INTERVIEWER: Today is June 27, 2011. I'm Barbara Moran, and today we are speaking with Jeffrey Shapiro as part of the Infinite History project. Dr. Shapiro, who received his Bachelor's, Master's, and PhD in electrical engineering from MIT, is a Julius A. Stratton professor of electrical engineering at the Institute.

Dr. Shapiro's research interests have centered on the application of communication theory to optical systems. He is best known for his work on the generation, detection, and application of squeeze state light beams, but he also works in the areas of atmospheric optical communication, coherent laser radar, and quantum information theory. Since 2001, Dr. Shapiro has been the director of the Research Laboratory for Electronics at MIT.

Thank you very much for joining us.

SHAPIRO: My pleasure.

INTERVIEWER: Great. So you've spent almost your whole adult life here at MIT, which I think gives you a really wonderful perspective on the Institute. So I'd like to start by asking you to go back in your mind to that teenage boy that you were, deciding where to go to college and what to study, and tell me about what attracted you to MIT in the first, place back in the 60s.

SHAPIRO: It actually goes back into the 1950s. I was in sixth grade when Sputnik went up in 1957. And there was a tremendous fear, I suppose, which I didn't feel as being a child, but certainly I think the rest of the country did, that the Soviets were becoming far ahead of us and there was a great enthusiasm for science and engineering. And I was good at that sort of stuff and I liked it, and so I became increasingly interested in pursuing a career. And I thought of engineering even though I had no close relatives who were engineers-- I didn't know what it was really like.

So I became interested in high school in amateur radio and ham radio. Not so much circuits-- I wasn't really enamored of that-- but I got interested in the hobby, and MIT was the place to be if you were going to be an electrical engineer. And it still is.

INTERVIEWER: What was it like when you came here? What were some of your first impressions, if you remember that, as a freshman?

SHAPIRO: It was a little scary living away from home. I was 16 when I was a freshman, which was not uncommon for students who had grown up in New York City because you got to skip eighth grade if you passed a certain test. And I was a young-looking 16, so it was an interesting thing being away from home with lots of other bright people. And I enjoyed it a lot.

INTERVIEWER: Did you immediately know that electrical engineering was going to be your field, or did you explore a little bit?

SHAPIRO: That was not as easy as it is now. When I was a freshman, you didn't get-- very few students got a lot of advanced placement credit. I placed out of a year of calculus, but most of my contemporaries, most of my friends in the freshman class had no advanced credit. We all took the same flavor of calculus, pretty much the same flavor of physics, the same flavor of chemistry. And on a rotating basis, every Friday morning at nine am there was a freshman quiz on top of Walker Memorial. So your life was driven by that clock-- this week is chemistry, next week it's physics, the next week it's calculus.

During my second semester of my freshman year, I said, well, I'm going to major-- MIT students choose their majors at the end of their freshman year ordinarily-- and see what electrical engineering is like. And so that's what I did, and I liked it. I didn't like the circuits as much as when I took courses in signals and systems, the stuff that underlies the theory of communication. And it was the theory of communication that I pursued when I went on into graduate school.

INTERVIEWER: Tell me why you decided to stay here for graduate school.

SHAPIRO: Well, I don't know how to explain that. First of all, I had no plan of going to graduate school. In fact, I think in my friends, sophomore friends, very few of us had any thought beyond, well, we're going to get a Bachelor's degree and we're going to go out and work in industry and launch a career. And I was doing so well at the end of my second, oh excuse me-- my first semester of sophomore year, my adviser urged me to apply and get into a 6.2 program. Electrical engineering. This was before it was electrical engineering and computer science. Electrical engineering had this program, 6.2, for students who were sufficiently strong that the department felt it was likely they should go on to graduate school, at least to get a Master's degree.

And although I was not fond of taking on extra work, it seemed like a good program. We had to take more required courses in all the regular undergraduate subjects, we had special recitation sections, and extra homework. But nonetheless I signed up for it, and that launched me on a path towards graduate school. And when I was in graduate school I became very excited about the prospects of doing research and went on and got my PhD, at which point, having been a teaching assistant, I thought it would be a great career to become a professor.

INTERVIEWER: What excited you about the research?

SHAPIRO: Oh, research is wonderful because when you're in the fourth week of a particular mainstream undergraduate subject you get your weekly problem set. And you can be certain that what you've just been hearing in recitation and lecture is probably the kind of material that's needed to address that problem set. And you can get into a kind of compartmentalized way of thinking. When you're doing research, first of all, there may not be an answer. And second of all, in addressing the problem you're working on, or even better, in defining the problem, which for doctoral students and faculty and leading researchers is almost more important than solving the problem, picking the right problem, you have to reach into your collection of knowledge and pick out the things that are relevant to address what it is you're trying to accomplish. And it's fun when you succeed. It really is. And of course, as a professor, it's really fun to see your students develop that capability.

INTERVIEWER: Tell me a little bit about-- I mean, having been here at MIT so long, can you tell me some things that for you define MIT?

SHAPIRO: That defines MIT. Well, there are certain core principle that MIT has that I regard extremely highly. We have a long-standing commitment two need-blind admissions, and a long-standing commitment to need-based financial aid. This is for undergraduates. It's a very special place to be able to do that. There are other schools that are using merit-based aid, and there's nothing wrong with that, but MIT has been an entryway, a ladder up for students who come from households where there had been no college education prior to their coming here, and launches them into a professional career. Unlike many universities where there's a separate college of engineering, a college of arts and sciences, a college of humanities and so forth, admission to MIT it to the Institute as a whole. On your application, you probably said something about what your interests are and what you might major in, and a significant number of freshman change their minds between when they enter and when they choose a major. But we are pretty much one place.

And it's a kind of strange and unusual place in a number of ways. You can major in the humanities here, but you get a Bachelor of science degree. You've taken two semesters of calculus, two semesters of physics, one of chemistry, one of biology, a laboratory course, and two restricted electives in science and technology. My daughter, who's now an attorney, went to Brandeis undergraduate-- and she has a Bachelor of arts degree-- and she had to take one math and one science course. My son, who has two degrees-- Bachelor's and Master's from MIT-- had to do all those things for the general Institute requirements, plus eight humanities and social science subjects. We do try to balance the science and technology here, perhaps more so than some other schools.

INTERVIEWER: Thinking over your time here, are there any big changes that stand out?

SHAPIRO: There have been lots of changes. When I was an undergraduate I typically went back to New York City for a summer job, and I'd come back and there'd be some parking lot that now was growing a building. That's what it was like in the 60s. So that's a change of the physical plan, which is continuing, of course, all over the place.

INTERVIEWER: Can I-- I just want to ask you a little bit more about the physical plan changes. That does seem very dramatic to me. I mean, is there a sense of it going more utilitarian to more architecturally interesting? Or do you have a--

SHAPIRO: We went through a real utilitarian period with these glass curtain wall buildings and these concrete and glass buildings. And then we got things like the Stata Center, which I find to be-- I don't have my office in the Stata Center, I know some people who are enamored of the way it's set up on the inside or that are not so happy-- but the architecture of the Stata Center I think is just fabulous. And the opportunities are provided, particularly to my department, by bringing the computer scientists onto the main campus and to provide those interconnections. And the faculty dining room, and the child care facility, and the student street, these are all wonderful additions to the Institute.

And of course, we have other signature architecture. In the 50s we built Kresge. And we built Baker House. And then we had a long time where we weren't building so much. Oh, I left out the chapel. The chapel is a beautiful Saarinen design. And then we have Simmons Hall, which is a signature building, I think, for the Institute. So we're getting more of that now.

INTERVIEWER: Before I interrupted you, you were talking about changes other than the physical, the physical plant.

SHAPIRO: Oh, there's been a tremendous change in the student population. When I was a freshman, I think my entering class was maybe 900 or over 900. There was something like 20 or 22 coeds, they were called. The women were called coeds. I don't know anyone who'd call an MIT woman a coed anymore. And now it's about 50/50 in the undergraduate student body. It's not quite as high, but it's still very significant in the graduate school. And of course, the ethnic diversity and the diversity of nations represented at MIT has grown tremendously.

And there are many other things that have changed. I told you a little bit about the rigidity of the freshman program when I was here. Now it's much more flexible, and there are many more things. Undergraduates are almost all engaged in research, some perhaps starting even their freshman year through the UROP Program. There was no UROP Program when I was a student in the 1960s.

There are many other things that are different. I pointed out that I came here expecting to go to school for four years and go out and work in industry as an engineer. I've been an undergraduate registration adviser now for a long time, and I ask my sophomores-- I get them as sophomores and I stay with them until they finish either their Bachelor's degree or in EECS, since a good many of our students stay on for a Master of engineering degree, I would stay with them as their adviser through that. And in getting to know them in that first semester that they were majoring in EECS, I asked them about their ambitions. And with the rarest exception, they all have something beyond getting a Bachelor's degree. They are going to go out and work a little bit and then get an MBA. They're going to get an MD degree. They're going to be a patent lawyer. They're going to get a PhD and be a faculty member. And that's quite different I think than when I was an undergraduate.

And of course, there's a great deal more entrepreneurial fervor I think even among the undergraduates than there was when I was a student. Certainly there were students who went through MIT and created companies, but there were not as many students who were looking to participate in these entrepreneurship competitions with the thought that if they got some seed funding, they might go out and create a company.

INTERVIEWER: That's very interesting. Do you think that's particular to MIT?

SHAPIRO: No, I think that's true elsewhere, as well.

INTERVIEWER: I was wondering if you have a sense of MIT's role in the world, and how you fit into that?

SHAPIRO: Me, personally?

INTERVIEWER: Yeah.

SHAPIRO: Oh, I don't know about that, but certainly MIT has a major role in the world. We are viewed repeatedly over many decades now has the leader in science and technology. In fact, there are many great schools in the United States, but the farther you get from the United States, the more people want to ally in these various countries with which we're building collaborative opportunities with MIT. We have advanced many fields. Certainly electrical engineering, certainly computer science, but molecular biology and many other branches of engineering and science have come from here.

And my personal role? Well, I'm a faculty member. I've taught some students who've become quite successful. I've taught some students who've gone on into the academy. I have created some courses. I've spent, though, a significant fraction of my senior faculty career in the administration. I spent nine and a half years as Associate Head of the EECS. EECS is the largest department here. And I've spent 10 and 1/2 years directing the research lab of electronics. So that's 20 years out of the 26 years that I've been a full professor.

INTERVIEWER: I wanted to go back a little bit and talk about just your upbringing. I think it's always interesting for people when they see somebody who's become a professor to see where does it come from, where does it start? And so is there anything before Sputnik?

SHAPIRO: Oh, I had all these building toys as a child. And some of them were these electricity kits with motors and switches and other things, and so I'd been playing with that as a little boy. And I liked that, and that led me to-- well, I was good in math and good in science in primary school, and it just went forward from there.

INTERVIEWER: And you grew up in New York City.

