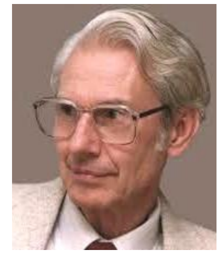
My Life at HP Labs
by Paul Stoft



Foreword

Mr. HP Early Lab Manager—Paul Stoft

If I were to ask you to name the birthplaces of the most creative technologies of the second half of the 20th century, you would probably list Bell Telephone Labs, IBM, and maybe some large government labs like the National Institute of Standards and Technology, and others. I would argue that one of the top applied research labs of that era was located in Hewlett-Packard's R&D laboratory at the top of the hill on Page Mill Road in Palo Alto. This was the fabled HP Labs, led by Barney Oliver, a 180 IQ genius, who did his best to stimulate and manage an entire floor of other creative geniuses.

Over decades, the new technologies that flowed out of HP, enabled so much industrial progress. HP Cesium Beam frequency standards populated the world, and provided global time management, even serving a key role in rocket ship navigation for the US Moon Shot Apollo Program. The dual-mode laser tube technology of Don Hammond was the key to dimensional measurements to 1/10th of a millionth of an inch, and made such crucial measurements easy and routine.

Possibly the pinnacle of the products that revolutionized the daily work of individual engineers around the globe, was the HP desktop technical computer, the HP 9100A. Even before reasonable computational memory circuits were invented this amazing desktop did transcendental functions, including trigonometric, hyperbolic, and logarithmic functions with the click of a key. And it necessarily used a "brute-force" 16-layer printed circuit board and 2400+ discrete diodes for its Read-Only-Memory. Some early evaluators of the calculator looked for an umbilical cable to a larger computer underneath the table! They could not comprehend the power that HP gave to the everyday engineer.

But Bill Hewlett wanted all that HP 9100A computational power to fit into his shirt pocket. And he kept nagging Paul Stoft's 9100 team to find ways to shrink all that circuitry and algorithmic computation into the HP-35 pocket calculator. Paul's team, led by Tom Whitney, accomplished that with the rollout in 1972, during a business recession, which pumped up HP profits and revenues during a critical time.

Paul's role in Barney's Advanced Labs came in about 1960, when the four "charter" divisions were formed. All of the centralized research and development was divided into those four new self-contained operations; Loveland Division (audio video), Frequency and Time (counters, etc), Oscilloscopes (which moved to Colorado Springs), and Microwave (which stayed in Bldg 3 and the new Bldg 5). When those divisions formed, they took all of the lab engineers who were responsible for developing products. What remained was TRULY an Advanced HP Labs. Paul's Lab Section was one third of that remarkable organization.

In those days the term Mission Statement was not yet known. But the idea was that Barney's lab-full of geniuses would be looking for new measurement product ideas and technologies which fell between the charters of the 4 product divisions. They would also push out new technologies, such as quartz crystal research, Cesium beam frequency standards, custom integrated circuits, and the brand new capabilities of personal computing and later, ink-jet printers, among many other fantasies of brains like Hewlett and Barney.

As in any company which ran on the visions of two creative men like Dave Packard and Bill Hewlett, Barney's lab also caught the jobs which reacted to ideas coming from Bill Hewlett. In one sense, that part of Paul's Lab Section might be called Bill Hewlett's Job Shop. Bill was an internationalist, and when visiting technology centers and customer companies in Europe, he would sometimes be so enamored with some of their technologies he would buy the patent rights to some particular product idea. Then it was up to Barney's Lab to take the idea to product status. One such project was labeled the "Bandsaw multichannel recorder," which will be explained in Paul's story.

In Paul's decades of management of creative ideas and creative people, possibly his best contribution was his vision in exploiting the integrated circuit revolution of the 1970s. It almost goes without saying, that if HP product designers had to depend ONLY on commercial ICs, from Fairchild or National or Intel, that they could not build unique measurement properties into their new brainchild. Competitors had the same building blocks. It was Paul's vision to bring the genius of our HP Labs to bear on research into the material science and physics and chemistry of integrated circuits. He gathered a team of engineers who set out to understand the manufacturing processes, the best and most efficient techniques for production and testing of new custom circuits to support the product divisions.

Paul's contributions included selling Bill and Dave on the idea of building a state-of-the-art IC facility in a newly-purchased building (from John Atalla at Fairchild), which became Bldg 25 at Deer Creek. It is hard to overestimate the impact of this lab on the fortunes of HP, because the circuit innovations that came out of the lab affected almost all of HP's new products.

As other HP Lab Sections moved into Inkjet printers and Laserjet printers, Paul's Section cooperated in the custom ICs needed for new personal printer functions. His work contributed in such an important way to the growth of the worldwide reputation of HP as it moved into the 21st Century.

--John Minck

My Life at HP Labs

by Paul Stoft

Contents

Born into the Booming 1920s

I was born in Pittsburg, Kansas in May, 1922. My father was a minister and my mother, a homemaker, in a little city on the southeast border of the state. But we weren't there long. When I was just 3 months old, my father moved the family to Philadelphia. We lived in Pennsylvania for 6 years, then moved to Wichita, Kansas for another 7 years. We ended up in Colorado, where I attended high school in Denver. That would have been in the mid-to-late 1930s.

During my high school days, I never considered myself a geek or a technical nerd, like some young people label themselves today. I did join the high school radio club, since that radio technology was booming in the late 1930s. Two of my friends and I joined a college science club, which was a national organization. Those activities gave us young people some concept of electronic circuitry and vacuum tubes and the technology of receiving the RF signal transmission of the local radio stations.

During high school, when I was 14, my Dad got me a part-time job at a local electrical company. Their main functions were to wire electric power into homes and commercial buildings, and to repair electric motors. I remember biking to work, and enjoying the regular small wages I got. This job also gave me some valuable perspectives into electrical circuitry and the various concepts of power control and circuit diagrams, and the like.

I graduated high school in 1939, and had already decided to go on to college, encouraged by my parents and my own fascination with electrical and electronic technology. I enrolled at the University of Colorado, in Boulder, and proceeded with my degree of BSEE. Interestingly, one of my professors at CU, John Cage, was a man I would later work for at Hewlett-Packard. John turned out to be a personal friend of Dave Packard, when they both worked at General Electric Company in Schenectady. That would've been in the 1937–38 period, when Dave spent one year as a engineering intern in the GE "Test Engineer" training program.

The electric department at CU was quite large, since much of the academic work was involved with electric power and generation machinery and the like. It was moving towards electronics as were most of the other colleges of the late 1930s. During my college years, Prof. Cage offered three of us students a school research project. I was also able to work a summer with a local Denver company, the Hathaway Instrument Company. I also got jobs for two of my college friends at the same place.

US Navy Duty

Of course, during this period as I completed my degree, WWII was raging around the world. When I graduated in 1944, I was immediately drafted, and unfortunately, was not able to use my engineering degree to obtain a more technical officer role. I was just a Navy Seaman. The other interesting fact was that although most people thought the Selective Service draft put people only into the Army, in my case, I was drafted directly into the U.S. Navy.


The Carrier, USS Tarawa, commissioned in mid-1945, was my first duty assignment.

