The History of Data Acquisition for High-Energy Physics - a Corporate Perspective

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It is a great pleasure for me to contribute to these proceedings. My acquaintance with some of the people at Fermilab goes back a long way. When I was an undergraduate at Columbia, having just come up from Alabama to go to school in New York City, there was an illness in my family. I had to apply for an absentee slip to miss sophomore physics lab. The young assistant professor who signed that slip was Leon Lederman, later Fermilab's Director. That was my first meeting with Leon. A few years after that I graduated from Columbia and was working as an engineer at Columbia's Nevis Laboratory where Lederman did some of his most important research. I thought it would be nice if I could go to an IEEE or Wescon meeting in California. I'd never been to a meeting like that. With great diffidence I approached the power structure at Nevis for permission to go. I was sure my request would be denied. The word came back: Tell LeCroy he has to go to the damn meeting! That word came from Leon Lederman.

My subject is the history of instrumentation for particle physics from a corporate perspective. In preparing this material, I was struck by something that I thought was more interesting than just the story of this electronics. What struck me was an interesting and important mechanism for technology transfer. It is nothing new, but the pervasiveness of it and the potential of it got my attention. The mechanism could be called "Technology Decentralization" or maybe something even catchier, "Making Technological Progress Contagious."

The context of these observations is the present situation of the United States in competition in a world economy - particularly the situation of U.S. manufacturing and U.S. industry. A few decades ago, we were told by persuasive pundits that the United States was about to enter something called the "Post-Industrial Era," in which the importance of manufacturing would wither away.

Manufacturing would become irrelevant and we would all somehow generate wealth by making each other hamburgers, selling each other insurance policies, and doing each other's laundry. We would all be in the service sector. But these works on the glories of a service economy and the demise of manufacturing apparently was never translated into Japanese. Too bad, because the unenlightened Japanese have been clobbering us for a long time now through their manufacturing prowess.

That manufacturing prowess has a firm foundation on technology. Laboratories like Fermilab are in a great position to contribute to our country's technological base. My further remarks will deal with how, in my experience, this has worked in the past, and how it can be encouraged in the future. The subject is important because the United States is going to face, in 1992 and thereafter, the competition of something very like a United States of Europe. And developments are under way in the Orient that may result in something like a United States of Asia. These are going to be very powerful economic blocs. To compete we're going to need to get our act together. And that means making the best possible use of our technological base, of which Fermilab and its sister labs form an important part.

To provide a little background for my point of view, I'd like to start by briefly tracing the history of my company. Figure 1 shows sort of a snapshot of our first 25 years. During this period there were a lot of important developments in high-energy physics. Many of these landmarks appear in the figure. The timeline has a ''progressive'' upward slope, and there has certainly been a lot of progress during this 25 years. LeCroy Corporation was founded about the time of the observation of the omega-minus in 1964. Important events in the history of the company are shown above the line, and in particle-physics research below. Our mutual history continues all the way up through the start-up of the Fermilab Collider and supersymmetry theories. Along the way there are exciting experimental results, theoretical results, and new facilities. Above the line are some of the electronic products that we generated during this period. Later I'll review a few of those to give some flavor of the field for non-high-energy physics people.

To begin the story, I want to go all the way back to 1919 and a paper by Alois Kovarik of Yale, from which Fig. 2 is taken. It is entitled, ''On the Auto-

