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THE SOUND OF ONE CHIP CLAPPING: YAMAHA AND FM SYNTHESIS

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MITJP 94-09

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The Sound of One Chip Clapping: Yamaha and FM Synthesis

If you were to meet John Chowning at a reception, say, or a Palo Alto cocktail party, it is not inconceivable that you might guess what he does for a living. The high forehead, the serious demeanor, the slightly owlish features, all the physiognomical clues point to an artist of some sort. The French and German words that pepper his conversation - properly pronounced, mind you - suggest time spent abroad, in bohemian Paris and Berlin perhaps. But no tell-tale flecks of paint or whiffs of turpentine, so not a painter -- a poet, then, or ... a composer? Got it in two.

It is highly unlikely, however, that you would guess the other claim to fame of this modest composer and professor of music at Stanford University. That is, that John Chowning also has an invention to his name. And what an invention! One that has brought Stanford millions of dollars in patent license fees -- second only in terms of revenue generated to Stanford's basic biotechnology patents, second moreover at *Stanford*, whose licensing income far outstrips that of any other US university. An invention that has earned the computer music center that Chowning founded pride of place on the Stanford campus, in what was once the university president's residence, and ensured its permanence through endowment. And one that has made Chowning himself a rich man, with a yacht named "Paradise" moored at Sausalito marina to prove it.

Chowning's invention was FM synthesis, a simple way to generate complex sounds. In the form of a microchip, FM synthesis became, first the sound generator for the most successful music synthesizer ever made, then for a whole range of keyboard instruments. Most recently, it has become the key component on sound boards, personal computer accessories that in 1994 are multimedia's first billion-dollar market. The market for FM chips is dominated by one company: top Japanese musical instrument maker Yamaha. The chip and its derivatives form the bedrock of a fast-growing business that is currently worth about $300 million in annual sales to the company.

For almost 20 years, from 1975 until 1994, Yamaha had an exclusive license on FM technology. This was one Japanese monopoly that need never have happened. Before contacting Yamaha, Stanford offered the technology to leading US electric organ makers; in particular, to the most famous of them all, Hammond. Today, the brand name is all that remains of Hammond Organ. The company was purchased in 1985 by Suzuki, another Japanese musical instrument maker. As it happens, Suzuki's headquarters are located in the small Japanese city of Hamamatsu, just down the road from where Yamaha makes FM chips.

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When John Chowning arrived at Stanford's music school in 1962 as a 29-year-old graduate student, he had never so much as seen a computer before. He was fresh back in the US from three years studying composition in Paris with Nadia Boulanger. There, Chowning had gone to concerts of electronic music that featured pieces by Pierre Boulez, Karlheinz Stockhausen and Luciano Berio. "The idea of speakers as musical instruments was very much in the air," Chowning recalls. He was keen to have a shot at composing for these new instruments himself.

Back in the early 1960s, a major barrier to would-be electronic music composers was the almost unbelievably primitive means of sound creation at their disposal. In the early 1960s, the most familiar technique for creating new sounds was *music concrete*, which itself had been invented in Paris. In Germany, composers like Stockhausen would record onto 1/4-inch magnetic tape sounds like the bleeps and bloops made by audio oscillators (the sort of device that radio broadcasting stations use to test their equipment). Then they would chop up the tapes into short strips with razor blades, splicing them back together in whatever order sounded good. Creating a few minutes of concrete music could take weeks or even months of painstaking work.

There had to be a better way -- and, sure enough, it turned out that there was. Chowning found out about it quite by chance. In his second year at graduate school, he was passed an article from the November 1 1963 issue of *Science* by a colleague in the Stanford orchestra, in which Chowning played percussion. The article was by Max Mathews, a researcher at Bell Laboratories, and it was the first publication of his work outside the laboratories' technical journal. It described how computers could be programmed to play music. Intrigued by the possibility, Chowning wasted little time before heading back to his native New Jersey to find out how it was done.

Mathews worked in the acoustic and behavioral research department of Bell Laboratories, a group which consisted of around 80 researchers, including computer scientists, mathematicians, experimental psychologists and electrical engineers like himself. There, in order to simulate the behavior of new telephones, researchers had figured out how to digitize speech, squirt it into the computer, run their experiments, then turn the bits back into sound waves. Mathews immediately realized that it would be relatively straightforward to adapt this process to the writing and playback of music. In 1957 he wrote a program called MUSIC I that made computer technology accessible to non-scientists. Then he invited composers to come by the labs nights and weekends to try it out.

Though less primitive than cut-and-splice, composing music on the computer was anything but straightforward. As Mathews recalls, "we had decks of punch cards on which the computer scores were produced, which we would carry around in boxes." These they would load into a car, drive into Manhattan to the IBM building [on Madison Ave and 57th St], in the basement of which was a mainframe computer on which time could be rented, at the astronomical rate of $600 an hour. "We would queue up," Mathews says, "then, when it was our turn, we would run down the stairs, stick our cards in the deck, and press the button." The result would be a tape full of digital sound samples, which they would take back to Bell Laboratories and play back through a specially-built digital-to-analog converter.

Despite all this to-and-fro, the composers loved the computer. It offered a solution to one of the thorniest problems they faced -- how to get your music performed? Finding an orchestra willing to play your latest piece was a perennial headache for the profession, especially for its more avant-garde practitioners. ("The reason I keep these expensive gentlemen with me," said the late Duke Ellington, referring to his orchestra, "is that unlike most composers, I can immediately hear what I've written.") One composer became so enamored of the computer that he began spending all night, every night at the labs. Eventually, Mathews recalls, his wife left him.