I spent the usual three months in Navy boot camp, about 50 miles north of Chicago. I took the well-known Navy technical knowledge test and showed appropriate skills for electrical and electronic duty. I then transferred to South Carolina for the Navy's radar maintenance school. I might mention in passing that one of my classmates at the school ended up later as one of the early engineers to join the Fairchild Semiconductor Company, here in Mountain View.

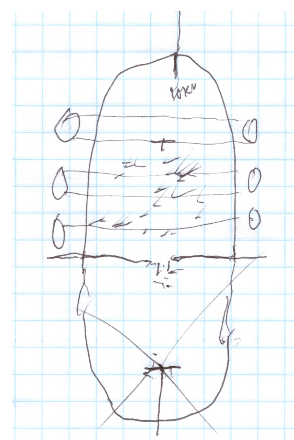
The radar course took about 6 months, and after my graduation from that functional training school, I was assigned to the USS Tarawa, a brand-new aircraft carrier. I still remember its size, 888 feet long. With a brand new crew, we were just getting acquainted with carrier crew operations when the war ended in Fall, 1945. We took the ship out for what they called the "shakedown" phase, where all the systems undergo trials and performance evaluations. Another of our missions was a cruise to Cuba, to the Guantanamo Naval Base. The Tarawa was based in Norfolk, Virginia, and that's where I was mustered out. It didn't happen immediately, but after due time for all of the long-serving wartime crews of hundreds of thousands to be discharged first.

Dorothy and I were married in Denver on July 12, 1946.

After leaving the Navy, I returned to Boulder, and got a two-month job with the Bureau of Reclamation. I also resumed my courtship with Dorothy Jones of Denver. I had known her since I was 13 years old. We had carried on our courting with letters while I was on duty in the Navy. We were married in Denver, in July, 1946, right after I left the service. Sadly, Dorothy died in 2002, after 56 years of marriage.

My Path to MIT

During my Navy duty, I had determined that I would go back to college to continue my engineering studies, and considered that I would probably aim for a Doctorate. To that end, I submitted 6 applications and resumes to suitable schools, and was stunned to get ZERO acceptances. That was pretty depressing, to be sure.



My neutron source project. The upper half of the glass envelope was filled with deuterium gas, excited by the RF coils. A 70 kV potential on the tritium target (bottom) accelerated the deuterium atoms, through a tiny hole (horizontal plate), and released neutrons from the tritium target.

About September 1, as I was wondering what to do with my life, now with a new wife, and no immediate college pathways, I got a phone call. The call came from a Professor Tucker of MIT. It was not an admissions acceptance, but instead he offered me an Instructor job for an undergraduate course. The good news also was that it offered enough time on the schedules that I could begin my own work on my Masters Degree. I immediately said yes, without even asking my wife. Professor Tucker gave me an instruction to be there to start teaching in 15 days, so without much convincing, my wife and I got on the road to Boston.

My teaching career was relatively uncomplicated, and I received my MSEE fairly quickly. By then I was convinced that I would embark on ScD work. I sort of cheated on my EE thesis, by my interactions with the Physics Dept. They had a thesis-level research project I worked on, which qualified as my EE thesis requirement. It was funded by the Schlumberger oil well instrumentation company. Schlumberger was a prominent global company in the technology of characterizing oilfield reservoir drilling and production. They did this with various kinds of techniques. Some used surface explosions and an array of sensors which measured sonic reflections from sub-surface strata. They had other sophisticated instruments for down-well probing of drilling strata. This was relatively recent technology, which meant they were doing research on advanced sensing technologies.

My project involved inventing a neutron source which went down into an exploratory oilwell hole. The neutrons would excite various earth and rock constituents, and then associated sensors could determine crucial reservoir parameters and other valuable data. This data was able to guide the drilling company in optimizing their expensive operations.

My neutron source was contained in a glass envelope, as shown. The upper section contained deuterium gas, which was excited into ions with a radio frequency coil outside the glass. Deuterium ions were accelerated through a tiny hole in a horizontal plate, by a 70 kV potential on the tritium target shown at the bottom of the glass tube. I had obtained the nuclear materials, deuterium and tritium from the MIT Materials Science Dept. The result of ions hitting the tritium was helium gas plus 17 MEV neutrons, which scattered in all directions. Schlumberger had other projects working on the sensing equipment which detected the results of the neutrons reacting with the rock strata.

My ScD project was successful. I graduated in about 1956.

California, and HP, Here I Come

As I finished my ScD, there was a another MIT professor, who had worked at GE, and was familiar with the General Electric Company operations. I wanted to go West because Dorothy wanted to attend San Jose State to get her degree. He suggested that I apply to the GE division in San Jose, California. This particular division at the time was focused on nuclear power plant design, and actually built a small test reactor over on Route 84, as it goes into Livermore. The design labs were in San Jose, but I found that I got really frustrated with the work, and became quite discouraged. I thought it was a terrible job. So I determined I would look at some other companies.

I interviewed Varian to start. Then one day I drove up to Palo Alto to just do a cold call interview at HP to see what they were doing. By this time John Cage had been hired and moved to Palo Alto, to run one of the four R&D labs which reported to Barney Oliver, Vice-President of HP Labs. I don't remember now who I interviewed with, but most likely John Cage, who was to be my boss. Soon after, they made me a job offer, and in 1958, I joined HP, reporting to Cage.

At that time there were four lab managers reporting to Barney: John Cage for Audio/Video, Bruce Wholey for microwave, Al Bagley for counters and frequency standards, and Norm Schrock for oscilloscopes. I believe that at that time John's group consisted of about 40 engineers. Very soon a major corporate decision was made which decentralized all of the product engineering. The four new "Charter Divisions" now contained the R&D for their own product lines, Audio/Video in Loveland, CO, Scopes in Colorado Springs, CO, Counters in Santa Clara, CA, and Microwave stayed in Palo Alto. Barney's "Advanced" HP Labs was now responsible for new technology research and for products which fell between the cracks of division interest.

HP Labs

My first assignment was to work with a project team, on a manufacturing machine that we called a meter scale calibration tool. At that time quite a lot of HP's audio instrumentation consisted of products which had their readout on the an analog meter. These included AC and DC voltmeters, My first assignment was to work with a project team, on a manufacturing machine that we called a meter scale calibration tool. At that time quite a lot of HP's audio instrumentation consisted of products which had their readout on the an analog meter. These included AC and DC voltmeters, Multi-meters, RF Voltmeters. We produced them by the thousands. The meter products used a deflecting needle-pointer movement that was called d'Arsonval, after its inventor. The HP Journal of March, 1961, described in this preamble the advantages and disadvantages of such meters movements:


The typical voltmeter used an analog meter movement based on the d'Arsonval principal. Their linearity vs drive current was poor.

