# Oral History of Dov Frohman

Interviewed by:
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**Jeff Katz:** Good afternoon, I'm Jeff Katz from the Computer History Museum [on May 2, 2009]. We're here with Dov Frohman, who was the inventor of the EPROM, Erasable Programmable Read-Only Memory, semiconductor type, which we'll learn a little bit more about later. Let's first delve into a little bit of your background, Dov. Could you tell us where you grew up, where you went to university, and what you studied and things like that?

**Dov Frohman**: Well, I was born in Amsterdam in Holland, and that was 1939, so naturally a pretty hectic time. Then I went through the underground to southern Holland, to a, to a Protestant family and was hidden there during the war. After the war I was transferred to an orphanage in Belgium, then to France, and then from Marseilles in 1949, I got to Israel. Basically primary school, secondary school, then I went to study electrical engineering, at the Technion, which was mostly at the time electrical engineering, electrical machines and stuff like that, with a little bit of electronics, too.

**Katz:** Let me interrupt there. You arrived in Israel at age 10, and as a young adult, sometime later, you entered the technical study field. What got you from an immigrant at age 10, to an aspiring engineer?

**Frohman**: Frankly, I really don't know. I know one thing, that I was always fascinated by electrons. When people were talking about the fact that electrons were doing this and that, it sort of caught my attention. I think I basically went to engineering to figure out what electrons were all about. And to date, I don't know what they're all about, so--

**Katz:** Fair enough. All right, so you chose a technical field because you were curious about physical events or activities.

**Frohman**: That's right, because I'm not really technically oriented basically, so it was curiosity more than anything else.

**Katz:** Interesting. At the Technion, what did you study there, and what happened after your studies there?

**Frohman**: I studied electrical engineering at theTechnion, it's a four year program, and of course I was in the army before that. That's a forming experience, but not technically, necessarily, and in those four years, in the last year, one of my professors was Professor Yoeli, he came back from the US, and brought back knowledge in switching systems, logic and stuff like that, and he taught the course. I was fascinated more by the phenomenon of an Israeli going somewhere, to the US, picking up some experiences, bringing it back to the country. That's where some of these drives struck me: that I really need to go somewhere,, bring back something, I didn't know what. Switching theory was fine, and logic was fine. It was interesting. But it was not really the driving force at the time. We did have a very minor exposure to semiconductors. It was completely accidental, I think, that I eventually wound up in that area.

**Katz:** Well semiconductors were in their infancy at that time.

**Frohman**: That's right.

**Katz:** Not many universities had major programs. In the US, where did you study and what did you study?

**Frohman**: In the US, I went to Berkeley. I had actually applied to MIT, and to the University of Indiana, or something like that. I actually got acceptance in most of these places, but somehow I got intrigued by Berkeley. It was '63 when I arrived. I think Berkeley attracted me because tuition was lower, and it was easier to get some kind of research assistantship. There wasn't any research assistance at that time, it was some kind of a support package for international students. There I studied electrical engineering, computer science. Again, I think, completely randomly I drifted into the computer science end. I started working on some, what was called at the time, step recovery diodes, for my masters thesis, with the professors on the semiconductor end of the spectrum. But slowly I started gravitating, from step recovery diodes and switching, toward the computer science people. I really switched completely only when I got my Masters degree in 1965, I went to work for Fairchild. It's interesting now that I think about it, because I got acceptances from HP and IBM in San Jose, but I went to Fairchild, I think for the same reason I went to Berkeley. Because Fairchild R&D impressed me as sort of an environment, an open environment similar to what Berkeley had very strongly planted in me: do your own thing. The Berkeley experience was a major forming experience beyond the computers and electronics. I chose Fairchild, really on the basis of an impression at the interviews, rather than a keen interest in semiconductor R&D research.

**Katz:** Had you known any of the Fairchild people?

**Frohman**: No, I didn't. I didn't know anybody. I knew only the professors at university and they were not really tied very strongly to Silicon Valley at all. Stanford was really more tied to local industry than Berkeley. The overwhelming experience in Berkeley was the free speech movement.

**Katz:** Berkeley in the '60s.

**Frohman**: And that was incredible, especially for somebody coming from Israel, where you go to the army and then you go and study very seriously. You don't have time to protest, even when the issues are very grave, you're just very committed, All of a sudden, you land in Telegraph Avenue, and you see all these activists at ‘Hyde Park’. That was a very overwhelming experience and influence.

**Katz:** I imagine it contrasted pretty sharply with the Fairchild R&D experience, then.

**Frohman**: Well, culturally of course, but really-- I think some of the Berkeley attitude did apply, in retrospect. I look at Berkeley: it showed that a small group of people can make a major impact. I think

Fairchild was the kind of place where, though it wasn't written on the mission statement, that if you join the team, we can make a big impact, The atmosphere was one where you could really contribute quite a bit. So it wasn't that far away from Berkeley in terms of the general cultural overview.