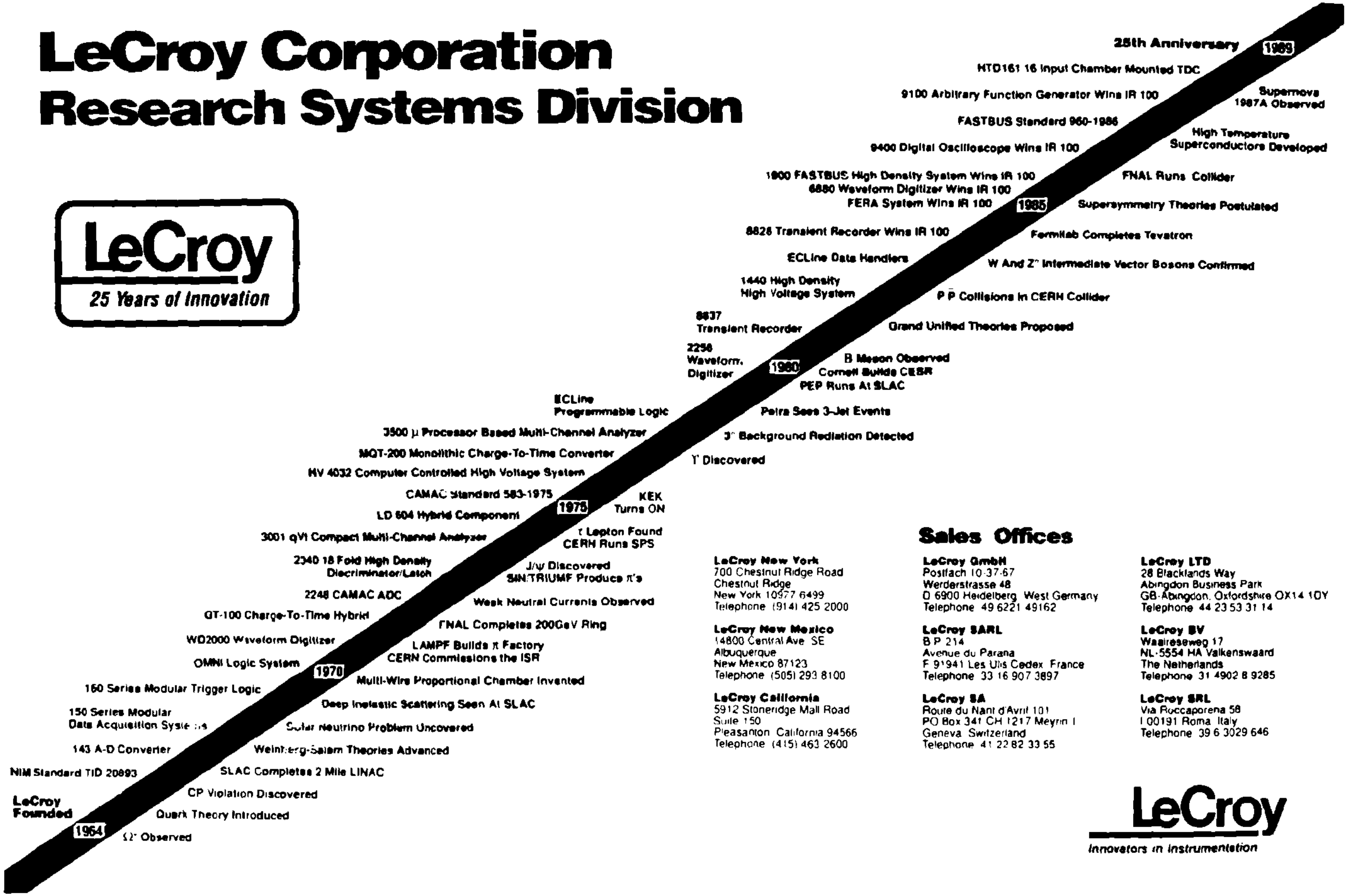
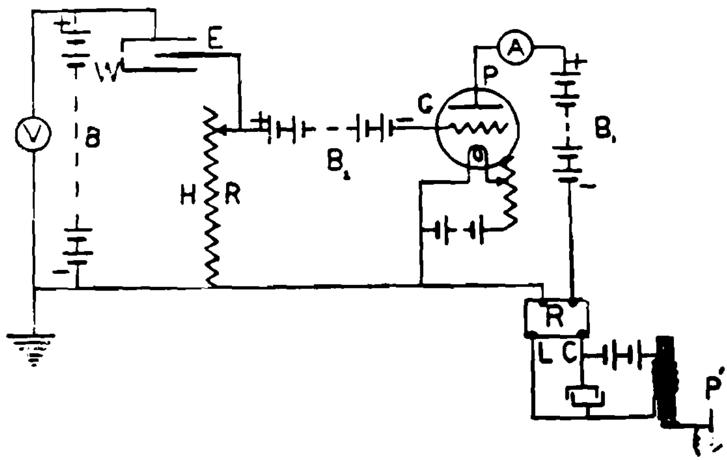
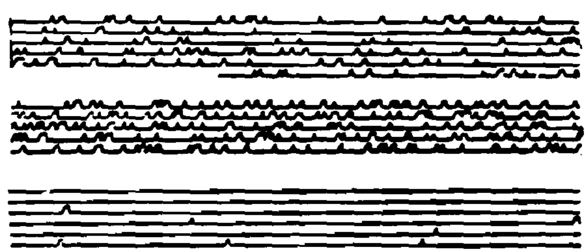


Figure 1: Timeline showing LeCroy products correlated with major events in physics over the last 25 years.

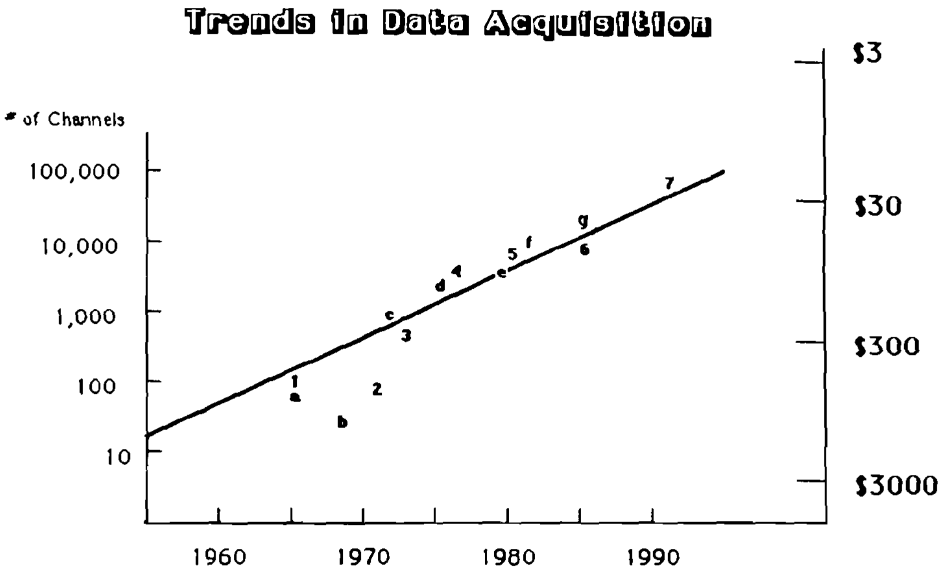
ON THE AUTOMATIC REGISTRATION OF α-PARTICLES, β-PARTICLES AND γ-RAY AND X-RAY PULSES