SHAPIRO: I grew up in New York City. I went to the Bronx High School of Science, one of the exam schools there.

INTERVIEWER: And brothers or sisters who were also--

SHAPIRO: No. It is interesting. I said I have no relatives who have been interested in science and math. My father did extremely well in math in high school, and he had to quit college to go to work. And of course, he was very lucky to get a job during the Depression with a major insurance company and to hold that throughout the Depression. And he stayed and spent his entire career there. So he might have gone on and done some other things had he the opportunity, but he never really had it. My brother was a history major and is an attorney, so it's very different.

And some of that lives on in my children. My son is a software engineer, and my daughter is an attorney. One has the math and science orientation, the other not.

INTERVIEWER: And were your parents pleased with your math ability and your choices to go into--

SHAPIRO: Sure. I think they were very happy about that.

INTERVIEWER: Do you feel that there are any values from your youth or memories from your youth that have sort of shaped the person that you became?

SHAPIRO: I don't know what to say there. There was always a deep commitment to education. For my brother, it was a different orientation, but still, the importance of education and learning and going forward and getting into a profession, that, I felt very strongly from my parents.

INTERVIEWER: What about outside events other than Sputnik? Do you remember anything from the 50s and 60s that might have persuaded you that engineering is a good path there to choose? It seems like a number of people I've interviewed have cited that time and Sputnik as being-- or getting the impression as a child that this was a really important field, worthwhile field to go into.

SHAPIRO: Yes. Well, I never became an aerospace engineer, but certainly when John Kennedy said, when I was in high school, that we would take a man to the moon and bring him back-- not a woman, mind you, but a man to the moon-- and bring him back safely in this decade, that was a great challenge. And that required all sorts of fields to participate. There was a lot of enthusiasm about that. People followed developments in manned spaceflight quite closely.

INTERVIEWER: Did you have any science or math teachers before college who encouraged you to--

SHAPIRO: I had, in high school, the opportunity to take a physics course. The Physical Science Study Committee, which was started by Jerrold Zacharias, here, from the physics department, really revolutionized the teaching of physics for my generation. And Charles Hellman was that the physics teacher that I had in my high school, he was quite inspirational to me. I found physics very interesting. We also had, that I get to take, a biology course, a similar thing. BSCS-- I can't break down the acronym anymore. That was very biochemistry oriented. I did well in it, but I didn't find it nearly as interesting as the physics work. And so I was launched towards engineering more, but physics basis of that was very exciting to me. And as it turns out, I do more physics work now than really electrical engineering.

INTERVIEWER: Did you have any especially influential teachers or classes or mentors as you went through your education at MIT?

SHAPIRO: Well, I certainly had great inspirational teachers. I had Amar Bose for Introductory Network Theory. He lectured that. And Amar Bose is an unbelievably talented instructor. I had Paul Gray for some of the semiconductor lectures. He, too, was-- he taught when he was the president of MIT and electrical engineering and computer science was having an unbelievable glut of enrollment and we needed all hands on deck. So he helped teach by I think teaching recitations in one of our large undergraduate circuits courses. And he got very high marks on the student evaluations in all categories but one: availability outside of class. After all, he was the president.

INTERVIEWER: You can't blame him.

SHAPIRO: No, you can't blame him.

INTERVIEWER: Interesting.

SHAPIRO: So I had some great teachers. And I did my Master's and doctoral theses for Bob Kennedy in the area of optical communication. And Bob was one of the early people to start research in that area in the mid-1960s. And he had a lot of great students, if you want to leave me off the list, and we did some very interesting stuff. And he gave us great mentoring and nurturing as we became from neophytes to people who could really carry on.

INTERVIEWER: So tell me what drew you into optical communications in particular.

SHAPIRO: It's a very interesting thing. I was looking for a research activity. I hadn't liked optics all that much in sophomore physics. I did well in it, but I wouldn't enjoy it as much. And I was looking-- I had a National Science Foundation Fellowship, I was in a new graduate student, and I went to orientation for new graduate students interested in communication related activities that the department held, and I went and talked to some faculty. And I want to talk to Bob Kennedy, and he said, well, you know, you have a fellowship. I've got some general areas of interest, but you should really find out if you like this stuff. We're giving a series of lectures on things that would lead into optical communication by some of us and you should go. So I went.

And one of the-- maybe two of the early lectures were given by his colleague Estil Hoverston. And Estil was talking about optics, about diffraction, things that I dan't liked all that much. But he was talking about them in terms of Fourier Theory, signals and systems, convolution, all the stuff that I loved from that of course that I had as an undergraduate, except now was in two dimensions-- in space instead of just in time. And thought of that way, which is not the way the sophomore physics course can teach it because you lack that mathematical background, I said, this is great stuff. And so I wanted to pursue that.

INTERVIEWER: What year is this that we're talking about?

SHAPIRO: 1967.

INTERVIEWER: Okay. And what were the big questions at the time, or challenges in optical communications?

SHAPIRO: Well, when the laser was invented, you got-- 1960, Ted Maiman--

INTERVIEWER: Yep.

SHAPIRO: There were pronouncements how it would revolutionize communication, because you can think of a communication link as having a carrier frequency which is modulated with the information you're trying to transmit. And the technology gets harder and harder the larger the fraction of that carrier frequency you want to use as bandwidth for communication. And so you just took the carry frequency of the microwave backbone, which is what AT&T, Ma Bell in those days, used to do long distance and say, all right, if we did this on the laser, we'd have so much more bandwidth, we could send so many telephone calls. No internet then. Telephone calls. And we could transmit everything practically on a single laser. But there was no good way to do that.

The microwave backbone went through the air. I think it doesn't take much contemplation to realize that sending a laser beam through the air suffers if there's a cloud in the way, or fog or rain or snow. But even in clear weather, there are problems. There are problems associated with refractive index turbulence. Stars, you know, don't twinkle outside the earth's atmosphere. That's due to this turbulence. And if you've ever seen the shimmering of things over a hot highway or looking out over a radiator in the wintertime into the outside world, that's also affects due to turbulence. And it can be a very severe impact on trying to do laser communications.

So if you're looking at things that needed to be done in the 1960s, we were thinking of going through the air and nobody knew enough about that. So that's what I started working on. In fact, the vast majority of optical communication is now carried in fiber, in glass fiber. And that didn't begin until around 1970 when Corning Glass made the breakthrough of getting the loss low enough that it became practical. And so I've not worked a lot on fiber communication, really only very peripherally.

But I've been interested in optical communications in the following sense: look at things that are truly fundamental. The text books that I studied communication theory in have a diagram. There's a source of information-- it's a block. And next to it is a block that's a transmitter, and the transmitter might have inside it an encoder for error correction and a modulator. And that connects to a block that's called the channel, which has some ill effects-- noise, distortions of various sorts. And then a receiver, which may have inside it the demodulator and the decoder, and then the information that's received gets delivered to the user at the other end. That block diagram of a single source to a single user is good at any frequency, any kind of-- it's good for me speaking to you right now. It's good if we think of spatial information if you're looking at me.

But if we think about sending bits-- let's make it digital-- and it's optics as supposed to a much lower frequency, with the exception of the single mode fiber that's used for long-haul communication, optical communication has two fundamental things that differ from the lower frequency world. There's an enormous number of spatial degrees of freedom. That's why you're able to see me clearly-- you have all those spatial degrees of freedom to form images. And the second thing is that light wave frequencies, like all electromagnetic waves are quantum mechanical, but at light waves we have detectors, and have long had detectors, that are sufficiently sensitive that the noises that limit your performance are actually quantum mechanical in origin. And so quantum effects become demonstrably important whether you model them explicitly that way or not. And so that's what I've been looking at principally, sort of spatial effects and quantum effects in optical communication and communication construed not just to be transmitting of bits, but formation of images, and remote sensing, and things of that nature.

INTERVIEWER: When you were starting out in electrical engineer, did you ever think you were going to end up in quantum communication?

SHAPIRO: I didn't think I would end up in that. In fact, when I was a doctoral student there were some students working for my supervisor on quantum issues-- I was working with several other people on these atmospheric issues-- and I didn't understand much about the quantum stuff at that time. Although I heard talks on this topic, I hadn't been following it closely. And when I came back to be a professor here in the early 1970s, and one of my contemporaries in graduate school came back here on the research ladder, he started to continue his work in the quantum area and pursued some new ideas that led him to a claim that with quantum techniques you could avoid all propagation loss. Well, diffraction loss, should we say, in vacuum. And this would have been a phenomenal-- I said would for reasons I'll get to-- a phenomenal achievement. So I said, I know a lot about diffractional loss in optical communication channels-- I have to understand what this is all about that you've been doing. So we started working together, and our first major paper proved that his idea didn't work. But we went on and did other great things after that.

INTERVIEWER: It's very interesting, it's just--

SHAPIRO: So let me just make one more statement. I learned a little bit about quantum mechanics in junior year physics here, but some of the stuff, the bedrock on which my work for the last 20, almost 30 years-- I would say 30 years in some cases-- his base was just getting published in original journals. Roy Glauber from Harvard was publishing his work on coherent states, for which he shared the Nobel Prize in physics a few years ago, when I was studying as an undergraduate. So it was not in the textbook that had been published a few years before. So like many of us, in fact, all engineers who stay in the professions, scientists, you have to keep learning.

INTERVIEWER: Yeah, right. You always have to stay right on the edge there. A little beyond the edge, I guess.

Tell me a little bit about your work in quantum communications. And I wonder if you could phrase it in the question that you're trying to solve, or the problem. the big overarching problem that you're working on there.

SHAPIRO: Well, there are several. Let me pick one and talk about that for a while. Before Claude Shannon published his famous 1948 work, *The Mathematical Theory of Communication.* people thought-- and the Bell labs, where he was at that time, is the place for communication work, both theory and hardware, shall we say, systems-- that noise prevented you from communicating reliably, perfectly. And of course, the early telephony was all analogue, and you'd go for a while in the signal would get weaker and noise would creep in and then you'd amplify it and filter it and send it out again. And it was clear that it would get to a limit where you couldn't communicate perfectly, and it was understood you could try to do some sort of digital communication, but then not enough was understood about whether you could get all the bits correct. Claude showed that there is at a capacity in a noisy channel such that if you're communicating at a rate below capacity and you code, you provide error correction, you put redundancy in, in a very appropriate manner, which he didn't show, he just proved that it could be done, you could get error probabilities as small as you would like. In your entire message, not just on individual bits.

And of course, that has been applied-- it took many years-- in many channels to the point that we now, for sort of classical world things, we can get very close to that capacity. And the capacities for certain basic optical communication channels were already understood when I started working on this topic in the quantum domain. They were understood if you said, if I use this kind of detector, I know, although it's quantum mechanics under the hood, that the statistical models for my noisy data are this. And there are three basic paradigms for photo detection, and they all have statistical models that don't explicitly show the quantum mechanics. So that was known. And people have worked out capacities, or at least bounds on the capacity.

