Oral History of Charles Trimble

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Rino: It is September 25th, 2018. We are in the Computer History Museum. We have the pleasure of recording the history of Charlie Trimble. The names "Trimble" and GPS are so intimately connected that they're almost synonymous, but I think many people might be surprised if, for example, they wanted to buy a GPS for their automobile. They might not find one that they could really be happy with in the Trimble library of high-end GPS equipment, and they also might be surprised to think about how the GPS got into their cell phones and small devices like that. Again, those are something that Trimble had a lot to do with, but it isn't in their product line right now. So with that, Charlie, tell us the story of how you've come from an avocado orchard to founding Trimble Navigation.

Trimble: Well, all right. I grew up on an avocado ranch in Fallbrook.
That's about, oh, 70 miles south of Los Angeles, and it actually was Sputnik I think that affected me the way it affected many people in my generation and focused my attention on math and science and space A couple years later I ended up going to Cal Tech, and I thought I wanted to be a mathematician but soon learned that at least at Cal Tech you had to be absolutely brilliant and probably lazy to be able to make it as a math major. I followed the normal course of things there and was interested in physics but actually for the sake of summer jobs I switched my option to engineering because I could take the same physics courses in engineering and it was an awful lot easier to get summer jobs as an engineer than it was as a physics major.

I think it was my senior year I came to the conclusion that it was going to take me five years to get a Ph.D My time schedule had been three. I did have friends that did make it in three, but I wasn't going to be able to do it and besides that what I learned at Cal Tech was there was no way that I could be at the top level of academia but if I pursued the realm between technology and business most of those people that could be at the top rung in academia couldn't survive. So I made up my mind to come back to Cal Tech and get an easy master's degree and then go to Harvard and get an MBA.

Rino: So this was a tactical decision at the time.

Trimble: It was a tactical decision, and actually I got only one offer for a summer job after getting my master's degree from Cal Tech. Al Bagley, who was then a division manager at Hewlett-Packard and had actually pulled Hewlett-Packard into the digital era, hired me for the summer and unbeknownst to me he had set himself the goal of keeping bright young engineers from going to either Harvard or Stanford Business School. And so by the end of the summer he bribed me into staying at HP by offering me my own project.

This project led to what was then known as the Computer of Average Transients, basically pulling repetitive evoked responses out of the noise, and these were the days before microprocessors and the most complex integrated forms where things like four-bit full adders so a state machine was the approach at this point in time, 1964, Hewlett-Packard had an in with Stanford and Hewlett-Packard employees were allowed to learn how to program and actually submit programs for the B5500 over at Stanford. I ended up using the B5500 to simulate my state machine to be sure that signal averaging worked. Along the way I came to realize that Shannon could be turned around and if you're dealing with signals that have signal-

to-noise ratios that are less than unity there is less than one bit of information available per sample and this turned out to be awfully important later with GPS.

So I was at HP for 14 years; last job there I was R&D manager for an integrated circuit facility. Actually it was a bipolar integrated circuit facility. We had the capability of putting down 500 matched five-gigahertz FT transistors on a chip so you could do things like make very fast four-bit quantizers or make flip-flops that actually would toggle at two gigahertz. Along the way computers started coming into HP. I built my first 2116 computer by parts. It was late enough in the year and I needed it for an IC tester project. It was late enough in the year that they had frozen capital equipment budgets, but if you bought things by the part you could assemble things and get around the system and so that's how my first 16K 2116 came into being.

Rino: Did Hewlett-Packard at the time even have a commercial computer?

Trimble: Yes. It was the 2116.

Rino: The 2116, yeah.

Trimble: They competed with DEC for the mini-computer market and later they got into the computing calculator market and later still the handheld Model 35, but by '78 Hewlett-Packard had transitioned from being a technology-driven company to a marketing-driven company to a resource allocation-driven company, and to work on things that were entrepreneurial you had to be working on things that were ten years out. Five years was fine for me, ten years a little too long, and there was a reorganization that took place at that point in time. Al Bagley was kicked upstairs and a fellow by the name of John Blocker came in to take over the Frequency and Time Division. He had been entrepreneurial and with Al being kicked upstairs Al's pet project, a LORAN-C navigation product, was canceled. I actually had the audacity to offer to buy it.

Rino: And they wouldn't let you do that.

Trimble: Well, they gave me a hard time because I was offering $50,000 and they wanted $200k and in retrospect the $200k was perfectly reasonable. I mean it was fundamentally a final prototype. They hadn't done the complete tooling. There were final prototypes around and I got a couple of bays of test equipment and lots of reading material.

Rino: Could you describe the product itself? What was it going to look like in the market?

Trimble: It actually was going to be something that was about the size of an old unabridged dictionary. It had a single line display; it would read out in either latitude or longitude, you had to toggle, but then you could only write one of them down at a time. And what was special about it was that there were bias corrections put in so that the time difference lines actually would lead to accurate latitude, longitude positions. The propagation velocity of radio waves over land differ greatly by whether it's arid or irrigated and so the LORAN-C maps with these overprinted difference lines that the Coast Guard put out in that time were off by 1.3 miles in Los Angeles and 2 miles in San Diego.