> Despite the development of newer indicating methods such as digital display systems and accurate oscilloscopes and recorders, the long-used d'Arsonval meter continues to be a very important indicating device in electronic measuring equipment. It is cheaper than any other readout device of comparable accuracy, except perhaps in the case when the data is already in digital form. Being an analog device, it is more convenient than a digital readout for such operations as tuning for a maximum or a null. It is relatively simple and can be made rugged, long-lived and trouble-free. Because of these advantages it will undoubtedly continue to be widely used in applications where accuracies of one percent or slightly better are sufficient.
>
> Since many -hp- instruments use and will continue to use d'Arsonval meters for indications (vacuum tube voltmeters being a specific example), a program was begun several years ago at -hp- to improve the accuracy of the meters used in -hp- instruments. It was our original intent to develop a machine that would automatically produce individually-calibrated scales for our precision meters. This plan was based on the fact that, in general, even supposedly linear meters actually exhibit considerable departure from a linear deflection vs. current characteristic. This occurs because the flux in the airgap is not absolutely uniform due to such factors as variations in the radii of pole faces, centering of pole faces, partial saturation of pole tips, centering of the core, etc. The resulting departure from a linear deflection characteristic is called "tracking deviation."


My project on calibrating meter scales made a unique improvement on accuracy of HP analog meters.

> Because of the tracking deviation effect, in many cases the only difference between a meter of higher accuracy and one of lesser accuracy is the scale match. For simple indicating meters of low accuracy a single pre-printed scale is usually used. For meters of higher accuracy, however, several pre-printed scales may be prepared to take into account the non-linearities in the deflection vs. current characteristic of the meters. Thus, for meters having in the order of 2% accuracy, past practice has been to prepare three standard pre printed scales differing slightly in shape or linearity. . . . .
>
> Click http://www.hpl.hp.com/hpjournal/pdfs/IssuePDFs/1961-03.pdf to read the complete HP Journal Article.

It was probably Barney who envisioned a way to photographically produce an individualized meter scale for EACH meter movement, rather than rely on a single averaged scale. Barney was author of the HP Journal article. The semi-automated manufacturing tool, shown, inserted each meter "motor." (the magnetic field and coils which deflected the pointer needle) As the calibrator increased the current through the meter, the needle began to move upscale. Photocells tracked the needle movement and began to adjust a photo mask which was photographically exposing a film sheet as it moved. So, as any non-linearity showed in the deflection path, the mask was moved slightly to put the markings on the film in precise correlation with the driving current. These custom film scales brought linearity to well less than 1/2%. Our Materials Engineers who worked with our meter suppliers saw to it that their production lines were upgraded. It gave HP a unique competitive edge, at least for a time.

That HP Journal article concluded with another HP contribution. Most d'Arsonval meter movements used what was called the pivot suspension. That meant that the deflecting needle was suspended by a tiny axle with two sharply pointed ends (pivots) which sat in into the tiny pockets of two jewels. The principal was exactly like expensive "diamond" watches which provided two contacting materials with extremely low friction. In pivot techniques, there was friction which caused an effect called hysteresis, meaning that the needle reached a different point moving upwards compared to downwards direction, yet with the same electrical current going in.

HP took full advantage of the automated scale calibrator by combining it with a new meter movement design called the Taut-Band suspension. In this case, the deflecting needle is suspended with a tiny flat band under tension. As the current flows into the deflecting coil, the tensioned band twists and provides a spring effect. More current, more deflection, but zero friction because there are no pivots. So the custom meter scale process plus the taut-band idea gave more HP uniqueness in our voltmeter products. And proved that creativity can exist in new manufacturing processes as well as new product ideas.

My First HP Promotion was Unexpected

I was only on the job for about a year, when John Cage was selected by Bill and Dave to move to England to set up manufacturing operations in Bedford, about 40 miles north of London. A year or two previously, Hewlett had decided to establish manufacturing on the continent by opening the manufacturing operation in Boeblingen, Germany. Cage and John Doyle were part of the team that opened the Bedford, UK factory. Doyle was responsible for the manufacturing operations and Cage was the managing director.

Imagine my surprise when I was offered the job of taking over Cage's Section management job. It was a stunning development because I had only been at HP for a little over a year, and yet here I was to chosen to manage a very important HP laboratory group. Cage had recommended me to take over his position. But Cage didn't last long in England, and surprisingly, he left after a very short time and returned to Palo Alto. When he got back, Packard told me that Cage wanted his old job back. So I told Dave that was his decision, but if he returned Cage to his old position, I would leave HP. Packard said, "No-no don't leave, I'll take care of John." I guess this makes me look like an ambitious person, but I felt that I could do just as good a job managing the HP Lab group as John.

As soon as I was put in charge, Jack Petrak, who was an old time design engineer, said, "No way, I'm not going to report to that guy!" So he moved out of my lab. I guess that was logical because I was just a brand-new young manager and he was an older World War II-era engineer. I didn't blame him, and he certainly realized it wasn't my fault, it was Packard's decision to promote me over older engineers.

Cage stayed on in HP Labs with the title senior scientist, and Packard agreed that he and a small team would write a measurement oriented book, (Bernard M. Oliver & John M. Cage ***Electronic Measurements and Instrumentation*** McGraw-Hill Inc. 1971), each doing the various chapters. About this time Cage also started a small team to work on some oximeter sensors. By this time HP had bought the Sanborn Corporation of Waltham Massachusetts, which was in the medical instrumentation business, electrocardiograph's and such. In 1964, a San Francisco surgeon, Dr. Robert Shaw, assembled the first absolute reading ear oximeter by using eight wavelengths of light. Cage's group productized the concept for clamping to an earlobe, and transferred it to Sanborn.

In my project management of that time, we had Barney looking over our shoulder regularly. He would come through our side of the Lab, and sit down with anyone he felt like, to see what they were doing and how they were progressing. At that time there was also an annual review with Bill and Dave and other corporate managers visiting HP Labs. Barney would organize a show and tell exhibit to demonstrate some of our latest inventions and projects. We would be asked to defend what we were doing. so we were quite well prepared.

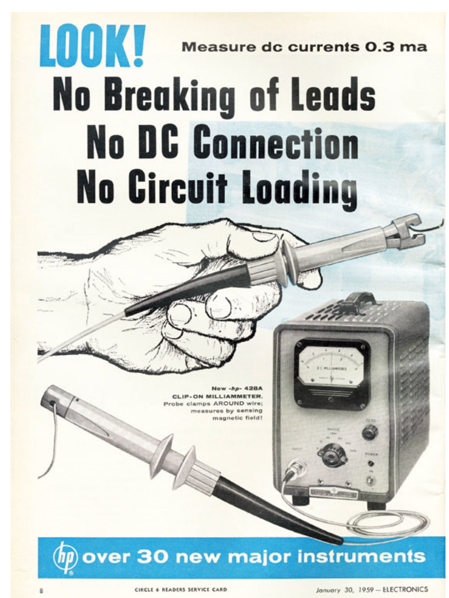
In later years, the new CEO John Young embarrassed me one day, when he was exercising his "Management by Walking Around" practice. We were talking and he asked, "What new things are you working on?" And I said, "We don't have any new things." That was the wrong thing to say to John, who expected his managers to direct well-planned operations. He usually asked for 5-year thinking and as much detail as one could configure into the future.

