

HERWIG KOGELNIK

An Interview Conducted by

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IEEE History Center

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Interview: Herwig Kogelnik
Interviewer: Robert Colburn
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Colburn: I was wondering if I could first take you through the early days, early education and early interests that led you to branch out in the various directions you have, even before the famous “think of all that bandwidth” challenge?

Kogelnik: Where did you pick that one up? That’s out of the *IEEE Spectrum* article. That certainly was one of the things that persuaded me to even get to Bell Labs actually. But you wanted to cover earlier material?

Colburn: Yes.

Kogelnik: Well ask anything, but you may or may not know from these background materials that I was born in Austria, that I went to various schools. They shifted because there was war then, so you had to move to avoid bombs all the other stuff. So I went to school in Austria, and until high school graduation, I certainly wasn’t quite sure what I was going to do later on. I think there were three things that were high on my priority list before I went to college. One was to do classical music—I fancied that I might be a composer or something; one was to be a medical doctor, which would have been the normal thing to do as I’m out of a medical family: my brother is a doctor, my son, my grandfather, my great grandfather, are all doctors—lots of doctors in the family. These were the two things I toyed with.

Then there was this counselor coming to school before one does one’s college choices, and he somehow must have said that the toughest line of studying is electronics, and somehow that must have intrigued me because that was then

what I picked. I had no background in electronics at all from school, but that somehow intrigued me. Obviously there were all these potential applications. Actually I thought there were going to be very good medical applications. While the first part is true, there are lots of medical applications of physics and electronics these days, think of all the CAT scans and electron microscopy, I never did that. But I am still intrigued by that. One of my sons is now a doctor. Now he's going to do some research, so I'm trying to get back into that line. Again, it sounds intriguing, but I haven't done anything. So as it turns out I never did any of the medical electronics.

But I decided to go and study electronics at the college. So I went to Vienna first and I studied there. It had a strange name in German, Schwachstrom Technique. They divided EE, electrical engineering, into Starkstrom Technique and Schwachstrom Technique. That's a very antique division. There are strong currents and very weak currents, "schwach" means weak. So it was strong current technologies is the one and the other one is the weak current technology. With electronics, you don't need too much current, so this is the weak stuff.

So I did that and there is a different cycle there. You make a diploma in engineering at the technical university. It's sort of the equivalent of MIT, the Vienna Institute of Technology. That's sort of equivalent to a masters degree when you finish. Then I became an assistant professor and at the same time worked on a PhD thesis. So this is my first line of research really, to work on this PhD thesis, and that was in noise and microwave tubes. So it was primarily on linear stuff. Microwave tubes are hot and trapping wave tubes for

satellite communications and stuff like that, and radar. So that was my first line of research, and then I got a PhD in Vienna.

During that time somehow there was a contact and there was an opportunity to do a sort of a post-doc at Oxford in England. So that seemed intriguing. It's a scholarship that's almost exactly a Rhodes Scholarship, except that countries that got their Rhodes Scholarship taken away after World War I, like Austria and Germany, Italy and so on, because somehow the Rhodes Foundation didn't want former enemy countries to be treated the same way, but the British then compensated for that after a while and created something that seems to be rather equivalent. It is a British Council Scholarship, and so those countries that didn't have the Rhodes Scholarship got the British Council Scholarship, and I won one of those. Then we were all bunched together with the Rhodes Scholars same parties, same sort of events and stuff like that.

So that got me to Oxford. Shortly after I got there, I was going to switch fields. There was a guy there Froit Montz [?], a professor at Oxford. He was very good in plasma physics and things of that nature, so I switched from microwave fields to plasma physics. These were the days where the first experiments were done in nuclear fusion, and they worked closely with the guys at Oxford. So I picked a topic in plasma and it was electromagnetic wave propagation through magneto plasma, that is plasma in magnetic fields, but they are not just magnetic fields to contain the hot plasma. You have to heat it up to the temperature of the sun to make nuclear fusion possible. It was funny, at that time, in 1958 or something like that, everybody was saying it would take ten years before this technology would be practical. Looking back now

it's really funny because every 10 or 20 years they would increase the years that it would take to be practical. When you talked to people in the 1970s, they would say it would take 20 years before it becomes practical, and now they are saying it will take about 30 years before it becomes practical. So we were even making jokes looking at these plans and saying, "Well if you extrapolate back the gaskets now, it obviously was already practical in 1940." Anyway, we discovered a lot of difficulties, but it's a very interesting subject, so in Oxford my PhD thesis was this.