Rino: And these are very low-frequency systems?

Trimble: One hundred kilohertz; it was a ten-kilohertz bandwidth. We named the company Trimble Navigation not because I wanted my name on the company, but we had gone through two different ad agencies for names and when the second one came up with Xodiac spelled with an 'X' I punted and said, "All right. Enough is enough" and so it became Trimble Navigation. And so the first product was the LORAN-C product that read out in latitude and longitude. Interestingly enough, the Coast Guard couldn't understand why you would want to read out in terms of latitude and longitude when time difference lines were perfectly adequate and perfectly good. And it took us a little while to realize that the main reason you wanted to read out in latitude and longitude is what you were interested in wasn't so much where you were but what you had to do to get to where you wanted to go and your destination would be in latitude and longitude and if your current position was in latitude, longitude it was real easy to calculate; if they were in time difference lines not so easy.

In any event, we did that. The company started in November of '78, and by early 1982 I was looking for the next product. We had launched our first product. Basically we were ready to launch the follow-on. We were headed towards a two-million-dollar-a-year and I needed another product. There was a satellite system that was currently being used at that time by the navy called Transit, and this was a system that actually came about really inspired by Sputnik. If you know the satellite's orbit and you simply record the Doppler shift as the satellite goes overhead you can get one line of position so if you put up a number of satellites in polar orbit and form a squirrel cage around the Earth you can end up with intersecting lines of position on the Earth giving you position. And this actually allowed the submarines at sea to establish their position with a periscope showing for no more than a couple of hours. And we were looking at that and came close to buying a company, but I knew that Hewlett-Packard had been working on a GPS product at the time I left in '78. It was something that Ralph Eschenbach had designed under the table.

In those days, if you were at HP Labs you could work on anything you wanted ten percent of the time and he being a pilot fell in love with the concept of GPS and started building something. I had gotten word that John Young had canceled the GPS project. A few days later a fellow I knew very well, Zvonko Fazarinc, a section manager at HP Labs, came down to the air-conditioned garage that we had in Mountain View and said, "Charlie, I know that I advised you not to leave HP with the LORAN project because I thought you would fail. You haven't and as you know John Young has canceled the GPS project. He's given me the right to sell it. I want you to buy it because you'll do something with it." At that point, I mean it seemed like a fabulous opportunity. There were really only four concerns. First, what was behind John Young's canceling the project because Zvonko was absolutely convinced that it was a billion-dollar opportunity, and he related to me the story that he went to John Young with this argument and John Young had said, "Well, you know, I have 50 percent of a four-billion-dollar instrumentation market and 5 percent of a forty-billion-dollar computer market. I don't need a third market that has nothing to do with the first two."

I think the real reason that it was canceled was that there was very substantial concern that the U.S. government would not complete the system. In the waning days of the Carter administration, the system had been downgraded from 24 satellites to 18 for cost-saving measures so the first question I needed to answer was will the system be there. The second problem I was going to face was how was I going to

beat the Japanese to a hundred-dollar navigation receiver. Chrysler had shown a concept car at a world's fair with a navigation unit involved and it had gotten a tremendous amount of press. In those days, the most expensive option for a car was $750 for automatic transmission and the car companies the minimum margin that they would operate on for a factory-installed option was three to one so that said the car navigation unit had to be $250 and the navigation portion of it was no more than 40 percent of the whole problem.

Rino: And this was a GPS system they were thinking about.

Trimble: Maybe not as the crysler car predated Stan Honey's etac navigator. But GPS clearly would be a great technical solution. The opportunity was the billion-dollar car navigation market, and we were going to have to race the Japanese to that. Okay, that's the second one. The third one was can I actually come up with the money that John Young is going to require and the fourth problem was that Zvonko let me know that it wouldn't make much sense if I hired any of his engineers so I had to promise not to hire any of his engineers. Okay. So these were my four questions. I figured my first step was to go to my mentor, Al Bagley, and ask him what he thought because I knew that the frequency and time division at that point had an atomic clock, a cesium standard that was one of the finest frequency standards in the world, and I knew that he had had conversations with people in the U.S. government about the GPS market. And so I asked him and he said, "Well, I don't really know but I've got two people that you can talk to." One was a fellow by the name of Gerhard Winkler at the naval observatory and the other was a colonel by the name of Brad Parkinson at the Joint Program Office. So I called both of them and they gave me the words I wanted to hear and they were reasoned arguments of why the system in all likelihood was going to be completed.

This wouldn't have melted the heart of any CFO but it was good enough for me, and I figured if this problem were out of the way the other three problems that I had could be solved in time and so it was all speed forward and damn the torpedoes so that's how we started. I negotiated with Zvonko to offer consulting to the project team on the basis of pizza and stock and so this became our Wednesday evening meetings, and when we looked at it we knew that we were going to have to tie into integrated circuits and Moore's Law and use the investment in integrated circuits to drive the cost down and what we had to do was to come up with a block diagram approach that could be iterated on an 18-month schedule. We did that.

Rino: The company at that time had four founders?