**Katz:** What kind of work did you do at Fairchild?

**Frohman**: At Fairchild, I interviewed two departments, the Physics department, run by Andy Grove, and Digital Integrated Electronics department, which was run by Bob Seeds. Now, naturally, because I came from Israel, I wasn't very much into semiconductors. Andy was pressuring me to come to his department, but I chose to go to Bob Seeds' department. I don't think Andy ever forgave me for that decision. He probably doesn't remember it by now, but at the time, it was a big deal. Of course, within half a year, we collaborated on papers and projects. Collaboration was not a major problem there. I worked for Les Vadasz at Fairchild, he was reporting to Bob, and I worked basically on digital integrated circuits. And with time, because I had done my thesis on MNOS, Metal Nitride Oxide Semiconductor non-volatile memories, we started drifting into that area. So I started getting really seriously involved in MNOS devices. We made some, we never really sold any, but it was an R&D facility, so we made some, we gave papers, I did some work on it, but we didn't get it to the point of any kind of an impact. MNOS was the mainstream of non-volatile memories so there was no big technology rivalry, except the normal company rivalries between Fairchild and RCA, and Bell Labs and IBM. But everybody was doing the same thing, basically.

**Katz:** At that time, when you started at Fairchild, you had just got your Masters. Did you continue as a night student or take time off from work somehow to finish your PhD?

**Frohman**: No, no, no, In about '67, I asked to go back to school part time, and continue to work at Fairchild. This was a great decision, because it allowed me to really work-- do the Doctoral thesis on MNOS devices. Of course only after I searched for a thesis advisor. That search got me even further into computers, because nobody in semiconductors wanted to even touch the MNOS subject. My Masters thesis advisor was Dick Evans [ph?], (I think he died recently. ) He was also in Computer Science. I finally got to Bob Graham who was completely in Computer Science. Evans was still a little bit closer to circuits. Graham was in Computer Science. I went to him, and I said, "Look, I want to do a thesis on this." He looked at me, and said, "Look, I don't know anything about all this stuff. I don't mind being your advisor. I will come to your thesis defense, but on the condition that you're on your own. You just do it, and you defend the thesis, and yeah, I'll be your advisor, but I can't contribute very much." And that's the way it was.

**Katz:** So the PhD that you got was then closely related to the work you were doing at Fairchild.

**Frohman**: Yes, absolutely. That really allowed me also to finish the PhD in about a year and a half, because going through the exams is one thing, but,I did much of the practical work at Fairchild. And because I had the kind of advisor that couldn't care less, there was no problem. He didn't have a lab where I could do it anyway.

**Katz:** Nobody told you to do it over?

**Frohman**: That's right.

**Katz:** Okay, so now let's go a little further from that experience. When you got your PhD, did you continue your work at Fairchild on similar things, or did you move on, or what?

**Frohman**: No, I got my PhD in the summer of '69. Intel was founded in '68, August '68, I think. Of course I had worked very closely with Andy, with Les. Les was my boss at Fairchild. Andy said, "You know, why don't you come over?" I said, "No, I want to finish my PhD first. I'm close to finishing it." And so I stayed at Fairchild, actually, until the summer of '69. It was a big problem for me, in retrospect, because even though I stayed at Fairchild for my own reasons, when I announced that I was leaving to go to Intel, the rumor circulated was, that I stayed behind for a year to collect all the information that these guys didn't pick up when they left. <laughs> So that was not a very good reputation to have, but it was very temporary.

**Katz:** You got to Intel in '69. What were the first things that you worked on there?

**Frohman**: I came to Intel, and of course my intention was to work on MNOS, but Intel was a startup, and in a startup, you usually don't get to work on what you want. When I came in, there were two products in development. There was 1101 256-bit NMOS RAM, and the 3101 64 bit bipolar memory. Immediately when I came in, the issue was that we had to make a decision as a startup in '69, whether we're going to go the next step to do the 1K memory, do it monolithic or do it hybrid. It was a question of taking either four 256-bit chips hybrid to make a 1k, or with a single monolithic 1K design. So they put me and Tom Innes, who was working on bipolar development, on doing flip chip technology for hybrid packages. I didn't know anything about flip chips. We worked on it for two months, did the flip chip of four MOS memory chips, and then we brought it to the bosses. We said, "Okay, we have a working hybrid prototype, and we'd like to know which way are we going?" We came into a meeting, with Gordon, Andy, and I think Noyce was there, too. We were very happy, very proud, you know, young engineers, who had made the flip chip hybrid thing work. We said, "Okay, now we need the decision." There was a little bit of talking between Gordon, Andy, and Les. And then Gordon said, "It's good work, guys, but I think we're going to go monolithic." So then they diverted me, finally, to MNOS, because I didn't have any added value any more in any urgent projects.

**Katz:** Your work on MNOS, how did that proceed, and was it successful?

**Frohman**: Not very well, and no. Basically I made a test pattern chip. I knew what I had to do. I needed to get this test pattern chip through the processing line. But you know, it was a startup; there was a processing line for silicon gate MOS, and one for bipolar. I had to really twist arms and call favors and everything, to get this strange nitride deposition through. I had some success, but nine times out of ten, when it came out of the line, I had very few devices processed well enough that I could even look at and check. After about a month, I got pretty frustrated, but I continued doing it.