My HP Lab

My Section of HP Labs was honestly a magical place. It was our job to do research on both new products and processes. So we ended up with creative products that served customers across a wide range of technologies. Sometimes a project would be taken in support of a product division, such as the blood oximeter , mentioned above, which we transferred to the Sanborn Medical Division. But we also researched processes, such as the emerging integrated circuits of the 1960s. We knew that HP was going to need high performance and customized integrated circuits, and that we could not depend on the commercial ICs of Fairchild or Intel or Japan. Our HP competitive advantage would require that HP develop the most advanced IC technology. And that IC work, carried on by engineers like Jim Eaton, was perhaps my section's best accomplishment.

Most projects however, were taken on to advance HP's moves into new markets and applications. Over my HP career of almost 40 years, there were dozens of individual research projects. So many I can't even recall some of them. But to give an idea of the diversity of our work, I'll explain a few in the following pages, which are not necessarily in time sequence.

Clip-on Milliameter—HP 428A



The HP 428A clip-on milliameter was able to read current in a wire without cutting or unsoldering, to insert a regular wired ammeter.

HP legend has it that at an evening dinner between Barney and a Field Engineering manager, they were discussing what instrumentation was missing from a customer's design engineering bench. This was the manufacturing era, some time before printed circuit boards, when bundled wire harnesses carried signals to and from vacuum tube sockets and resistors and capacitors mounted on terminal strips.

The HP 428A project likely evolved from such an informal dinner discussion of customer engineer needs. But projects also advanced because of particular personalities. In this case, one of my engineers, Arndt Berg, was an expert in the field of magnetics. Once a creative engineer like Arnie got challenged to check out feasibility of measuring the magnetic field around a wire, good things often happened.

To diagnose problems or performance and measure current in one of those wires, the engineer had to unsolder one end, and clip on the test leads of an external ammeter to read that current. Barney wondered if the external magnetic field could be sampled with a flux-gate sensor? To do that, it would be necessary to capture the magnetic field in an iron core ring surrounding the wire. And then driving the same core in and out of saturation to provide an output signal proportional to the wire's current.

It remained to my engineers to determine whether the sensitivity of that technique would be adequate to amplify and display? Moreover, interestingly the earth's magnetic field is quite large compared to a magnetic field generated by just 1 milliampere of wire current. Could we shield the effect of the earth field? But all of these drawbacks were overcome, and the resultant product was quite popular. Alas, it wasn't many years until electronics manufacture processes moved to printed circuit technology, which took away most of the internal hookup wiring of electronic products.

Another product application fell out of this clip-on sensor. When the banking industry began to roll out their new bank check magnetic ink processing system, the accuracy and reliability of those check readout machines, which moved hundreds of checks per minute, depended on super consistent ink deposit for the numbers coming off the check printing presses. The 428A team arranged the clamshell in an open configuration so a test check blank with numbers could be magnetized and pulled across the 428 sensor for quality control. It was soon replaced with a dynamic read head in a competitive product.

Click http://www.hpl.hp.com/hpjournal/pdfs/IssuePDFs/1958-06.pdf to read the HP Journal story on the 1958 HP 428A. The Journal article was authored by Berg, Chuck Forge and George Kan.

Instrumentation when Digital Technology was New

From the discovery of the transistor in 1948 at Bell Labs, our product design world was going to benefit from the low voltage, reliable, tiny germanium and silicon components, which replaced large, hot, limited-lifetime vacuum tubes. As the early manufacturers like Fairchild and Texas Instruments turned out new improved products with enthusiasm, transistors quickly found perfect applications in switching functions for digital parameters.

The HP 405AR DVM

One of HP's first digital-readout products was designed in my lab, the HP 405AR Digital Voltmeter. Its circuit elements were still vacuum tubes, but it reflected the customer needs for measurement data in digital format. It was a bit clunky, available only in rack mount configuration, and displayed numeric data with NIXIE indicators. One major innovation was that the numeric readouts were capable of interfacing with a newly-introduced HP 560 digital printer. This made it ideally suited for production line measurements where an operator was not needed to manually log digital readings. The HP 405 was almost immediately transferred to the Loveland, CO Division for manufacture.

The introduction of the HP 405 went well, so my engineers immediately began the next follow-on DVM which would become HP's early use of transistor circuitry. This new technology offered increased lifetime reliability, low power and heat, as compared to hot vacuum tubes with fans. The product strategy we developed was to use a plug-in configuration so that customer's applications could be matched at the customer's bench. There were automatic ranging plug-ins and later a true-rms detection capabilities. The product photo shows the associated digital printer, HP 560. This product too, was transferred to Loveland, as the last of the DVM families to be worked on at my Palo Alto lab.

The HP 3440 Series DVM

Civil Engineering—Surveying Station

One of Bill Hewlett's visions was to use electronic measurement of angles and distance to replace the traditional surveying transit (for angles) and the physical "chains" for distance measurement. Although the project team was in Loveland, my Labs section had some expertise in infrared technology. This surveying application is fraught with environmental considerations that impact the measurement beam. The product utilized precision modulation of a 910 nm infrared transmitter, and a retro-reflector at the measured point. Atmospheric effects are most crucial, temperature, altitude, and others interfere with the accuracy needed to replace traditional mechanical transits.

The infrared-based surveying "Total Station," HP 3810A replaced tedious chaining measurements.

HP launched its first Total Station, the Model 3810A in 1976, and it was well accepted. Nevertheless, that market represented a customer group that our Sales Engineers were not calling on, Civil Engineering companies mostly. The product and later improvements did satisfy Bill Hewlett's desire that we invent products to serve customers with better technologies.

Click http://www.hpl.hp.com/hpjournal/pdfs/IssuePDFs/1976-04.pdf to read the HP Journal story on the HP 3810A

The HP 9100A Scientific Desktop Calculator

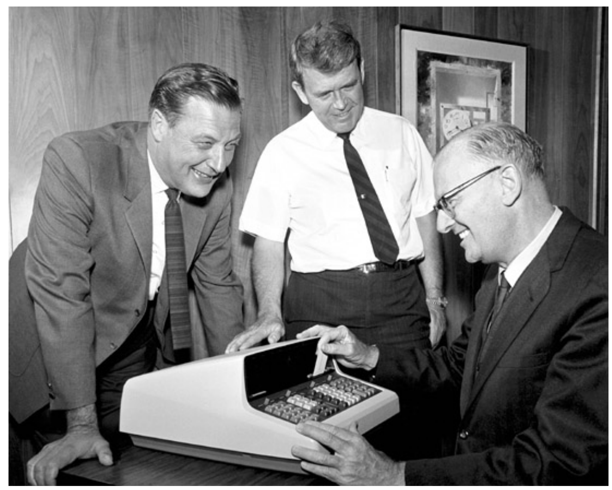
Some of the real contributions began in my group in the mid-1960s, when the HP 9100A desktop computer project got conceived. This involved true serendipity. The story is told in many places on the Internet, and it is described best by one of the key men on the project, Dave Cochran. Dave was responsible for the crucially important algorithmic software which performed the mathematics necessary for its functions.

To paraphrase Winston Churchill, the HP 9100A Scientific Calculator was our finest hour, from HP's start in 1939 through the 1960s.

