

IRWIN JACOBS

An Interview Conducted by

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IEEE History Center

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INTERVIEW: Irwin Jacobs
INTERVIEWER: David Morton
DATE: 29 October 1999
PLACE: San Diego, California

Morton: Would you tell me a little bit about your childhood education and how you got into engineering as a career?

Jacobs: I entered engineering in a roundabout fashion. I grew up in New Bedford, Massachusetts. In my senior year, my high school guidance counselor told me there was zero future in science and engineering and neither would be a wise career direction although math and physics were my major subject interests.

Morton: What year was that?

Jacobs: I graduated high school in 1950. It was just after World War II and the direction of the economy was not yet obvious. My senior counselor suggested a good agricultural school, but I was not interested. My folks were in the restaurant business, so he next suggested the Cornell University School of Hotel Administration. I applied and was accepted. After about a year and a half, though, I decided engineering was more interesting. That decision was partly driven by a roommate who was an engineer. He egged me on by saying, "You couldn't possibly get those grades if you were in engineering." I could only listen to that challenge for so long. During the winter break, I went to the Dean of Men and told him I wanted to transfer from hotel administration to engineering. He said, "You mean engineering to hotel," and we went through that loop awhile. Then he asked which area of engineering and I mentioned either engineering physics or electrical engineering. He had a faculty friend in electrical engineering, and that's where I ended up, although I took a great math sequence in engineering

physics. Cornell was a five-year school and I had been in hotel administration a year and a half, so I lost a year's time and graduated in 1956. One of my last courses at Cornell was a vacuum tube course with laboratory, which involved some interesting field mapping work but which otherwise has not been too useful but did support a job at Cornell testing failed vacuum tubes returned from World War II. My senior thesis involved leading a team to build a digital differential analyzer using parts including a magnetic drum from an IBM 604. Interestingly, the Hotel School courses in accounting and business law have ultimately proved very valuable.

I attended graduate school at MIT, receiving my Master's in 1957 and my Doctorate in 1959. At Cornell, I had taken electromagnetic theory courses from Henry Booker and antenna courses from William Gordon and was leaning towards graduate work in that area. After arriving at MIT, I quickly became involved with leaders in information theory, including Claude Shannon, Norbert Weiner, Robert Fano, Peter Elias and Y. W. Lee. I became quite interested in information theory, and luckily decided to pursue communications. My doctoral thesis involved probabilistic networks. After graduating, I stayed on to teach. In the 1964-65 academic year, I took a leave of absence to be a NASA Resident Research Fellow at the Jet Propulsion Laboratory (JPL) in California. That was where I first spent significant time with Andy [Andrew J.] Viterbi and we became good friends.

Soon after returning to MIT I received a call from Henry Booker, the professor from Cornell. He told me he was going out to start a EE department at the

University of California at San Diego, which was then a brand new university, and invited me to come out and join him. At first I turned it down, but my wife, Joan, and I had enjoyed California and agreed an opportunity to teach at a brand new university was interesting. The fact that it was a public university meant a broader selection of students, and the opportunity to form a new curriculum was a challenge. After thinking about it for two days, I called back and accepted the invitation.

Shortly after starting at UCSD in September, 1966, I received requests from a number of aerospace and defense firms in Southern California to do consulting because of my MIT background in communications and information theory.

Flying down from NASA Ames one day with Andy Viterbi and another professor from UCLA, I mentioned that I was being offered more consulting than I could handle and they suggested we set up a company to share the work. That was fine with me, I agreed, as long as I didn't have to manage it. That's how we started the first company, LINKABIT. It was a day-a-week consulting company.

After a couple of years, it became clear that the company would grow rapidly, and I took a leave of absence during the 1971-72 academic year to organize it.

Running LINKABIT turned out to be challenging and fun, so I resigned from academia after 13 years to continue full time, and I have been in industry ever since. The company continued to grow and in August of 1980 we sold LINKABIT to M/A-COM. I stayed on with LINKABIT until April 1, 1985 when some M/A-COM management changes made it less interesting, and I retired. We did develop a number of innovative products at LINKABIT, including a 1970's

micro-coded multi-satellite terminal (still in active use) supporting TDMA, FDMA, and frequency-hopping CDMA, with almost all functions performed in a proprietary RISC processor; the first Ku-band VSATs for business use with early customers Schlumberger, Wal-Mart and Southland (sold to Hughes after I left); VideoCipher for scrambling and descrambling TV signals from satellite to home or cable headend (sold to GI after I left); and the first commercial TDMA wireless phone under contract to IMM (later Interdigital).