Sometime around three months into my project, a reliability problem developed in the 1101, the company's main 256 bit MOS memory product. We couldn't really sell the parts because they were unstable. At 85-85, 85 degrees C, 85 percent humidity, they were failing the test, they were drifting and they were unstable. Les called me in and said, "Okay, enough fooling around with this MNOS, here's a real problem: Figure out what the reliability problem is, and, more important, find us a solution for it." Of course I started immediately working on it. It turned out that, basically, the insulator interfaces were becoming conductive in high humidity. There was metal contamination on some of the interfaces, and electrons basically drifted off the metal through the interfaces. There was a reasonable level of conductivity because of the humidity. It slowly developed a sheet of ‘’metal” on the interface of the insulator. It was a very thick insulator, but still, it impacted the junctions and the performance of the devices. ,Finding out what the problem was, was relatively easy. Also with the pressure of a startup, you know, you work 24 hours if necessary to find out what's going on. The solution was also pretty straightforward, because it was a matter of really controlling the deposition conditions, so the interfaces would be more inert, and would not be conductive. This study and the solution took a period of a few weeks.

**Katz:** Roughly when was this?

**Frohman**: This was something like October, November 1969.

**Katz:** Oh, shortly after you had arrived.

**Frohman**: Yeah, yeah, I didn't do much until that point, except for the flip chip. And that's really the time when the idea of a floating gate MOS memory device came about.

**Katz:** There had been discussions in the industry, of floating gates made of metal, earlier than that.

**Frohman**: Yeah.

**Katz:** Were you consciously trying to improve on those discussions?

**Frohman**: No, no, no, there was no relation. First of all, the ideas of Kahng and Sze of Bell Labs and some others, were all following the MNOS model. Instead of using a nitride interface, you used a gate. But the concept was basically the same, and even then, people didn't always publish papers on good ideas, you know. When was the Kahng and Sze paper published? I don't remember.

**Katz:** '67 possibly. Late '60s.

**Frohman**: Yeah.  I was already in the process of developing the EPROM memory I think, when the Kahng and Sze paper came out. Before that, we weren't really aware of any of that work. And I don't remember exactly where they published it in a conference. I don't know which conference it was.

**Katz:** I don't know if it was at a conference. The “67 paper I read was published by the Bell Systems Journal. And I don't know in what context.

**Frohman**: Most likely at that time we didn't even see it. Later we started being aware of it, because I applied for a patent to improve on the floating gate by putting another gate on top to erase it. That was something like ' 71 when we were confronted with the Kahng and Sze paper.

**Katz:** So how did you get from curing the 1101 problems to working on what became EPROMs?

**Frohman**: Frankly, I don't know. There's a lot of talk about identifying the “ah-ha moment”. But  A, I don't know what it is, and B, I'm not sure there is an “ah-ha moment”. Why? Because my belief is that you come to realizations like that through daydreaming. And you never remember how it came about. In retrospect, it's a combination of a random opportunity, which was that 1101 instability, and daydreaming. When you work on something like that intensively, at some point you say to yourself, "You know, these charges are causing a lot of problems at the silicon surface, maybe we can use it as a memory device." But how, when, where, that insight occurred, I don't know.

**Katz:** So you had been working on non-volatile memories, and you, apparently at some point, became aware of the idea of storing charge on a floating gate. Was there an immediate leap to, a plan:  “let's do it on a silicon gate”?

**Frohman**: Pretty much, because it was very natural. I mean, a silicon gate was very well understood at Intel. It turned out to be an ideal technology for storing charge by complete coincidence. ,Because a metal gate would not have worked as well. And by the way, the answer is yes for another reason. We didn't have any other technology.

**Frohman**: And after my experience with MNOS, when I couldn't get it through the line, I wasn't about to propose another unusual technology.

**Katz:** When it dawned on you that you could harness the stored charge, and control it, were you working then to make sure that you could do that reliably, or were you looking for a way to make it reversible, to erase it? What was the main goal of the project at that time?

**Frohman**: The main goal of the project was to make it reliably. It was a complete deviation from main stream Non-volatile Memory at this point, to the point where, in the '70s, there were two camps, the non-volatile semiconductor memory and the, what I called the FAMOS device with the floating gate. The deviation of FAMOS from the mainstream was that you just stored charge in the gate in the middle of nowhere with no connection or access. The idea of the two gates with MNOS, or even with oxide, was comprehensible, because you put the voltage on top, and you tunnel charges through a thin oxide and you take them off through--

**Katz:** Was the thin oxide the main distinguisher between the mainstream and the non-volatile? Is that the thing that made it different?