Alois F. Kovarik
Sheffield Scientific School
Yale University
New Haven, Conn.
January 25, 1919

Figure 2: Earliest "modern" particle physics experiment.



Number of Channels/Instrument/Experiment vs. Time

and

Cost/Channel of ADC or TDC vs. Time

ADCs	Model #	TDCs	Model #
a	143A	1 NIM	108H
b	243	2 NIM	226
c	2248	3 CAMAC	2226
d	2249	4 CAMAC	2228
e	4300	5 FERA/FERET	4303
f	2282	6 FASTBUS	1879
g	1882	7 On Chamber	HTD161

Figure 3: Channels and cost/channel in a typical experiment over time.

matic Registration of Alpha Particles, Beta Particles, and Gamma Ray Pulses.'' This was, I believe, the first time that particles had been detected and automatically recorded. Before that, they were observed as flashes on a phosphorescent screen by Rutherford or, in an evolution of technology, as clicks on a set of earphones driven by a vacuum tube. The paper is interesting because even though the technology has changed a lot since 1919, the fundamental pieces of this little circuit are still employed in every high-energy physics experiment, although they've gotten a lot smaller. The object labeled ''B'' is 2000 volts worth of batteries. That's a big stack of batteries. There is a Geiger tube which allows current to flow when a particle passes. That current develops a voltage across the resistor marked HR (for high resistance). Mr. Kovarik notes that the resistor is variable. I'm inclined to think that's an understatement. He made the resistor with a stripe of India ink on paper and it was probably quite variable. His amplifier was a vacuum tube. Vacuum tubes, invented in 1908, were new technology then. In his paper Kovarik calls it an audion. Further amplification was achieved using a relay which was loaned to him by Western Electric, the world's leader in relay technology for many decades. The relay drove a solenoid that made a pen on a paper chart recorder twitch. The output of the experiment was a strip of paper that showed a random pattern of little blips indicating passage of particles. The nice thing, to Mr. Kovarik, was that he could take this piece of paper and analyze it at leisure. He notes that manually recording the passage of particles by watching faint flashes or by listening to clicks in earphones was hard on the experimenter because of the random rate at which the information came in - perhaps another understatement.

The basic one-channel particle detector of 1919 has led to a succession of progressively denser, less expensive, and more capable measurement channels. Figure 3 illustrates this for the period from about 1950 to approximately the present. It shows the number of channels in a typical high-energy physics experiment, starting from just a few channels in the 1950s and going on up at an exponential rate to about 100,000 channels at present. Now we are discussing the possibility of million-channel experiments in the Superconducting Supercollider (SSC). The interesting point is that a million-channel experiment is what you might reasonably expect from extrapolating this curve to the time of the SSC. Exponential growth always has to stop sometime, and one can never tell when. Nevertheless, we may be justified in the reassuring belief that this one will hold out at least for the next generation of experiments.

To continue this story just a bit, Fig. 4 shows a contemporary analog-to-digital converter module. It has 96 channels of particle recording built into it. Each one has a resolution of one part in 16,000 compared to the simple on/off of the 1919 channel. The cost per channel of this box is about $50. Figure 5 is a recent 16-channel time-to-digital converter used for measuring short intervals of time. It is also very compact. Figure 6 illustrates an integrated-circuit chip that stores about 600 samples of an input signal at a 200-MHz rate. This kind of modern electronics technology is important in high-energy physics, and its development, its refinement, has been driven by high-energy physics. Through this technology, circuit density has gone up and the cost has gone down. The approximate cost per channel for high-energy physics electronics with time is shown on the right-hand side of Fig. 3. We can see that the cost per channel of doing experiments has gone down in a rather gratifying way, in fact at an exponential rate. Naturally one could wish for a better slope. We always need more channels than we can afford. While the number of channels needed goes up exponentially, funding has not been observed to increase in the same way. So it's nice that the cost per channel has dropped significantly.