It did transcendental functions, trigonometric, hyperbolic, and logarithmic actions, and had to be jammed into a terribly-small memory—the vast and cheap memories of today were only dreams for those intrepid engineers of the 1960s. Dave Cochran's own HP memoir is published on this Internet website.

The HP 9100A was the happy confluence of several activities. Tom Osborne had created some of the internal computational ideas and brought the idea to Hewlett. He even built a balsa-wood model to go with his circuit block diagrams. Amazingly, he designed and trouble-shot some of the circuitry without the use of any test equipment other than a voltmeter. He did not even have a scope or any digital test equipment. It is quite remarkable that his creative mind could do circuit troubleshooting with next to nothing. Other engineer contributors were Tom Whitney and Chris Clare. Chris worked on a printer interface which greatly enhanced the functionality of the basic desktop computer.

The Sept 1968 HP Journal has great stories on the project design. Plus Barney used the entire back page to credit me and my design team for a remarkable job. The design team was led by Dick Monnier, and included Dave Cochran and Chuck Near and of course Tom Osborne, who was in an unusual status at that time, a paid outside consultant. I won't tell you how much Tom was paid for his entry design ideas, but it was HUGE for those days. It impelled him to stay on for years, and to help with the succeeding HP-35 project.



Barney Oliver and Bill Hewlett present a gift of the HP 9100A to Arthur Clarke, science fiction writer and author of the science movie bombshell, [2001: A Space Odyssey](), The gift offered a media testimonial windfall for our HP desktop mathematical computation.

I also could see a developing gap in the design knowledge of product development engineers across the many divisions. Many had graduated before digital and logic design technologies were taught. I realized that Chris Clare would be an ideal author, building on the circuit design of the HP 9100A, to take 6 months to write an internal HP design book about logic design which could bring the entire corporation up to current semiconductor industry technology. Chris accomplished this in the early 1970s, moving our product strategies into the digital age. So in addition to our Lab mission to research new technology, as ordered by Hewlett, I also felt that it was up to our HP Labs to take a teaching role in support of our global divisions, which at that point had grown to maybe 15.

The HP-35 enabled the ordinary engineer at their workbench to eliminate the drudgery of computations. It was a "brain-power multiplier."

Click http://www.hpmemoryproject.org/timeline/chris_clare/hpj1968-09.pdf to read the Sept 1968 HP Journal story on the HP 9100A.
Click http://hpmemoryproject.org/timeline/dave_cochran/a_quarter_century_at_hp_00.htm to read Dave Cochran's HP Memoir on the 9100A

The HP-35 Engineering Hand Calculator—Can you say WINNER?

So much has been written about the HP 35 engineering hand calculator that I don't plan to spend much time reviewing that project. But I will say that from a personal point of view, the dramatic effect that this hand tool offered to individual engineers across the world, gave us in management a true sense of satisfaction. As you would watch a customer engineer pick up the product and start to realize all of its functionality, you knew that HP had made a major contribution to science.

As it turned out, the HP-35 was rolled out in 1972, just at the time that the nation was in a technology recession, and Bill Hewlett directed that all personnel would work nine days every two weeks to keep our costs in line with our revenues. But the HP-35 sales took off so dramatically that the effect on the company revenues was remarkable. Tens of thousands of calculators per month. For an electrical engineering company, the results were sensational.

The HP-35 project had Tom Whitney as the project manager. Tom Osborne continued on at HP after the success of the HP 9100A, to which he contributed enormously. By this time the integrated circuit technology and the miniature LED digital displays enabled this powerful computational tool which would fit into a shirt pocket. But the algorithmic software necessary to pack in the trigonometric and logarithmic and other functions into 35 keys was still an enormous mountain to climb. Our algorithm genius, Dave Cochran (still working), who had made those same functional processes work in the HP 9100A went back to work and shoehorned it all into a very small onboard ROM. It was Cochran whom Bill Hewlett kept nagging, from the time the HP 9100A was put on to Hewlett's office desk. He wanted that power in his shirt pocket.

I remember Hewlett following our project with great excitement, but I don't think he exerted much management pressure. The pressure came from Ralph Lee, who was VP of manufacturing. I believe that Ralph's concerns came from his responsibility for the supply chain of parts we were going to need for production quantities that were far higher than any of our traditional electronic measurement products.

Our lab followed the HP-35 success almost immediately with a financial version which was called the HP-80, developed by France Rode in our Labs. Once financial people saw the HP-35, they found they could use a few of the functions for financial purposes computing the time value of money, interest rates, etc. I believe it was Bill Hewlett who saw the advantage of building a purely financial version of the hand calculator. It was much loved by the investment and banking industry and real estate personnel.

That incident also shows a bit of how Hewlett operated. Bill called France to suggest that he should design a purely financial pocket calculator. France objected that he did not know anything about financial computations. Bill suggested that France just learn them. Bill probably thought that teaching a financial guy about HP-35 algorithms would be less successful.

By this time, the Advanced Products Division was well established in Cupertino, and was taking full new product engineering responsibilities, as well as building their large plant in Corvallis. But before we transferred our work, we created the HP-65, which contained an innovative memory card function. The card was about 1/2 x 3 inch magnetic backed size. I still marvel at how my mechanical designers were able to pack inside a tiny motor drive which drove the card over a read/write head. By storing custom computation routines created by the customer, it offered more power to engineers right at their desk.

We also began work on the HP-45 which expanded the engineering calculator functions. I credit my engineers with the clever idea of adding an "up-shift" key, which almost DOUBLED the number of calculation functions. Other display functions were improved. After beginning the HP-45 in my lab, the project was transferred to the Cupertino calculator group.

After carrying out one of the most successful projects in HP's total history, Tom Whitney moved on to Apple Computer Co., where he was an early contributor to the Apple product line and one of the first 10 engineers there. But Tom's life story ended in tragedy. He sadly had a genetic defect which ultimately killed him. But not after some tremendous contributions and the HP-35.

Click http://www.hpl.hp.com/hpjournal/pdfs/IssuePDFs/1972-06.pdf to read the June 1972 HP Journal story on the HP-35

Click http://hpmemoryproject.org/timeline/dave_cochran/a_quarter_century_at_hp_00.htm to read Dave Cochran's HP Memoir on the HP-35

Click http://hpmemoryproject.org/timeline/john_minck/inside_hp_00.htm to read John Minck's HP memoir on the HP-35 LED displays

Hewlett-Packard in the Integrated Circuit Technology

Over my 40 years at HP labs, I have managed and witnessed such a large number of remarkable breakthroughs that I still thank my lucky stars that I was hired back in 1958. I have described in this HP memoir just a few of the typical projects that my people created. Some, like the HP-35 were rock stars. Some were common technology, but taken to new computerized and functional performance levels.

But in looking back, I think that a more enduring legacy for our HP lab section was the influence that my people had on the onrush of integrated circuit technology in the 1970s. Of course, through the decades the integrated circuit technology was driven by companies like Fairchild and National and Intel. But early on, Dave and Bill had decided that ordinary commercially available ICs from the industry would not perform the unique measurement oriented functions that HP would need for uniqueness in products. This meant that we would need extended performance that enhanced measurement and storage functions, which would include data acquisition and display uniqueness.