Three months after leaving M/A-COM, I decided retirement wasn't much fun, and, with six others from LINKABIT, decided, "Let's do it again," and we started QUALCOMM on July 1, 1985. Within the first six months, we came up with four ideas that have driven us ever since. One idea had to do with what we call OmniTRACS, which is a satellite communication and tracking system for the trucking industry, now in use on over 400,000 trucks worldwide. The second idea had to do with low earth orbit satellites for a military program, and that led to the Globalstar system. Globalstar is technically successful but has not attracted enough subscribers yet to be financially successful. The third idea involved all digital (compression and transmission) HDTV proposed to DARPA. We won one of three contracts awarded after a competition involving more than 100 teams of companies (we bid on our own). We were not able to propose the technology for the FCC commercial HDTV competition because of presidential industrial policy at the time, but continued to develop the technology for digital cinema - the first commercial movie to use this technology on a number of screens is "Ocean's 11". The fourth and perhaps most important idea occurred during work on a contract

we had with Hughes to look at a mobile satellite system which later became AMSC. They had filed with the FCC and asked us to review the filing to see if any technical issues needed to be addressed or if there were improvements that might be made.

Driving back to San Diego with Klein Gilhousen after a meeting with Hughes in Los Angeles, it suddenly occurred to me that using code division multiple access (CDMA) could increase capacity in the mobile environment. During a phone call, each party generally speaks less than 50 percent of the time including all pauses, but in conventional systems, it is not possible to gain capacity by switching to another user during the quiet period and still recover the channel when the original user again begins to speak. With CDMA, the number of users is limited by the interference each generates to the others when using the same shared channel. But, whenever you are quiet, you do not generate interference and more people can share the channel. As we studied the implications of CDMA, Klein Gilhousen came up with the realization that with a multi-beam satellite (or a multi-sector, multi-cell terrestrial network) the fact that CDMA uses spread spectrum modulation and is resistant to interference allows reuse of the same frequency in every beam (or every sector of every cell), providing further capacity gains. Further analysis and simulation showed that CDMA could increase the satellite capacity by up to a factor of three. Of course, everyone was skeptical when we first proposed it. We convinced Hughes to support implementation of a prototype satellite terminal and transponder, with the effort led by Butch Weaver. It worked as predicted. However it soon became clear that FCC approval of a

mobile satellite system would take years, and we had to set aside the work on CDMA.

We were trying to get OmniTRACS going as our first commercial product, so we left the CDMA and low earth orbit satellite work and concentrated on OmniTRACS. In October of 1988 we won our first major contract with a large transportation company Schneider National, for which I was the chief salesperson. We then had time and resource to look at the use of CDMA for terrestrial as well as satellite communications. We've been having fun with that ever since.

Morton: That's interesting. Were you a consulting firm for Hughes while you were developing the CDMA satellite system?

Jacobs: We had a contract with Hughes when we did the satellite piece of it.

Morton: Was Hughes able to eventually commercialize this as well?

Jacobs: We never did convince them to use the technology. There were a number of supporters, but not enough and when the program was delayed, other decision makers became involved and Hughes decided not to use CDMA. The first commercial CDMA mobile satellite system is Globalstar.

Morton: Would you speculate that the established nature of Hughes had anything to do with their decision? Was an entrepreneurial force needed in order to get this going?

Jacobs: Hughes was a fairly progressive and entrepreneurial company and they have done a lot of very good things. This was a high-risk program, and I suspect they saw CDMA as another risk. Rather than pushing the envelope in too many directions, they decided not to follow that particular direction.

Morton: It almost sounds like you are answering my question in the affirmative and they had their own definition of what was an acceptable risk.

Jacobs: They needed to raise a lot of money and to do so they had to convince a lot of investors including a number of strategic partners. A mobile satellite system had never been done before. Basing it on a new modulation technology not yet in commercial use probably did exceed their threshold of acceptable risk.

Morton: What was your relationship with the IEEE Communication Society? This interview is part of an anniversary project and they nominated you for it. Sometimes people's careers have been greatly helped by their involvement in the society, and sometimes it's the other way around and the society is greatly furthered by an individual's involvement. What was your experience?