But we start looking at this, and there have been some early work, but in about 2004 a group of us started looking at that and we knew from some general work in quantum information that there was a different theorem, not Shannon's theorem, you needed for the ultimate ability to transmit classical information over a channel that's governed by quantum mechanics. And that's the Holevo-Schumacher-Westmoreland Theorem. And so we obtained the first capacity theorem for a meaningful optical channel in about 2004. And not surprisingly, it's better than all the known techniques. And in some cases may have an interesting gap that you would like to bridge.

One of the basic things about going after fundamental limits on communication, going back to Shannon, is you know the ultimate limit is, then you look at what we know how to do, and if there's a substantial gap, you say, well, we should look to find out how to bridge that. So we're working on some of those bridging issues right now in some collaborative efforts.

INTERVIEWER: I wanted to ask you a little bit about your collaboration with Franco Wong. And not necessarily about the work, per se, but about how it works. Why do you have such a close collaboration with someone, and how does it actually-- is that common? And how does that work in your research?

SHAPIRO: For me, it's an absolute necessity. In the early 1980s, I was developing the theory of these things that are now called squeeze states. These are non-classical light beams. That's a technical sort of term. All those models I was talking about for photo detection systems that people have done capacity for, they're all based on treating light as a classical electromagnetic wave. And there are states of the electromagnetic wave-- quantum descriptions for electromagnetics-- that won't satisfy the assumptions that are made in those models, and so those things are said to be non-classical.

And my friend from graduate school, Horace Yuen, who was later a research scientist here, had been focusing on a particular class of these things, which appeared to have very interesting properties for communication or for position measurements. And we were trying to get some money to generate them experimentally. He's a theorist, I'm a theorist. You don't go and do major laser labs experiments without bona fide people who know how to do that sort of stuff.

So I had briefly a collaboration with a faculty member here, and then I hired a research staff member, Prem Kumar, who is now senior faculty at Northwestern University. So when he left, I knew I needed an experimenter in my group, and Franco came here in the mid-1980s and has been here ever since. He's now a senior research scientist. He's the lead experimentalist. I'm the lead theorist in the group that we have, which is called, well, quantum communication, quantum propagation and communication, something like that. I don't remember-- I should, I'm the director of the lab-- I should know my own group's name. Optical Propagation. I don't know.

In any case, he does experiments, I do theory. Sometimes the experiments are an outgrowth of theory, things that I've come up with. There's a new approach to make an optical communication link completely immune to what I call passive eavesdropping, somebody who's just listening to the light going around the link, that we're doing an experiment-- he's doing an experiment with that one of his postdocs on that. And there are other things which come more out of his end that he thinks about, this would be a really great thing for us to do, but how does it really work and what could be used for, that I work on those aspects.

INTERVIEWER: Why did you end up in theory rather than experimentation?

SHAPIRO: I don't know. I think in equations more than pictures. And I'm maybe not as good with my hands as I should be. Something like that.

INTERVIEWER: You ever dabble?

SHAPIRO: Only a little bit. I did do some of the photo detection measurements when we were doing atmosphere things trying to understand what would happen to laser light propagating in bad weather. So we had a transmit station up on top of the Green Building and we had a receiver station out on the Air Force research lab. I guess it was still the Air Force Cambridge Research Lab had a millimeter wave observatory on top of Prospect Hill in Waltham. And we found that space-- Bob Kennedy was still here on the faculty and we were in the same group-- we found some space there that they would let us have. It was in a little sort of aluminum shack up on a small tower, a rotatable room because they used it for some antenna testing. It was referred to as the doghouse. We were in the doghouse for a couple of years making measurements there.

So I was involved both with my students in putting together the equipment that we used for those measurements, and sometimes going out there and taking measurements. Which could be extremely frustrating because we wanted to get measurements in the lowest visibility weather that we had sensitivity for.

Because what happens is, you can think of light as just going in straight lines. If you want to think of light as comprised of photons, particles of light, being billiard ball-like things going in straight lines. What happens when there's bad weather is they scatter in a variety of directions, and you can have multiple scattering, scatter off many things in heavy fog and clouds. And so they're moving at the speed of light all the time, but if their path has become lengthened because of all this bouncing around the pulses get stretched and we wanted to measure that pulse stretching, and we wanted to measure the attenuation and other properties.

If there was nothing in the way, the light you see should just be arriving-- these were line of sight connections-- on a straight line. And so if you have the focal plane of a telescope it should be arriving right on axis. But if there's all this scattered, it can come in off axis. We wanted to measure that, too. And we discovered, unfortunately, that weather conditions are not stable around our sensitivity limit. We could have visibility that was pretty good and we didn't see anything interesting, and then briefly have it just around the point that we wanted to see and then it crashed to the point that you could see nothing. So I had fun sometimes driving on snow storms, get all the way up the hill, which was not easy to do, and then discovering that we couldn't see anything and then driving all the way back.

INTERVIEWER: Right. Just as it cleared up.

SHAPIRO: Just as it cleared up.

Oh, the other hands-on thing I did was as a graduate student. We were then trying to measure clear atmospheric effects, some of the doctoral students-- I was a Master's student. And so we had a helium neon laser, red laser, established up on the roof of the Museum of Science out by the tower under that steeple there. And we had a room that was lent to us in the Smithsonian Astrophysical Observatory behind Harvard Square-- we had telescopes put in that little room and so forth. And we were making photograph-- I was doing photographic measurements of what turbulence could do, and a doctoral student was doing interferometric measurements. And not that many people in the mid-60s had seen laser light. It was before laser pointers and other things.

And there were small telescopes and little domes on that roof, and I think the graduate students in astronomy would take their girlfriends up there and show them the stars. One night I was working there alone in that room and I had a very tightly helium neon beam focused. The spot was only about this big, a red spot on the back of the wall. And I had the lights on-- the lights off, excuse me, in that room because I was taking photographs and so forth. And this couple walked up on their way to the small dome at the end of the roof where I was, and somehow they looked toward MIT and that light was-- it wasn't dangerous. It was eye-safe at the source, really. It's weaker than laser pointers you can buy now. They walked into this exceedingly bright red light and they saw it, and then they moved two feet one way or the other and it was gone. And they were staring at it and they were saying, what is that? Have the Martians landed, and all that.

I came out of the room because they couldn't see me-- the lights were off-- and I explained who I was and what it was. And, please, would you leave so I can make my measurements?

So I did those experiments as a student and I did the other experiments as a faculty member, but I was mostly in the measurement end of things, not in developing lasers or getting them to do the complicated things we need for this quantum information work.

INTERVIEWER: So how do you day to day work with someone like Dr. Wong. Do you meet every morning?

SHAPIRO: No, we don't meet every morning. No, no. We stay in touch. We have group meetings with all our students maybe every other week. We have meetings whenever we feel we need them. And we typically have lunch at least a couple of times a week.

INTERVIEWER: Interesting. Tell me a little bit how an average day goes for you.

SHAPIRO: I don't know if I have an average day. I live about 25 miles from MIT, which is a long trip for many people here. We moved out there--

INTERVIEWER: Yeah. Most people seem to live--

SHAPIRO: Yeah, yeah. I know. You see, I'd been an assistant professor at Case-- it's in the Cleveland area-- and we had a beautiful house in Shaker Heights. And we had lots of furniture and a washer and a dryer and a two year old daughter when we moved here. And believe me, the comparable neighborhood to where I lived in Ohio would have been in Newton. And the price in Newton was two and a half times higher than what my house in Ohio was worth. So we looked in concentric circles and we landed up living in Sharon because that's where I have a cousin, it's a very nice community, it has an excellent school system. And we liked it there, and we still like it there. Although we're thinking that we may downsize. Our kids are grown and out of the house. We haven't decided because we have close friends there and we have our congregation there. I don't know. Haven't decided yet.

So I have a 25 mile drive. And I have lots and lots of meetings. I had that when I was associate head, I have that now, and I'm director of RLE. So I get up very early and I'm in here maybe by 6:15 in the morning. And that gives me at least a couple of hours to do email-- and I get over 100 day. And that's after the spam filtering. And catch up on some things.

And then I have meetings. I have meetings associated, regular meetings associated with running RLE. I have a senior staff meeting with my senior people, the assistant directors. I have ad hoc meetings with a variety of people. I have faculty who are coming to me with, I wouldn't say complaints, let's say needs. I care a lot about the young faculty. I think it's an important part of my job to help them succeed. I can't do their research for them. I can't teach their classes for them. But certainly in terms of the resources they need, if we can't get that for them, then we can try to help. And I say we because the department does this, as well, to provide them ways to find what they need. So I'm quite proud of the young people in RLE and what they've been able to accomplish. So I have meetings like that.

I have a number of committees that I sit on. I teach. Right now, my group consists of myself and Franco. Between the two of us we have four postdoctoral associates, 10 graduate students, and three undergraduates. So it's a substantial group. I try to meet with my research students once a week individually. I try to write papers with them. Sometimes I write my own papers. There's a lot of things that go.

I'm on a variety of things. I'm on the Extended Engineering Council. I'm on the Research Council. I'm on some Institute committees. I do some consulting for MIT Lincoln Laboratory. I couldn't tell you what a typical day is except to say that it's busy.

INTERVIEWER: It's full?

SHAPIRO: It's full.

INTERVIEWER: What time do you go home?

SHAPIRO: Lately around five.

INTERVIEWER: Oh, not too bad.

SHAPIRO: That's only about 11 hours on campus. And then there's homework sometimes. It is interesting, though, there is a benefit, if you're theorist, to having a long drive home. Because there's only so much algebra you can carry around in your head. And so when you're thinking about a problem-- and my wife hates me when I tell her this-- she says, you're driving and you're thinking about this. Who knows what's going to happen? I say, look, I've been up and down this route so many times for so many years, the DPW calls me up before they install a pothole.

Anyway, can only do so much algebra in your head. You have to think about a problem very clearly and formulate it in the most appropriate and efficient fashion, and then maybe you make some headway. So I've actually gotten some things done that way.

INTERVIEWER: That's very interesting. I wonder--

SHAPIRO: In fact, I had a meeting with one of my collaborators, a former student at Raytheon BBN out in Fresh Pond. And we spent the morning together and then I had to be on campus for a meeting. And so between Fresh Pond and getting to MIT I called him on his cell phone, I said, I've just proven the following result: you ought to write it down before I forget it.

INTERVIEWER: That's interesting. Some people will go jogging in the morning, and you have the 25 mile drive to--

SHAPIRO: I have the 25 mile drive.

INTERVIEWER: To sort it out.

Tell me a little bit-- talking about your work, you're a very clear explainer of things, which makes me feel like you're a very good, must be a very good teacher and take care to explain ideas to people. And I wonder if you can just tell me a little bit about your experience teaching and the importance of teaching in your career.