In the earliest years of IC developments, Frequency &Time Division Manager Al Bagley built a bipolar integrated circuit facility in Santa Clara, managed by Ed Hilton. This included functional processes for preparing the complex multilayer photo-masks for all of the various process steps, silicon oxide isolation layers, metallization, etc. Designs were laid out by graphic artists, usually women at first, on huge drawing papers with amberlith (red) blocks and interconnecting lines. I remember one IC where the drawing paper was 8 x 15 feet in size. Those huge drawings were photographed and reduced, then were step-repeated and photographed in a large specialized camera stand. These photo masks produced the required chip layers on silicon wafers. It was logical to install such a manufacturing processing facility at Santa Clara because of the high content of digital technology in Bagley's frequency counters.

Around the mid-1960s, John Atalla at Bell Labs invented the Metal-Oxide-Semiconductor (MOS) transistor technology, which then moved to MOS processes in integrated circuits. Atalla soon came to HP Labs, and took over a semi-conductor materials group, with experts like Paul Green, Bob Burmeister, and Egon Loebner.

My IC team was dedicated to a scientific approach to quantifying the various process steps, so we would understand the crucial factors to high yield IC chips. Early on, I hired an outside IC expert, Dave Hilbiber, to consult and teach Jim Eaton and Chris Clare and other team members, all of the intricacies of this technology. Dave had founded and built an IC company, which for various reasons had not survived. I am indebted to Jim Eaton for reviewing my IC writings and offering suggestions for added material. Jim was one of my key researchers for the IC work, for decades.

We soon realized that the complex layouts and the severe requirements that EVERY mask must register precisely with all others. We knew we could improve yields dramatically if we could create the photomask without the manually-created amberlith step. So Eaton and team developed a computer-based system, consisting of HP's new 2116 mini-computer, a Datadisk company disk memory, and a Teletype input keyboard. The system concept was that every element on any given mask was some form of a tiny rectangle, even the connecting metal lines. Our system could automatically size the rectangle from a square form to a long connecting line. From this system and creative software, we were able to program a rectangle-forming mask, moving it around and clicking a flash lamp, and doing that maybe a thousand times to build one photo sheet.

From this system, we created our first test masks, AAA-001 which was a transistor parameter test, and AAA-003, which was an 8x8 memory (made of 4-layer diodes). We had continued to maintain an HP Labs fabrication and process facility, and these first test models worked beautifully. We were on our way. Eaton told me recently that he still has these masks in his artifacts at home.

The IC Labs at Bldg 25, Deer Creek

About this time I was convinced that HP would need to move to the MOS technology, across the corporation. It used dramatically lower power, adapted to IC chemical processes readily, and packed more functions into a given wafer space. I retreated to Yosemite Park to ponder the problem and write a proposal for a well-equipped research and manufacturing facility within HP Labs. Upon my return, I presented the proposal to Bill and Dave. We settled on the CMOS process. With Bill and Dave's approval, it was decided that a new facility should be built, away from our location in Bldg 1. I was proud that my work resulted in Dave's approval, because that new lab did such breakthrough work on IC design and research.

The HP Deer Creek facility was established several miles West of the HP headquarters, to develop processes for CMOS chips for the HP 45C meaning continuous memory. Loveland was championing NMOS, but we needed CMOS to store data in products with only the batteries for power, such as the handheld calculators. Dave Cochran fought those battles of CMOS vs. NMOS, which took seven masking steps over only five for NMOS. Now CMOS takes 25, but among other advantages, saves substantial power for portable applications.

Just prior to the decision to build our own process labs, Bob Grimm had moved to HP Labs, reporting to Barney for advanced planning. Bob had several decades of HP experience, including managing the HP 2116A minicomputer program at Dymec. Barney asked Grimm to take over the job of building the IC Lab. One of the primary reasons for building a new IC facility was to gain better process control so that complex processes could be developed more quickly. When Bob Grimm enlisted Pat Castro to be facility manager he also asked Chris Clare to be the automation manager to bring computer control to the process equipment. The end result of this project plan was that HP bought a brand new already-built building on Deer Creek, which was named Bldg 25. It was built by John Atalla, who had been lured to Fairchild to manage their LED programs.

During a business downturn, Fairchild needed to sell it. Bob Grimm tells the interesting turn of events in his Memoir, online here. One charming sidelight was that before Bldg 25 was purchased, Grimm and his team were serious about building the IC Lab in spare space in the Santa Clara Division. But that building had thumping sheet metal presses. Imagine such vibrations hitting a super-precision camera. They tried extensive rubber isolation schemes with huge I-beams to mount those presses, to keep the vibrations from the building foundations. Fortunately the new Bldg 25 eliminated those brute-force rubber foundations.

Click http://hpmemoryproject.org/timeline/bob_grimm/bob_grimm_memoir_150419.html to read Bob Grimm's HP Memoir story about the HP Labs new semiconductor building

My lab group soon moved into the new Bldg 25 and we continued our broad project assignments. In addition to work on the MOS processes, I assigned Zvonko Fazarinc to invent a new HP CAD, an automated design program for transistor circuit simulation. I also hired Bob Dutton from Stanford to enhance our transistor characterizations, so Zvonko's model would reflect the actual operating parameters. Out of these simulations came a highly-effective computer program for MOS devices. It was similar to the industry CAD modeling called SPICE. Jim Eaton developed a theory of charge-loss for these simulations, and Dutton developed his "Don Ward transistor model," which became very popular and was used everywhere.

Chris Clare remembers Dave Hillbiber as a really crazy guy full of off-the-wall ideas. He did significantly contribute the first IC technology manual that we used to design a suitable IC process. Pat and Chris were involved in selecting all the equipment in that new facility, Pat for the process capability and Chris for the controllability. Chris recalls spending months sitting in the Santa Clara facility working on ideas about how we could build a facility there before the Deer Creek building came into the picture. Our people were SO delighted when they first walked the empty Bldg 25 with Bob and Pat, discussing the potential before the decision was made to buy the building.

The Corvallis CMOS facility initially copied ICL’s automation system. Chris Clare's group trained their engineers and built some of the equipment they needed. Recall that the Deer Creek facility was dedicated to process research, and not production. HP labs took on those complex processes, to understand the physics of integrated circuits as well as the material science and chemistry of processing those wafers.

Soon I became a cheerleader for moving all of HP from NMOS to CMOS. Jim Eaton and I fought a few strategy battles with division leaders who weren't convinced that CMOS would ultimately take over. While CMOS required more active elements per cell, its other advantages were clearly the way to go. We paralleled the Corvallis CMOS facility, and dramatically increased the automation of processing equipment in the Deer Creek lab.

Chris built up a group of up to 20 engineers who designed software and hardware to make this automation a reality. Chris directed the effort of some really talented software engineers among whom were Shane Dickey and Gary Modrell. They built an interconnected automation system network of more than 20 minicomputers.