**Frohman**: No-- the thin oxide was in the mainstream standard process.

**Katz:** Oh, it was.

**Frohman**: Well it was either nitride, which was equivalent to thin oxide, because it was a very thin nitride, and/or a thin oxide, because you had to tunnel through it. All of a sudden we realized you could make a memory device with exactly the same technology, 1,000 angstrom oxide. We didn't touch that, of course, in passing. The main impact was really that you didn't have to change anything in the process. You just had to disconnect the gate, and that was trivial. Now clearly there were some assists in the thought process, because you still had to inject charge into the floating gate. We didn't do it by tunneling, we did it by avalanche injection, which was a second sort of main difference from the mainstream products. That idea came through the work on reliability, where I had noticed quite quickly that the reliability problem got very bad when I put a junction into breakdown. And then I started thinking, so when the idea of the floating gate device came about, and I asked myself, how was I going to charge the floating gate. A pretty obvious conclusion was that the first thing you could do was bring the junction to breakdown. Now that was not a great idea, because you don't want the whole 2k memory chip to breakdown the junctions in order to write. So effectively what it evolved to pretty naturally, was that you could inject charge from the channel. I didn't think about all this stuff. We had a device, with only two contacts, drain and source. You put a voltage on the drain with respect to the source. Now what magically happened was that there was capacitive coupling to the floating gate, which turned the channel on. That allowed charge to avalanche inject into the floating gate. It was a much more complex process than I ever considered. So what I'm saying is, I don't think the “ah-ha moment” exists. I don't know what the main insight was, but once you had that, the rest of the process was almost predictable.

**Katz:** Did you do the work essentially solo, or did you have a team working with you? How was the project organized?

**Frohman**: The project was not organized, it was a startup. I was by myself at the beginning. Of course I consulted Les Vadasz at various steps but at the beginning I worked all by myself. Keep in mind it was a completely crazy idea, and the first time I came up with it, and I started talking, even to enlightened scientists and engineers like Gordon, Noyce, Andy, Vadasz, there was a lot of skepticism. It was not something that was intuitive or obvious., that it would really work and be reliable. The main struggle was showing that the new kind of device was reliable.

**Katz:** So injection from the channel was the way to get the device charged. How did you happen upon the way to get it discharged, or erased?

**Frohman**: Well, first of all, to erase it, the most straightforward thought was x-Rays. You have charge floating in the middle of nowhere, you x-ray the chip, the charge bleeds off. You give it energy, the charge goes back to the substrate. The problem was, it was too easy. X-rays create a lot of instability at the silicon interface. We didn't quite anticipate that. I said to myself, "Well, X-rays doesn't look like it's going to work." So we needed to go to something that's really non-destructive. I started working on ultraviolet light. It was, again, not a brain explosion. I mean, it was obvious that you needed some radiation to get the charge to bleed off, and X-rays didn't look like it would work. Ultraviolet would be non-destructive. It worked very well, but then, of course, I remembered that we were in a startup.

I was starting to be very preoccupied with this issue of the erase. The ultraviolet was fine, but in order to erase with ultraviolet light, you needed to take the product package and have a quartz window molded into it, so you could shine the ultraviolet through the window. I felt that our production people would just lose their hair if they heard this idea. I was walking in the hall in Mountain View, and Bob Noyce came toward me, and he looked at me. He was a people-sensitive guy. He looked at me, and said, "Dov you look preoccupied this morning? What's the matter?" And I said, "Look, we have the basic device working, we can program it. I can erase it with X-rays, but X-rays are not reliable. Now I am using ultraviolet light, it works very well, , But the problem is, if I go to the production people with an idea of a quartz window in the package, they'll throw me out the door." He looked at me, sort of slightly annoyed. And he said, "So what?" —I said I hadn't even considered seriously that a quartz window could be done. He said,, "Why not?" We got an agreement that there would be a quartz window on the package.

Then there was another important stage, which was that we had to come up with a demo for management before we started developing the idea into a product. This was to get the authorization to go ahead and design the product, which was a major investment expense. And so we made a demo-- I wish I had a picture of the demo. Nobody would believe it. It was sort of a kluge box with 16 TO5 cans, TO5 cans, they were cylindrical and long legged, they were stuck in there. There were 16 red lights, I came into the conference room with this kluge. There was Gordon and the same crew. I showed that I could program it, and I could erase it. To erase we simply took the TO5 cans' caps off so we could shine UV onto the chips within.. I don't remember right now whether the quartz window package issue came before or after that, but for now we simply cut the tops off. We erased, it worked very well, everybody was impressed, but still extremely skeptical. As a brash young guy, I said, "Well, looks like it works. I propose that we make a 2,048 bit memory." <laughs> And there was quiet in the room, and everybody looked at Gordon. He was supposed to be the decision maker. Gordon was quiet for about 30 seconds, then, to everybody's surprise, he said, "Sure, let's do it."

**Katz:** So Noyce was not involved in that decision?

**Frohman**: I don't know if he was there or on a marketing trip, but he would have been for it, for sure. Noyce was the least of my problems on that one.

**Katz:** All right, so you had the 2,048 bit memory authorization, and you got it working. What happened then? How did the world find out about it, and the customers begin to adopt it?

**Frohman**: Well, once we had really the prototype product, not a production unit yet, of course we went to the International Solid State Circuits Conference (ISSCC) in '71, and presented it. It was a big hit, because it was a complete surprise. I mean we didn't give any advance indication of our success. The paper simply was written and submitted to ISSCC. You know, the people who need to do the work, you write a paper, it doesn't mean you can make a product out of it. After the excellent reception at the conference, we started doing marketing trips.