SHAPIRO: I think teaching is extremely important. It's important to me. It's something I care a great deal about. When I was associate head I didn't do any teaching because there was so much going on and I was trying to keep a research career going. I'd been advised by my predecessor in that position, and my predecessor in RLE, both of whom I consulted when I was offered that position. And they pointed out to me, at that young age that I was, 20-something years ago, that I ought to try to keep research going because if you're out of it for five years or so, it's very tough to get back in. And so you have to make time for something. And I missed teaching. It was something I don't relish giving up, didn't relish giving up.

And when I became RLE director, my first semester was the spring semester. And I was a little foolish-- I taught a class that time because I didn't realize that the spring semester was when the heaviest load of committees and administration fell. So I made a deal with the department that I'd only teach in the fall. So since then, I've taught in the fall either an undergraduate course doing recitations or, one time, sharing lectures, or teaching my graduate subject on an alternate year basis.

And MIT in general, I think, and certainly EECS care very deeply about classroom teaching. And it's one of the things I believe that distinguishes MIT EECS from the school's departments with whom we compete for the best faculty candidates and for the best graduate students. We have simultaneously a very large undergraduate program-- some of the other schools we compete with don't, some do-- but of those that have the large program, I think we're unique in the amount of faculty commitment to that program. And I don't mean lip service. I mean having top senior faculty, the best teachers teaching the lectures and faculty, by and large, teaching all the recitations. You're not taught by special instructors or by graduate students. You're taught by faculty. And that takes a lot of effort, and I think it's worthwhile. I think it's something unique about the MIT undergraduate experience. I believe it probably goes on in many other departments, I just don't know them well enough to say it with the same assurance.

INTERVIEWER: What's it like teaching undergraduates.

SHAPIRO: Well. undergraduates are different from graduate students because if you teach a required subject, you're apt to find some of them who are not interested in that subject, or even worse, saying, why do I need this for what I want to do? And you know, you've got to get over that. You've also got to get over the fact that not everybody learns things the same way. When you're teaching a graduate subject, frequently you have students who are keenly interested in what you're doing and will learn that material well and pour time into it, almost regardless of how good you are.

One of the things that I've found in teaching-- and I certainly tell my graduate students before they take a teaching assistant position for a term to get some experience that you may have gotten a high A in this course when you took it, or the equivalent if you took it elsewhere as an undergraduate student. That doesn't mean you shouldn't be studying it hard to teach it. Because you got that high A by understanding the material in a way that made sense to you. Now you have to be explaining it to students who may look at it in a different way, and you've got to unravel what's wrong with their thinking if it's leading them down the garden path and incorrect directions. And that's harder.

And then you have to learn all sorts of things. No one told me how to teach.

INTERVIEWER: I was going to ask you about that.

SHAPIRO: I don't think engineering faculty take any class, even the ones that we have now, the next generation. I started teaching by trying to emulate the faculty whom I thought were especially effective when I was in their classes. And eventually, you develop your own style, but it's still based to some degree on the people that I had. And I had a great many excellent faculty instructors.

INTERVIEWER: Are there some tactics that you find particularly effective? Or some things your tried and you were like, well, that was a flop?

SHAPIRO: Well, the worst thing I did was the term-- we had a program in quantum information as part of the Cambridge MIT Institute. And they didn't have a course that lined up with my graduate course, so we decided, between the MIT and the Cambridge people, that I would teach it in a way that made it accessible to the students there. Now, their semesters don't line up with ours, so they weren't going to have any students enrolled, but what we were going to do was use one of the video classrooms. And my class would be recorded and it would be sent over there and posted on web sites, and they could make use of it. Not really taking the class for credit, but asynchronously to learn the kind of material that was not covered, at least at that time, in their program.

And that put me in a room with white boards, only a few of them, and the big video screen. And I said, I can't teach from white boards and a video screen unless I make up slides, PowerPoint slides. And I taught with PowerPoint slides and little bits of the white board. And my handwriting is atrocious on a white board. I don't know if you've ever tried white boards versus chalk boards. White boards have almost no friction, and my writing, which is I think reasonably good on a blackboard, chalk board, doesn't look that good on a white board.

So the year after, two years after those videos were made, I taught the class again just for campus people. And I had the slides, and I had a classroom that had plenty of boards and the built-in projector. So I tried it with the slides and writing a lot of stuff down and teaching with the slides, and I decided I don't like teaching from slides. I know some faculty do and to developed ways to do it, and I took some advice from them that first term that I made the sides up. But I find you can go too fast, and you find students can rely on those things too much. I prefer to teach from-- well, it's old fashioned-- chalk and talk.

INTERVIEWER: So you chalk and talk and it unravels at a certain pace.

SHAPIRO: Well, if you're teaching theory stuff-- and you may want to have handouts. In fact, what I did was write lecture notes. I have lecture by lecture notes, something like 280 pages of single-spaced stuff for this course now. And I hand that out with copies of the slides that I don't use so the students have those materials to rely on. But I'd rather teach it from the board. So they have in print anything that I need graphed accurately, stuff that I couldn't draw accurately on the board. But I'd rather teach it that way.

Now, in other areas, I can see where if you're teaching circuits and you need to bring up the specs of something and show them circuit diagrams and other things, that you would need that either as handouts or have up on the board. And I taught recitations-- the last undergraduate subject I taught was our big undergraduate probability course, and the lecturer, who is really quite talented, he used slides and the chalk boards, too. And the combination worked very well, but he was very careful about what he put on the slides not to overwhelm the students by going too fast.

INTERVIEWER: What's surprised you most about teaching?

SHAPIRO: I'm not sure. Maybe how much I enjoyed it. Maybe how many strange questions you sometimes get from students.

INTERVIEWER: Such as? Any stick out in your mind?

SHAPIRO: I can't think of any. But the undergraduates can be very curious. You know, I think when I was an undergraduate, maybe we were more reticent, didn't ask as much. Faculty were more awe inspiring. I think this is something that maybe comes with UROP. Faculty are less out of touch with students. They work with undergraduates, and I think undergraduate advising has gotten closer. I mean, I see my undergraduate advisees at registration day and we have email conversations back and forth when they're trying to change their program for some reason. And I try to get them in to see me. And lately, I have I think about 18 undergraduate registration students, so my wife and I take them out to dinner every semester at Legal Sea Foods so they get to know each other. Thankfully, I have a discretionary fund that allows me to pay for that, because otherwise it's more than I would want to. But they get a good meal-- they'll come out for food-- and they get to know each other, and they get to know us, and I think it's really quite nice.

INTERVIEWER: Is there any particular moments that stand out from your teaching career as especially rewarding? Some moment, some student got something that he or she wasn't going to get? Or somebody changed their major to electrical engineering because of you? Or anything?

SHAPIRO: Well, I had one student whom I'm particularly proud of who took an undergraduate course from me, and he liked what was in there so he did his bachellor's thesis for me and won a thesis prize. And he did his Master's thesis for me, and his doctoral thesis for me. He started that way. And I had another soon, again, who got interested in research by working with me in UROP. And he did his theses with me, and he's out. And I'm still collaborating with him. He's now at the Jet Propulsion Laboratory. So some of these things continue. You get to see their entire development as a professional. It's really quite nice.

INTERVIEWER: Yeah. It must be wonderful to see the little chickens.

SHAPIRO: I was going to tell you a different story about a moment teaching I remember. I had been teaching the-- this was in the late 70s-- the large graduate course in stochastic processes. And at that time, the EECS department-- still has an annual spring party to which graduate student RAs and TAs and faculty are invited and we give out awards at that time. And I went almost every year, and my kids, even when they were little, came with us, and my wife, because the kids they ate the hors d'oeuvres. They liked that. They didn't care about anything else. So in those days, it was held at Endicott House, MIT's estate in Dedham. And now we can't hold it there. We invite more people, we're too big for that facility.

So we didn't go one year, even though I was in town, because my wife and daughter had been on a girl scout overnight weekend or something. And they came back, this thing starts at four o'clock in the afternoon at Endicott House. They get home about three in the afternoon. They're tired, they're dirty, they don't want to go anywhere. I said, all right, we won't go.

So I come to campus early-- in those days, not quite as early, maybe 7:30 in the morning-- the next day, and I meet someone, faculty, who said, we missed you at Endicott House. And I meet another person, we missed you. Three or four different faculty. I don't know what's going on. It's a big group there. So then one of my graduate students, one of my registration advisees comes in and presents me-- I'd won a Graduate Student Council teaching award.

INTERVIEWER: Oops.

SHAPIRO: So it was announced there, and I wasn't there.

INTERVIEWER: Oops.

SHAPIRO: I went home with my award and said, guess what? You should have taken the shower and come to Endicott House with us.

INTERVIEWER: Oh, dear.

SHAPIRO: Oh, dear.

INTERVIEWER: I guess it's the--

SHAPIRO: I still have it on my wall, you know, with a couple of other things.

INTERVIEWER: Tell me a little bit about UROP, too, which is one of the things that I find really wonderful about MIT.

SHAPIRO: UROP is a fabulous thing. Margaret MacVicar, late Margaret MacVicar created that. Research and teaching are indelibly intertwined at MIT. The mantra is, what we're doing in research now, we'll have in a graduate student course in a few years. And later, when we really understand it, we'll teach it to undergraduates. And that's really something to get the students to do something. It may be a little thing at first. And of course, in many cases, say, a freshman can come in and do something. Some have computer background enough to do some programming, but also, when I've worked with UROP students, I've always tried to have them learn something, even if they were doing something that was of some value for the research program that I was paying them from. I'd rather they learn something.

Long ago, I had a UROP-- I think it was during his freshman year, maybe first semester sophomore year-- and at that time we were trying to do a quick design for what we needed for one of these atmospheric optical things where we were going to measure propagation parameters. And I gave this student the idea of helping pick some of the parameter values. He went off and he had-- this is in the mid-1970s-- he had a calculator and he was doing the numbers. He came back to me and had all of his calculations. He wrote down all the numbers to eight decimal places, which I think turned out to be as many decimal places as this calculator had. And what he learned more-- he didn't I think learn much about optical communication, he went on and did other things for other people.

But we sat down, had this interesting discussion that the parameters I had been giving him to try to evaluate all had a sort of 10 percent precision, either because the electronic parts had that precision or that was the range, or maybe even less precise, that we knew some of these things. I said, what do you think about all these eight decimal places? So maybe he learned that you shouldn't respect everything that comes out of a calculator, I learned something about thinking about what stuff means. And it was useful, it was useful to him.

INTERVIEWER: The UROP students, do you often have students come from completely different areas such as humanities or something like that?

SHAPIRO: I have never had a humanity student do UROP for me. I've had students mostly from the EE side of EECS, and I think occasionally one or two physics students. I've had some physics doctoral students.

INTERVIEWER: I was wondering if you've ever thought of doing something completely different, if you had ever had a moment early on in your career-- is there any alternate career you would have or might have chosen, or ever think about having chosen?