His software designs were elegant, and provided for complete control over those nasty chemicals and toxic gases which were used. Luckily it was in place when a totally unforeseen incident gave

Chris's system a test we weren't expecting. Those were the years of campus unrest, related to the Vietnam conflict, and a local secret terror group called the SLA (Symbionese Liberation Army) was active. The SLA placed a powerful bomb outside our Bldg 25 walls, out back, near the lab's hydrogen supply tank. One of the tasks of the automation system was facility monitoring, and it was that part of that system that detected the SLA attack and time-stamped it to the second giving the FBI a valuable piece of information. It went off at night when nothing really important was happening in the facility.

We never found out if they were targeting that hydrogen tank which could have caused massive damage, or was just a warning bomb at the sidewall? The sobering result of that bomb blast was that Chris's complex automation programming shut down those chemicals and gases in proper sequence and brought that process to a complete stop. A job well done, and proven.

Clare and his group continued to be busy designing new automated IC test systems. They proposed hierarchical CAD to Corvallis, which was accepted and implemented. Later this became a program nicknamed "Chipbuster" at Santa Clara. These advances in design and test were used to create a complex IC in cooperation with Intel, which later became the industry standard called Itanium. We were really proud of all that state-of-the-art work. HP Labs was at the forefront of NMOSIII dynamic logic, as chip logic content went through 1 million transistors.

Of course those numbers seem trivial now, with hundreds of times more power you now hold in your smart phone hand.

As you can imagine, with IC activities going on all across the HP corporation, political battles would come and go. Who gets the budgets? Who leads particular developments? How do we share management of crucial technologies? Managing such turmoil at the corporate financial level demanded the best strategic knowledge and vision. By this time, Barney had retired, and new management came to HP Labs. I feel that I made proposals and carried out programs for the good of the corporation as a whole.

Click http://hpmemoryproject.org/timeline/bob_grimm/bob_grimm_memoir_150419.html to read Chris Clare's HP Memoir story about the HP Processing Lab automation in Bldg 25.

The Forerunner for HP's winning Digital Oscilloscopes—HP 1980A

Catching up and running ahead of Tektronix in the oscilloscope business was a daunting task. Packard directed that HP should enter the scope market to offer our Sales Reps competing scopes to complement our broad line of other test instruments, in the early 1960s. For a time, our Sales Reps carried both HP and Tek product lines.


One of the earliest digital oscilloscopes depended on state-of-the-art Analog-to-Digital converters.

HP did make fairly good progress in low frequency scopes with the Models HP 120A and HP 130A—500 kHz bandwidths. HP then exploited the sampling technique of repetitive waveforms right at the time that ultra-fast digital data (ie., <1 nanosecond risetimes) was booming. The HP 185A sampling oscilloscope was a real winner. And yet, the 10 MHz and above scopes stayed strongly in Tek's domain for decades.

It was too soon for HP's later innovations in ultra-fast A-to-D converters to provide true digital scopes. A useful interim product concept would be to break new ground on digital-controlled analog circuit technologies. So my Lab Section would develop the product and transfer it to Colorado Springs. My team leader was Zvonko Fazarinc, an extraordinarily creative engineer. Zvonko has already published his HP Labs Memoir on this website. This following excerpt from his memoir follows:

> John Young wants to improve HP's oscilloscope reputation
>
> One day I was approached by John Young, who succeeded Bill Hewlett as CEO, to do something about the bad reputation of HP oscilloscopes. Paul Stoft sent me to our oscilloscope division in Colorado Springs to gain an understanding of their views and thoughts on the problem. Jointly we soon agreed that we needed a drastic new approach to this classical instrument and the Labs would cooperate to come up with new ideas. After gathering a few smarty's from the lab into a number of vivid discussions of the ways to tame the HP oscilloscope, we soon concluded that a digital approach was the answer. But the 400MHz requirement instantly eliminated a fully digital oscilloscope because the analog to digital converters were far behind such capability at that time.
>
> The next best possibility was to digitally control the otherwise analog oscilloscope. But the combination of high frequency analog circuits with digital logic on single chips sent chills down our spines. There was no lack of ideas on how to design the human interface. Barney Oliver felt that we should have only one rotary knob for the adjustments of all individually selected functions. I felt that this would be too drastic a change for a classical instrument but it was not easy to quarrel with Barney. Our argument that, "the world may not be ready for a one key piano with a pitch selector," finally convinced Barney and we quickly completed a computer simulation of the new oscilloscope with a proposed front panel containing controls familiar to customers.
>
> Bill Hewlett's kind toughness
>
> Invited to the demonstration of a possible future oscilloscope front panel, behind which was a big computer, were the division and R&D managers of the Colorado Springs and other HP units. After a fairly enthusiastic acceptance of the proposal, Bill Hewlett asked me to have the prototype ready in one year. Knowing that we had to design 14 integrated circuits containing 400MHz analog hardware with digitally controlled parameters, none of which has ever been tried before, I vehemently objected and pointed out that we were not talking about a calculator. Bill Hewlett just smiled politely and walked away saying "Zvonko, if you have something better to work on just let me know!"
>
> The proposed controller of the new oscilloscope was to perform automatic calibration of time and amplitude scales among other vital functions and there was no question that we needed the former designer of the HP35 calculator processor, France Rode, who joined my laboratory at that point. Fortunately Mr. Hewlett's deadline of one year was not firm enough to harm me after we took a few years to complete the prototype of the 1980 oscilloscope, which received the "Product of the Year Award" by the "Electronic Products Magazine," for 1982.

Click http://hpmemoryproject.org/timeline/bob_grimm/bob_grimm_memoir_150419.html to read about Zvonko Fazarinc's work on the HP 1980A

Not all Projects Worked Out

Bill Hewlett would occasionally speak to an HP engineering audience. He had specific ideas for R&D prioritizing. He noted that R&D projects should be a combination of sure-thing ideas as well as some proposals that were really stretching the technology. He said that if you didn't occasionally have a few losers then you weren't venturesome enough.

I had one project that qualified for Bill's R&D strategy. It was a multichannel strip chart recorder which provided 10 channels of analog recording, plotted out on the 12 inch wide paper roll, with the backside coated with a conductive carbon. The recorder was known by a nickname, Band Saw Recorder. The product concept was that there were two discs about 6 inches in diameter, around which was threaded a 1/4 inch-wide stainless steel band. So it literally looked like a band saw blade placed horizontally. The band ran at 100 mph.

On the band periphery were three tiny nibs or protruding points, which made contact with the recording paper which moved upwards, perpendicular to the path of the band. As any particular nib entered the paper, a linear voltage ramp was initiated, and when the voltage ramp reached the input voltage of any particular channel, a 2000 V pulse was sent to the band which burned a tiny black hole in the recording paper. Since there were 10 channels, there were 10 tiny dots plotted across the paper, at the points where any of the 10 input channel voltage equaled the rising ramp.

The reason this project ended up in my HP lab section was that Bill Hewlett purchased the rights to this recording technology from a European company named Sintef. I think he paid about $100,000 for the license. And since this particular technology didn't fit well with any product division, it ended up in my lab. We took the project into what was called the engineering prototype phase and actually had built 10 units, and were ready to transfer to a division. John Young in the Microwave Division convinced Hewlett to transfer the product to his division which had extensive mechanical fabrication capabilities, and matched well with this instrument construction.

