Sue Nelson
Hello, I'm Sue Nelson and this is a rather special edition of the Create the Future podcast because my guests are the winners of the 2019 Queen Elizabeth Prize for Engineering, awarded for the development of the Global Positioning System – GPS. It's the first global satellite radio navigation system, a huge engineering infrastructure, and if you've got a smart phone it gives you both your exact location, and the precise time within billions of a second. It's used for everything from navigation and banking to precision farming and science.
As you might imagine, there are several crucial components to GPS: it uses a constellation of orbiting satellites, ground stations, a receiving device, and an atomic clock. I'm delighted to be joined by three of the engineering pioneers who spearheaded the advances that culminated in an invention that revolutionized the world and benefited humanity. They are Bradford Parkinson, Dick Schwartz, and Hugo Fruehauf. First of all, congratulations to you all. The Queen Elizabeth Prize is as a considerable accolade. Is it special winning a prize like this?

Brad Parkinson
Well I would say it is without a doubt a prize that is unexcelled by anything else, particularly for engineers. We don't win Nobel's because, generally, we make stuff that works. That's supposed to be a joke but, nonetheless, I am deeply, deeply honoured. The ceremony was impressive, and the whole reception was obviously well rehearsed. It gave me a great feeling about what a team of engineers have produced.

Sue Nelson
Did you ever think, Dick, that you would be at Buckingham Palace?

Dick Schwartz
No, I never thought I'd visit Buckingham Palace. I grew up in New York City and Buckingham Palace was the other side door. No, I've never thought I would. But it was quite impressive, the ceremony; the Prince of Wales is a very impressive person, and very congenial. He's very easy to talk to, and so the honour is outstanding, just outstanding.

Sue Nelson
That's wonderful. Well, Bradford, let's start with you, because I'm going to start chronologically. You're a Colonel in the United States Air Force, a graduate in engineering from the US Naval Academy, and your role came from working for something called NAVSTAR. Can you explain what NAVSTAR was?

Brad Parkinson
Well, that's a name that we gave to a satellite-based navigation system. It turns out that the name itself was generated because one of the persons that I had to get to [say] yes, to give us the money to produce it, suggested the name. So I said "okay, if you like Navstar, then that's what we're going to call it." The idea was that if he had called it that, then perhaps he would approve. He ended up approving.

Sue Nelson
So, is it short for navigation using the stars, which is what you might guess from that?

Brad Parkinson
No, it was just a nice name. On the other hand, GPS had a real meaning: Global Positioning System. It was global, and it was positioning, and it was a system in the sense that a user would supplement it with a receiver and, as a result of listening to at least four satellites, you could figure out where you were anywhere in the whole world.

Sue Nelson
So, how did Navstar become GPS? Was it a straightforward switch of name or did you have to go through specific roles?

Brad Parkinson

The names were used in parallel and it was evidently my prerogative; I was running the program, and I decided what it was going to be named. I have a law of the assumed decision; if there's a vacuum in decision-making, you simply make the decision, and move on and unless someone stops you you keep running.

Sue Nelson
In terms of designing and developing the system, what for you was the most challenging? Because that's, you know, an enormous project to bring together.

Brad Parkinson
Actually, a project like this has a balance of very difficult things, and it depends on whether you're talking about the satellite. For the satellite it was probably the clocks, although Dick Schwartz was responsible for making the whole satellite reliable, and that was essential if it was to be affordable. On the other hand, the ground control system had to calibrate where the satellite was going to be ninety thousand miles into the future, and the user equipment had to listen to those ranges, listen to the signals coming from satellites and from that derive information that positioned it to perhaps a few meters. Along the way, by the way, it has to has to correct for both the general and special theories of relativity; were it not to do that, you would be miles off.

Sue Nelson
As an engineer, what skillset did you find was the most useful? I know mathematics is a key part here, but you've got physics with relativity, you've got your engineering, as well as the application.

