now, I'm looking towards a new book. We finished a book on GPS theory and applications in the late 1990s. And now, we're looking forward. I've been giving lectures around the world from China to South Korea to Germany, all over Europe. And indeed, now we have not only GPS phase three, but we also have navigation satellite systems with constellations of satellites being orbited and launched in China, and in Japan, Europe, Russia, India. So, this is a system where we're going have literally hundreds of satellites all performing and aiding this new navigation system for the 21^{st} century.

Rino: There's a few little details that we skipped over here. At the time that GPS testing had been done and they were just bringing the satellites online, the company you founded, Stanford Telecommunications, then found its niche with both building the test equipment and then the station keeping equipment, the ground segment for GPS. Could you say something about that?

Spilker: Yeah, GPS has three general segments, one, the satellite segment. At this point in time, we have about thirty-two GPS satellites in orbit, and newer ones being put forth. And in fact, I have a new signal for the FAA that I designed for the world's airliners called the L5 signal. And so, newer satellites are going to have this new L5 civil signal as well the other civil signals. But in addition to the new satellites and so on, at this point in 1978, I began designing and implementing three new types of receivers that are different than the production receivers, but critical to GPS. The first is with a special receiver for testing the satellites just after they're launched and the GPS satellite payload turned on for the first time. So, now is this satellite really working completely or not? How do we determine that? So, I designed receivers that we could use to test the satellites and all of its planning structure just after launch of the satellite. So, this is something that's needed to test, to see is everything working. If you look at these satellites through an electronic microscope that sees everything of the satellite's, is it all working correctly?

For example, the GPS satellites must operate in what's known as the Van Allen radiation belt. This means that the satellites are flying through areas of high radiation that can destroy or adversely affect the electronics on board the satellite payload, the GPS satellite payload, in orbit. And so, how do you determine is everything really working correctly, including the military signals, which has fine structure that changes every billionth of a second? And so, you have to track all these details to see is everything working right. Now, you can't determine this with a GPS navigation receiver. It takes something much more that is looking at the signals like with an electric microscope. So, I did that. And it takes the special launch receiver must operate with a sixty-foot antenna that can look at the signal like with a microscope. And so, we were able to do that. And for the first satellite we launched, we were in the Bay Area in a place called Camp Parks, where we have a sixty-foot tracking antenna that can track the satellites as they move with a very high velocity in their orbit and make these measurements. And we did that and did that for years successfully.

And then we had, in the various segments of the GPS system, we also have a control segment. Control segment, what the heck does that do? The control segment is required because we need to know where the satellites are as they traverse their orbit. When we measure the signal, it comes from a satellite. But where was that satellite at the time of transmission of the signal that I'm receiving now? It was moving very rapidly. So, where the heck was the darn satellite when the signal that I'm receiving now was transmitted, not when it was received, when it was transmitted. And so, you have to measure the precise orbit and clock. We had atomic clocks that measure signals with a clock that keeps track of things to a billionth of a second. So, the receiver and the system that I devised for this function, I said I want to be able to track each of these satellites in orbit and GPS. At that point where there were going to be twenty-four to thirty-two of these satellites. And I want to track the satellites from horizon to horizon, in other words, from where the satellite comes over the horizon and is visible to my receiver at this particular location. And then it goes overhead. And then it goes down to the other side of the Earth. And I want to track it until it falls out of view on the other side of the Earth. So, tracking the satellite from horizon to horizon and doing that with tremendous accuracy. And I was able to do that with tracking both the code of the signal and the carrier. And I was able to reduce the noise error to only seven millimeters. And noting that the satellite is tens of thousands of miles away, we could track it to a noise error of only seven millimeters. Millimeters are thousandths of a meter and just a small fraction of an inch. And so, that was successful. And that measurement, the precision of the measurement, was made by not me but by IBM Corporation. And so, that system proved to be very accurate and key in having GPS at the accuracy that we have been able to reach. So, that was critical. The GPS civil accuracy would not be possible without being able to measure the satellite orbit and satellite clock accuracy.

Rino: And so, all of that is being provided to the user community free of charge. It's a remarkable investment.

Spilker: That's right. So, all of that is part of the function of the United States Air Force and also, in many cases, the FAA, Federal Aviation Administration.

Rino: So, what came of Stanford Telecommunications then as it went on in this work?

Spilker: So, as the years went on I was able to add different divisions in different states. And so, I built the company up with offices and divisions in six states in the country, all in the U.S. not overseas, but six states. And we were able to build an employee base up to one thousand, three hundred people. And then we also, at that point, were also selling semiconductor chips with a special design. And I then sold the company to four other companies including Intel and a military company, military communications satellite systems, and a manufacturing company, and sold the company for zero point five billion dollars. So, we were able to start a company with three people and no money, no venture capital, zero, no venture capital, and build it to a value of one half billion with a B. And so, that was not my doing. I happened to be the leader for much of that time, but this was a team effort of a wonderful team of people that operated from Boston to the West Coast, and wonderful, wonderful people that I will value forever.

Rino: That's nice. So, where did you go then from Stanford Telecommunications?

Spilker: I was approached by some people at Stanford University to join the university as a consulting professor for a research center that would study and do research in Internet communications. And after that I approached the dean of engineering, Jim Plummer, and the dean of research, and proposed having a research center of our own that was focused on precision navigation and time measurements. And not only could you add people from the engineering school, but also from the physics department. And I wanted one of the key physics professors at Stanford. And so, we were able to form that research center, which exists until today, and will hopefully continue for a long time. And we also have a symposium, a yearly symposium. This year will probably be our fourteenth symposium. And the research center is funded by industry, mostly by just contributions, gift contributions, by aerospace companies for the most part.