Trimble: Yeah, there were four of us, three technical and a gal by the name of Kit Mura-Smith. and at that point in time there were 10 of us We recognized that we needed seven breakthroughs to get the GPS approach that could compete with the Japanese and we basically kept poking around the Valley until we got the breakthroughs. They weren't quite what we wanted but things could be jiggered around so that everything worked. It took us a year to get that block diagram approach and then we started building. By the next September, I actually took two final prototypes back to an ION conference in Boston to show in my hotel room. I figured I needed to have two because no one would believe that it was reproducible if I only had one.

Rino: It wasn't a backup?

Trimble: No, it wasn't a backup. Now we didn't have money to have a booth at the show, but I did have a hotel room and actually the reactions that I got there in retrospect border on the amusing. I can remember this one fellow handing me a card and saying, "Give me a call when you sell the second one" but out of that show actually I got my first customer. A division manager in charge of the Boston-area Northrop bought one of these things for a hundred thousand dollars, and so that actually was my first GPS customer and that led Northrop to making the first real investment that the company had. Up until that point in time, II'd been using an R&D limited partnership form; this was basically an angel financing scheme that allowed investors to take 90 percent of their investment against taxes as we lost money. There was a change in the tax law that prevented that from happening later on but it worked in the beginning and so in the beginning I was raising a quarter to a third of a million dollars a year to fund things. We starved.

Rino: You were still marketing your LORAN systems?

Trimble: Oh, yeah, absolutely, and actually we continued marketing LORAN systems up until the beginning of the twenty-first century; we added GPS to the LORAN later on. In any event, that first one led to the first real money. Northrop put in three million dollars for twenty percent of the company and I figured it was a pretty good deal because that represented about five times what our sales was and in the end game they came back to me and said, "Would you mind using a form of debt rather than equity, so basically convertible debt, but the interest wouldn't be due until you paid it off and it had to be paid off if you went public or there was change of ownership. Otherwise you could repay it and if you did repay it the warrants went away."

So this was the deal and it turns out and about four years later when Northrop ran into trouble and they started consolidating everything back together they came and wanted to sell this note but since we had the right to repay it no one would give them substantially more than the face value of the note. So we actually found AEG was willing to put in three and a half million dollars to clear note plus interest for five percent of the company so it went from somebody having 20 percent of us to somebody having five percent of us and that clearly was one of the better stock transactions that we made pre public, but as I said in the beginning the whole business plan was the thought we were racing the Japanese to the billion-dollar car navigation market, and so that meant driving the cost of the GPS receiver to zero and we were well on our way to doing that.

We get to the end of 1985 and the Joint Program Office has a whole bunch of satellites ready to be launched into space on the shuttle. Our first custom GPS integrated circuit has greatly reduced the size and power of GPS receivers. We have a licensing deal with a Japanese company for the car navigation market, we have introduced a LORAN GPS receiver into the marine navigation market, and we have a GPS sensor that could go into the business aviation market. It looks like the navigation business is about ready to take off; this is December. In January the shuttle blows up and with it the GPS satellite ride into space is put on indefinite hold. The first satellites had gone up with refurbished Atlas boosters. Those had all been used up to save money. The GPS program had agreed to use the shuttle to get up into low Earth

orbit before launching things out to the 10,000-mile radius. So at that point it looked like we were going to be very lucky if the seven satellites that were in the sky were going to continue to be there until the next satellite went up.

The early markets we had found for GPS for precision time or position had to do with precision time transfer, keeping timekeeping standards in centers like Washington and Paris and Sydney all synchronized, or oil exploration and so we had to find another market. Our Hail Mary approach was to go after the long baseline land survey market. We figured that if we could come up with one very accurate position fix a day we could disrupt this market. The only way we could see to approaching this problem was to do differential phase measurements on the reconstructed carrier signals from the satellites, and our approach was to make measurements on the satellite signals for the entire two to three hours that four satellites were in view and then postprocess that with similar data from a bay station on an HP minicomputer for three hours. We actually made that work, almost.

We took an order from Caltrans for 7 systems for $500,000, but just after we took the order we found that occasionally we would get a second answer that differed by 12 centimeters for our 10.8-kilometer baseline. This clearly meant that we had a bug somewhere in the Moras of software. We didn't ship. As a consequence the bank pulled our line of credit and in the near-death experience that the company faced it almost came apart and actually I ended up losing a key software engineer that later was to become our only major competition in the GPS land survey market. We got the bug resolved and basically started shipping this improbable system to mom-and-pop survey outfits around the world and it really started to disrupt the land survey market. Later, with increases in computational power and the addition of communication, we were able to field survey products that provided real-time sub-centimeter accuracy and later still figured out how to make those things work on moving platforms.