Brad Parkinson
I was trained as a space engineer and as a controls engineer, and both of those I found to be very useful. In the case of controls, the estimation of position, the calculation of position – in our books I wrote the error analysis for GPS – all that was useful. But, as well, knowledge of how you get into space – what Kepler's laws are all about, how a rocket works – that's pretty fundamental, but we had to look, listen, and think about that a great deal. Dick's satellite had to fit on the top of a booster, and they had to make it all the way up or we weren't going to have a system.

Sue Nelson
So, Dick, it's a good point to pass over now because you joined an aerospace company, Rockwell.

Dick Schwartz
That's correct.

Sue Nelson
In 1957. So what were you doing, then, when this was going on? What were you doing at Rockwell?

Dick Schwartz
The company first had started as North American Aviation, and later became Rockwell. When I joined, I worked on the Apollo program, and Rockwell – North American Rockwell, at that time – managed the capsule, but they also managed the second stage booster. I worked on the second stage booster, and as that program kind of wound down at the end of the 60s and the beginning of the 70s, we started to do other things. We pursued satellites, and GPS came along right at that opportune time. We were fortunate enough to win the GPS satellite program and then went forward with that.

Sue Nelson
What was the obstacle at the time for putting satellites into orbiting the earth, and to distribute GPS signals?

Dick Schwartz
The obstacle I guess was "don't let him fail"; that was the no. We had to get them up so they're working.

Sue Nelson
Well it's also the environment, isn't it?

Dick Schwartz
Well, there's an environment, but they there were some constraints. Brad mentioned the boosters – the Air Force was working on a limited budget, so they got some old boosters out of their silos, initially ballistic missiles, and limited the amount of weight it could put up. Then we had to go through all the shaking and rattling and all the stuff to get up and have it not break. We had to recognize that we were working in the Van Allen belt, and so we had to protect the components, and I think the most difficult thing – or maybe the most fun thing – is setting a very very high standard for the people, for whom perfection was the name of the game. We couldn't fail, you know, and that actually turned out to be a lot of fun, where people work together and challenged each other about "is it right?" We worked and worked at that, and it turned out it was, it was relatively short-term. The pleasure for me personally, working on some of these aerospace programs is that: these programs are usually 20 plus year programs, but from the starting piece of paper, to putting the first satellite up, was 44 months. So our group of people could see the beginning and the end. There are people in the industry who see the beginning and not the end, or see the end not the beginning, but [in this instance] it went from papers to flying to producing a signal; it was very very rewarding experience. The experience was not 'Eureka' it was kind of "one's up; two's up; three's up; four's up", then it was 'Eureka', that they all worked and you could navigate.

Sue Nelson
Does not describe engineering though, Bradford?

Brad Parkinson
Well that does describe engineering, and I should make a comment on selecting Dick Schwartz and Rockwell because there were four competitors, four companies that wanted to build our satellites. Of those four, his was the second highest price. He won because I persuaded the authorities that he was the company – or he represented the company, at least – that was most apt to succeed. I have never had any remorse whatsoever about having made that decision. He indeed was a wonderful program manager to work with, his statement was that if something is broke, we're going to fix it but we're not gonna hide anything from anyone. There were some contractors that had a reputation that they didn't want the Air Force to know they had done something bad. He never did that. In essence, from beginning to end, it was an open teamwork environment and I think that's what led to success. Having four first-of-a-kind satellites all operate virtually flawlessly is almost unheard of. Initial failures, infant mortality frequently happens. Not only that, but by placing it the satellite in the upper end Van Allen belt, we were putting it into the harshest environment you can imagine. If you were a human, unprotected at that altitude, not including the vacuum of space, radiation would kill you in less than a minute. This is a very hot region, and to make the electronics work required a lot of care and feeding and his people did it.