SHAPIRO: I don't know. Let's see. I got propelled into graduate school, as I described, and I was looking for jobs. I was on the verge of finishing my doctorate in the 1969/1970 time-frame, and I was looking for jobs in a variety of places. We had, in the group where I was doing my graduate work, support from NASA. NASA had the Electronics Research Center in Cambridge here. And I knew the key technical person there because he'd interacted a good deal with my thesis supervisor about perhaps working for them, and I was applying for faculty positions in a variety of places. And that was a very bad time economically. The Vietnam War was still raging, and we had been-- what is it they say in the economics textbooks? You can't have guns and butter? But The United States economy was trying to have guns and butter, and it turned out the basic economics books were right-- you can't do that for any protracted period of time.

And there came a point at which jobs were disappearing faster than I could apply for them. I was newly married. My wife's family's is from New York. I'm from New York. So we had been back over the Christmas break visiting family and friends, and we were I think probably eating Kentucky Fried Chicken or something in front of our little black and white TV set in our first apartment in Arlington watching the news, and they were announcing that the Electronics Research Center was being closed. I had an informal job offer to work there, and I said, well, that's not good.

I got a faculty offer from Case Western Reserve University in Cleveland to be a member of their EE department. EE applied physics, I guess it was called. And I did take that. And I got there-- I actually finished my PhD about a semester earlier than I thought I would. So I showed up there in February of 1970, and my department head was happy to see me. And he said, it's a really good thing you finished early. I said, why? He said, the dean came by the other day to say that they were taking the slot away.

INTERVIEWER: Wow. That was a tough time, huh?

SHAPIRO: That was a tough time. I'm not sure that it's true, but the rumor, or the story is that-- of course, the aerospace bust hit Seattle very hard with Boeing and so forth-- that somebody paid for a billboard that said, will the last one leaving Seattle please turn out the lights? I don't know if that's true. But I do know because of the societies that I'm a member of, I get something called *Physics Today,* the general interest journal of the American Institute of Physics. And they had letters to the editor in the early 1970s from people like high energy physics PhDs who were driving taxi cabs. They couldn't get jobs. It was a very bad time.

INTERVIEWER: Wow. Wow, I never thought it got that bad for engineers.

SHAPIRO: I was glad to be at Case. And after I had been there a few years, I got contacted by my thesis supervisor, Bob Kennedy, who said there was a slot coming up in EECS for somebody working in optical communication. And he been writing to several people he knew to interest them in applying, and I applied, and that's the job I got. So I came back here.

INTERVIEWER: Did you ever think at that time, like, oh no, I should've-- I mean, I don't know what would be more practical than electrical engineering-- were there other fields? Did you just think, well, I just need to ride out this storm, or maybe I should have done something else?

SHAPIRO: Well, I liked the faculty position. I came here, and of course, I came as a junior faculty member. And you have-- I know the general populace men have their midlife crises when they're 40 or something, whatever it is, 45. Young faculty have it when they're coming up for tenure. However good you are, you always think in the back of your mind, am I going to get tenure or not? So when I was coming up for tenure, I said, well, if I don't get tenure, where am I going to go? Should I go to industry? Should I go to another university? As it turned out, I got tenure, so I didn't have to push on that very hard.

INTERVIEWER: Right. Did you have a thought in your head about what you might do?

SHAPIRO: Some thought that I might go into industry. I'd actually talked a little to some people. Of course, it would have been a big move because some of the people that I was interested in working with were in California, and all our family was on the east coast.

INTERVIEWER: And is your wife also in--

SHAPIRO: No, my wife has been sort of a professional volunteer. She has done-- well, she was able to be home with our children when they were very small. And then she's been in many volunteer capacities. She served two two-year terms as chair of MIT's Women's League. And she started a variety of activities here and was very active, and she's been very active in our synagogue and other places.

Her family was very big on scouting. She was a brownie and a girl scout leader for our daughter. And then when our son got to be-- I was never a scout, mind you-- when our son got to be cub scout age, she said-- actually we started with something called tiger cubs, which was new. Which didn't exist when I was a child. Pre-cub Scout. So we did that together. That was easy. And then we became-- she got me to be a cub scout leader. She said, you be the den leader, I'll be the assistant leader, but I'll do all the work. And she said, besides, these little boys won't know they're doing girl scout crafts, anyway. Oops. Now my son will see this and he will find out the truth.

In any event, in those days, women were not allowed to be boy scout leaders. And my brother-in-law, my wife's brother was a big time scout-- eagle Scout, scout master, everything-- and he has only daughters. My son is his favorite nephew, and he wanted his nephew to be an eagle scout. So I became a boy scout leader.

Now, I had never gone camping, really. I went to overnight camp as a boy, and on a nice night in July or August we'd make bed rolls and we'd go out and camp. I figured that's what boy scouts might do, too, but no, the troop that I was in, I became assistant scout master. And I took scout leader training, advance leader training, and these things. And I was acting scout master in scout camp for a couple of years for our troop. We camped all year around.

It was really something. I consult for MIT Lincoln Laboratory, and when I was taking the first part, the practicum part of advanced leader training, I had to be down in Plymouth. You know where Lincoln Laboratory is out at Hanscom Field in Lexington. I had to be down at scout camp in Plymouth by 6 o'clock at night or something, and I'm working Fridays at Lincoln in those days. And I have to be down to scout camp in my class A's-- you know what that means. That means the knee socks, the short pants, the scout shirt, the red jacket and the scout hat. So I would change in the men's at Lincoln and then go out to my car. And some of the other members of the group would laugh.

INTERVIEWER: That's very funny.

SHAPIRO: I didn't think so at the time.

So anyway, my son is an eagle scout. We went through Order of Arrow ordeal together and other such things, and we had a lot of fun. A lot of fun from that.

INTERVIEWER: That's interesting. Wow, that's a whole-- that was a huge part of your life.

SHAPIRO: I spent a lot of time doing that. I spent six weeks of summer vacation being a scout leader in scout camp over six years.

INTERVIEWER: Well at least you got to hone all those experimental skills. You don't get to use it.

SHAPIRO: You mean knot tying?

INTERVIEWER: Knot tying. Fire making.

SHAPIRO: Well, you get leadership skills. And some of those are good, I think, rather generally.

INTERVIEWER: Now, did you encourage your children to go into science?

SHAPIRO: No. I decided they should go into what interested them, and we would nurture their interests. Our daughter is an attorney. I think she had an attorney written all over her early on.

INTERVIEWER: How so?

SHAPIRO: Well, first of all, she writes extremely well. And she speaks extremely well. And she argues for her point. So she's been great at that. And our son was fascinated by numbers. When he was still in a little stroller, his maternal grandmother had him while his mom was off shopping for something. And she was walking him through I guess a card store, and he saw the-- you know the birthday cards with the numbers on them? He was reaching out-- I have to have these. He wasn't expressing himself that way. And you know grandmas can't resist, so she bought him a collection of birthday cards with different numbers. He played with them. He loved numbers. And of course, when I got my first computer at home, he took to that immediately. More so than his sister did.

And in fact, I was out of town-- he has a wonderful sense of humor. He had it from childhood. He still has it. When I was out of town one day and she had to finish a report for high school English, or maybe junior high school English-- this was the old dot matrix printers. Make horrible noise and they'd jam. She jammed the printer. Or, the printer jammed. Nothing she did had jammed it. And she didn't know what to do, and the computer and the printer were fairly new. And in those days, these were relatively expensive items. And I was out of town, no one knew how to reach me, and the report was due the next day. And he said, I'll fix it. So he--

INTERVIEWER: And how old is he?

SHAPIRO: Eight or nine. He popped the top off, he flipped this out, he did this other thing, and he got the paper going again. And had it all going, and he didn't-- there's a little plastic piece that sits on the top that-- it just helps the paper move smoothly. It doesn't affect the printing particularly. He didn't put it back on. So the printer is printing and his mom is happy and his sister is happy. Then he says to his mom, but what do I do with this? And he holds up this piece, and she almost had apoplexy. And then he smiled and he said, okay, I'll put it on.

INTERVIEWER: That's so funny.

SHAPIRO: She didn't think so at the time.

INTERVIEWER: So he went into--

SHAPIRO: He came here.

INTERVIEWER: Oh, really?

SHAPIRO: He was here when I was associate department head. And he had faculty who taught him whom I hired. In fact, when he entered the department as a sophomore in the fall of 1994, the recitation instructor in the circuits course he had somebody I had just hired from the EE faculty search the year before. He didn't know David was my son. He does now, but that's many years later. Because Shapiro is not that uncommon a name, and he looks like his mother's family and so forth. So there were a few people who knew, and if anyone asked, we wouldn't hide it, but we didn't bother.

INTERVIEWER: wow. And what is he?

SHAPIRO: He's a software engineer. He never took any class from me because I wasn't teaching when I was associate head. And the things that I would have taught, he wouldn't have taken. But he took probability theory from the same faculty member who taught me, and that wasn't unusual. This man taught that course superbly for-- he's sadly deceased now, this is Al Drake-- he taught that course for 20-plus years. Maybe close to 30 years.

INTERVIEWER: Wow. That's pretty neat.

SHAPIRO: That's pretty neat.

INTERVIEWER: Do you-- and I don't know if this is advice you gave to your son or that you give to undergraduates or anybody else-- how do you have a successful career in science? Because I feel like it's not just getting a PhD from the best institution. It's not just being the smartest people. There's a lot of different factors that go into it.

SHAPIRO: Well, one thing I want students to think about, my undergraduates, is they should have a short-term goal. I think they all have that. That's their getting their Bachelor's degree. But they should already have some mid-term goal beyond that. I mean, are they thinking to get a Master's degree here or go out to industry or do something like that? And maybe have on a softer basis, less degree of commitment, a long time goal. Some come in saying, I'm going to be a faculty member. Some come in and say, I'm going to get my medical degree and do medical research. And others are less clear about what they want to do.

A while ago, a lot of them wanted to go into finance. Maybe the plug got pulled on that a little bit with what's happened lately, but some of them did. One of my doctoral students went on in that area. And I said to him first, you know, you're really doing great stuff here. Why are you going on in finance? He said, I use all the same mathematical tools-- all the estimation theory, the random process theory, and stuff that I learned from working with you and from the classes, I can apply here. And I think he's done well.

INTERVIEWER: Any other advice you give people?

SHAPIRO: Well, with respect to the doctorate-- and I do this with students as they're getting up particularly into their senior year-- I tell them, you really have to want it. Not because your parents want you to have it. Not because he didn't get the dream job and therefore you're going to go on to your doctorate and hope that you get your dream job at the end of that. Not because your girlfriend/boyfriend is going to be around in the Boston area, so you might as well hang around, too.

You have to have the fire in the belly to do this. Because if you're going to be an experimentalist, sad to say, you're going to be up all night a bunch of times. Because it takes maybe half day to get the stuff aligned and going, and then another half day to get those measurements. And you have to have a real commitment. If you're going to be a theorist, you're going to wake up in the middle of the night thinking about whatever it is and get up early in the morning and be frustrated that things aren't going the way you expect. So it's hard work, and you have to want to do it. And in fact, it's extremely rewarding, but it's not for everybody.