**Katz:** Were you involved in those trips? —Did you go to try to convince the customers that it worked?

**Frohman**: —Yeah, yeah. I was involved also in marketing trips to convince customers that dynamic RAMs worked. We did not really intend the EPROM to be a long-term use memory. We considered it at the time, as a prototyping device that system designers could use on the PC board, check their system and then put the program into cheaper mask-programmable ROMs. It was the customers, well, one customer, I don't know which one, who said, "I don't see why,we need to spend the time and expense to switch to ROMs. after the system works with EPROMs everything is fine. You just supply us some more EPROMS, and we'll use them in the system for production."

**Katz:** Your original paper had suggested that, through simulations or some accelerated testing, you predicted ten year retention of the data. Was that a major factor in getting customers to use EPROMs?

**Frohman**: It was a major factor for two reasons: First, to convince the customers that it would last, and second, to convince ourselves that we were selling something that will not lose its charge. Actually we did not have any scientific proof of that, because it is impossible to make a long-term extrapolation of this charge loss process. You never know where it's going to happen. It could be though some silicon dioxide defects. But it turned out that that was not the case.

In retrospect, the ten year projection was conservative. Some customer systems lasted for more than ten years, and we never got any complaints about charge loss. If you sold a whole lot of devices to customers who had them working for, say five years in systems and the devices started leaking and started losing charge, then the systems would fail and we would have gotten major feedback from those customers. It was a risky extrapolation. I was convinced because of the testing we did. We put devices on the roof, to see whether ultraviolet from the sun would impact them through the quartz window. And of course we had long term accelerated life tests at high temperature tests. We had to guarantee ten years, but we couldn't really ***guarantee*** ten years.

**Katz:** Yet still the customers fell in love with it.

**Frohman**: Yeah, because for most customers, if they don't have a military or space system,  certainly five years was a pretty sure bet. If it worked, they would go for it. I remember one thing, though,that the first time I heard that there was an EPROM in one of the space applications

**Katz:** Well there are X-rays up there.

**Frohman**: That's right!  My heart sort of lost a beat. <laughs>

**Katz:** In thinking about the whole EPROM project, what was, in your mind, thinking back, the biggest problem you encountered? Was it figuring out how to get it charged up, or how to get it erased, or how to get a quartz widow on it?

**Frohman**: No, I think it was how to get it sold internally. The decision to go into making a product was really the critical one, and you know, I think without Gordon, it wouldn't have happened.

**Katz:** Interesting. Well now let's move ahead a little from the point where the EPROM is working and becoming accepted in the marketplace. You didn't stay at Intel a lot longer after that, did you?

**Frohman**: Well,  I —left Intel in '71,  I went to Africa, to Ghana.

**Katz:** What prompted that move? Why stop on a high point when you could have gone further in the company?

**Frohman**: Well, first of all, I'm kind of a crazy guy, you know. It wasn't really a super-sane decision, but that's sort of a way of my life. At Berkeley, I learned all about doing your own thing. Already in Berkeley, I wanted to travel. First of all, I thought about South America, then I thought about Africa, and I started writing letters while still at Berkeley. And I got responses, it's a different story in itself, but I got all kinds of responses.

**Frohman**: In Africa, there are, or were at that time, Anglophone countries and Francophone countries. If you were not coming from Paris or from London, they didn't want any part of you. —For my first job, I didn't do my own thing, I went to Fairchild, and then later I went to Intel.  I said to myself, "Wait a minute, you know, when am I going to do my own thing?"  I didn't think my career should be in the US, I would be better off going back to Israel. The memory of that Professor bringing back knowledge was still with me. I figured that my impact in Israel would be much more significant than my impact in the US. And so when I completed the prototype of a 2k EPROM memory, I thought it was a good point to go. Andy didn't agree. He thought there were Engineer A, and Engineer B; Engineer A was the one who developed a product and brought it to production. Engineer B, was the one who developed the product and left somebody else with the problem. In his mind I was Engineer B, of course. But I went anyway. It was a very fulfilling experience in Ghana and in Africa in general. , and then came back to--

**Katz:** What, exactly, were you doing in Ghana?

**Frohman**: Ah, in Ghana, I was teaching electrical engineering and electronics. You know, at the time, '73, I thought that Ghana was a dump. Many people today still think Ghana is a dump, But Nkrumah, in '57, I think, when he took over, he sent a whole bunch of Ghanaian academics to London, to all kinds of places to study.

Eventually there were a lot of academics who came back to Ghana, There was really a very competent faculty there in the University of Kumasi, where I taught electrical –engineering. Of course, my purpose for going to Africa was to travel and learn, not to teach. Every vacation, long or short vacation I was out of the country on a trip somewhere else in Africa, Three times out of five, I got stuck on the border because there was a coup d'état in the—area. I told the students I wanted to set up a traffic light system on campus, not that it needed one. There were only two roads crossing each other. I said, "Let's design it." So we designed the system. Then I started writing to all my colleagues at RCA and Intel, every place I could find components for the system. We set up a traffic light system that worked. I'll have to go back to Ghana to see whether it's still there. Though I doubt it. So yeah, I really had a good experience—in Ghana.