Dick Schwartz
I wanted to say something, just on that the management of it: our technique at the beginning was that on Monday morning at 08:30 we'd have an internal meeting of all the people responsible for all the elements of the satellite, and they produce a list of "what did I do last week, what am I going to do next week, or what's my problems", and we would go through that. Then the Air Force would visit me in the afternoon and I'd kind of repeat everything so they'd be up to speed on it, but then I'd get to the end of Monday and I hadn't done a lick of work. So I said well to get at first hand, they don't have to take my interpretation, the Air Force, why don't you just join my meeting? But there's only one requirement: you cannot speak. You can listen, and then you can come to my office after the meeting and say anything you want to me, but you can't take over the meeting or we'll get back to where we were. That turned out well because they heard everything first-hand, you know raw data, raw information, and they were pleased. And they got used to not speaking.

Brad Parkinson
Not really…

Sue Nelson
Going back to the hardening of the spacecraft how did you actually do it? What did it involve?

Dick Schwartz

Well, putting metal around these critical components and shielding them.

Sue Nelson
You make that sound very simple.

Dick Schwartz
It turns out to be weight. Weight is very critical, so you can't just pack them all in lead. Then we tested them on the ground and it worked.

Sue Nelson
And you improved the antenna as well.

Dick Schwartz
Well, the antenna – if you're flying up there, right below you is pretty close to the edge of the earth. It's pretty far away. So, we had a pretty good antenna designer, he kind of designed the antenna so that it produced little power down here but spread the rest of the power out to the edge. That way, there's essentially equal power from edge of Earth to edge of Earth, which is a long way off. That, I think, was one of the 'inventions' of GPS.

Sue Nelson
Hugo, you're an electronic engineer, and you joined Rockwell International in 1965. You were working on the Saturn 5 rocket, what were you doing?

Hugo Fruehauf
Well, first of all, Dick was my boss at the time, and we – Rockwell – had won the contract for the second stage. Rockwell was into everything; they had the Apollo capsule itself, and they also had the second stage of the huge rocket. It was a liquid hydrogen–liquid oxygen high-energy stage, so we kind of absorbed all the sins of the other people with the extra weight. We were able to have enough lift to have some of the problems solved, and what I was assigned to do is to static fire the vehicle several times in order to find whatever glitch there is. Now, von Braun had a kind of a rule that everything that flies with a person in it has to be testable. Now, why is that? It's because the shuttles use solid boosters, and you can't test them first. So, it's so all the things that we learned in first generation NASA, which did a fantastic job, was somehow lost in the second generation. The vehicles are so big that you cannot transfer them by land, so at the vehicle that was made by Rockwell was done in Seal Beach, California, and it had to go through the Panama Canal, through the Gulf of Mexico, Mississippi River, Pearl River, and we actually had it take it through a 30-mile canal. Those huge things, which are like 40 feet (~12m) in diameter and about a hundred feet (~30m) tall, are then on barges. And they go through that whole process and, for our particular stage since you're asking about us, it journeyed through all of those things and then there's a crane waiting for it which lifts the vehicle out into a huge test stand. The whole idea is to make it think it's flying, even though it goes off at hundred thousand feet. We did everything – we count down and do all the necessary testing for the home office that did a fantastic job designing it. And, in 1967-68, I was the Chief Test Conductor at Mississippi working for Dick and, basically, I kissed all the stages that went to the Moon. Then they go back on the barge and then they get floated all the way around, and put it in a vertical assembly building where everything is stacked up.

Sue Nelson
I've been in a VAB before actually.

Hugo Fruehauf
Really?

Sue Nelson
Yeah!

Hugo Fruehauf

But once you get it tested, God has to give you a permission to do anything to that vehicle. Move a wire, anything. Once you're done, you can't do much more in the vertical assembly building. I think at that point any major problem you would not fix it in a day, you'd probably send it back.

Sue Nelson
I must admit, I'm gonna do a bit of a fangirl here: I can't believe I'm with people here who've worked on Apollo and Saturn 5! This is just, you know...