For about the first 15 of LeCroy Corporation's 25-year history, most of our products were devoted to high-energy physics. About ten years ago, we began to diversify into other areas. In particular, five or six years ago, we moved into the test and measurement market. Please excuse the slightly commercial flavor of Fig. 7. It illustrates our Model 9400 digital oscilloscope, which was a watershed product for us. We introduced it about five years ago, and it has really changed the nature of our business. And the technology that went into it comes directly out of the high-speed trigger circuits involving some logic. Every high-energy physics experiment has to have triggers of many kinds. We knew how to do that. The scope has to process a lot of data in real time, so that when the user turns a knob, the screen updates in a comfortable way. So there has to be a great deal of real-time data processing in the scope. This too comes right out of high-energy physics. The front-end circuits for the analog-to-digital converters also came out of high-energy physics via fusion research. So, when we thought about doing a scope like this, we felt confident we could do it tech-

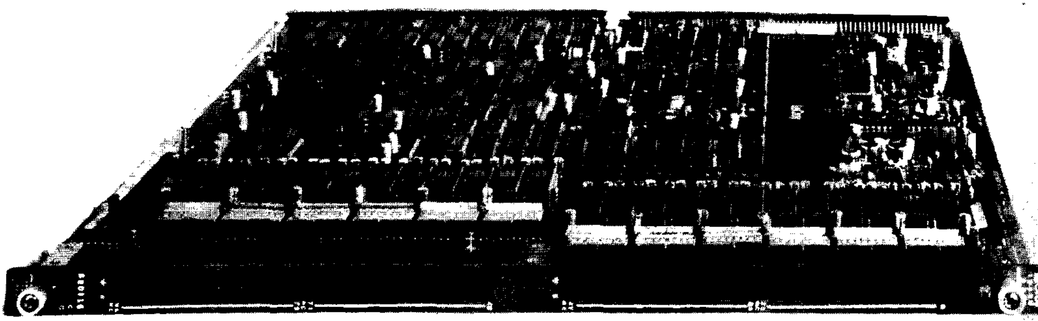


Figure 4: 96 channels of 15-bit ADC's in a Fastbus module.

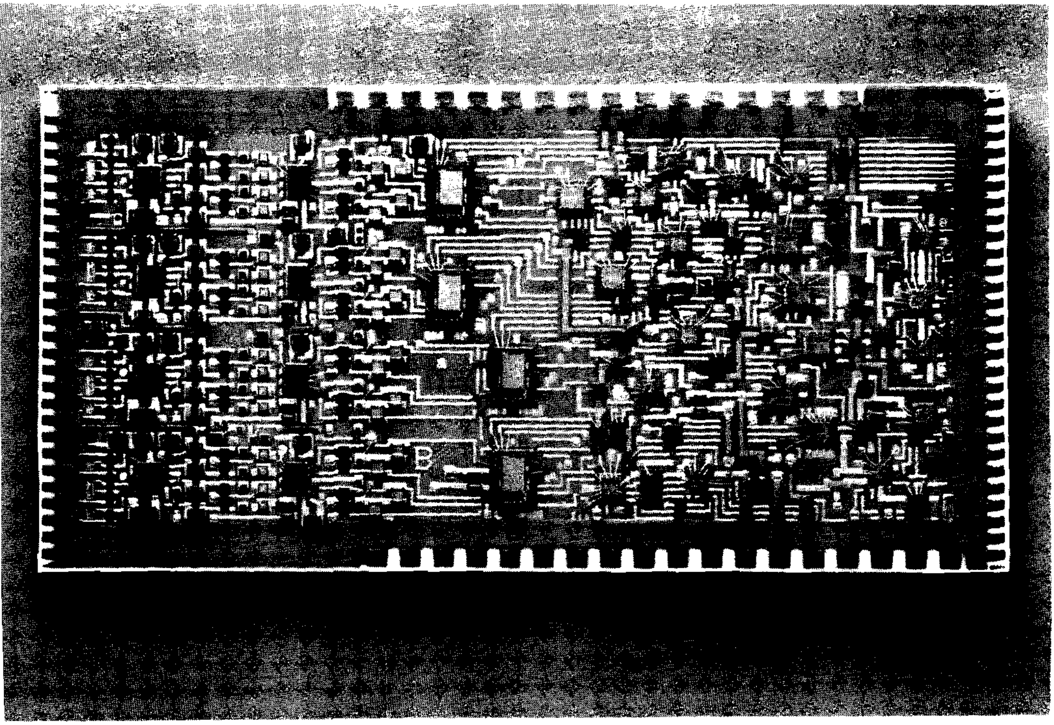


Figure 5: Very compact, 16-channel hybrid-circuit time digitizer.