Then I started working with them, and they said, "Okay. What you're doing seems worth a PhD thesis, so why don't you submit a PhD thesis?" So I did, so I got another PhD in physics at Oxford for the thesis on magnetoplasma fields, basically.

So I moved around quite a bit. I moved several more times, of course, and at Oxford, close to the finishing of my two year term there, just before my PhD, there showed up this man called Rudi Kompfner who was a Bell Labs executive, who really started optical communications at the Bell Labs based on the laser breakthrough. So he visited me there and tried to persuade me to come to the US and join Bell Labs.

Then something else happened. Sputnik had just been launched, and America launched this effort to catch up in science, catch up in technology. All of a sudden people were moving all over, and I got this offer to come here and have interviews, and if I didn't like it, they would ship me back again all on the US government's cost, basically. So that was a win/win situation, so I took that chance. They shipped me over and I was a government employee for three

months, GS-12, and my job was to have interviews. It was really very funny. So I had a lot of interviews. They really made me work, 52 interviews, something like that at government labs, university labs, industrial labs, and one of them was Bell Labs. I did a lot of thinking on what to do, and I guess I got 52 offers or something.

Then I had the problem of picking, and it was very tough because of the space program. Actually I think I wanted to go into the space program. For a while, my number one choice was to go out to California, North American Aviation at the time, and work on this project to land a man on the moon. John F. Kennedy was talking of the subject. My plasma background really was a good fit because when a space vehicle reenters through the ionosphere it creates a lot of glowing gas stuff, and to communicate through that so you would know what to do at every moment of coming back, it required all kinds of interesting technologies.

Colburn: I remember during the reentry there would be a minute or two of blackout.

Kogelnik: Yes, that's because of plasma. As the vehicle comes through the Earth's atmosphere, it creates a lot of hot gas and that would block out communications and stuff like that. There were lots of problems that needed solving, so it seemed interesting.

So I was leaning towards that when Rudi Kompfner called, and then came this line, "Here, why don't you switch fields and work on lasers, and think of all of the bandwidth they have compared to microwave sources." And that line and the quality of Bell Labs intrigued me, so I switched my line. Bell Labs sent me number two and I switched and I came to Bell Labs. That was January 1961.

Colburn: And was there a sense then of a brand new, wide open field like the space program?

Kogelnik: Oh yes. To me it as even more brand new because I had already known a little bit of plasma physics. After all, I had written a PhD thesis. It required a switch, but it seemed full of opportunities. The laser was so new and so intriguing and had just started. During my job interview at Bell Labs they showed me the first gas laser that they had just put in operation. Thinking back, this is just enormous—you have a job interview and you get shown something that nobody has ever seen before. And here was this gas laser they had built at Murray Hill. It was obviously intriguing to be seeing this as a job interview, and then to be offered a job to work with guys like that. And indeed, my first job at Bell Labs in research was to improve this gas laser and make it more practical. It was a huge first thing. That was one of my first projects at Bell Labs, to make the gas laser more practical, improve the angle to make it a much more practical thing, so immediately you could do all kinds of experiments that were very hard to do with the early work.

So that was a big transition from the plasma physics. First from microwave tubes, and then plasma physics, and then came the big switch to lasers actually. Then I worked for a long time on lasers, and obviously were buying optical communications.

Colburn: So from almost the very beginning, then, people were seeing those lasers as communications tools?

Kogelnik: Oh yes. Yes, that's a point that's often overlooked, but I wrote a recollection article once for the millennium issue of the *IEEE Journal of Quantum*

Experiments in 2000, that main issue. And I thought this through and it's really amazing that it's not that emphasized. The Charles Townes' patent, actually it says optical lasers, but translated into today's language it says "lasers and optical communications". So I was intrigued that optical communications already showed up in the early Charles Townes' patent, which is after all 1958. The paper was 1958. The associated patent was actually dated as issued 1960. Anyway, it says, "Lasers and optical communications," using today's words right, and then it has eleven claims. Three claims in the patent are actually for optical communications systems; four are claiming the laser; and the last four claim optical amplifiers. So it's a three-way patent and it's lasers, optical communications, and amplifiers.