So I would like to see them have some plans of where they want to go. I want to see them use their four years here in the undergraduate program to establish a foundation on which they can build a career. And you know, I think of a career as different than a job. I find myself extremely lucky because I get up very early in the morning, but I'm happy to get here. And one of the things I've cared about in the headquarters in which I've worked is that the administrative staff members who work here, and they were pretty hard, many of them-- all of them, pretty much, at least some of the time. I hate it when you have to go, oh, another day-- I can't stand it anymore.

The Research Laboratory of Electronics, which I've been a member of starting from when I was a graduate student and during my entire time as a faculty member-- and I still have a very active research program, so I see it both as director and as a rank and file faculty principal investigator-- he has had a very strong headquarters in terms of supporting the faculty research staff and students who are in the laboratory in helping them get their things done.

INTERVIEWER: So describe-- how would you describe RLE?

SHAPIRO: Well, I always go back to the history a little bit. RLE was created immediately after World War II to carry on some of the work that was done in the radiation laboratory. In I think starting in 1944, it was already becoming clear, although the war was far from over, that the radiation laboratory was extremely successful in this government/university partnership in advancing research in radar and electronics. And so keep people like the head of the physics department, the head of RLE the dean of science and so forth-- not RLE at that time, the Rad Lab, excuse me-- wanted to see this sort of activity continue.

So the Radiation Laboratory was disbanded 31 December, 1945. On the first of January, 1946, something called the Basic Research Division was created with some of the space and some of the equipment that came over from the Radiation Lab. By I think September of that year, it was renamed the Research Laboratory of Electronics and incorporated into being a larger entity.

This was so long ago, the charter for RLE says, among other things, to train a cadre of young men in fields such as electronics and so forth. No women, just men. Well, we've gotten over that. Big time. And the other thing was that it was supported by an umbrella contract from the Army, the Navy, and the Army Air Corps. We hadn't even created the Air Force at that time.

Now, by the point that I became a junior faculty member, that original umbrella contract had morphed into something known as the Joint Services Electronics Program, and it was only a small fraction of the funding of the laboratory. And JSEP, as it was known by its acronym, completely disappeared by the middle of the 1990s. So RLE has been a very entrepreneurial place in terms of faculty finding the support to do what they want to do.

And we do some things that are very fundamental, and some things that are applied, and we do everything in between. Now, it is had some incredible directors. We'll leave me off that list for the time being. Two of its directors, the founding director was Julius Stratton, who went on to become president of MIT. Its second director was Albert Hill, who went on to be the director of Lincoln Laboratory and was later, I think, chairman of the corporation of the Draper Laboratory. And it's third directive was Jerry Wiesner, who went on to be presidential science adviser for Kennedy and president of MIT. So it's very exclusive company that I'm part of.

And those early directors broadened out the agenda of the laboratory. We are the oldest interdisciplinary laboratory at MIT. And we are the second biggest. We have 60-plus faculty, hundreds of students representing electrical engineering, computer science in terms of the faculty. Physics, material science and engineering, mechanical engineering, mathematics, nuclear science and engineering, biological engineering, the engineering systems division, health sciences and technology. It's a broad spectrum of work that goes on.

INTERVIEWER: It seems to me to be one of the most interdisciplinary labs here at MIT.

SHAPIRO: I would argue it is the most intellectually diverse of the laboratories at MIT.

INTERVIEWER: So what is it like managing--

SHAPIRO: Oh, really?

INTERVIEWER: Attempting to manage, administrate so many different types of researchers and engineers, all those different cultures?

SHAPIRO: You don't really manage it. Different laboratories at MIT have different cultures. Different departments have different cultures. MIT, in my view, is all about excellence. These departments, labs, and centers-- I think we have about 100-plus of them-- have disparate sizes, styles, and cultures. And what works in one place won't work in another. RLE has a collection now of research themes, is how I like to think about it. Within the themes, there are different research groups. Within research groups, there may be only one or two faculty, or maybe five or six-- it depends. And they interact in a variety of ways. There are certainly a significant number of individual investigative research programs-- one faculty PI with his students-- but there are increasingly these multidisciplinary activities.

The defense community has these multidisciplinary university research initiatives. Myriad topics that come out every year, and we've been quite successful in winning them. And sometimes we've had them, and I've led several, that involve researchers from different universities. And sometimes we've had them entirely within RLE. We had one in RLE-- it's now over-- on alll-optical clocks that involved world leaders in atomic physics, world leaders in ultra fast optics, world leaders in molecular beam epitaxy growth. World leader in optical frequency division technology. World leader in hollow core fibers for special applications. All these people in RLE, they came from EECS, physics, material science and engineering, and an RLE research staff member. We can do that entirely within the laboratory.

INTERVIEWER: So what he see as your key role as the leader of RLE?

SHAPIRO: I have several. I have the role of trying to help the young people get started and succeed. And part of that is helping get young people here. I've served on the EECS faculty search committee for years as RLE director. So I'm involved in helping select people, and those that belong, or should belong to RLE, I get them situated in space and try to provide them with as much of the initial startup as I can in conjunction with what comes from the department and the School of Engineering. And provide them with some advice and some guidance as they're coming up the junior faculty ladder.

I also work with the senior faculty in helping them find the resources they need. And the key resource that many of them need is space. I like to joke with people that Gene Roddenberry said it all: space is the final frontier around MIT. And for a lab director like me that's a big deal, because we're running out of space with the cadre of young people that have come on board, and with new research that they've grown plus existing programs. We've done a hell of a lot of renovations at great expense to the Institute in part and to RLE. We've, of course, shared heavily on them and in some cases departments have contributed to make things possible.

So what I have done in terms of, I wouldn't call it managing so much as stimulating research, is I have three associate directors right now in RLE. And they don't have in my administration a lot of line responsibility. They sit on some key committees and I consult with them on major policy issues that I need faculty input on. But each one of them has been a major person in putting together large efforts within their own research themes. RLE has seven research themes, to give you a flavor for how broad we are, and it's a challenge to me to try to name them correctly.

So we have atomic physics, and Wolfgang Ketterle from physics, who shared the Nobel Prize for his work on Bose-Einstein condensation, is associate director of RLE and also the leader of our Center for Ultracold Atoms, this big NSF physics frontier center that is joint with Harvard. And we have work in them multiscale, bio engineering, and biophysics. We have things that are down at bio, micro, electrical, mechanical systems working at the molecular level, working at the cellular level, all the way up to people who are doing magnetic resonance imaging-- both the technology and the applications of that. People who are doing molecular dynamics. And wet lab experiments to figure out things that might be causing Alzheimer's disease. Lots of things in between. We have neuro technology that may lead to techniques for neural regeneration. Lots of great things going on in that area.

INTERVIEWER: So are there any areas that RLE doesn't touch?

SHAPIRO: Oh, I'm sure there are areas that we don't touch. We're not CSAIL, the Computer Science and Artificial Intelligence Lab, although we have cooperation with some of the activities there. There are things that they do that we don't do in many ways. There are things that go on all over the Institute that we're not involved with. But we are very broad. We have worked in the energy area. We have energy power electromagnetics, including a large ARPA-E program on wide band gap power electronics.

We have-- one of the fun programs one of our faculty has, he likes to speak of as "no watt left behind," to promote energy efficiency in a variety of ways within homes and elsewhere. We have work in photonic materials, devices, and systems that range from growing materials to subsystems that may combine optical processing and electronic processing on single chips that will be produced by major chip manufacturers. There are really very interesting things going on.

We have the work that I'm involved with in quantum communication and quantum computation. I was saying that the associate directors and myself have been sort of research rainmakers a little bit. Because I'm director, I've hidden myself as co-director or co-principle investigator, but I've primed some other people. Seth Lloyd, for example, is the director of our W.M. Keck Foundation Center for Extreme Quantum Information Theory. And Isaac Chuang is the director of our Interdisciplinary Quantum Information Science and Engineering Program. That's an NSF IGERT program. IGERT stands for-- let's see if I get this right-- Interdisciplinary Graduate Education and Research Trainingship program. It's a premier program out of NSF and it's aimed at, for our case, at creating the first education to employment pathway in this field, which spans a number of different departments. And maybe someday downstream it will become an interdisciplinary doctoral program at MIT, but it's too soon to tell.

INTERVIEWER: Now, you mentioned earlier that you'd been in administration here for about--

SHAPIRO: 20 years.

INTERVIEWER: 20 years. And did you ever imagine when you started out that that was going to be a path for you? And obviously you must find it rewarding. Can you tell me just what led you into it and what you enjoy about it?

SHAPIRO: Well, let us say the following happened: in 1989, Joel Moses was stepping down as head of EECS, and the search committee reported to the dean, and the dean did his dean thing and Paul Penfield was named as the next department head. Now, EECS had for a number of years before that an associate head from the EE side of the department and the associate head for the CS side of the department because the team of three is really necessary to do the kind of work on administration for this department.

So Paul offered me the position as associate head. I had never had any administrative experience. I didn't know whether I was going to be good at it. I didn't know whether I would like it. I was scared about it. So I went to talk to the outgoing associate head, who had known me well during my junior faculty career. And I went to talk to the director of RLE, who knew my research career quite well, and he knew about administration from his work in the laboratory. And they gave me some advice, but they didn't tell me, take it or not take it. You know, that was left for me. And I went home and I agonized with my wife about it for a while, and I said yes, ultimately.

INTERVIEWER: Were you scared because you were worried you might be bad it, or scared that it might derail your research career?

SHAPIRO: A little of both. Because if you get out of research, it's very tough to get back in. And the other thing is I didn't know whether I'd be good at it, and you want to be good at everything you do. So it turned out that in those days, these appointments were not term appointments. I got a letter appointing me as associate head and it said nothing else. Now these appointments are all term appointments. So nine and a half years passed very quickly. I discovered, I think, that I was good at it. And I had a lot of things that I was very happy about, things that in terms of the faculty who were hired out of searches I ran, faculty whose promotion and tenure cases I managed and ran, research things that I managed to help with-- and most of this is done behind the scenes. You don't get to promote yourself by saying, I got you this, or, you won that award because I did the nomination. But there were these things that I felt good about, and felt good about the way the department was continuing its pathway of excellence, in part because of what I was doing.

So I came in with something like 10 or 11 doctoral students when I started that job. And all of them finished before the nine and a half years was up. That would be a really long doctoral program. And I had some new students, but my amount of research had shrunk. And so when I got out, I actually join the Laboratory for Information and Decision Systems. I retained my RLE affiliation because that's where my experimental optics work was, and I wanted to build up some other type activity that it really dwindled. And LIDS was the good place to do that.

The new director of LIDS was Vincent Chan, who's a longtime friend of mine whom I had helped recruit to the campus from Lincoln Laboratory. And we did get some joint programs together. But that put me-- LIDS is now in the Stata Center, but at that time, it was in Building 35, which, if you know the campus, is at the Mass Ave, Vassar Street corner. And so I was running back and forth, and Franco Wong who had been my staff member by that point probably about 12 years, running back and forth between Building 35 and Building 36 because whatever we wanted to do, we were always in the wrong building to talk about it.