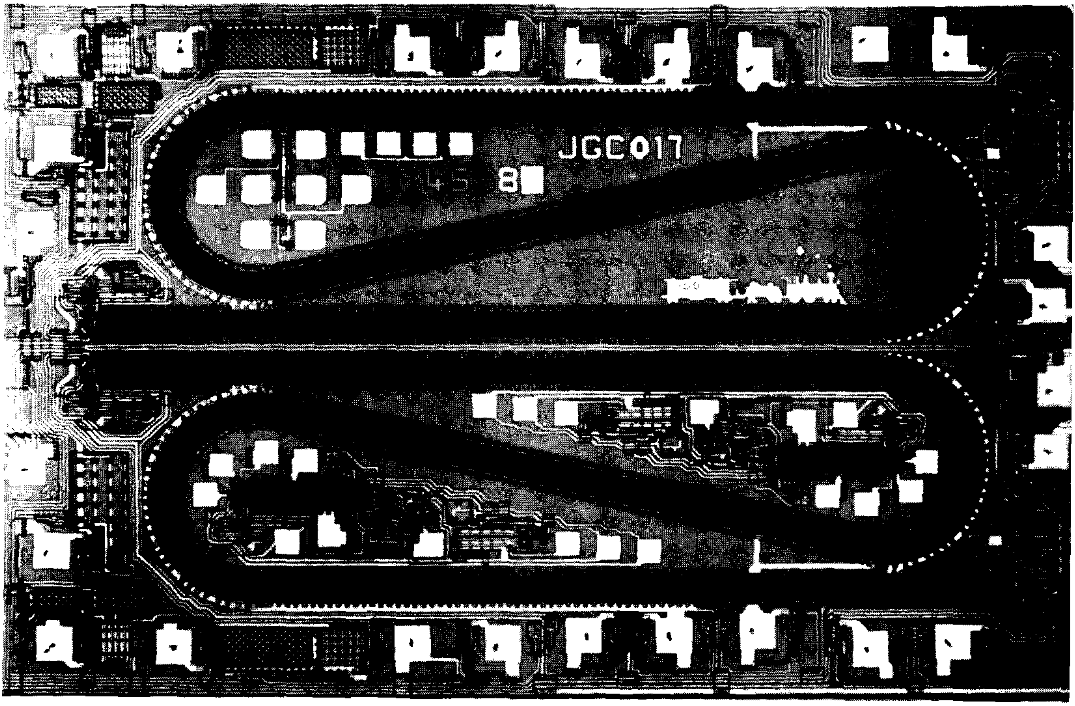
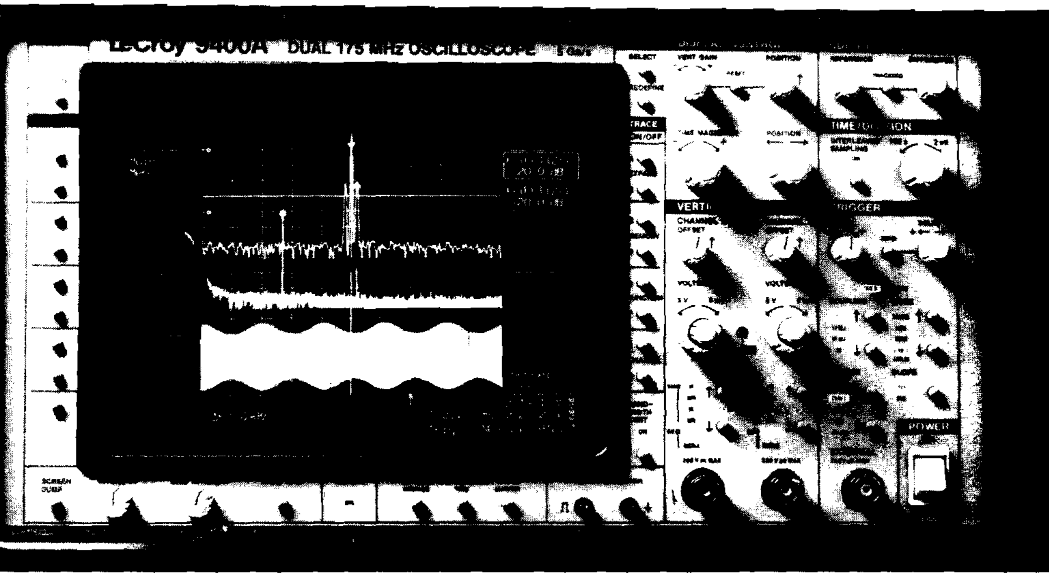


Figure 6: A recent analog storage chip in CCD (charge-coupled device) technology.



gure 7: The Model 9400 digital oscilloscope — HEP technology invades Test & Measurement.