This was good, but still there weren't an new satellites in the sky and as parallel effort, we started looking at the only customer that was convinced that there were going to be satellites in the sky and therefore might buy things and that was the military. Our first approach was to sell to the Israeli military. The Israeli military basically takes civilian products and tried to harden them for military applications, so they would buy something that they thought they could use, test it until it broke, tell you what broke, and if you would fix it they would buy another one. So in the process of doing this, we figured out how to harden GPS sensors for the drone market and at that point, we decided to go after the Army. That was the number-three player among the services for GPS receivers. What had been planned for them was a, basically a 40-pound backpack for the foot soldier and by this point in time, we had gotten the power down to about 3 watts so 6 D-cell batteries would be fine and a couple of pounds and we started working with the Army to define what the form factor ought to be. Is it going to be something that is worn on the arm like a first aid kit, or is it going to be used like a pair of 735 binoculars and held up? Well, they decided on the binocular approach and came up with a four-line display with two toggle switches and a twist knob and oh, it had to be really rugged. You had to be able to drive a truck over it. So we finished this. They loved it. Then, they wanted to figure out how to buy enough of these so that they could actually test them. This was a clear problem because the people that were currently serving the military definitely did not want an upstart selling stuff into the military that was vastly different and their traditional way of keeping small companies out of this sort of business was to simply buy contracts. So we had to come up with a contracting vehicle

that couldn't be bought. The solution was the Army said, "We have $4 million to buy GPS receivers. How many receivers will you supply us for $4 million?"

Rino: This was an open competition?

Trimble: This was open competition and we won it. We offered to supply 1000 GPS receivers for the $4 million. Now, this was an unheard-of price because the Air Force had gotten SRI to do a market study and come up with a projection of what GPS receivers, civilian GPS receivers would cost in high volume by the year 2000 and the number they came up with was, in high volume, they would be $10,000 apiece. This is '89, and we found out later that the only reason that award wasn't protested was that at the last minute, one of the government contractors had convinced a general to put a late penalty clause in that they figured would bankrupt us if we took the contract. Well, we delivered the 1,000 units, I believe, about a week early, and actually I was told later that we were the first contractor ever to deliver on time and on budget to the JPO.

The Army started using these things and they found in war games in Germany that the squad with a GPS receiver always beat the squad without the GPS receiver. So by July of 1990, the Army was convinced that this was what they wanted. During this period of time, a fellow by the name of David Townes from Needham convinced first my board and then me that it was time to take the company public. Now, I was running the company at the thinnest margin possible for profitability so that I could keep normal banking relationships and I was reinvesting between 25 and 30 percent of sales into R&D and my comment to Dave was, "I don't think I'm ready because I'm not going to stop investing heavily in R&D," and Dave looked at me and said, "Wall Street is willing to judge you on any basis you have the guts to sell. Look at Cray Computing." So anyway, we went public first part of August of that year and the day we went out, Saddam Hussein invaded Kuwait and our stock was above water at the end of the day but it dropped below water the following day.

So the Gulf War started and soon after it started we got a call from the Pentagon asking us if we could start making more of those receivers that we had delivered to the Army and oh, by the way, if we wouldn't charge any more than we charged on that contract they could simply extend the contract and know it was going to take a couple of weeks to get the paperwork started but would we start the process. So this started a basis of our doing this with ever-escalating numbers of receivers. The total orders got up to 10,000.

Our lisencing deal with the Japanese had completely transformed the way we were designing our low cost GPS receivers. Because of the licensing deal I had with the Japanese company, I had gotten rights to put an engineer into their factory and I had also gotten the rights to buy components that they used but in the process of putting an engineer in their factory, we actually learned how they were so successful at cutting the cost of things. While we thought in terms of iterations having improvements in block diagrams, they would simply make a material list and take the most expensive item on the material list and figure out how to reduce the price. So the deal we had done with the Japanese was explicitly for that generation and we were turning things on an 18-month schedule and we were two-thirds of the way well, half the

way to the next generation. Well, in six months' time they had reduced the projected factory cost of what we had licensed them below where we thought we could get to with our next generation.

Rino: What were you providing for the Japanese?

Trimble: We were providing a design so that they could go after the car navigation market.

In Japan for a licensing fee and they had paid us $5 million for this license and since that was equal to our total revenue in 1985, that was a pretty good deal, especially given the shuttle disaster and there was no market for a while. But in any event we had been using the low cost product approach for the product we made for the military, we were using Japanese cellular parts, and the way they got the price down was they found suppliers that would fiddle with things until something worked and then freeze the design. They did not work on specifications. They worked on frozen designs. That way you didn't have to understand the second-order effects of changes in how something was made and how it might affect how things worked. Well, in any event, that slugger product was made with cellular telephone parts because they were in high volume, they were cheap, and they were reliable. Well, during the fall and winter of 1990, the cellular market went ballistic in Asia, and when Japanese manufacturers hit the limits, they started holding shipments to American customers, U.S. customers, because we're second-tier markets. We're not first-tier markets. So our production control was not yet automated. We went to positions where we were running 10 percent shorts on manufacturing and we did manage to get 4500 units out before the Hail Mary maneuver through Western Iraq and the rest of them came out in the early spring. But as spring wore on, I kept seeing inventory numbers rise and it was then that I found that my production VP had cracked under the pressure and started triple-ordering things and so we had all this inventory coming in and at that point, the JPO decided that, well, since what we had produced for Iraq worked so well that they really ought to do it right and they really shouldn't be using a civilian receiver. They should be using one with a P code. Now by the way, we built a civilian receiver because we couldn't get clearances for the P code. It wasn't a problem with technology. So anyway, they redesigned what a handheld was supposed to be and then set up a winner-take-all competition between us and Rockwell. I clearly was naive because I bit on that, and we actually got crushed because even though the requirement was for 50,000 units, Rockwell bought the order.