Rino: That's at SLAC. The —Stanford Linear Accelerator

Spilker: Yes, the symposium we have yearly at SLAC, at either the two-hundred-and-fifty-person auditorium or the newer Panofsky auditorium, which seats approximately four hundred people. So, at these symposia, we have speakers from around the world and attendees by invitation only. So, that's-- this funding funds our-- many of our students, our research students working on their PhDs or on their degrees, their masters.

Rino: That's very nice. So, having founded a company and built an institute, you still weren't finished. You started yet another company.

Spilker: Yes, I started two other companies. The one I'd like to mention is a company with physics technology from atomic physics to quantum mechanics. And here, we are using technology that we have licensed from Stanford based on Steve Chu's Nobel Prize in Physics, which is widely knowns as molasses coolant where you can use a laser to cool clouds of atoms, and then use that cooled cloud of atoms to perform inertial navigation that can complement GPS. So, this is yet another technology that we're trying to develop with, again, three people and no money initially. So, that's our latest effort and hopefully, that will be successful as well.

Rino: Okay, and the second company?

Spilker: The other company was a company that said we have a worldwide network of television stations that have a broadband signal in the ten million hertz level. And can we use this system to make precision measurements indoors as well as outdoors? And indeed, it could, but the company eventually just sold the technology because it was run by venture capitalists in this case. Other companies were not run by venture capitalists.

Rino: So, you're thinking of TV signals coming into a building? Is that the idea?

Spilker: Well, the TV signals are coming in through walls and ceilings because they are transmitted from towers, from television towers, at very high power and their relatively close. For example, in San Francisco, they're transmitted from San Francisco. And that contrasts with the transmissions from satellites many miles away that are transmitted at relatively low power. So, eventually, I think people will use that. There was a military application, but it turned out to be a sensitive application. So, the venture capitalists were not interested in that type of work with those security considerations that restrict what you can do.

Rino: Well, you said there are many contrasts between the two companies, one trying to exploit digital TV signals, and another one trying to exploit a brand-new novel discovery at the Nobel Prize level. It's a breadth of all of that work. In your mind, I guess that's all straightforward and easily connected.

Spilker: That's right. And along the way, when I was working, training with the grants professor on how to meet his grants, I was able to meet somebody that was a very bright master's in business administration that has been a big contributor to our gifting at Stanford as well other functions.

Rino: And so, your association with Stanford has been very, very productive, both for Stanford and for you. So, I think we've come right up to the present. How do you see all this evolving now? GPS is going to be more and more accessible, larger markets, and all of these new ideas. Is there a synergy or something that you see coming together now that's going to change or absorb the dynamic in some fashion?

Spilker: One of the key things that I have as a real objective in life is since I work with students in so many different universities, for example at Tsinghua University in China, also Peking, their neighbors, and in Germany with the University of Munich, and other schools, and of course here at Stanford, students here at Stanford, and we just had a big celebration a couple weeks ago for women in science and engineering, really a tremendous asset because I said that, when we donated one of the Stanford buildings here, I said that no nation can be truly successful and ignore the talents of half their population. And I dearly believe that.

The students of female sex are of critical importance to our country and to this university. I point out that our dean of engineering right now is a well-qualified female who is the head of the computer science department. The previous dean of engineering, Persis Drell, is now the provost of the whole university, a physics professor. And these people are models for all students, and I believe for all universities. At our celebration for women in science and engineering, we were pleased to have one of the well-known professors of aeronautics and astronautics from MIT. And it's my hope that we will have some joint projects with students from MIT with Stanford. And as I have the opportunity to talk to our students, not only from Stanford, but other schools around the world, I think that one of my messages to them is that as they develop world breaking technology that serves the world, they should always look to see how can I create functions that serve the world and benefit humanity in all continents around the world. And I was able to do that a trifle. They will be able to do that in wondrous ways that we will not even understand at all now.

Rino: That's a beautiful sentiment and deeply felt.

Spilker: And there are two awards. They're engineering equivalents of the Nobel Prize, one by Japan, and one by the United Kingdom with the Queen Elizabeth Prize. I contend that Queen Elizabeth has done wondrous thing by creating that prize based on benefits to humanity. That's a marvelous contribution that she has made.

Rino: Let's see. Is there anything we've left out?

Spilker: My other comment is that I've started without the best hand. I started with sickness. I'm nearly blind. I'm still am blind in my right eye now. I didn't have a really wealthy mom to help me. But along the way, I had marvelous help from other people for which I'm eternally grateful.

Rino: Maybe on that note, could you tell us how you met your wife?

Spilker: I met a Bavarian very bright girl when I was running the hundred-meter training at Angell Field at Stanford. For months, I would do no more than hike around the campus, month after month.

Rino: So, you met her here at Stanford on the track?

Spilker: Yeah.

Rino: Was she running faster than you?

Spilker: No. But she was very smart, full of energy, got her MBA as well as her economics degree and her real estate broker's license and has been key to all my big and little successes.

Rino: Well, I think that's been a wonderful journey through your life. We're sitting here looking at Hoover Tower outside your office, so a very sincere thank you for taking the time to tell us your story.

Spilker: Well, thank you. Thank you very much.

END OF THE INTERVIEW