Jacobs: I joined the Institute for Radio Engineers (IRE) after I transferred to electrical engineering, while still at Cornell.

Morton: You published a paper in one of the last IRE journals, shortly before they changed it over.

Jacobs: I moved ahead into the IEEE with that change, and I joined the Communication Society fairly early in the game. While at MIT, though, I was most active with the Information Theory Group. However, after arriving in San Diego, I had an opportunity to work with the Communication Society as chair of a conference. We had a very successful conference and I became a board member. I was reasonably involved with the Comm Society over a period of several years. Starting a business in communications, the Comm Society met an important need for networking and information. I made a lot of significant contacts through my

involvement with the Communication Society.

Morton: What was your sense of the makeup of the Communication Society at the time you were doing digital communications? That was a pretty early stage in the history of digital communications. Was the society still populated by a lot of people doing more traditional things?

Jacobs: Of course early on most engineering was focused on analog communications. While at MIT, Jack Wozencraft and I wrote one of the first college textbooks on the use of digital communications, *Principles of Communication Engineering*, published in 1965. Digital communications was still a controversial subject at that time. Several MIT professors advised us, “Don’t try to write it as if it has practical implications, but more as applied mathematics.” It was clear to us, however, that digital would play an important role in practical communications. What was not clear at the time was how quickly the technology for implementing digital communications would improve.

Morton: I guess people didn’t anticipate microprocessors and integrated circuits.

Jacobs: They certainly didn’t anticipate how fast it would evolve and the impact of Moore’s Law. In the early ‘70s LINKABIT was invited to work on a satellite equipment program for the Air Force. That turned into a powerful, flexible, and cost effective terminal we called the dual modem, and that was probably the first time we implemented CDMA technology. The Air Force program was a complicated one. We decided to use a microprocessor to perform the modem, coding, encryption, frequency control, acquisition, and networking functions. We first had to give lectures at Lincoln Laboratory and several Air Force laboratories

on the power of digital signal processing for the above functions, and how performance could be improved at lower cost and size and with improved reliability. At the time, there was no such thing as a single chip microprocessor, but one could implement one using components such as an Arithmetic Logic Unit (ALU) and register and memory chips. Klein Gilhousen pressed developing a small (32) instruction set, five-stack processor to achieve the speed needed while minimizing required ROM, and I worked on a number of the algorithms.

Because it was fully programmed, we first applied the Dual Modem to operate with the LES 8/9 experimental satellites, then added capability to support all modes of AFSATCOM, an Air Force satellite system, and later to support MILSAT as well. Originally we were just developing a modem with little chance of entering production, since we were competing with a major aerospace company with a few years lead time. When the development was nearly complete, we went up to Los Angeles to have a discussion with the General in charge of the program. He made a statement I've never forgotten. He said, "As a program manager, it's clear that I should proceed with the other terminal. It's already gone through certification and tests and we could go ahead with production quickly. That would be the cleanest way to continue my program, by far."

Morton: He was talking about the competitor's system.

Jacobs: Yes. But then he said, "However as a taxpayer, there is great opportunity for cost savings and flexibility in going with your system. I will continue to fund it to see if you can get it into early production." We did, and ended up with just about all of the production. The dual modem is still in use.

Morton: What type devices were used previous to the dual modem?

Jacobs: They were built out of hardware components with very little digital signal processing and little programming.

Morton: They didn't take a software approach and built a hardwired sort of thing?

Jacobs: Exactly. One interesting aspect of that involved a frequency-hopping algorithm. The algorithm was specified as hardware with detailed interconnection of a huge set of flip-flops and shift registers, with the output sequence depending on an entered key and time-of-day. Our competitor built it that way. There was a specification that said it had to be able to synch within two seconds following entry of a new time of day. With a hardware solution, they could not meet the synch spec because the flip-flops and shift register couldn't go fast enough following entry of a new time-of-day. Further, they had to incorporate a big box of capacitors to provide energy to keep the synchronizer going in case the main power failed. Flying back home one day I finally figured out how to implement the algorithm in software. Initialization required many calculations that took some time, but less than two seconds from a cold start. Once that was accomplished, the sequence could easily be calculated in real time by the RISC processor while performing all the communication functions. By going to software, we implemented the frequency-hopping algorithm with no new hardware, no separate capacitor box, and fully met the synch time spec. I bumped into the program manager from the competing company at one of the meetings. He said, "I understand that you claim you can meet the synchronization specification in under two seconds." I said, "Yes, we can do that." Then he said, "I hear that you're

doing it all in software.” I said, “Yes, that’s right.” He said, “You’re lying.”