Rino: Rockwell was the prime supplier already?

Trimble: Yes, they were. They bought the order. Their winning price was 38 percent of our projected factory cost, and I had never known Rockwell to be a low-cost supplier. In any event, the silver lining the lesson is that aerospace companies have trouble competing in commercial markets, and commercial companies have trouble competing in government markets largely because the customer is different. We learned the hard way that the customer for the government is the purchasing agent, not the end user, so providing more for the end user doesn't buy anything if the cost doesn't go down. In any event, the silver lining was because of what happened in Desert Storm and I think in part because we didn't have a dog in the fight, I had access to the top civil and military people in the Pentagon, and this access was used through the GPS Industry Council not to try to sell something but to give feedback on what the likely consequences of various policy decisions would be.

So we played the role of the canary in the mine shaft and actually we were forced to do that because directly following the Gulf War, the intelligence community decided that they had only about two months to place export license controls on GPS, which they wanted to do, and we were told that the people in the Pentagon couldn't talk to us as an individual. They could only talk to us as an industry association. So actually, we put together an industry association in 10 days and got 7 CEOs in the most fiercely competitive gunslinging market that you can imagine together to talk to people from the intelligence community and come up with a plan for avoiding export licenses and ITAR controls on GPS. We agreed to put software traps to keep the GPS receiver from working above 1000 knots or 60,000 feet. We agreed to provide a Surgeon General warning that the L2 signal belonged to the U.S. military and they could change it at will. That worked and was crucially important but that was only the first of the wins. Actually, Trimble drove the industry council but we drove it for the benefit of the entire industry and we operated that one on a shoestring. Member companies, I believe, paid $10,000 a year and then we supplied our own people to do whatever needed to get done.

Rino: You were talking about going beyond in civilian code systems, so you had to have access to the P code?

Trimble: No. Well, if we were going build receivers for the military, we had to have the ability to build that portion of the receiver and later we did get the security clearance for it. It didn't buy us very much because frankly, small companies get small orders, big companies get big orders when dealing with the government, but it was something that we tried.

It wasn't enough just to innovate with receiver design. The transition from focusing on driving the cost of GPS receivers to zero in end-user products and basically monetizing the information aspect of GPS. It was sometime during the early market phase when there were only seven satellites in the sky. We started to realize that there was something fundamental about the time-tagging of events and the geotagging of data or objects We started to realize that knowledge of space and time was an information utility and that caused us to think about the other utilities that we're familiar with and it got us to focus on the telephone and looking at the multitude of applications that had been generated as the telephone transitioned from analog voice to digital data.

It was then we started to realized that GPS could have a transformational impact on the way people live and work, that fundamentally the GPS satellite system provided a global grid to which augmentations could be added to provide solutions that added efficiency, accuracy, and assistance and so markets like mining, construction, transportation, precision farming, emergency response, were all open to us and that we continued to follow a high-volume thread but Garmin had also benefited from the Gulf War. Both Magellan and Garmin had benefitted from the Gulf War. We were so tied up in providing units for the military that there were no units left over for civilians and so parents were buying civilian units to...

ship with their kids to the Middle East. We realized, it was sometime late in '91, that the cost of the display was now more than the cost of the GPS receiver, and so our leverage in terms of driving things down wasn't in a finished product. We continued to make OEM products for the car navigation market

and actually for other markets where cost indeed was a driver and we drove things to cost below $100 per set but these didn't end up being commercial products.

Rino: Now, these are all single-frequency systems?

Trimble: They're all single-frequency systems because the only thing that we had that was dual-frequency was the survey receivers, and actually we had those only because the Japanese in 1987 were being put under excruciating pressure on trade. They weren't buying enough from the United States and so the Japanese government decided that what they wanted to do was to buy GPS receivers for their earthquake monitoring systems, but they wanted to go beyond that. They wanted dual-frequency receivers so that we could also remove the effects of the ionosphere. This was a marvelous story, our agent in Japan, Hero, calls me up in May and says, "They have this requirement, and they want three of these systems," and I thought to myself, well, you can make three of anything, and we don't know whether there will still be seven satellites in the sky by the time that we're supposed to deliver these things. So we might as well take the order and gamble that we can find it.

At that point in time we had not seen L2 energy from space. All right. About a month goes by, and he calls me again and says, "Oh, the number has gone up to 10," and I grumble a little bit. I mean there's a huge difference between doing 3 of anything and doing 10 of something. Two weeks later, the number goes up to 25, and I say, "Hiro, know that we have never seen, I mean we're now into July and we have never seen L2 energy. If they ask us for anything, all we can give them is simulator data," and he says. "Fine. They're not going to need anything more than simulator data." Now, the Japanese government procurement system is supposed to work is that they decided during the summer what they want from off-the-shelf things. They sign the contract in September, and delivery is the 1st of April and if you fail to meet the delivery the 1st of April, you are forever —blacklisted.

Rino: Let me clarify a point that you said, you'd never seen the energy. I mean it was there. You just hadn't built the unit to pick it up?