So obviously communications was on their minds even when they invented the laser. That's why Bell Labs pushed it. That's why I was hired to Bell Labs. Rudi Kompfner, this guy who hired me, was clearly pushing optical communications. Obviously he was pushing laser research too because he needed them for this, but no question, optical communications what was on their minds.

Almost all of the things I did in the early years at Bell Labs were all laser basics—extremely interesting, everything you touched was new, if only tried a little bit. But there was always in the background the question, "Okay, what would be hard to do in lasers that would be good for optical communications?" So there was always this intervening of stuff. So while you worked very hard on laser breakthroughs and stuff, you always argued, "This is a good breakthrough, for example, because it will be good for optical communications."

So the two were sort of separate, but yet inseparable, and obviously optical communications can't do without the lasers. These are the two basic building blocks for these days: the semiconductor laser and optical fibers. These two technologies mixed together make optical communications today. We know it today, but then the fibers were not known, but the lasers were already here. But I think it's true to say that the laser breakthroughs, and there were lots of them, stimulated the fiber breakthroughs that would come later, maybe ten years later. Some first thoughts on fibers of course were already in the mid-'60s, five years later than the first laser. So the fibers came later, but they were stimulated I think by the laser breakthrough. That breakthrough obviously came first and obviously has a lot more implications than just communications, and there are still new implications for that. The big new field, totally new as compared to electronics.

Colburn: If the fiber optics hadn't come along, were there ways that people were imagining that the lasers would be used in their absence, or was that almost a necessity?

Kogelnik: Oh yes. There were experiments even before the fibers doing optical communications, some with just free space. We studied laser beams and how they propagate very thoroughly and fundamentally. I did a lot of work on laser propagation and how beams of light when they hit a wall, that is laser modes, and I wrote several papers on this. This is of course the beam you want to use. This is called the fundamental mode, the simple spot, and what would happen to such a thing if it goes to long distances it would grow, but how much does it grow? What do you do to keep it together and bundled so you can

communicate through free space?

All of these issues were active in these years, and that's still happening. There are the satellites coming up that use laser links to communicate between satellites, and there is no atmosphere that borders the beam. The atmosphere in Earth, they broaden the beam and break it up. But then there is no atmosphere out where the satellites are. They use lasers for high capacity satellite communications and then satellite networks. That's the hot topic right now. So you don't necessarily need lasers for communications when you're out there, and the atmosphere doesn't interfere. You can go through free space, and for short distances you can go through free space too. There are quite a lot of experiments in use of lasers where you go building-to-building or something like that. So it's a complementary technology. I think some of these things are commercial and they would go across a valley when it's hotter than the fiber. Sometimes it would go across a railroad track or whatever. It's a complementary technique. It's not as high capacity as a fiber. A fiber has a wonderful capacity. But yes, lasers don't necessarily need fibers, but the fibers certainly made it extremely attractive here on Earth.

It's funny; in this recollection article I even put an article about Charlie Townes. He wrote a paper about interstellar communications. He was considering the potential of communicating with a planet that was associated with a star many light years away, and doing that using lasers, and he wrote a paper on the subject. So using lasers for communications in free space was obviously studied before fiber. Then actually this very place here, Crawford Hill, studied another predecessor of the fiber for use of communications with

lasers. This was before the fiber had really clicked. What they would do was prevent the expansion of the laser beams. Laser beams sent a long distance expand by diffraction, and we knew all of these rules and how they would do. So to keep the beams bundled like fiber does, like all the space in the fiber, there have been some inventions to use what's called gas lenses. So they would have pipes into which they filled special gases, and then they had like temperature gradients and flow and stuff. They were able to create gas that was thinner in the center of the pipe, and then the outside, just like the refractor beam that's in the fiber. I don't know how much background you have in those things.

Colburn: I actually can remember doing these labs in physics in college using lasers and the waves and so forth. So I have a little bit of the basics in that stuff.

Kogelnik: Oh, okay. So a fiber bundles the light because it has a less dense core. You know, fiber is like a hair, but they make it less dense optically in the center. That's called the core. The light would go faster there and it would be more dense outside. That's called the cladding. So it's actually a structure inside of the cross section of the hair. And that by total internal reflection basically will bundle the light into the center of the fiber of and not come out. These early starts were actually the same except using gases. So you would have gases that would be less dense in the center of the pipe and more dense outside. So you would shoot laser beams through this thing and it would be bundled and stay together, but you would have to put a pipe over the whole distance. But there were experiments done with three miles of pipe and stuff like that.