Morton: Why is it called dual modem?

Jacobs: It was initially designed and coded to work with the LES 8/9 satellites. Then code was added to work with AFSATCOM, resulting in the dual modem name.

Additional modes were added for the Army (they then called it the tri-modem) and the Navy and it was later extended to work with MILSAT. Luckily, over time, ROM capacity increases allowing the new code to fit in the same package while adding functionality. Dual modems remain part of the inventory today.

Morton: Getting back to the Communication Society, I’m wondering if you had a global perspective of the society at the time. There was an interesting changeover or change of the guard in those years from people who were interested in and knew about analog techniques to people who were using digital techniques. A kind of revolution happened in some societies, and it wasn’t always a happy one. Did you get a sense of that kind of thing happening in the Communication Society?

Jacobs: I wasn’t aware anything other than an evolution in emphasis. There were meetings in the 60s where some people argued colorfully that coding and digital communication theory did not merit additional work – all of the useful research had been done - and many felt digital communications would be useful only in niche situations, such as deep space communications. This view gradually changed as digital technology improved and more engineers were trained to use the technology. I don’t recall a major revolution between the young and the gray hairs. A lot of the more senior people ultimately progressed from analog into digital.

Morton: Did you get a sense at that time that some societies within the IEEE were more theoretical than the rest?

Jacobs: The Information Theory Society was much more theoretical than the Communication Society. Then when we entered mobile communications we discovered interesting work in the Vehicular Technology Society.

Morton: Right. That was an oddly named society.

Jacobs: I used to subscribe to a fairly large number of the *Transactions*. I rarely had time to read through things in great detail but tried to keep track of what was being done in different areas. Occasionally I read an article in depth, and I always found that helpful. When you're actively teaching, you're must try to keep abreast of what is new, and the *Transactions* and *Proceedings* played an important role. In industry, it's even more important. It is easy to get locked into a narrow view while working on a given project and keeping to a time and dollar schedule. If you yourself don't keep current and encourage your company to do so, you have problems. We have provided employees with paid IEEE memberships to help them stay informed.

Morton: Sometimes new communications technologies depend upon the establishment of an industry standard for their success. Everyone has to start using the same standard before the new technology can succeed. In those cases sometimes a single firm's technology has become the standard due to commercial or economic factors. In other cases, standards being set by a third party or patent or some legal mechanism has been important. The digital telephony standard is a technology apparently in the process of taking over the world. We'll see if that happens. The

Globalstar system seems to be becoming a national standard. How did that come about in reference to these terms? Has it set standards truly dependent on the attractiveness of the technology or did standard setting bodies play a big role?

Jacobs: With Globalstar we didn't go through a standard setting. However there is now an ongoing effort to try to standardize radio techniques for satellite systems.

Morton: Is this mainly for telephony?

Jacobs: No, it will run on the terrestrial system too.

Morton: I thought that Globalstar was mainly a data transmission system.

Jacobs: No, it's voice and data.

Morton: The things I have seen on TV look like boxes that are installed in the passenger seat of truck.

Jacobs: That's the OmniTRACS. We didn't go through a standards process with OmniTRACS either. With standardization there is always an issue about the kinds of systems. If there are going to be many manufacturers assembling a product then generally standardization is needed. In the case of OmniTRACS, we are the only ones manufacturing. It's a proprietary system that we operate around the world. They are all manufactured here. We do share interface information to attach a variety of devices.

Morton: How have you prevented competitors from entering the field? Surely it could be done in a slightly different way.

Jacobs: In the case of OmniTRACS, we came up with the idea of using existing Ku-band satellites designed for fixed terminals to support mobile communications with no constraints on where the trucks might drive. To do so, we combined a hybrid

spread spectrum technology, direct-spread plus frequency hopping, and an innovative high-gain but low-cost tracking antenna design. Others have tried to compete by using specially designed satellites, but since we use a general purpose satellite which also carries many channels of TV and VSAT traffic, we can buy or rent transponders as needed at much lower cost. We have always had a financial advantage. The companies that have tried to compete with us over the years have mostly gone out of business. We had a good technical design that no one else has been able to replicate, and we continue to improve it.