Trimble: No, with spectrum analyzers or anything had never observed it. It is so far in the noise.

Rino: But I mean the signal is there. You just couldn't extract it.

Trimble: Oh, the signal was there. Absolutely. The satellite emits it and we know that and we know all of the physics of the satellite signal structure. We just hadn't seen it. I mean it is devilishly difficult to find and, as a matter of fact, once we started looking it took us six weeks to find it.

Rino: And that's because there's no C/A signal to help you out, or what?

Trimble: Well, there is no C/A signal. You actually have to use a C/A signal and know the relationships between the L1 and L2 to actually be able to find things but we hadn't done that and so there was a sequence of things midway through August that the Japanese wanted data. We sent them data and said, "This is only simulator data." Forty-eight hours later, Hiro calls and says, "They say it's simulator data,"

and we say, “So?” “Oh, they need data,” and we said, “We don’t have it.” Finally, he calls up and says, “If you can’t supply data in the next 24 hours the deal is off.” Well, that night Timo sees his first L2 data and we send them a record and we now have this contract to build 25 of these systems. I mean, we’ve seen data, but we have nothing else, okay, for a codeless L2 receiver. We have basically eight months to build these 25 things and I bring Jim Sorden from HP because he’s an engineer and he was a project manager, but he’s truly an Army sergeant and he actually is a finisher and he managed to get the 86 boxes delivered to the Japanese before the 1st of April and they worked. Now later, I found out how Sony had made the delivery on their L2 receiver which never worked but they got paid and they weren’t blacklisted. They delivered the receiver, and all of the software was coming later. All right.

Rino: So it had two channels but no software.

Trimble: So all right, now back to the set of stories. We first realized that we were going to have to get involved in protecting the availability of the GPS signals when we got word that there was a troublesome rider that had been added to the Senate version of the Armed Forces Appropriations bill. This rider called for the military to limit the accuracy of differential GPS in the Gulf of Mexico to 10 meters. I mean we were routinely doing it to a foot at that point in time. Since differential GPS fundamentally takes out any of the errors in the satellite, there was no way that they could do something with the satellite. So we weren’t sure how they were going to do it, but this wasn’t going to keep people from trying and making a mess of things.

Fortunately, on my first visit to Washington I met Scott Pace, then an assistant secretary of commerce. Scott was to become our guide and trusted ally in the Washington maze and when he heard the story he explained to us what was going on and introduced us to Jay Kimmitt, the senior staffer on the Senate Armed Services Appropriations Committee. Jay was really surprised that there was a problem with the rider. In his words, “This rider was supposed to be apple pie, motherhood, and the American flag.” When he understood the issue, he volunteered to try to get it removed in conference committee but warned us that this couldn’t be a guarantee because this, there was frenetic activity in merging the two bills. The only way that we were going to be sure that this didn’t make it into law was to get the senior senator from Louisiana to withdraw it and probably the only way we were going to be able to do that was to get the rider’s beneficiary to request that it be withdrawn. And to make life a little more interesting, we had between 10 days and 2 weeks to get this done. I mean they were in conference committee, and it was going to come out. Fortunately, the following week there was an oil industry conference being held in New Orleans and a Shell exploration VP called for a straw vote on the rider. The rider was 13-0 with 1 abstention. At that point, the Shell VP is reported to have turned to the abstaining oil service company CEO and saying, “I think the industry has spoken. If you want another contract from any of us, you’ll get that rider removed.” And then for insurance, the senator was called and told that if he wanted any further campaign contributions from Big Oil, the rider would be withdrawn. It was.

Now, this wasn’t the last of the political battles. Another one on the international front has to do with the World Radio Conference. The World Radio Conference is an arm of the United Nations, and this conference allocates radio spectrum on a, on an international basis. Now, historically this had been a technocratic gentlemen’s club made up of representatives from the telecommunication agencies of

countries around the world, but all that changed in 1994 when the United States proposed granting a block of spectrum to Teledesic for an 840-satellite constellation, communication constellation. They not only proposed it but had locked up the votes to pass it. As the story goes, well, first the Europeans cried foul, but they lost. As the story goes, Bill Gates had hired two past WRC presidents to go around the world offering telecommunications agencies payment of back dues for their vote on this proposal.

Rino: He was for it?

Trimble: Oh yeah, he was for the proposal. The British and French proposed taking the bottom 5 megahertz of the GPS spectrum and putting it as the top 5 megahertz of Inmarsat's telecommunications satellite band. and by the time we found out about the proposal they had locked up 47 of the 93 countries eligible to vote on it. Payback time. While this was problematic for us, it was a real problem for NASA. They had no standing to argue the issue because they had no protection to use GPS in space, and they were highly vulnerable. Coupling NASA to our cause, we interested some of the top people in the Clinton White House and got an ex-governor appointed as WRC ambassador.