There were lots of other ideas. There was continuous refocusing that was also

something that was experimented with. Rather than have the medium bundle the light over long distances, you could - like in a periscope - shoot the laser beam and then it wants to expand; then you put the lens there, then it focuses it again. Then it wants to expand again; then you put another lens there and you would have a train that would be like this slide start wide, go narrow, go bright, another lens. You would do this kind of stuff. That was called sequence of lenses. They pretty soon discovered that these lenses are much too low, because even going through a window you lose 4% of the light. So if you do this too much at once, but when you do it often you lose a lot, so that wasn't practical. Then they used focusing mirrors instead, they had less losses. So you go around the corner then. You can't do it quite straight. So they used mirrors. So periodic focusing was another technique strategy before fiber also here. But I'm sure in many other places.

Right then the fibers came along, and it was clearly the best medium, much less complicated than all of these other things we just mentioned and you could even bend it, the light would follow the bend unless you bend it too much. It was flexible and the loss was extremely low. These losses are incredible, only occurred at .2 db per kilometer. That's about the loss for a window, but after a whole mile or something like that. A *clean* window!

Colburn: Were there unexpected applications for this work too? It sounds like there was a definite idea of some of the ways it was going, but have there been ways that have been used that have totally surprised you?

Kogelnik: Now the laser field produced a lot of unexpected new applications, and it's still happening. If you go to a laser meeting every year, there are new ideas on how

to use those things. It's so new. It has so many dimensions. Yes, there were things people thought of, but clearly there were also things that people didn't think of. But the very existence of these tools created new applications. In the early years I certainly heard nothing about eye surgery, and now there are all kinds of medical applications. I don't know what they're using things now for. It's growing so much, like sorting of genetic engineering tests or something like that. There is an incredible amount of laser applications, and that's still going. This has so many dimensions it's technically hard enumerate it all. You can't write an article about this it's so big; you can't even write a book, you have to write many books. Laser applications that are quantum electronics, also called in laser science, has proliferated in a lot of specialties, and that still keeps going. So there are very fundamental applications like spectroscopy to find out more about nature. There are very practical applications like a survey will sometimes use a laser beam. Or a pointer.

Colburn: Yes, we now carry them around in our pockets.

Kogelnik: Exactly. It doesn't cost much. Compact disc player. Lasers are just about everywhere now.

Colburn: What would you say are some of the greatest benefits, in terms of human well-being, of that technology?

Kogelnik: Of laser technology? Wow.

Colburn: I know, given that we still don't know some of it, but what are some of the things that you know?

Kogelnik: Well, obviously communications—information transmission is obviously one of them. Storage of information when you look at it is already very, very big—

CDs, CD ROMs, all of this stuff is totally impossible without lasers. All the laser machining in industry, like laser welding and all those things. There is obviously laser surgery, medical applications. There are a lot of applications in physics and spectroscopy and chemistry. Every word I'm saying is a whole discipline that would have an annual meeting of a thousand or more people. Books are being written. It's just vast.

And it's very hard to keep track of, actually. I go to one of those meetings, called the CLEO meeting that the IEEE organizes every year, sometimes associated with the quantum electronics meeting. I chaired both at separate times. These meetings still generate so many new ideas every year, it's just awesome. So it has blown up way, way beyond what people even imagine. Obviously there are military applications. You hear about smart bombs and all of this stuff and the high precision of that kind of stuff. But these are just a few samples. It's just incredible the way this thing has grown.

Colburn: Speaking of your IEEE activities, I also wanted to ask about when you became involved with IEEE and some of your IEEE activities over the years.

Kogelnik: Oh, I became a member of the IEEE almost instantaneously after taking my first job. The IEEE is a wonderful organization. It has so many disciplines also of course. And what did I do for the IEEE? All kinds of stuff. I chaired one of the early laser meetings, CLEA it was then called. Now it's called CLEO, but there was a name change in between. So I was a program chair and a meeting chair of CLEA. Then there was a very basic meeting. It was not just IEEE, but I think IEEE had a share in it, the quantum electronics conference. That's more basic. CLEA, or CLEO is more applications oriented.