Hugo Fruehauf
It gives you goosebumps.

Sue Nelson
It does!

Hugo Fruehauf
I just talking to you about this.

Sue Nelson
And also it's amazing because your background includes something that was involved with the moon landings and GPS. I mean, this astonishing in terms of what you've done. So how did you know go from that to GPS? Were you just told what to do by Dick?

Hugo Fruehauf
No, he only made sure that I had ties that were completely accurate. Anyway, I had five years of launching experience before I came to Rockwell so we were launching Atlas Agenas and spy satellites out of Vandenberg Air Force Base. How did we get to GPS? Well, we were very busy for the last launches and Apollo 17 never really went. At that point in time we started looking at things to build for the future. We were building some small satellite programs that never really went anywhere, and then the government puts out what's called a request for information – RFI – and so after a while things get kind of technically levelled. So you hear a little bit from RCA and you hear a little bit from [unclear], and some of it is on purpose and some of it's not. But anyway, it starts to get the people that are not government involved, and then finally after that process for about a year, then they put out a request for a proposal. Dick had the guts for us to actually think we could win this; we had never built a 3-axis stabilized satellite like that before, and he selected the team and thank God he chose me as to be a chief engineer again. So away we went.

Sue Nelson
What was Dick like as a boss? I know he's sitting next to you but.

Hugo Fruehauf
What about him? I basically hate his guts. But he is just so doggone good that you got you just gotta forgive him for all that, you learned so much. He basically formed my career; I've had a fabulous 60-year career and I'm still not retired.

Sue Nelson
Dick, are your ears burning?

Dick Schwartz
Correct to the second stage of the Apollo vehicle. There's something called the mass fraction when you build the booster. What you'd really like to have is a balloon full of propellant so that the booster weighs nothing. The second stage had the thinnest walls, the most propellant, and had the highest mass fraction of anything in it. So it was very tender to handle, and that was part of the challenge. On the satellite, I think putting together a team was the thing that did it. People who were interested in doing the work and who had a perfectionism in them and they wouldn't let go unless it was correct. Brad Parkinson talked about the fact that we did not ever have problems under the table. Any problems we had were up on a table; I always said if you stick them under the rug they get pretty smelly in a hurry so you might as well put them up on the table and deal with them.

Sue Nelson
Engineering is always about teamwork, but I also like the way that Brad said that it was just unusual with contractors that they didn't go for the lowest bidder, that they went for the second highest bidder. And particularly within the space industry – that famous joke by John Glenn I think it was, saying that he was sitting on top of a rocket built by the lowest bidder.

Dick Schwartz
But he sounded very generous when he said that. We won the first contract for four satellites for 42 million dollars. Just think about that.

Hugo Fruehauf
Because the latest GPS right now costs almost a billion dollars.

Sue Nelson
So, what you're saying is that they got it cheap at half the price then basically, then. Hugo – the key for accurate timing, at the heart of a GPS satellite, they needed an extremely accurate method of timekeeping: an atomic clock. But there was a shortcoming, wasn't there, at the time? For using an atomic clock on a spacecraft.