When we arrived in Geneva, the state of play was 47-6. On our side stood Russia, Syria, Senegal, and Tonga. Internationally, the airline industry was aghast at the proposal from a standpoint of airline safety, and United and American sent pilot executives to help. Our strategy was to get the issue remanded to study and taken up and voted on at the following WRC, but technical arguments and reason were having no effect on cracking the voting bloc. Our first break came from the American pilot. His father was head of the Lockerbie 103 group in Scotland and he knew how to get a fax into 10 Downing Street, and the fax was supposed to say something to the effect that is Great Britain going to place narrow commercial interests above airline passenger safety. He gave us a phone number and told us, "When the operator answers just say, 'Incoming fax, hon,' and hang up." The following morning, the British ambassador came by and commented, "A little below the belt, old chap," but nothing more. At this point, we were three days away from a vote. Fortunately, we were able to get to Wesley Clark, then Supreme European Allied NATO Commander, and he placed a call to the British prime minister. He is reported to have said, "We're carrying your water in Kosovo. Stop screwing with our GPS." The following day, the British ambassador proposed remanding the issue to study and having it taken up at the following WRC. Another bullet dodged. In the time between WRCs, we joined with NASA and the U.S. Department of Commerce in an outreach effort to the telecommunication agencies around the world.

These people knew a lot about telecommunications but nothing about GPS. None of the constituents that they served had anything to do with GPS, and so we showed how GPS was used in their countries. We demonstrated equipment, and we had test data showing how realized GPS performance would be adversely affected with this proposal. The vote at the subsequent WRC was unanimous, 102-0. The lesson here is that innovation had driven realized GPS receiver performance, and this realized performance protected both the spectrum and the pristine noise floor. If minimum design specifications had been used, innovation could have been applied to compromised satellite system capability.

We fought frequency wars with Time Domain. The1996 Telecommunication Act had stripped technical expertise from the FTA. FCC and stripped the technical expertise from the FCC. Congress wanted them

to rely on their constituents to supply it, and Time Domain had convinced the FCC that they were using only half of the available spectrum. They were allocating frequency in the spectrum, but they weren't allocating time domain. I guess none of these people had in college heard of Fourier and the mathematical connection between time and frequency, but in any event, we had a major political battle. All they wanted to do was to allow the Time Domain signals to raise the noise floor up to the unintended limit that the FCC had found. Well, when you have a operating system, and you have some unintended emissions, you're not using the entire noise floor, the entire spectrum of the floor. You may have a line or two but this was going to use up the entire spectrum and they wanted the total spectrum from DC to Daylight. We were fighting back that if you're going to this, you want to do this at higher frequencies and as a matter of fact to protect the cellular system you had to be well above the 2 gigahertz region and actually we were proposing that if they wanted to play in the sandbox they could play above 3.2 gigahertz. There was an FCC vote, and fortunately the FCC has a rule that after something is voted on clerical errors can be addressed. Fortunately, an assistant secretary of defense who belongs to the National Academies paid a visit to the FCC chairman and found that the clerical error was not including the words "above 3.2 gigahertz." This was, in my mind, real payback from losing out to Rockwell for the military market.

Later still, there was LightSquared which was another political free-for-all, and again, it was realized GPS performance that was the issue that pushed back against them. They're not dead. I mean there's a reincarnation now that is still after the frequency, but now that the GPS has actually migrated and more or less, with the exception of the dual-frequency or multiple-frequency GPS receivers or multiple satellite system receivers, GPS has actually disappeared. You won't find it inside of your cell phone. GPS is actually a cell that is one of the digital chips in the cell phone and Garmin is having a really tough time now selling car navigation sets because they can't tell you that there's traffic ahead and you should take an alternate route and then route you on the alternate route, which of course you can do once you have a cell phone. And actually I found, talking to people at Trimble, they now have programmed a smartphone to solve the GPS problem totally in software inside the cell phone and well, when you think about it, compute power has increased by more than six orders of magnitude since we started in this game and we knew that-- we knew that-- two things, that the only way to make GPS ubiquitous was to drive the price to zero and once we drove the price to zero it would become ubiquitous. And actually our easy alliance with the military came about because we convinced them that since they had the levers to turn back on selective availability in the satellites they could in theaters of operation really degrade civilian GPS, and if we could make GPS free then it would become the world standard because it is really tough to compete with a utility and almost impossible to compete with a free utility. And so it was just after the Gulf War that as the company we focused our attention on exploiting GPS information or the information involved in position and time and specialized software for market-specific applications. That was how we monetized GPS.

Rino: You were talking about earlier of actually digitizing the signals up front and then doing all the rest in software? Did it go that far?

Trimble: Yes.

Rino: Yeah, so like you're working maybe at a couple of megahertz, sampled signals and feeding them right into a processor?

Trimble: Yeah. As a matter of fact, our first GPS, we did a single-stage down conversion to 4 megahertz. In fact, one of the seven things-- breakthroughs we needed was how in those days to make a single-stage down converter for GPS. A doubling image reject mixer was the solution, but...

Rino: And that's good enough.

Trimble: It was good enough.

Rino: That's amazing. Okay, so you survived the wars.

Trimble: We survived the wars, thanks in large part to Ann Ciagner, currently a Trimble VP, who quarterbacked the Washington scene.

Rino: That was frequency allocation and communications?