As noted earlier, we returned in late October 1988 to examining CDMA in the cellular environment. During 1988, the industry had been battling over which technology to use to transition from analog to digital with the intent of improving spectral efficiency and voice quality. The choice was between time division multiple access (TDMA) and frequency division multiple access (FDMA), and after a long battle TDMA was selected, with no serious attention to CDMA, because it was believed to have too many unsolved and possibly unsolvable problems to use commercially. After a vote in January 1989 in favor of TDMA, a standards group was assembled to develop a standard by committee. In June 1989, I made a presentation to the CTIA arguing that CDMA has a number of strong advantages for capacity and quality. This suggestion wasn't well received because of the earlier battle, but no one found a hole in the technical presentation, We received some encouragement and continued (day and night) to work towards a demonstration to show that we had practical solutions to the previously unsolved problems and to better determine the capacity improvement for CDMA.

Chuck Wheatley, Roberto Padovani, and many others made significant contributions. The demonstration to a large group of industry representatives took place in November, 1989, and was successful, and we repeated it three months later in Manhattan to show CDMA would work in congested cities as well as San Diego. The cell equipment and “portable” telephone were not commercial size of course and we then proceeded to develop a set of integrated circuits to minimize the size and cost of commercial quality equipment. In November, 1991, we gave a second demonstration using the new chip sets, following cooperative efforts with a number of companies to openly test the system under normal and highly stressed conditions. In January, 1992, the industry decided to consider standardizing CDMA and voted to proceed with a standard in June 1992. In contrast to the TDMA standards effort, we began the process with a draft standard and a physical layer that had been already designed and well tested. The standard was published in January 1993. Although some signaling and other details changed during the standards process, the chip set used in 1991 remained usable.

Morton: Who does the standards for this industry?

Jacobs: The standards work was under the auspices of the Telecommunications Industry Association (TIA). It later became an ANSI standard and later was adopted by several international standards groups.

Morton: Have standards been important? There have been cases where the standard setting bodies have debated things only to end up establishing a number of standards and saying, “All of all these are viable standards. Let’s see what happens.”

Jacobs: Standards are important since most countries will not allow a non-standard

cellular technology to be used. The analog AMPS and a later NAMPS version, TDMA and CDMA are all cellular standards. A GSM standard was introduced in the U.S. for PCS. Thus, in the U.S., operators could and did select among several competing standards, although all but GSM shared a common mobile-network standard, ANSI 41. Thus, there are several standards in this country, which is fine. Companies can build equipment to the different standards and let the marketplace decide which works best and has the most desired features. CDMA had the opportunity to prove itself and is the basis for just about all third generation systems worldwide. Operators who chose second generation CDMA now have a rapid, low cost and powerful evolutionary upgrade to third generation cellular, which would not have been possible if the U.S. had allowed only one digital cellular standard as in Europe.

Morton: That's interesting.

Jacobs: Standards have become important in that sense. Standards can have proprietary information. When you are part of the standards process, you are generally required to inform the standards body if you believe you have proprietary information in the standard and, if so, whether you agree to make it available either freely or in a fair and equitable fashion to any company that wants to build equipment to that standard. Each standards group has slightly different rules, but each has a means of dealing with proprietary information imbedded in the standard.

Morton: If I'm interpreting this right, in the case of the recent work in telephony they went with a sort of licensing arrangement so that competitors could be included.

Jacobs: In the case of OmniTRACS we decided not to license it to others, whereas in the case of CDMA, we recognized the need for competition and many manufacturers and now have over 100 companies licensed to support what will soon exceed a billion users of wireless phones and devices. CDMA technology is advancing rapidly with high-speed wide-area wireless data and access to the Internet rapidly becoming available. Phones are supporting more and more multi-media functions, PDA capabilities, and precise GPS position location. QUALCOMM is developing and rapidly introducing many new functions into chip sets and associated software so capabilities can be brought to market quickly, new applications from many developers can be downloaded to phones using these chips, and so phones can work seamlessly with networks built to different standards. I believe competition is beneficial and will continue to drive rapid growth.