Conference of Laser Applications and CLEO now means Conference of Laser and Electro Optics, but implicitly it's more applications oriented, while the quantum electronics is the sibling on the fundamental side where the neutrons are always being studied. So I was chair of that one too once. Then I was on all kinds of committees like the awards committee and obviously a member of the LEOS Society, which was started because of the laser. It somehow grew out of the CLEA or CLEO meetings. Then I sit on various other panels, like I'm now on the Subatomics Award committee. It was professional stuff like that, like being on program committees, running meetings. There was an integrated optics meeting too that I ran once.

So IEEE really organizes the professionals in various disciplines in wonderful ways, very much to the benefit of the members. Like a meeting I'm going to next week is the Optical Fiber Conference (OFC), and IEEE has a sort of a double share in there. It's now gotten complicated—there are these big, international meetings. Like the OFC meeting is the biggest every year on optical fiber communications, and I think that's shared between the Optical Society of America and the IEEE LEOS Society and the IEEE Communications Society. So it's a three-way thing, probably more, but I don't worry about all of these organizations too much anymore as long as the things work well. These are big meetings. I mean, this Optical Fiber Communications Conference, OFC, started with about 100 people or something like that in the late '60s I guess it was, and it's now blown up to such proportions they can't go everywhere anymore. They have to make sure that there's a big convention center. There are exhibits associated with it.

Actually it's becoming too large for my taste. You hardly have a chance to interact with your colleagues anymore. The big, commercial show is attached. But it's a very healthily growing field, and very interesting.

Colburn: Yes indeed. Would you like to add any observations or advice for the future? Pitfalls to avoid or anything like that?

Kogelnik: Boy, I have so many pieces of advice for the future. One thing, it's clear that obviously humankind always wants applications, right? They are good for humankind. But looking back, it's clear that if you support work on the fundamental breakthroughs and the fundamental understanding of things, there are always some new applications coming up, mostly unplanned. So the support of fundamental research I think is a very important idea, even if you don't quite understand where things are going because the breakthrough in understanding has to come first, then later you get the applications, and you really create wonderful new tools like technology laser. People would think up a lot of applications later once they have the tools. You don't think of a laser application if you don't have a laser. Why waste your time? The existence of those tools really stimulated the mind. Looking back, that really has happened over and over again. So just to restrict yourself and say, "Okay, I want to have an application for such and such," wasn't really the way to get it. It was to create new tools and they would have all kinds of applications, and then you follow those ideas up from the basics.

Oh boy, I have many pieces of advice. One was to have a very broad background. Obviously these are times of lots of change. I have switched fields so often I can't even list them all, but there was certainly microwave

tubes, plasma physics, lasers, optical communications, and all kinds of things in between along the field and so on. So it's clear that switching fields is good for your mind, but there is also a lot of change out there in industry which indeed suggests that you should be switching. Obviously if I would still be working on microwave tubes, I would be a poor man and very sad. And nothing against microwave tubes, actually they have revived. But clearly there is a lot of change out there, and to be able to adapt to this change, it's a very good idea to have a very broad background and very broad interests. Then it's actually a joy to switch fields and get into new things.

I think this is particularly true for EE and those kinds of disciplines. There are clearly other fundamental fields where you can stick to the same field all of your life and just understand things better and better and better. But I think in our profession, moving around actually helps create new thoughts and new breakthroughs and new ideas. So yes, to have a broad background and broad education makes it much easier to adapt to this change that seems to be required these days. It's been very healthy in the past too. Many new breakthroughs came about because of not just one field, because of blending fields. That's probably another point that they seem to be happening at the interface between disciplines. Like what is happening in laser medicine would be a good example, or nano-structures in biology. It's always when several such fields come together that you get another breakthrough.

Well, we didn't talk of any of the things I'm getting all of these prizes for. And sometimes I don't even know, but you have them in these pamphlets. Do you have this one? [Kogelnik, "High-Capacity Optical Communications: Personal

Recollections,” *IEEE Journal on Selected Topics in Quantum Electronics*]

This is just about the optic and communications field, reflections just about that because that’s what they wanted me to write at that time, but it hits two or three things that I did that I probably got several of those prizes for. One is the invention of the distributed feedback laser, which is a very tiny little semiconductor laser that controls the spectrum very well and it’s fitted for the advanced optical communications. It’s now in just about every advanced fiber communications system, and it also fit very well with this breakthrough that we here in Crawford Hill engineered as a group, which is this wavelength division multiplexing technology that hit in the early ‘90s, basically. We did a lot of work for that one. Basically, Bell Labs got even the IEEE an award for the first large-scale deployment of wavelength division multiplexing. That was sort of an industrial work. All kinds of our guys are getting prizes in that direction.