**Katz:** It lasted how long, that experience?

**Frohman**: That experience lasted from, end of '71 to the beginning of '73.

About a year and a half. And I travelled a lot during that period, and occasionally got caught in a tribal environment. Even though they were very proud tribes, they wanted to emulate the west. I had a lot of very, very forming experiences in that year and a half stay.

**Katz:** So after that year and a half, you then went back to Israel?

**Frohman**: No, I went back to Intel. They agreed to take me back for as long as I wanted, but I didn't want to come back for very long. I came back for half a year and mainly started pumping Andy. I had started that already at Fairchild, to try to get some kind of an R&D operation into Israel. I was not successful doing this at Fairchild. When I came back to Intel, I started talking again about—it.

**Katz:** Were you at Intel on an assignment, or had you given yourself your own mission?

**Frohman**: No, no, no, I got a project. They were still working on N-channel, on EPROMs and so supposedly I had some added value there in that area. And then it was a very, very short period of time. In '73, there was a very strong shortage of engineering power and professionals in the US. Intel had a lot of designs to complete, especially for the demanding automotive industry. Andy went to the automotive people, and told them, ”We'll give you all the design rules for our manufacturing process, you design the product and we'll run it for you.” But they said, "No, no, you design it." That created a need for incremental design capability. I saw that as an opportunity that I basically latched onto. Andy came back from some kind of a trip. He brought up the subject of, could we start a design center in Israel? And of course I said we can do it.

**Katz:** Had you already planted the seed with him, or was it his idea, from scratch.

**Frohman**: Oh yeah, yeah. I planted the seeds beginning in the days of Fairchild in 1966, and many times afterward I'd been talking about it. I kept the thing alive, even when there was no chance. Even at Intel, at that period of time, we were, I think-- barely a 100 million dollar company. To set up a remote design center overseas was not exactly the most straightforward decision. But that shortage really was a trigger point for the idea.

**Katz:** Why did you pick Haifa?

**Frohman**: Mainly because Haifa had the Technion, which was a source of professional manpower. At that time it was important. Later on there were a few more universities and you could get talent anywhere. Israel is small, but still for somebody to go to study in Haifa and take a job in Tel Aviv or Jerusalem, that was still a bit-- took a lot bigger opportunity than staying in Haifa to work, to do that. So this is another interesting story, the recruiting trip.-- the people were to come to-Israel- I was going to go to Haifa back and prepare candidates for interviews. The idea would be to hire enough to start a very small design center, five engineers, start with some kind of insignificant project.

The people coming to interview candidates were Andy, Les Vadasz, and Art Rock . It was scheduled for the 16th of October 1973. That was very interesting, because the 6th of October, the Yom Kippur war erupted. Now any sane, normal executives would have said,. “Sorry, Dov, that doesn't look good.” Not Intel. I don't think Andy got too much backtalk on that. I did not have to twist arms or anything, it was obvious we decided to do it, the worst is already over, and we were going to do it. It was the mentality, the philosophy of the operation. The company invested something like $300K, which was not negligible at the time. We went back in April '74, and started with five engineers. I guess, like they say, the rest of it is history.

**Katz:** Did you need government approvals and sponsorships at that time, just for a five person lab?

**Frohman**: Yeah, because it was the first really high tech type of operation in Israel. I'm not including software, I'm talking about circuit system and device development. There were a lot of government systems, defense systems, obviously. Since there were incentives that the government was giving, we were after them. There was not a very difficult negotiation, because the investment was not very large, so the government didn't have to do very much. And it helps to have an approved project by the government, because, after you deal successfully with some of the bureaucracy, it definitely makes it easier to keep going.

**Katz:** I imagine that the original operation there became sort of a cult draw to the students who would love to have a local job instead of have to go overseas.

**Frohman**: Well, in retrospect, not so much. Overseas was attractive if they could get a job, and afford to fund their way. But I think the impact was really way beyond what I envisioned. First of all, even with this development center which grew pretty rapidly, and from insignificant projects, we soon went to, among others, the important 8087 math co-processor and other very complex chips. But the point is that we accomplished two major things: One is we showed to other multinationals that you could be successful operating in Israel. Before that, there were almost none to speak of, except for some partnerships. And second, we came in with a lot of management systems, quality philosophy, integrity, all the stuff that was pretty much nonexistent in Israel. Over a period of time, this had a very, very major impact. As a matter of fact, this was very visible to us, at least to me, during the gulf war. By then we already had a manufacturing facility in Jerusalem as well as the development center in Haifa. To meet our business objectives, we called the people to come to work during the scud missile attacks.

**Katz:** I guess you were a pretty high profile potential target.

**Frohman**: In retrospect, I don't think so. Haifa was really out of range. And it turned out, though we didn't know it at the time, Jerusalem was also not a target, even though some scuds fell, because it's a holy city. Scud accuracy was not good enough to make sure they didn't hit the Al-Aqsa or one of the mosques. The main issue was that we needed to continue operations mainly for the future of the high tech industry in Israel.