Hugo Fruehauf
There was a very smart German in Munich that came over the United States and he made this he made a laboratory piece of equipment that was around twice the size of a microwave into a very small item 4x4x4 inches. I'm a German, and I could speak the language, and he wasn't all that good in English. I was tipped off by one of my employers. He looked at my staff and he kept saying that he was going all around the country trying to help them to build something smaller than the laboratory piece of equipment they had. I got absolutely nowhere. I was actually worried, I was afraid that without the clock we weren't going to be able to fly.
Brad had a lot of problems with money and so therefore he assigned 21 Atlas F ICBMs that they had in stock they weren't going to use. We had to fly on an ICBM that only had fourteen hundred and fifty pounds of throw weight. The satellite, by the time you have another kick motor to put it into this twenty thousand one hundred and forty mile orbit, can only weigh 850 pounds so my problem was even bigger. Today they weigh four thousand pounds so you could put anything you want on there today, but then, you know, three 50 pound clocks? That took about 20% of my weight. I kept being told to go see this guy, Ernst Jechart, he's got this thing you'll want to see. What he said just didn't make any sense, it was just too much; it's like something falling out of heaven you know? So, finally I went to see him and what I saw just blew me away. I got emotional. There was just so much luck it could not happen. But I got home that night and I get this phone call and Ernst is swearing at me with every 40 syllable German swear word; he was so upset. The next day I go in and I asked what was going on and he said "you're trying to trick me". I asked what he meant; apparently, this guy that was working for me was working for another company to which Ernst was selling these small things for about $3,500, and they were trying to reverse-engineer it. He saw that guy in the laboratory when he went over to his customer and he thought we were pulling a joke. Of course, he had a responsibility to tell me that he was moonlighting at night, so I felt no remorse about walking him out the door four hours later. Long story short then having his knowledge I sucked him dry for everything he knew, and began to realize that this was our answer. Then we made a deal with them and one of our Rockwell divisions, and together, then, taking some of his parts we redesigned a whole new package around it that was radiation hardened both for neutron fluence, total dose, and flash.

Sue Nelson
What's the answer? What was it?

Hugo Fruehauf
The answer is we got down to a size that was about five by five by six, slightly bigger than what he had. Basically, today we pay four million dollars for clocks. At that time can you imagine?

Sue Nelson

How did you do it though? How did you get from something that was huge, to doing the same thing but lighter?

Hugo Fruehauf
Smart engineering on the German's part that we then excelled in and went nuts with.

Sue Nelson
So was it much lighter materials all round? Did you have to change anything?

Hugo Fruehauf
He changed the game; he went from large tubes, large rubidium vapour oscillators – it uses a lamp and a glass cell that was about the size of my thumb. Other people had cells about six inches by four inches. They never thought to try making that a hundred times smaller. Then, some of the things that I had learned added together with that, and now we could suddenly make that same thing the size your fingernail. It was that kind of thing. There was a good team relationship there which was thinking out of the box. As a matter of fact, it was a German product made by Rohde & Schwarz – famous company – and Ernst began to realize that they weren't really interested in this thing. So, he gave them the reward money back and said "can I have the patent? I'd like to do something with that." Rohde & Schwarz had absolutely no use for something that was 4x4x4 inches that worked as good as a lab device.

Sue Nelson
And this is where your experience of working in space really helped.

Dick Schwartz
Ernst Jechart was a genuine genius. Absolutely genius; he was fantastic. He knew his stuff in spades and if you could get that and extract it – and that's what Hugo did – and put it together... He was one of the heroes of GPS.

Hugo Fruehauf
He died in 1993, I think, and I think it was a loss of a national asset. I would put it in that framework. The reason for that is that he was a German, he had a German company, and Americans don't go for military equipment of a foreign country. So we actually contacted Governor Rounds' son in the 70s and got so much hassle. A guy told me one time I went to the Pentagon that it wasn't going to happen; we're not going to fly German hardware. Of course at that time it was American-made. But we got the work on it and we ended up getting him citizenship papers in two weeks, so he was a citizen six months after he came to the United States. So there was somebody else thinking he was a national asset.

Sue Nelson
There was another important aspect involved in enabling GPS to operate successfully, and that was designing a signal for civilian use. It involved building the receiver that processed the first GPS signal, using something called Code Division Multiple Access (CDMA) which is essential for accuracy. James Spilker was involved in that process, a key component in fact. Sadly, James passed away a few months ago, but I'm delighted that his wife Anna Marie is with us to pay tribute to James. He knew that he'd got the award didn't he, because it was announced early in February. How did he receive that news?

Anna Marie Spilker
He was thrilled, delighted. And, more importantly, he acknowledged the importance of this award in recognising engineering globally and he personally wanted to thank Queen Elizabeth many times for putting her name on this prestigious award.