Sadly, once John Young's marketing people went out to look for customer feedback, the general consensus was that the recorder had several fatal flaws. One was that as the 2000 V spike pulses hit the paper, a small amount of smoke was emitted, but with 10 channels plotting hundreds of dots per minute, that still resulted in a fair amount of unwanted smoke in most potential customer lab locations. A second major problem was that the very high voltage created a radio frequency interference emission from the carbon backed paper as it spilled out onto the floor, and acted like an antenna for the electronic noise. This RFI was virtually impossible to shield. The upshot was that Young's microwave division chose not to proceed with production and sale.

But there is a charming end to the story. One single customer interview from the original market research travel was that Woods Hole Oceanographic Institute near Boston thought the product might work well on their ocean-going research ship. So Young's marketing manager John Minck donated all 10 engineering prototypes to their oceanographic program. But the end of this story was not completed until Minck visited Boston approximately 10 years after the donation.

In a tradeshow he was talking with a visitor to the booth with a Woods Hole badge. The man revealed that he actually served his main job on their oceanographic ship. When Minck asked about the 10-year-old recorders the man exclaimed, "We love those recorders. Most of our measured parameters are slow-moving, like ocean bottom data." When Minck asked about the smoke and the RFI, the man noted that they simply leave the ship's door open for the smoke, and that the rooms are steel walls so the interference is no problem.

Sometimes there is a serendipity to life. In this case the good idea with several flaws still found a customer who made excellent use of that technology. I'm sure Bill Hewlett would smile when told the story, and would still approve the whole thing. And not just because it was Bill who had sunk $100,000 for the patent at the beginning.

Click http://hpmemoryproject.org/timeline/john_minck/inside_hp_04.htm to read John Minck's story about the Bandsaw Recorder

Remembering Other Significant Projects

1. As HP moved aggressively into the mid-range computers, other sections of HP Labs needed new expertise. To exploit a new computational concept called RISC (Reduced Instruction Set Computing), Packard hired Joel Birnbaum, who was a top manager of RISC work at IBM. The RISC concept called for custom IC functionality as well as advanced software, and HP made bold commitments to base new computer systems on these more efficient and faster machines.

2. In my lab, we started a new effort which we called the Wide-Word Computer Architecture project. The objective was to explore computer architectures of 64-bit words. Recall that at the time most computers used 16-bit words, and some were going to 34 bits.

3. As the new Global Positioning System of 24 navigation satellites were launched for military navigation capabilities, engineer Ralph Eschenbach, working in Zvonko Fazarinc's group, began to design a commercial GPS receiver. This happened before the US Defense Dept had decided just how much to open up their secret codes for commercial applications. Ralph's work resulted in a functional positioning system, which could plot locations. So he decided to run a test. He loaded his system in a mobile home vehicle, with a motor-generator, printers and such. He then drove down the Skyline Highway, Hwy 35, plotting as he went. The result showed that his location coordinates were some 200 feet away from the US Geological Survey maps. Upon the end of his experiment, he called the engineer at the USGS, who told him that another engineer had failed to enter more recent data into the USGS map database. Ralph's data was dead-on correct.

Down at the Santa Clara Division, Charles Trimble was actively working on another location receiver, this one using the WWII era LORAN navigation system. When we had proven that we could make a GPS navigation system Dave Packard was still in charge of HP and wanted us to pursue the project. But later Packard moved to the Department of Defense, and John Young became the CEO and did not want to pursue the GPS while he was trying to get HP into the computer business. With heavy heart we stopped the work and wrote a paper with results.

While these two project budgets were not large, either Barney or Hewlett reasoned that neither technology, even if carried through to saleable products, would be in the right markets for our Field Sales engineers. A year later some NASA people inquired what we had done with the unique GPS navigation instrument, and Zvonko went back to John Young and asked him if we could "sell" the knowledge? He agreed and after a few outside attempts to buy our GPS info (in Zvonko's estimation soon to kill it) John agreed that we sell it to Charlie Trimble whose business was losing ground at that time. As a result, Trimble proposed a buyout of both HP navigation technologies, and formed his company, Trimble Navigation. Trimble hit a growing navigation equipment market at just the right time, sold his technology into the military's first invasion of Iraq in 1991. His product line broadened and his company now operates in 32 countries.

4. My Lab Section (now called a Center) also contributed to IC designs for HP's newest success stories, the Ink-Jet printers and the LaserJet printers. Those products changed the face of our high-tech company into a consumer product company, which became comfortable talking about printer production rates beyond one million PER MONTH. Custom chips were crucial to the amazing graphics functionality being designed into those printers, WYSIWYG (what you see is what you get). Our earliest inkjets printed simple alpha-numerics. Our newer printers handled images and image processing to make the HP printers among the industry's easiest to use. My teams assisted in those breakthroughs which makes me extremely proud.

5. Prior to the HP 9100A and HP 35, my lab was also involved in the early work on what became the HP 2116A, HP's first entry into computing. I had "saved" Kay Magleby for HP, by offering him a chance to earn a PhD at Stanford at a time that Hewlett and Packard had become disenchanted with the beginning Honors Co-op program. Magleby's thesis work led to an HP Labs prototype of a 16-bit minicomputer, that Packard didn't want us to build. For his own reasons, he never liked the idea of HP going into computers. But he did support the idea that it could be an instrumentation controller, for automating data collection from HP instruments. The product development shifted to Dymec (with Bob Grimm as mentioned above). The HP 2116A and its derivatives became the basis for HP's eventual strong industrial position in minicomputers.

6. In the mid-1970s, after the stunning successes of the HP-35, 45, 65, and 80 hand calculators, France Rode and I were determined to try to anticipate the next big product in portable computation. The objective was to build a computer into a briefcase-sized package, with keyboard and mouse and a telephone modem, and a display screen. Today, we would call it a laptop, but in those days it tried to be an Apple desktop computer, made portable. The personal computation business was in a HUGE race those days, really before necessary components were ready. We started with our display being just 32 LED alphanumeric characters, which was not nearly enough for suitable customer operation.

This was some years before liquid crystal displays were reliable enough, so we then focused on using a cathode-ray tube that was 2 inches diameter. We were able to make the character resolution satisfactory. So we then designed a mirror magnifying system to make it readable. But sadly, the display intensity was woefully inadequate. France actually kept his mockup from that project and told us he had it in his home storage, but then he died suddenly, before he had made time to go looking for it.

Acknowledgements

I had not considered writing about my HP career, in my early retirement. As I reached my advanced years, it seemed unlikely that I could record my memories of that great time in my life career. Hewlett Packard offered all of us engineers and employees the best of our 20th Century world; challenging work in advanced technologies, lifetime employment, a work culture second to none, and interesting personalities to work with.

Then John Minck contacted me and informed me of the HP Memory Project, a welcome project to record the personal histories of HP retired employees. I agreed to several interviews and I applaud his efforts to look at legendary HP personalities and products and technologies. I would also like to acknowledge the assistance of Jim Eaton, Chris Clare, Dave Cochran and Zvonko Fazarinc, who were key engineering team members for several decades. They have all reviewed my manuscript and offered comments and additions.

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Sept, 2018