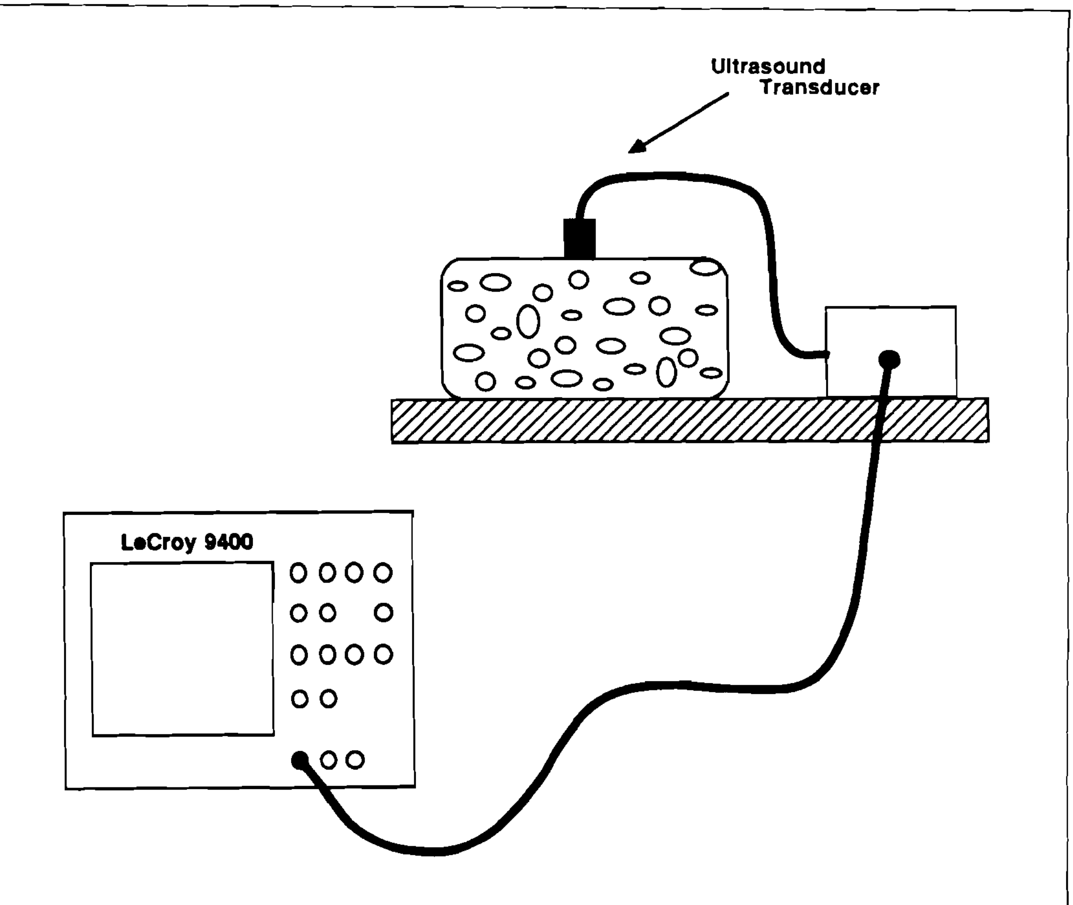
nically because we had the background from work that we had done for laboratories like Fermilab. We were not so sure that the world would accept it, coming as it did from a company unknown in that field. But it did gain wide acceptance, which I attribute to the fact that it really worked well because of our grounding in high-energy physics technology.

As I noted, this unit and its successors have changed our business. In particular, the range of applications has gone up a great deal. Table I is a partial list of areas in which LeCroy equipment is used now. The information comes from customer reply cards. When I first saw this list, I was impressed with the breadth of these applications, and I asked for a complete list of our customers for the oscilloscope. I imagined that I would get a half-dozen sheets of paper. What I got was a printout with 2500 names on it, of companies large and small. There are probably 3000 or more individual users of this LeCroy oscilloscope and its sisters scattered all over the world. Every one of these users is a direct beneficiary of technology developed for high-energy physics.

Among all these applications of this oscilloscope, one really stands out for me. It occurs in southern France at a cheese factory. The little old French cheesemaker (actually, the quality control department of a pretty big cheese factory) was unhappy with the variability in the consistency of the cheese. Now, people have been making cheese for 10,000 years. It has to be one of the oldest activities of mankind. I was intrigued when I learned that LeCroy had sold a state-of-the-art, high-speed digital oscilloscope to a cheese factory.

A schematic diagram of the experimental arrangement is shown in Fig. 8. An ultrasonic transducer sends a sound pulse into the cheese. The sound wave encounters holes in the cheese and is reflected back from them. The reflected signal, carrying information about the size and distribution of the holes, is picked up by the same transducer and displayed on the oscilloscope. The little old cheesemaker has learned to gauge the ripeness of the cheese, the flavor and the quality of the cheese, from the waveform he sees on the oscilloscope.

I've learned more about cheese-making than I thought I would ever need to know in the process of looking into this. Now I'm looking for applications in the wine business, but I haven't found any yet.



igure 8: HEP technology rescues the cheesemaker.

Recently, I tried to get a little more information about this cheese-making application. First of all, I wanted to find out for sure if it was real. I called the salesman who had reported it and he assured me that it was. He gave me the name of the cheese factory, and the name of the physicist at the Ecole Polytechnique in Paris who had suggested the possibility of the technique to them.

Then I said, "Jean-Pierre, what does the set-up look like? Do you happen to have any photographs?"

He said, "No, I don't."

"Well," I said, "just describe it to me."

He said, "I've never seen it. I've never been in the factory."

Getting desperate, I asked, "Well, do you have any waveforms? A print-out of a scope screen? I need something to illustrate this thing."

"No, no waveforms," Jean-Pierre replied. "Walter, you have to understand, this is an industrial secret. They won't tell me anything. Nobody gets to see it. This is serious stuff."

The technology in the cheesemaker's oscilloscope comes right out of the work done at Fermilab. Now, when a purchasing agent or a physicist at Fermilab decides to buy some electronics from us or from any other vendor, I really doubt that he is thinking about improving the quality of the cheese in the world. But the important message is that when you do buy from a high-tech company like LeCroy, you are improving the quality of cheese and many, many other things as well.