Sue Nelson
It is important that isn't it? It's like you said, Bradford, at the beginning that there isn't a Nobel Prize for engineering which is sort of outrageous. And that's why this has filled the gap.

Brad Parkinson

So engineers are an interesting lot. By and large I believe they're driven by achievement, by making something work. That excites them more than the fact that everyone knows they did it. If they know they did it, there's a deep inner satisfaction. So engineers as a group tend to be anonymous, but at the same time they don't necessarily invent things; they take little pieces of invention and combine them in creative new ways. They make them robust, reliable, and useful, and as a result the engineer turns around and gets his derived satisfaction from seeing that something is working and benefiting humanity. In the case of GPS, I think all of us who worked on it recognised it probably would help humanity, and of course what's happened in the intervening 45 years or so it's shown that in spades. It's even gotten to the point that GPS is taken for granted, your knowledge of where you are. You whip out your cell phone and there you are. We asked a cabdriver today – he was using GPS to get from one place to another in London – whether he knew how it works, and there was a long pause and he said "no, not exactly. I think it has something to do with satellites." That's fine, because he doesn't have to know. Instead, seamlessly, he takes it for granted.

Sue Nelson
And in terms of James Spilker's contribution how important was CDMA?

Brad Parkinson
The important part was not CDMA per se, it was that he understood the family of codes well enough to recognise what we had to do to make it robust, and he did that extremely well. Not only did he do that, but he also – and this hasn't been emphasised – was the person who built our first reference stations, which were used to monitor the satellites, and from that derive the prediction of where they were going to go. So he made a number of important contributions, but those two really stand out in my mind.

Sue Nelson
He was an electrical engineer, co-founded Stanford Telecommunications, a Professor at Stanford, and he co-founded the Stanford University Center for Position Navigation and Time. It's like everybody around this table that he had an incredible career as a man. Anna, what was he like?

Anna Marie Spilker
Well, the emphasis for Jim was to get the work done – to do the work of engineering and to do it to the best of his abilities. That was his satisfaction. Of course, he was grateful for people to acknowledge his contribution, but that was not his motivation; his motivation was to design the system so that it would work, to teach others his knowledge, and to mentor. So that's what he did with this company of about 1,400 people. Half of the employees approximately were PhD graduates; the other half were the support team. He mentored everyone, and many of his employees said that working at Stanford telecommunications was the best job they ever had. Others said that it was like getting another PhD – Jim challenged them, challenged them continually. More importantly, he had an open-door policy so that any of the employees, if they felt like they were stuck and they couldn't figure it out, they could come to him directly.

Sue Nelson
It sounds an incredible Anna. Did he take that engineering home with him? Could you get him to relax?

Anna Marie Spilker
His form of relaxation was to work on his physical strength, so he went to the gym practically every other day. He worked out for about an hour and a half, acquired the skills of bodybuilding, and became a national champion. He acquired national titles in bodybuilding at the age of 65.

Sue Nelson
Wow I did not know that, he sounds incredible. Thank you so much for sharing that lovely nugget of information – I have this beautiful picture in my head now of this bodybuilding engineer.

Anna Marie Spilker
You're welcome.

Sue Nelson

Now, I know you've had several receptions in London while you've been here and obviously receiving the Queen Elizabeth Prize for Engineering, and some of the people who were present, and for some of the people from the Royal Academy of Engineering, have got quite a few questions for you. I'm just going to play some of those questions and see if you can answer them (well, I know you'll be able to answer them).

Question 1
Hi, my name is Robin and I'm the Public Affairs Advisor at the Royal Academy of Engineering. My question is: would GPS ever work in the interior of the earth and, if not, why not?

Question 2
Jane Sutton from the Royal Academy of Engineering: will GPS work it outer space?

Sue Nelson
Bradford?