So wavelength division multiplexing is basically an old idea, but we really put it into practice, which is sending channels over a single fiber at different wavelengths, and thereby you can increase the capacity of such a fiber by many fold. A modern system might have 128 channels on a fiber, and each channel can run very fast. Now they keep jacking up the speed at which each channel runs, so we have capacities now that are so vast that they are exceeding terabits per second of the fibers. So there are some numbers in there. Several million data connections or voice channels and I guess half a million TV channels you can put over just one fiber now. These are vast capacities. And of course, first of all the laser helped create that fiber and then

doing wavelength division multiplexing helped even more.

Colburn: What was the creative process behind that development? Did somebody come and knock on your office door and say, “Hey, we need to expand this,” or was it something that somebody said, “Hey, maybe we can use this?”

Kogelnik: I think it grew inside. We just saw the opportunities. We knew that there was more capacity needed. First of all we knew nothing—there were fifteen to twenty years where nobody even wanted optical communications. It took a long, long time before it actually hit. To think of the fact that the laser was conceived in 1958 or something like that and the first laser was demonstrated in 1960, just when I joined Bell Labs. There was me and Alan Hughes and so on at the gas lasers at Bell Labs. So the first lasers were just getting demonstrated as a prototype kludges most of the time in 1960, but already then people were thinking of how to use the thing for optical communications. It took roughly 25 years of constantly improving all of this and exploring applications before there was a large-scale application in optical communications. So there was a long period where others sometimes were doubting whether this would ever work, where certainly your supporters were doubting whether this would ever work.

So it took a lot of progress and imagination and endurance, and really belief in what you were doing to get this thing going in the first place, and they had to combine many, many things. But once it had gotten started, then you could start plotting starts of progress on a large scale where it was clear that the technology improved a factor of 100 every ten years in capacity. It’s an enormous effect. Think of the effect of 100 in ten years in any other

technology. Well, will a car go 100 times faster ten years from now? Or a plane? Or can a car carry 100 times more load than ten years ago? Obviously not. The only thing that matches this progress is computing capacity. And in fact, they magically track that computing capability and optic fiber transmission technology. They sort of track each other. They both roughly increase by a factor of 100 every ten years.

Colburn: I notice here [referencing “Progress in Lightwave Transmission Capacity” chart in Kogelnik article] in the early ‘90s, it looks like around 1992, the increase became even sharper.

Kogelnik: Well, that’s wavelength division multiplexing. That is exactly wavelength division multiplexing. And now it’s coming back down again, of course. You can’t sustain those things too long.

But yes, that was a big breakthrough. I’m very proud of wavelength division multiplexing. We did this here as a group. That was a big breakthrough commercially too. There are lots of companies now founded on that concept, but we did the first large scale deployment because our research was there already. You have to be always there a little while. This is an interesting chart because these are the research experiments here and these are the commercial deployments of technologies, and obviously there is a lag of a few years, like five or whatever, but before this big telecom project, the lag narrowed and narrowed. Pretty soon it starts to cross over. Of course you can’t have commercial deployment before research demonstrations.

Colburn: There are some people who probably think you can.

Kogelnik: That was sort of the peak of the bubble—people were promising things that

will be under research as though they could be done. You could always, from that chart, predict the bubble, because when the commercial guys say they will deliver things that the research guys say they can't yet, you obviously have a problem. That's a joke.

Colburn: It's almost there. [laughs] A useful stock market indicator.

Kogelnik: Yes. But yes, the initial progress obviously keeps making us think what else can we do to keep that progress going. We somehow seem to know from the past that there is going to be progress. These Moore Charts in electronics—how many transistors for cheap, and it just keeps growing exponentially. You never know exactly how it's going to be done, but you know the charts are there and people are going to be working very hard to stay on track with those charts. Somehow magically they have always managed to keep going. And this is not physics. I think this is psychology or whatever.