On my first trip to Europe, in the mid-1960s, I met a young engineer at CERN, now a very senior man in the electronics hierarchy there, who asked me a question that puzzled me so much that I never forgot it. He said, "How can a guy just go and start a company? Where do you find the customers? How do you do it?" I didn't have an answer, because I didn't really understand the question.

This year the Swiss magazine *Le Temps Strategique* published a special issue on American companies doing business in Switzerland. There were articles on seven companies: American Express, IBM, Cargill, AMI, Philip Morris, DuPont, and LeCroy. We were surprised and pleased to be included in that group. The writer concluded the article on LeCroy with another question. He noted that the Swiss are clearly talented, they have a great feel for quality, and a strong technological base. A major high-energy physics laboratory, CERN, is located right in Geneva. With all these ingredients, then, how did it fall to some Americans to pull it all together into a going business? The writer speculated that maybe Americans have a greater taste for taking risks than the Swiss do.

I don't know about that, but my answer is different. It has to do very directly with the policies of laboratories like Fermilab. Their philosophy of operation differs from the philosophy of laboratories like CERN in Europe. In general, Fermilab and other U.S. laboratories maintain close contact with industry. They put problems to industry and take commercial solutions where they can. My perception of the general philosophy at CERN is that, at least in the past, they approached problems by trying to design everything in-house, using legions of staff engineers, and then putting out "copy" contracts to industry. As a result, a small number of little companies did grow up around CERN. They assembled things that looked like instruments, tested them, and delivered them to CERN. They considered themselves to be high-energy-physics instrumentation companies. But they were kidding themselves, because they did not do the designs themselves. In general, they did not work closely with the designers at CERN. And mostly they are no longer there. I believe they were not able to service the instruments that they delivered and didn't keep up with the technology. When the next copy contract didn't come, there was nothing they could do. There is little or no technology transfer via copy contract.

Eventually LeCroy and other U.S. companies were able to sell to CERN, which became a very significant customer of ours. The important point is that we got our start in the United States. I don't believe we could have done so in Europe. We incubated in the United States until we were strong enough to approach CERN and struggle successfully with that very in-grown system.

Our experience seems to say that a great way for a lab such as Fermilab to sustain and foster technological growth in industry, and get its own job done as well, is to work jointly, cooperatively, with industry. When a lab does that, the technology grows in industry, where it needs to be to immediately serve lots of other people - the world. I believe this to be an under-appreciated general principle. I have been struck by the leverage that we have been able to get out of technology that was generated in trying to meet the needs of laboratories like Fermilab.

This principle doesn't apply just to laboratories, but to any business. I looked at our experience and I found some examples that seemed to bear that out. They are not very profound, but they are illustrative.

Until about 10 years ago, we manufactured our own printed circuit (PC) boards. It seemed a natural enough thing to do. We started doing it when you couldn't buy them so easily, and we just kept on doing it. We considered stopping, but I remember one typical meeting late in the game when we discussed closing down our own PC facility and going outside. Our manufacturing engineer said we couldn't get the turnaround from outside. We wouldn't have control of the quality and we couldn't get exactly what we needed. By ''exactly what we needed'' our man meant blue boards - the company color - instead of the green ones that the world uses. The local PC houses didn't want to stock blue printed-circuit material.

Eventually we did make the switch and we found that the quality went up and costs went down, and there was no problem with turnaround. We were even able to get them in our own designer blue. We were better off in every way. And the reason, I believe, is that making printed circuit boards had been a marginal technology for us. It was not central to our main job. We didn't give it the attention that it really needed because it's an evolving, changing technology on its own, and our volume, our narrow application, didn't give enough leverage on the investment required to keep up to justify our attention.

Several years ago, a Xerox salesman called on us and proposed that Xerox take over our motley collection of office copiers, provide a central service, and provide a staff (consisting of one girl) to run a copy center for the company. We decided to take a chance on that, although it seemed outrageous because of the disparity in the sizes of the companies. But it has worked very well. Despite the wild size reversal, Xerox works very effectively with us as a subcontractor.

Now, I don't think the level of business that we give Xerox is going to advance their technology very much, but it does go in that direction. And it unburdens us of the need to keep track of all those copiers and worry about which ones are right for us. This illustrates the general principle I'm suggesting about how one gets one's job done effectively, and foster technological growth where it can do some good, by calling on outside expertise more generally than it is human nature to do.

This type of decentralization is a fundamental lesson that people are learning about organizational dynamics and getting work done in the world. It applies to governments as well as laboratories and businesses. That vitality and efficiency spring from decentralization is becoming more widely appreciated. Large companies are closing or distributing central research labs to focus those labs closer to their customers. They are spinning off divisions in areas such as semiconductor operations for the same reasons. In recent years, CDC, Tektronix, Honeywell, and most recently, Cray, have established their internal semiconductor operations as standalone units. This decentralization principle is important. Tom Peters, in his book, *In Search of Excellence*, talks about pushing responsibilities down in the organization to the lowest possible level. Subcontracting, rather than always trying to do it in-house, is in exactly that same spirit.