But I did build my research up. I got a MURI program. I took a sabbatical. And instead of really going one place for a semester, I traveled to a variety of places and landed up building up the collaboration that led to this successful proposal that began ramping up my research. And there were some other programs that I managed to launch. And then, sadly, John Allen died. He had been director of RLE for a long time, for 18 years, and done, I think, an excellent job. And at that time, I was chair-elect of the faculty, and I had been convinced that that was a job that I could do and I would enjoy. I had served on the faculty policy committee, which is the committee that the chair chairs. And I knew Larry Bacow well from some previous committee, and he'd been chair of the faculty when I was on the Faculty Policy Committee, and he was now chancellor. And I knew other faculty chairs and I talked to them. I said, all right, I'll do that. And then John died and I got offered the position of lab director.

And so I may be unique. I could be the only person who was chair elect of the faculty and never the chair. Because I resigned that position and created a little consternation for the Committee on Nominations because I decided after talking with the vice president and thinking hard about it that it was more important for me to be-- and more important to the laboratory-- for me to be the director than to be chair of the faculty.

But when I became director, I did have a term appointment. I had a five year appointment. And I was able to keep teaching, as I told you earlier, just one semester a year, and actually to have more research than I ever had when I was in the department administration. Because I think truth be told, it is less time consuming to be the director of the lab, or at least RLE, than it was to be associate department head.

INTERVIEWER: Why?

SHAPIRO: It just seems that way.

INTERVIEWER: Maybe you're just better at it. Maybe you're just more--

SHAPIRO: No, I think there are many more meetings you land up going to as a department head, and many more things that you are responsible for. And it could be different in different laboratories. In RLE, it's far too broad and diverse for me to be a rainmaker, to be the fund raiser for the entire laboratory. I'm happy that I've been able to stimulate and bring in some substantial programs in my research theme. And the other associate directors and other leaders outside of the associate director list have done that in other areas, but I could never pretend that I could handle that in all these fields.

INTERVIEWER: Have there been any surprises for you since taking over RLE? Has there been something that you thought would be easy that was hard, or something are that you thought was hard is easy? It sound like it's been kind of a perfect scenario for you. You get to do your research, you get to teach, all the--

SHAPIRO: Sometimes you don't get to sleep. That term that I was teaching in the spring, I wasn't getting very much sleep because there was just too much going on. There's always something that's happening in the laboratory, and there's always something that's happening in your research. So I don't know that I want to say there were major surprises.

INTERVIEWER: How do you now-- I mean, with all of the things on your plate, it must be hard to choose what to work on. I mean, that must be the sort of hardest decision you have to make on a yearly planning basis. I mean, how do you decide what to work on or what you want to teach and what research you want to pursue?

SHAPIRO: Well, I know every other year I want to teach my graduate subject. That is an alternate year subject. And in fact, what I'm hoping to do is to turn the notes from that class into a text for that area. In fact, I had started on a textbook in the late 1980s on optical communications, and I had a very ambitious plan for that. I was going to write up the basic stuff, which I had been teaching for years, and then I had on an alternate year basis been teaching an advanced topic subject where I covered this quantum stuff, but also laser radar and sometimes even fiber communication. And I wanted to write a sort of two volume set that would cover all of this. And then I became associate head and I never went back to it. And now I don't know that I want to write that book so much is just this quantum book. So I'm hoping to find time to do that in the future.

Anyway, long term, very long term plans are tough to make. There are a variety of things you know you're going to have to deal with. And I have a number of semi-facetious things I like to tell people. I've said a number of times-- I said this one to Susan Hockfield on a community we were both on and she kind of liked it, so if the president liked it, that's okay-- I am perpetually investigating the very fine line between just in time and not in time. So there's somethings that are deadline driven. And there's just no-- and that's true in research, especially for the experimentalists in our group. The night before the conference submission is due, some of the final data is being taken. That's almost inevitable.

In any case, I do write out to-do lists. And they're tough to keep track of. I write them out, and the act of writing them out is worthwhile. And I do get to cross things off from time to time, but there are many days in which more things enter to go on to the do list than I am able to get off the to-do list. And some things you just don't quite have enough time on and get pushed to the back.

INTERVIEWER: Is there something that always ends up getting pushed to the back?

SHAPIRO: My writing a book has been pushed to the back for a long time. I did get the lecture notes done, but that was a lot of extra time. I did-- there were 23, 24 lectures of notes. And one term I decided I had to have notes written for that, and I did them. For a while, I was sort of two lectures ahead at the start of the term, then I was one lecture ahead, then it was the night before, and then I just ran out of time, and the last three or four lectures got done the next time I taught the course.

Because I don't want to push back things that are really going to impact my graduate students. The fact that the course students didn't get to see readable notes-- they had references to go look up and they had the lectures and the problem sets, so I didn't feel they were being shortchanged as much. But the administrative matters you have to give very, very high priority to. You've got to answer your email all the time. Weekends, too. Nights and whatnot.

In fact, the only time I'm really off email for a protracted period of time is we take a vacation. We go to Maui in January for a little over a week. I've given up skiing. In fact, given my commute, I'd just as soon it didn't snow except on the ski hills and in the fields and so forth. Stay off the roads. It hasn't figured out how to do that yet. So we go and I don't read email for a week, and I have about 1,000 when I get back.

INTERVIEWER: Oh my god. Wow.

SHAPIRO: But it's worthwhile because it's very relaxing. You know, it's not like going to someplace where you have to tour the great churches and museums-- you can just relax. Rewind. Recharge.

INTERVIEWER: Have you ever failed at anything in your career and learned something from it? Or have you ever had any moments of professional crisis? And it's okay if you haven't.

SHAPIRO: I don't know that I have one professional crisis. There were things that I missed out on. You could call a failure of sorts-- we had done theory going back to work I did with Horace Yuen on these squeeze states. No one had ever generated them. We had ideas of how to generate them. In fact, Horace and I published an early paper on how to do that. He published some initial results, and then later we published a paper on what turned out to be the first way that the people did this. We did a somewhat simplified theory-- there was more detailed theory-- and so when I got experimentalists involved and staff members involved, we were working on that experiment, and the experiment was being worked at also at IBM in a different system, and at Bell Labs in a system somewhat related to what we were doing. And we weren't the first. Bell Labs was first.

And then a guy at Caltech got really superb results. And we did get results, but we were behind there. It's a little bit annoying that we didn't do as well.

INTERVIEWER: Deflating?

SHAPIRO: Deflating. But nonetheless. And the other thing was-- and I don't know where I was at the time-- there was a meeting at MIT's Endicott House that was convened on physics of computation. And I'm pretty sure I was invited to that, and I must have been traveling. Something else came up, I couldn't go. And that would have been my opportunity to meet Richard Feynman and hear him talk about using quantum mechanics to do computation. So I'm sad I missed that opportunity.

INTERVIEWER: Did you ever see him at another time?

SHAPIRO: I never saw him, no. I missed Norbert Wiener, you know, MIT's math prodigy. He was I think on sabbatical my freshman year and died the year. He was on the sabbatical the year before and died the year that I came here. I never saw him wandering the hallways. So I've heard many Wiener stories, and I've read some of his work, but never had the chance to meet him.

I did take a, not really a course-- I told you I was is this program for EE students who were going to go on to a Master's degree. So they didn't have to write a Bachelor's thesis. The feeling was, well, in a year, you're going to be writing a Master's thesis. You don't need a Bachelor's thesis. In lieu of the Bachelor's thesis, you're going to take these two six unit seminar courses where you have a senior faculty member meeting with you and you'll do some reading and make presentations and so forth.

So I had indicated I had some interest in communication, and the seminar leader for me-- not that he gave talks, he really just listened to us and talked to us a little-- was Claude Shannon. And as I said, in those days, certainly I was much more in awe of faculty than I think my undergraduates are these days. Because there was no UROP. You saw them in class and maybe outside class a little bit, but not the same. For somebody who wanted to go into an information communication theory to be sitting in front of Claude Shannon and try to explain some of his stuff to him, I was too scared to do that. I picked a different topic.

INTERVIEWER: Do you think it's a good thing or bad thing that the students are less in awe of the professors now?

SHAPIRO: I think it's much better. I think it's much better.

INTERVIEWER: What do the professors think?

SHAPIRO: I don't know what all professors think. Doesn't bother me. One of the things about research is you should challenge accepted wisdom. The fact that it's always been this way-- and I started on this in my doctoral thesis when I was talking about laser communication through the atmosphere due to these refractive index turbulence effects, the propagation modeling that had all been done for that, the classic books were coming out of the Soviet Union, the Russian writers. Used a particular kind of model that I said, this can't be what I need.

For each different type of source wave, they're going to go solve some new statistical problem. And I'm used to thinking about signals and systems, you know, my touchstone. And I said, it's a linear system. I should describe it in terms of impulse responses. And I'm interested in the spatial behavior because I want optimize how we use spatial patterning to do better things in communication. So I looked at it differently and developed what I think is the best way to think about this by myself and with one of my early doctoral students at Case. And I still find that the best way to deal with lots of these questions. Because we didn't accept, I didn't accept the way it had been done. It didn't seem useful for the problems I felt were important, and I've seen that in other places, as well.

INTERVIEWER: What are some of the big question facing you today?

SHAPIRO: You mean in research?

INTERVIEWER: Yes, in research. Not the big life questions, but the big research questions, yes.

SHAPIRO: Yes, well, quantum information is not a deployed technology very much. There are sort of three principal areas in which people have worked out theoretical predictions and have at least preliminary experimental systems, or actually some systems you might buy. A lot of interest comes from theory work that Peter Shor, who's now on our math department faculty, did when he was in Bell Labs. He showed that if we had a big quantum computer-- quantum computers are more capable in interesting respects than classical physics would give you-- you could break Rivest-Shamir-Adleman cryptography, the public key crypto systems that we rely on to purchase stuff over the internet. And of course, to build such a big quantum computer is an incredibly daunting challenge given the difficulties of doing so.

But at the other end of the spectrum, the fact that laws of physics tell us if you make a measurement on a system you're going to disturb it makes it possible to do quantum cryptography to provide a kind of cryptography that, at least in principle, is secure on the basis of laws of physics as opposed to, we think this mathematical problem is very difficult to solve with a computer. And in between, there's a whole range of other things.

People care a great deal about precision measurements. I mentioned atomic clocks as an example. We all rely on atomic clocks. Do you know why? You make use of GPS, the global positioning system. Global positioning system works because you have a receiver-- it could be a little hand held thing, it could be the GPS in my car-- that gets signals from a number of satellites. And you measure the timing with respect to those signals, and that timing has to be extremely accurate. And from that, you can infer where you are on the earth to quite good accuracy. If we can build better atomic clocks, we can do things like that better. And in fact, you can build better atomic clocks by exploiting quantum features.