Trimble: Well hey, let's face it. If you have to make a choice, you're going to take communication before you take information on position and time. You really want both. There is an incredible need for spectrum space, and the only way we're going continue to be able to get increased spectrum for what we need is by going up but there-- nobody wants to go up because it's more expensive to go up and besides that, you get into more and more environmental situations as you go up.

Rino: Rain, clouds.

Trimble: But at 77 gigahertz you can beam steer from antennas that are on an IC chip.

Rino: But that's fine for local.

Trimble: It turns out that most communication, unless you are in the air or unless you are at sea, most places in the developed world you have fiber, and frequencies can be infinitely reused by just adding fiber.

Rino: Yeah. I mean the internet is through cables.

Trimble: Absolutely, and so basically the place that satellite communication and well, hey, I still get my internet from satellite in the San Juan Islands out of Seattle. It's right on the Canadian border.

Rino: No cable?

Trimble: There's no cable, and I can't get a microwave link to somebody that is broadcasting.

Rino: So, but you can't cover the world that way.

Trimble: You can't. Actually we knew when China started burying fiber optic cable along the rail lines that they were not going to go down the path of using satellites for their basic communication. India doesn't have that yet and still needs it. Broadcast television in Asia is, from satellites, is clearly important.

Rino: So okay, we've covered a lot of territory here coming right up to, I guess, almost current time at.You left Trimble a decade or so ago.

Trimble: Two.

Rino: Two decades ago?

Trimble: What I'm doing now and I'm providing seed capital for high-risk research at Caltech and the most recent victory is the climate modelling initiative that basically is going to do a reboot on climate modeling, on fundamentally being data-driven and from space-based data and solving some of the really tough problems computationally, gapping computationally. And so they've just put together the consortium of private philanthropy that will be providing $5 million a year for 5 years for this effort and it's a consortium that involved Caltech, JPL, MIT, Naval Postgraduate School, and there will be others but so that's what my-- the high-risk research at Caltech is my passion right now.

Rino: Okay, and let's see, there are a few notes I'd made in here in this long history, a meeting with Bill Buckley.

Trimble: Oh, yes. Oh, yes. These are back in the-- he first discovered us with Loran because we were producing Loran-C receivers that read out in terms of latitude and longitude and if you had a sailboat you could find an ocean buoy based on the latitude-longitude of the Light List where you couldn't find them using the Coast Guard time difference things. So he first came across us in the Loran days and described us basically-- what did he say-- a Disney shop of elves doing magic. But in any event, at one point he decided he wanted to do his trip across the Pacific, and we had just produced the first GPS receivers. We had sold one to Northrup and we were starting to sell them into the oil service industry and he wanted to borrow a GPS receiver to sail with him across the Pacific and now we were a little bit leery because in those days you had to know your position to a degree to be able to make GPS work. Now, for most applications we were up to, this was going to be fine because navigation wasn't going to be one of them.

Rino: You mean to initiate the process?

Trimble: Yeah, to initiate it, to find the signals you needed to know it to a degree and he brought his technical person with him and so we went through the training, but we were sort of leery. When he was a day and a half out of Hawaii, he calls us and says, "It doesn't work," and so we start going through the operation again of entering approximate position and once we get the entry of approximate position. He has approximate position because he loves his sextant fixes he took it across the Pacific. And so on his way back, he calls me at midnight and he says, "I'm at Trader Vic's in San Francisco. I have the GPS

receiver. Do you want it now or in the morning?" and I tell him, "I'll take it now," and he says, "This was really pretty accurate. It was once within a mile of my sextant fixes."

Rino: Okay. Yeah, that's a great note. So let's see, is there anything that we've overlooked? I think you've given us a insightful, beautiful story of Trimble and how that all came to be.

Trimble: Well, I can say that it was a lot of fun, and there are very few technologies that you can ride for a couple of decades. GPS turned out to be one of them. As a young engineer at a Christmas party in 1964 I found myself sitting next to David Packard at the Palo Alto Country Club and got him to talking about early days in, at HP, and at one point he said, "When the company is small, luck plays a real part," and I can distinctly remember saying, "He's really humble." Now I know he was telling the goshawful truth.

Rino: Yes, the early days of Hewlett-Packard were quite a story in their own right.

Trimble: Oh, absolutely, and actually I had this concept of a ball which gives you either a good bounce and it bounces toward you or it's a bad bounce and it bounces away from you and I kept track of how many bad bounces I could have and still survive and I was down to zero tolerance of bad bounces on several occasions. If one wants to be entrepreneurial, one has to deal with a great deal of ambiguity, and I can remember being very happy when I got to the point that I didn't have to bet the company more often than once a year. It's there but for the grace of God go I. I mean that's truly what it is.

Rino: Yeah. Well, that's great. Okay, I think we can end it there. —Thank you very much for taking your time to let us record this story.

Trimble: Well hey, thank you for getting me to reminisce about things that I really hadn't thought about for well over a decade.

Rino: Yeah. We always think that this place where we're sitting was the company of Silicon Graphics, which is no more...

Trimble: Absolutely.

Rino: ...and up the street, Facebook is where Sun Microsystems used to be, but Trimble is still hanging on so the best.

END OF THE INTERVIEW