The call for employees to come to work, of which 80, 85 percent came to work, was, basically, driven more by Israel's future than by Intel's future. It was driven by our saying that if we are interrupted by war that will not be a major problem in the short term. A two or three week interruption is okay. At that time, we were already a major supplier in Intel's manufacturing system.. To me, this would have been something we could recover from. But the long term impact would be significant, 'we don't want even a temporary interruption experience like that again'. And so by not setting that temporary interruption precedent, that was really the key in terms of long-term viability as a manufacturer. And n retrospect, it was right.

**Katz**: And the employees, apparently, all agreed?

**Frohman:** No, not all.

**Katz**: Or enough of them.

**Frohman:** Most of them agreed. There was quite a bit of criticism about the fact that I was taking a risk with the lives of my people. They were coming to work under adverse conditions.

**Katz**: Let's back up a little bit to before there was the manufacturing system and the potential threat to it. When there was just the R and D center. What was your own personal involvement in that, were you still engaged in product development? Or were you into management or government affairs or what?

**Frohman:** No. I was actually at the Hebrew University in the School of Applied Science, starting a microelectronics lab and, as a side effort, developing the workforce for a future fab. And I was a consultant to Intel. I would spend two or three days at a time in Haifa. I was not involved in product development, at all. I would support it from the government standpoint. The first design center manager was American, Tom Innes. He needed a lot of helping hand, in terms of Israeli culture and how to go about things. And we had a lot of non-product-development issues, like the remote communication. We had to buy one of these big Fax machines, the first ones, at $15,000 a piece. They were to keep communication to the U.S.via the telephone system.

**Katz**: And those midnight meetings, when it was mid morning in the U.S.

**Frohman:** Exactly, exactly. So there was a lot of defensive interference that needed to be done with the government, and with Intel. That was the main thing I worked on. My job was to keep the government happy and keep Intel happy. And we managed. I still remember there were cases where somebody would call me up from the U.S to complain. Hank Blume, once called me up from the U.S. And he said, "You know, we can't work that way. I mean, it takes us three to four weeks longer to tape-out a product than we would do it here." And I said, "Why?" And he said, "Well, I need the answers to A, B, C, D." I said, "Well, no problem. We'll send you the people who have the answers. . What's the cost of a trip ticket, compared to delaying the project?" So we started this training and travel program. Travel at the beginning, one way and then, two ways. And that worked very well to integrate the Haifa design center into the company.

**Katz**: Very interesting. You mentioned you were planting seeds in the University system to have a manufacturing staff. But how did you get Intel convinced to build a plant there, as well as the R and D center?

**Frohman:** Well, the situation was, actually, pretty much, a replica of 1973. In 1978, there was a production professional manpower shortage in the U.S. I was patiently waiting for an opportunity. And, as usual, a random opportunity came unexpectedly. It was the very infrequent trip by Gordon Moore, the first time he came to Israel. He came just to see capabilities. He didn't come with any agenda in mind, as far as I know. I took him around, but I didn't push the fab idea, at all. I just took him around to show him the capability in Israel. We talked to the government. Very nice trip. What's nice at Intel, anybody who comes back from a business trip, even Gordon, writes a trip report. For one reason or another, I received-

- I didn’t always get all the trip reports, but this one I got.  It was a very, very positive perspective on Israeli capability.  He was very impressed.

I don't think there was a hint about the manufacturing capability.  But I decided it was a good time to hop on a plane and go to Santa Clara and see, not Gordon, but Andy.  And say, "Andy, I read Gordon's report.  Maybe your manufacturing guys are ready."  Of course, I got a lot of pushback and stuff like that.  But the result was that "We may not be ready, but we need some extra manufacturing capacity.  We want you to compete with Ireland on this.  And then, we'll decide.  We'll see both presentations and we'll decide'."  And so I don't know whether you knew or know Des Fitzgerald.  He was in charge of Quality Assurance at Intel.  He was an Irishman.  And so Andy just said, "Des, you go and represent Ireland and come with a package and everything."

Of course there was a major difference with me being really an interested party and Des doing it simply to compete with me.  So chances were that my presentation would be much more convincing.  And I came to Santa Clara, and there was a presentation by Des.  Then I went through most of my presentation, and it was very upbeat.  You know, you can sense the audience approval.  We had government incentives and everything, because I had done some preliminary work.  And then, I came to almost the last slide.  I said, "We will need to train some people for this fab, because we don't have that skill in Israel.  So we have to bring in our people to the U.S. fabs."  And Andy asked, "How many people are you planning to bring?"  I said, "Only 120."  He went through the roof.  He said, "Forget about it.  The answer is no.  And there's nothing more to talk about."  But I knew that Andy. In public session and in person are two different things.  So I ran after him.  It was Friday afternoon.  I ran after him on the stairway.   I said, "Andy, give me another chance."  He said, "Leave me alone.  I'm going skiing now."  I said, "Well, give me an opportunity."  He said, "Okay.  Come next week, Tuesday."  By Tuesday, I had worked with some of the people involved.  Over the weekend, I worked by myself.  But then, I had Monday to get the support of some of the people.    We did some charts, showing the load of the people on the fabs, versus their contribution after three, six months.  An estimate; right?  And so the load was in red and the contribution was in blue.  I first went into his office and talked to him a little bit one-on-one, and told him what he should expect in the main meeting, with a few more people present.  When I showed these  red and blue charts, he said, "Okay.  Go for it."