Brad Parkinson
The RF signals that GPS uses, it turns out, are at l-band and penetrate the ground very very little. So in terms of working in that sense, the answer is no. But the second question regarding use in space was actually a bit of a surprise. It turns out that you can put GPS receivers into satellites – one of my PhD students at Stanford demonstrated this – and the idea is that a GPS receiver in orbit around the earth is also bathed by the same signals as GPS, provided it's underneath that constellation at a lower altitude. What we didn't realize is that even at higher altitudes you can pick up on the GPS signal, and NASA today is working on receivers that will operate almost all the way to the moon and still receive the GPS signal and navigate. It turns out that's extremely valuable because it makes an otherwise hard job very simple.

Question 3
I'm Stefanie Houser, I'm a graduate student at the University of Iowa, and I was wondering how you think that GPS can be best used in the developing world to solve some of the issues that we face in periurban settlements.

Sue Nelson
Dick?

Dick Schwartz
GPS is worldwide so right away they start off with something that they didn't have to build from scratch. It's like plugging a light bulb into the wall; it's a brand new thing for everybody. So they got that to start with – all that intelligence – and they can do anything they want to do with positioning, from farming to autonomous cars to whatever, their ingenuity can take over at that point. But they don't have to build an electric farm or something like that; they've got that.

Sue Nelson
Effectively you've provided the tool, and it's up to them what they do with that tool.

Hugo Fruehauf
And GPS has interesting possibilities. The two areas that I would focusing on is space navigation – I'm not saying that you navigate on the moon but, as Brad was saying, the spillover signal of GPS doesn't just illuminate the globe, it has 15-degrees more. So that signal spills out past the navigation of the globe out into space. As Brad was saying, we can more accurately target the Moon (especially the moon right now, though signal strength is an issue). Another application in my opinion is autonomous platforms. Now, the application there is slightly different; in an autonomous platform, GPS is the only sensor that the platform doesn't control. They receive it. That means that there is a possibility that they can't receive it – for whatever reason, jamming for instance – so I think that that whole process with GPS interacting with autonomous platforms means that that GPS signal is going to be aided by these complimentary systems. Yesterday [at the GPS showcase event in London] we saw these scanning systems that the UK is doing. You'll have terrain recognition, accelerometers, inertial measurement systems, LIDAR, and sound, so you have all these things which will integrate with GPS so

when it's gone that the platform can continue as it was. Then, let's say we found whoever was jamming and stop that, then the GPS signal simply returns. So, to me, GPS is going to get more and more robust everywhere now; they're not just going to be using a GPS receiver, you'll have a chip that has all these other things in it that aid navigation.

Question 4
Hi, I'm a QEPrize Ambassador. My question is: what is the weirdest application of GPS that you've ever thought of?

Dick Schwartz
The measuring of the Earth's [tectonic] plates to millimetres of accuracy. That's almost unfathomable, and they're using it today.

Hugo Fruehauf
Tectonic plate movement and, of course, faults and measuring faults. We have a fault about 100 miles from our house and it's the San Andreas Fault; it's moving about a centimetre a year. That's a big number. China, I believe, we're moving closer to China almost six inches every year. Incredible, and that's all being done by GPS.

Sue Nelson
As somebody who was involved in the miniaturization of the atomic clock, was it ever conceivable at one point that GPS would be everywhere and everyone would have something in their pocket that would use it?

Dick Schwartz
No. If you've got a history of the receivers, it would be very interesting to just look at them in pictures. The first one was $100,000 or more. Gigantic. Then, when we started working on it, the army was going to use it and I still have pictures someplace of a soldier with a 40-pound backpack and a gigantic antenna sticking out like out of your car, and he was going to be lugging that around. Then it got better than that; we used to go to these GPS conferences and they were building military receivers for these folks, and they were pretty heavy. And their parents were sending these soldiers Garmin receivers that they could hold on hand. And you go into those meetings and you got the scientists who design them, but they have a section with the war fighters, – the people who have actually been using them – and they don't mince things. I use the Garmin. If I go out in my vehicle, I can use the military one but when I walk I use the Garmin. One of the commercial people were trying to make it smaller and smaller and they did a good job at it.