But the progress is clearly there. You look into the past and there are these straight lines like these ones, and they seem to have applied to quite a few fields. They certainly applied to computer processing power. That's the MIPs and stuff like that. They applied to the capacity of transmission through optical fibers. They applied to information storage, magnetic disk storage also is on a steep curve like that and a few related things. They don't apply outside this information technology very much, I don't think, or at least the growth curves are not that fast. The productivity of agriculture growth is in the one percent or whatever. But these, in a way, are productivity charts. How has your productivity increased? Well these say, okay, you transmit 100 times more information now than ten years ago through fiber. That's enormous.

And it's interesting that the things keep going in spite of the bubble and the stock markets freezing up and all of this stuff. The technology capabilities still keep going, and it's going to be interesting to watch what that means. But it's certainly been fun to work in a growing field like this where you can see it has enormous implications. Curves like this also mean that communications is becoming much, much more affordable because there is a law that we call the Dixon Clap Rule. There is no chart for it, but it's in words. These are old charts from other technologies. It almost says it doesn't matter what technology you use, but if you manage to transmit more information over any medium, like a fiber or a cable or whatever, if you manage to transmit more information, the cost per channel will scale like the square root of the capacity you transmit. So if you manage to transmit 100 times more, you have to take the square root of 100, that's 10, so the cost per channel will have come down a factor of 10. That's the Dixon Clap Rule, and many financial planners use that at least as a rule of thumb.

So increasing capacity is a pedestrian thing, and the average citizen may yawn, "Okay, capacity has gone up a factor 100." But then you say, we have decreased your cost of transmitting information, of communicating by a factor of 10 because per channel means viewers. Unless you transmit a lot more, then you have to pay more. But if you're stuck to the same kind of message volume, then your cost has gone down by a factor of ten because of this. So there is a big impact on humanity, a factor of ten every ten years, not just once every ten years. This has happened at least twice now because we have added since about 1980 or 1985, 1983. So there have been two cycles of a factor of

100 increase with fiber. So two times 100, and the cost therefore has come down over those twenty years by a factor of 100. You are paying a factor of 100 less than twenty years ago, at least what the technology costs. You're paying other things like, I don't know, the checks that you use or the banking or the building costs and whatever. But the technology cost is a factor of 100 less than twenty years ago.

That's a big impact on humankind, because it's availability of wideband communications. That's why you see all of these impacts. You hear a lot about video transmission, broadband. That's all made possible because the costs have come down so much. In fact, you know a picture is worth a thousand words, right? And it's pretty close in capacity needs of voice against video. So when you had a kilobit, you needed a megabit or something like that. Maybe it's not quite a thousand anymore because of compression, but say it's a thousand. What's the cost of transmitting a word versus a picture, like making a telephone call versus sending movies or video messages? Well, by this other rule there, in twenty or thirty years the picture will cost just the same as the voice had cost thirty years ago because we managed to reduce the costs by a factor of a thousand in thirty years, 100 in 20, 10 in 10. These logarithmic curves are very powerful. And I think that people in optical communications are right at the root of that contribution.

Obviously there is this parallel thing of the computer chip guys, they are doing the same things to the computers. Your laptop or your pc or whatever costs you the same. There people don't pay more; they pay the same price usually than ten years ago, but they get a lot more. Your computers are a lot faster

than ten years ago. So they are a similar contribution. They make a big difference.

So it's really those three things together, the information storage, information computing, information processing and information transmission that sort of track each other and allow you to do faster and faster stuff, which means more and more information. What you do with this information, that's another matter. That's up to you.

Colburn: May we use it well. [pointing to the *IEEE Spectrum* issue] [which issue?]

Kogelnik: They did a lot of work on this, I was amazed. When you get this medal of honor, the IEEE pours a lot of money in there. I mean this photographer was a genius. Even these ideas. This is all IEEE photography. It turned out before he did this assignment he had read all of this stuff. He had deeply thought about how he wanted to symbolize the work I'd done. He came up with this cat's cradle that you can interpret. It was just a string that he then blew up by defocusing. But I had worked on laser beams, so you can figure out various things on laser beams. I had worked on optical fibers, so it could be optical fibers. There was a lot of thinking this guy put in. I was just totally amazed. And people are still baffled by what on Earth is going on here. It sort of makes you think. He really did a wonderful job. But then this is one picture, and actually he worked three days here, all kinds of angles he considered, and then someone mentioned this one. He was really a genius I thought. It was a lot of fun to work with him. Then he worked with a writer. The writer of the article was also very good. In here you probably hear reflections of many of the things that we probably talked about. But I guess you have a different angle.

Colburn: Thank you for the interview.