**Katz**:  With the same 120?  Or you had to modify that to…

**Frohman:**  No.  I didn't take the number down.  No.  I knew that day, if I took the number down that he would say,  “You're not going to do a good job if you wanted 120 and, now, you're going to try to go with 50.”

**Katz**:  So you got approval finally.  And it was a raw construction job,because there was no fab you could move into in Israel at that time.

**Frohman:**  Absolutely.

**Katz**:  So then, I presume you had to become a construction engineer, as well as a microelectronics engineer.

**Frohman:**  Yeah, you have to get involved in just about every phase.  It's lots of fun, too.  There was concluding government negotiations.  And then,getting construction approved. We got some support from the U.S. for supervision.  I had to get involved in just about every phase of the program.  In the beginning, we were only about five people. Also, I did all the hiring.   I was full time Interviewer.  I interviewed everybody myself.  That had added value, because later I wrote an interview course, that other people could use.  And  of course, it allowed me to select a very good team.  Overall, it was very risky to do it. We did it in Jerusalem.  Jerusalem didn't have a basic manufacturing workforce.  And by the way, an interesting part of the story was that we sent more than 120 people to the US fabs for training..  But when we wanted them back, the fabs wouldn't let them go.

**Katz**:  They must have been in the blue section in your productivity charts, I take it.

**Frohman:**  So that chart turned out to be conservative.

**Katz**:  Well, our story's pretty much as far as I wanted to take it. And we've used as much of your time as I wanted to take.  But I'd like to close up the session with a few thoughts of yours, overall, thinking back on the full career.  From new kid learning microelectronics at the foot of some masters, up until Elder Statesman in Intel Israel.  Which were the most exciting and/or rewarding parts of that journey?

**Frohman:**  I think, in retrospect,  there were four.  The first one was the Berkeley experience.  That was, by far the most overwhelming one.  The second one was, of course, the EPROM.  I recently wrote a book.  Somebody asked me, "When are you going to write the second book?"  I said, you know, "You live once.  You do a significant invention once.  And you write what you think is a good book once."

**Katz**:  Yeah.  Well, before going on to the other two experiences, let's compare these first two. Very different experiences.  I want to hear about the next two, as well.  But the contrast is striking. me right now.  In Berkeley, you were surrounded by a new culture and a do-your-own-thing mentality and lots of noise.  And Berkeley, in the '60s they called "Berserkly;" right?  Whereas in the lab inventing the EPROM, you were mostly a solitary contributor and thinker.  Possibly, doing your own thing on a technical level, but certainly not part of a big society.  So how do those contrast, and how do they compare with each other, in terms of your emotional involvement?

**Frohman:**  I never was a part of a large society, all my life.  That's the point.  At Berkeley it was the same thing.  Because I was studying Engineering; right?  Doing my Doctorate.  But on some days, around five, six o'clock, I went to demonstrations and to other things that had nothing to do with my study.  So to me, the experience at-- the EPROM experience, was not that much different.

**Katz**:  Interesting.  You said there were two other major high points and/or exciting times in your career.

**Frohman:** Africa, Ghana is the third one. And the fourth one is Intel Israel.

**Katz**: Intel Israel spanned a long period. Is there any part of it that stands out as particularly exciting, other than worrying about being shot by scuds?

**Frohman:** I think the first part was the most stimulating. Getting the design center going. There was a lot of criticism to overcome, even with the first five engineers we hired. We were accused of hiring manpower for a competing foreign corporation. It took time, with all the multinationals criticism to figure out that there was no such thing as us supporting a competitor.

**Katz**: Well, I presume it was a learning experience, as much as a contributory one.

**Frohman:** That's right. So that changed considerably. And for some time I was public enemy number one. I mean, all the way along, the first fab was a major investment by the government. And the second one had something like 600 million dollars in grants. There was a point where columnists were hinting that I took some of the money into my pocket.

**Katz**: Wow.

**Frohman:** The most exciting periods were, I would say, a combination. The first period of starting the design center and then, the first period of starting the first fab. The second fab was much bigger, but it was not the same.

By then there was infrastructure, and there was a better understanding of the impact of something like that.

**Katz**: Okay. I know you're proud of all of your experiences. Does one of them stand out as the thing for which you hope to be remembered?

**Frohman:** Well, not the Berkeley experience, as I didn't impact Berkeley, , And I didn't much impact Ghana , I don't think. Of the two others, the impact on Israel is probably, by far, the most important. But I really don't think that I would have a chance to make that kind of an impact, if I hadn't invented the EPROM.

**Katz:** Well, I think we close up with one last question, which is typical at the end of these sessions. Do you have some advice for young scientists and engineers?

**Frohman:** That was unexpected. Not that I did any homework. I think I distilled all the advice I can give to young people in my book. Basically, it revolves around daydreaming, taking advantage of random opportunities. And making sure the survival of the organization is foremost on your agenda.

And finally, foster an open culture, which will lead to creativity, innovation. That about sums it up.

**Katz:** Those are good advices. I want to thank you very much for the time you've spent with us.

END OF INTERVIEW