Question 5
Hello, my name is Matt Ball, I am Head of Editorial and Content for Vodafone UK, I'd be interested to find out what you think about the new alternatives to GPS that are coming on like Galileo, GLONASS, the Chinese version of it. Are they better or they worse? Is GPS going to be a thing of the past? I'd like to know your views, thanks.

Question 6
Hello, Rhys Phillips here, my question is: does GPS have an expiry date? What's the lifetime of the technology and, if it does have an expiry date, what will come next?

Sue Nelson
Hugo

Hugo Fruehauf
Well the first satellite we built had you know four point seven years MMD – mean mission duration – which means roughly five year life. The satellites right now, I'm doing some consulting with the government, are now are made for fifteen. Well, the clocks for fifteen years and no less twenty-five, and the satellites are also twelve and a half years but they are expected to be well past fifteen.

Sue Nelson
So, the expiry date is extending and extending.

Hugo Fruehauf
Yes, fifteen years minimum for a satellite. Even our early satellites lasted fifteen years.

Sue Nelson
And what do you think of the alternatives that are around like the Chinese, and Europe's trying to set up Galileo as an alternative. Is more better?

Dick Schwartz
Yeah, the more satellites up there the better. You build the receiver, you can receive their singles. Instead of thirty some satellites that we've got up, suddenly you've got fifty. It gives you better navigation as long as you're not picky who you're using.

Hugo Fruehauf
Yeah, the receiver does all that. In other words, we have a band at 1542.75 MHz, and everybody can play in that thing. As for the reason other people have GPSs – why would the European Union do it? Because GPS is more than the commercial signal. Everybody wants to have their own capability for warfare. So, that is why they want their own system, rather than using an American system. Then there's a commercial signal then everybody has a code, different codes. Most of the time it's 1023 bits and it's like raindrops that fall; every satellite has different raindrops falling on different places, so everybody can navigate like Dick said from this clear signal, and a receiver picks the ones that that are closest in time and the best position to receive. It does all the work, and it's all you really need. It ends up with a solution with only four satellites, although it has a choice of, Like Dick said, maybe 20.

Sue Nelson
Well Bradford's had to head off for a quick media interview so I'm gonna get you [to talk] in terms of the future. Dick, where do you see the future of GPS going?

Dick Schwartz
I'm probably a bad one to ask because I didn't predict this future when I was working on it, but the bright people in the UK, Germany, and all over the world are thinking up different applications. We saw some last night that I had never seen before, so you got this new utility that has certain capability and the ingenuity of the people is going to be unbelievable for what you can do with it. And some things you can't even imagine; I remember being visited by Cadillac Corporation and, at that time, they said "can you build the receiver for $1000?" Because if anybody would buy a Cadillac, they'd put another thousand dollars on so they'd be the only kid on the block with a navigation receiver. Would you pay a thousand dollars for GPS receiver now?

Sue Nelson
No.

Dick Schwartz
No way. So the miniaturisation of the electronics that went on for lots of reasons and wound up in GPS for a receiver that's a couple of bucks now, compared to, well, I think it was 40 pounds and $40,000 when it was being built for the army.

Hugo Fruehauf
$150,000

Dick Schwartz
Oh yeah, the first ones were $150,000, so it's gotten smaller and smaller with this miniaturisation of electronics.

Sue Nelson
I'd like to thank all our Queen Elizabeth Prize winners for joining me today: Bradford Parkinson, Dick Schwartz, Hugo Fruehauf and, of course, Anna Marie Spilker on behalf of her husband, James. Next time my guest will be the chief engineer of the Panama Canal Expansion Program, Ilya De Marotta. Join me then.