So this is an example of precision measurements. In the precision measurements game, you always want to be able to measure more precisely. It will allow you to do something. And if you can't measure with greater sensitivity, maybe you can measure with greater bandwidth, see faster dynamics. There's a faculty member in physics here, Nergis Mavalvala, who works on LIGO, which is-- I won't get the acronym right. It's the Laser Interferometric Gravitational Observatory, if I'm correct.

INTERVIEWER: I think that's right, yes.

SHAPIRO: And they're going to put squeeze states in there to improve its performance, because she's been working in that area, among other things related to these sensing techniques.

So in all of these things, we need a combination of theory for new things that we could do, and some technological breakthroughs. For quantum computation, there are lots of physical modalities that people are talking about as, what will we use for the quantum bits, the qubits that will be the language of quantum computation? Some people are interested in using super conducting circuits. Some people are interested in using atoms trapped in optical lattices. Some people are interested in using ions trapped in electromagnetic planar traps. Some people are interested in using photons in a variety of ways. And there are other things.

Every one of these modalities has its advantages, and every one has its disadvantages. And so no one thing right now is good enough to say, we'll build it all that way. And instead, a variety of people, including myself and collaborators in the program that I have, are looking at ways to go from one modality to the other efficiently and with high fidelity. So that we can use what's good for memory for memory, what's good for communications for communication, what's good for processing for processing.

So there's a lot of work to be done here, and it's really fascinating because it's a field that draws on lots of disciplines. In that IGERT program, we have faculty from the electrical engineering side of EECS, from the computer science side, from mathematics, from mechanical engineering, from nuclear science and engineering, from physics. That's quite a broad array. And you need to know some aspects of all of that to really capture the field and move it forward.

INTERVIEWER: There's a lot of interest in the general public about quantum communications. Do you ever speak to general audiences or lay audiences about the subject?

SHAPIRO: I haven't spoken to truly general audiences. I've given talks to a variety of places where a company invites me in and says, come tell us about this. We have people with technical background but don't know that much about this issue. So I have done that.

It's very fascinating because it's kind of magical. Quantum mechanics does things that, if you saw them macroscopically-- because quantum mechanics are all over us right now in that the information age in which we live depends very heavily on the quantum mechanics of semiconductors. The quantum mechanics of semiconductors and semiconductor band structure is what allows us to build the laser diodes that are the transmitters for fiber optic communication and are the semiconductor devices, or the microprocessors, the millions of transistors on a chip, that provide the computers that get interconnected with these fiber optics.

But you're not seeing the puzzling pieces of quantum mechanics. Schrodinger's cat alive and dead at the same time. You're not seeing that macroscopically. and. So the challenge in this kind of area, not in terms of talking to the lay audience-- I'll come back to that-- but in terms of the research area is that these special effects, entanglement being I think the primary one-- entanglement is a kind of correlation. Everybody understands the notion of correlation. But entanglement is a quantum mechanical correlation that's stronger than anything that physics, classical physics permits. And it's something that puzzled and annoyed Einstein. His famous paper with Podolsky and Rosen in 1935 felt that the predictions of entanglement were sufficiently unusual, I guess he would say. Spooky action at a distance that he felt quantum mechanics may be incomplete, there may be something else that would resolve this difficulty. And there are people who have worked on that for years, but we still don't have anything that accounts for all these things.

In any case, when talking to lay audiences, let's talk to children. When my children were little, what do you work on, Daddy? I told them what I worked on, and it was too technical for them. It didn't have a good catch phrase. Now that they've grown and they understand me pretty well, recently, well, early in 2000 decade, I was working on teleportation. Now they know it's not, beam me up, Scotty. It's can you teleport the state of this photon from here to there, or something else like that. But still, when they were 10, to say you work on teleportation would have sounded--

I also work on something that's called ghost imaging, which has nothing to do with ghosts. It's a name that got applied because the image is originally formed with non-classical light, with light that doesn't have a good classical explanation, but later it's been shown that you could use laser light in the appropriate fashion. You have two light beams that get split. One just goes to an object, let's say, a transparency and gets collected by a detector that doesn't have any spatial resolution, doesn't form an image, just collects light. And the other one goes to a camera, but there's no object in that path. Neither detector alone can tell you what the image is, but the two together can in a particular way. And I did a lot of theory with one of my students on this, and we're doing some experiments now, testing some predictions that had not been tested before. But at one point, I came up with computational configuration that didn't use that camera. It just used one detector. And it's related to work that had been done in other places, but I had done it because I was trying to relate it to the quantum aspects.

And before we even got to do the experiment, I had posted the paper on one of these online archives when I submitted to the journal. And I was preparing a big talk because I was winning an award for my work in theory of quantum communication, quantum optics, and I got an email from some graduate students at the Weizmann Institute in Israel. They said, they love my paper, they've done the experiment already and it works. And I said, I shouldn't have posted that paper until Franco had done the experiment. It would have been nice.

But anyway, they had done a nice job, and I said, would you mind if I show some of your results with attribution at this talk I'm giving? And they said, sure. So they sent me a PowerPoint movie of the buildup of their image, and do you know what their image was? It was a transparency made by a sort of line drawing of Casper the Friendly Ghost. So it was the first computational ghost image, and it was made of Casper.

So you can talk to people in relatively simple terms about some of these things without their having much technical background. But you know, some of these are sufficiently counter-intuitive that they need some mathematics or physics to be able to understand what it is. And even for people here who understand it, it still has some properties that fundamentally seem weird.

INTERVIEWER: Yes. Well, what did Richard Feynman say? "You don't understand quantum mechanics, you just get used to it."

SHAPIRO: Yes, yes. I think that's quite fair.

INTERVIEWER: I was just wondering if you have any thoughts on just talking about sort of lay audiences and the general public. Do you ever find there's sort of a disconnect between the world of science and the work you do and what the general non-science, non-engineering public understands about science and engineering?

SHAPIRO: Well, I think it's terrible that we don't have as many students interested in pursuing careers in this area as we should, that it's not viewed as something either sufficiently interesting or sufficiently remunerative or what have you. I think it's important for us to have a technological society that has a strong technological workforce going forward.

I remember my son was a big fan of*Star Trek.* So when he was a boy I took him to a*Star Trek* convention in Boston, and he had a lot of fun and so forth. There was, what should I say? School age children, maybe high school, who were studying to take the Star Fleet Academy entrance examination. I guess they had to pay five dollars to take that and if you did well enough, you've got a certificate saying you passed. I don't know that they worked as hard in their regular classes, and I wonder about that. Maybe they did. I mean, my son was interested in all this, but he did well, very well in physics and math and computer stuff in high school. So it didn't affect him. But maybe it does other people.

And of course, the notion of the sort of pseudo science that you can see. I remember there was this book-- maybe you don't-- by Erich von Daniken, *Chariots of The Gods* or something about ancient astronauts came here and taught us everything, and that ancient civilizations couldn't possibly have done any of the things they did were it not for that.

INTERVIEWER: It's interesting when you talk about your boyhood and Sputnik and Kennedy and the space race and all that. It seems to me there is this era where science and engineering was kind of cool, or kind of a national thing to go into.

SHAPIRO: You're telling me Mark Zuckerman isn't cool?

INTERVIEWER: Well, that's true. I mean, I wonder if Mark Zuckerman has made--

SHAPIRO: There is an uptick in computer science enrollment around the country, I think directly attributable to the people watching *The Social Network* movie. Or maybe. That's speculation.

INTERVIEWER: Yeah. Yeah. So I wonder does America need another Sputnik or something? I don't know what? Is it just more things like *The Social Network?*

SHAPIRO: We see some of that in biology, the fascination associated with the decoding the human genome, the possibility that we'll treat disease genetically. And of course, the ethics of some of these things. There was the ethics in the physics community associated with nuclear weapons. Well, we have ethics, very serious concerns to deal with in terms of privacy in the computer age and bioethics. So there are lots of things.

You see, it's important that the scientists and engineers be more broadly educated than just their science and engineering. They have to deal with these issues. And global issues. Globalization is a very significant part of our activity. And this is something, too, that did not exist in my undergraduate program: now you can spend your junior year abroad at a variety of places. You can get summer internships. You cannot participate. And I've had students of mine, really registration advisees, who've been to Cambridge for their junior year who have taken part in the MIT-Japan or the MIT Germany program.

INTERVIEWER: I wanted to just bring up something you touched on a moment ago. The emergence of biology and the merging with engineering, must be something that you've seen quite a bit of in recent decades.

SHAPIRO: Yes.

INTERVIEWER: And even within RLE.

SHAPIRO: Within RLE we have growing activity in that area now. Yes, very much so.

INTERVIEWER: Has it been surprising to you? Or, I mean, have you been watching the gradual emergence of it over time?

SHAPIRO: Well, the revolution in biology via the understanding of DNA and RNA and how things are done and the ability to sequence the genome has driven a tremendous amount of activity. RLE is not directly playing in some of those areas. We're not working, to my knowledge, not very much, if any, with transgenic mice and so forth. But we collaborate with people who do this sort of work, and we're providing some technologies that allow you to do bio assays much more efficiently and effectively. And I think this is a key element going forward for MIT, and therefore certainly for RLE. The convergence that Susan talks about of engineering and science, and particularly in biology, chemistry, physics, engineering coming together with biology.

INTERVIEWER: It seems like that's only happened in recent--

SHAPIRO: The convergence has started happening recently, but there have been beginnings for a while, I think.

INTERVIEWER: What would you say has been your biggest contribution to your field?

SHAPIRO: I think my biggest contribution has been this work on photo detection of non-classical light and limits on communication and precision measurement that come from that. And some of the associated experiments that we got to do here, but more the experiments that have been done elsewhere.

INTERVIEWER: And what do you think has been your biggest contribution to MIT? Same thing, or different?

SHAPIRO: Probably some of the administrative work that I've done has been more important to MIT as a whole in terms of recruiting faculty, helping them keep going and succeed. Because the totality of what they have done certainly exceeds what I have done as an individual or with my own research group.

INTERVIEWER: It must be almost like having hundreds of children, right?

SHAPIRO: Yes, yes. One of the things that PhDs do, or at I did and I know some of my students did, is you go backwards through your chain. Who was your superviser, and who was that superviser's thesis supervisor? And I once-- let's see. Bob Fano is still around-- he's long retired-- and he was an early worker in electromagnetics here. He was in the Radiation Lab, I believe, and then was an early worker in communication information theory. And I am a student of a student of a student-- I told him once at a faculty lunch. I don't know if he still remembers. So it goes for a while.

INTERVIEWER: Yeah, that's pretty neat. I just got the tap. We have about three minutes left, and I think we've covered everything very well. Do you have anything else that you feel you'd like to add about yourself, your career, MIT?

SHAPIRO: MIT is an extraordinary place. It was when I got here, if anything it's more so now. I have spent 2/3 of my entire life here-- by far the majority of my adult life here-- and I wouldn't have had it any other way.