So I believe this principle for making technology contagious, for maximizing the leverage and impact of everything we do, applies to businesses large and small, to laboratories, and even to governments. We all have opportunities to apply the principle; sometimes we seize the opportunities, sometimes we let them pass.

I heard a wonderful story recently about seizing opportunities. It seems the dam broke above a town, and water was rising around the church. The preacher was on the front steps of the church when a boat came past. The people in the boat called to the preacher, "The water's going to keep on rising, Preacher. Come aboard. If you stay there you'll drown."

But the preacher replied, "No, the Lord will take care of me," and the boat left.

The water continued to rise, and several hours later, the preacher had climbed to the roof. A second boat appeared. The passengers called out, "Preacher, get in the boat; the water's going to keep on rising and you'll drown."

But the preacher answered once more, "No, the Lord will take care of me. I'm not worried."

A few hours later, the water had risen even further and the preacher was clinging to the steeple of the church. A helicopter appeared and hovered overhead and lowered a ladder down to the preacher. The pilot shouted down, "Preacher, climb onto the ladder. The water's going to keep rising - you'll drown."

He replied, "No, the Lord will take care of me. I have faith."

The helicopter left, the water continued to rise, and the preacher drowned.

When he got up to heaven he met the Lord, and said, "Lord, I have served you faithfully. I thought you would take care of me. I don't understand how you let this happen."

And the Lord said, "Well, to tell you the truth, I don't understand how it happened either. I sent you two boats and a helicopter."

And then there was the project manager, somewhere, who embarked on a wonderfully ambitious project. It was his life, and he gave it his all. But alas, before the project was finished, he was called to his reward. He arrived before his maker, surprised and bitter. He said, "Lord, you know how important that project was. You know how badly I wanted to finish it, and how hard I worked on it. How could you let this happen to me?"

And the Lord replied, "I don't understand how it happened myself. I sent you the Xerox salesman, the Hewlett-Packard salesman, the Phillips Scientific salesman. . ."

I want to conclude with a pledge and a plea. Having been struck with how important the openness of laboratories like Fermilab has been for my own company, and also with the generality of the principle involved, I want to pledge personally to look more carefully at my own build-or-buy decisions. And, I would like to make a plea that all of us do that. I believe it will help to get our own jobs done better and more efficiently. And it will invoke the power of *growing* the technology where it will be most widely used, with broad benefit to all.

Acoustic emission
Acoustical microscopy
Acoustics
Aerospace research
AM/FM radio
Analog design
Anti-submarine warfare
ATE
Automation
Automotive electronics
Ballistics
Beam diagnostics
Biophysics
Cable TV
CAD/CAM
Cardiology (ECG)
Coil testing
Compact disc r&d
Component testing
Computer aided testing
Conducted and radiated EMI
Data communications
Delay line testing
Destructive testing
Detector design and test
Digital cassette research
Digital design
Diode testing
Disk testing
Eddy current research
Electrical motor testing
Electrical traction
Electromechanical switches and relays
Electronic countermeasures
Electronic instrument design and test
Electronic intelligence
Electronic warfare
Electrostatic discharge measurement
EMP/EMI/EMC
Energy production and distribution
Engine testing
Explosives testing
Fiber optics
Fluorescence and phosphorescence decay
HDTV
High speed logic testing
HV protection
HV switching
Hybrid IC testing
Insulators
Laser Communications
Laser development and research
Laser diode testing
Laser Doppler anemometry
Laser engineering
Laser fusion
Laser ranging
Laser weapons
LED testing
Lidar
Lightning research
Linear IC testing
Local Area Networks
Loop controller testing
Magnetic field measurement
Magnetic material research

ıble I: Diverse application areas for LeCroy electronics (from customer response cards.)

LED testing
Lidar
Lightning research
Linear IC testing
Local Area Networks
Loop controller testing
Magnetic field measurement
Magnetic material research
Magnetic media testing
Mass spectroscopy
Mechanical engineering
Microwave research
Mobile telephone development
Noise source identification
Nuclear EMP
Nuclear physics
Oceanography
Optoelectronic components
Particle accelerator research
Particle physics
Passive and active filter characterization
Passive component testing
PCM systems
Pharmaceutical research
Photodetector testing
Photomultiplier research and design
Photon analysis
Photon counting
Physiology /neurophysiology (EEG)
PID control
Plasma physics
Power line analysis
Power supply testing
Process and control
Production engineering
Pulsed radiolysis
Radar jammer development
Radio frequency interference measurement
Raman spectroscopy
RF component design and test
Robotics
Rocket fuel testing
Satellite communications
SCR testing
Seismic research
Semiconductor testing
Servo controls
Shock testing
Shock tube physics
Software diagnostics
Sonar
Speech recognition
Switching transients
Telecommunications
Telephone
Television
Test engineering
Textile machines
TOKAMAK
Transducer design and test
Transformer testing
Transistor testing
Turbine and rotating machinery testing
Ultrasonic spectroscopy
Ultrasonics
Ultrasound imaging

Table I: (Continued)