A second attraction of computers was that they didn't screw up -- they would play your score exactly as written. And they offered composers the chance to go back and change bits as often as they liked. But for all their joy at having found a new and flexible way to organize and perform sounds, composers of electronic music could not help but be aware that there was still something lacking. As anyone who has ever heard a radio test tone knows, the sound that your garden-variety oscillator generates is not exactly fun listening. The human ear craves richness: overtones, stray harmonics, distortions -- in short, anything rather than the unwavering monotony of the oscillator's pure electronic tones.

Chowning returned to California for the 1964 fall semester clutching the box of punch cards that Mathews had given him. Now what he needed was a computer to run them on. He took a look around campus and discovered Stanford's newly-established artificial intelligence laboratory. John McCarthy, the AI pioneer who set up the lab, allowed him to freeload time on the lab's DEC and IBM machines, just like the composers at Bell Labs, at nights and on weekends. As it turned out, the AI lab was a wonderfully stimulating place for the young composer to work.

At the AI lab, Chowning recalls, "you had engineers, you had scientists, mathematicians, philosophers, psychologists, people using computers. So it was a very rich intellectual environment, on which I depended -- I could cycle through these people until I got an answer that connected, and that was a technique of learning that I often used, because I had no technical background. I had a lot to learn, but it was probably the most exciting learning experience I've ever had."

Chowning was now 30 years old, a long way from his last high-school math class. But with the help of an undergraduate he got Mathew's program up and running in short order. And because of the way that the lab's computers were connected, the set-up became the world's first on-line computer music system, enabling Chowning to interact directly with the machine. Other than a single course in FORTRAN programming, Chowning picked up everything through his own hands-on experience. And he quickly realized that "with a modicum of programming skills, one can accomplish some truly astonishing things."

One night in 1967, while experimenting with wildly exaggerated vibratos (vibratos are fluctuations in pitch often added to electronic sounds to give them a more realistic quality), fooling around with a couple of oscillators, using the output of one to control the other, half-fearing that he'd break the computer if he went too far, Chowning heard something remarkable. At a certain point, at a low frequency of around 20Hz, he noticed that instead of an instantaneous change in pitch from one pure tone to another, a recognizable tone color, a rough sort of *whoo-ch-ch-ch-ch-ch* emerged from the machine. It was what Chowning calls "an ear discovery".

"I kept pushing the rates and noticed that at 50Hz and 100Hz what I was hearing was no longer a pure tone, but one that was rich in harmonics." He also noticed that if he kept the frequency of the vibrato constant while altering the depth of the waveform output by the other oscillator, what happened was that the pitch stayed the same, but the richness of the sound changed. As it got deeper and deeper, more and more harmonics appeared.

It was a discovery that an engineer would have been unlikely to make. What Chowning had stumbled upon, he was later to find out, was frequency modulation -- the same technique that radio and television broadcasters use to transmit noise-free signals, only transposed into the audio domain. Of this, the composer was blissfully ignorant: all he wanted to do was make colorful sounds. Chowning began tweaking his algorithm and pretty soon, as he recalls, "using only two oscillators, I was making bell tones and clarinet-like tones and bassoon-like tones, and I thought, you know, *this* is interesting."

But not interesting enough to go dashing out yelling Eureka!. Chowning put his discovery to one side and got on with other things. He had not yet, as he puts it, connected his ear to the theory. This connection would not occur until 1971, when Chowning remembered some synthetic trumpet tones that a Bell Labs researcher had played for him and wondered whether he could achieve a similar effect using FM. It turned out that he could indeed produce some quite realistic brass tones. And it was at this point that he realized that his technique was a lot more powerful than he had at first thought. So, being a composer, the first thing he did was to write some pieces of music using FM. One of the first of these was *Turnenas* , written in 1972.

Turenas (the title is an anagram of Natures) gives a good idea of FM's versatility as a palette from which to mix new sounds. It is a lively piece in which sounds are constantly whizzing around from one speaker to another (reflecting another of Chowning's preoccupations, the use of sounds to create a sensation of space). The sounds the piece employs fall into three distinct categories: first, there are those that resemble those made by regular instruments, like organ, horn and bassoon, and chimes, bells and gongs. Then there are sounds that are more or less familiar, like water dripping onto a canvas awning, or the teeth of a comb being twanged. Finally, there are some sounds that are like nothing you have ever heard before. For Chowning, these previously unimagined sounds were "the wonderful part of art making contact with technology, of connecting your art with another domain."

Chowning gave performances of his work and explanations of the technique. Someone who heard him suggested that the music industry might be interested in FM. So Chowning went to see Niels Reimers, who ran Stanford's Office of Technology Licensing, and played him some examples. And Reimers agreed that Chowning's idea had commercial potential. So he began contacting the US companies that were most likely to be interested the idea, the electric organ makers. And among them, the key target was the company that had invented the electronic organ, which had created the market to go with it, and whose name had as a result become so famous that it had become a household word, listed in dictionaries, encyclopedias and text books -- a company called Hammond Organ.

* * *

There are thousands of different electric keyboard instruments out there. But with the possible exception of the Fender Rhodes piano, there is only one with a truly distinctive sound -- the rich, fat, shimmering, swelling roar of the Hammond Model B-3, introduced in 1953, the most popular electric organ ever made. It is a sound that anyone who grew up in the 50s and 60s can instantly recognize, the sound that first jazz organist Jimmy Smith, then subsequently Booker T. Jones - remember *Green Onions* ? - made famous. And it is a sound that even today merits a special mention on album credits and in on-stage introductions -- "On the Hammond organ, ladies and gentlemen ..."

The funny thing is that Laurens Hammond, the inventor of this illustrious instrument, could not himself play a note, could not even hold a tune. Born in 1895 in Evanston, a suburb of Chicago, Hammond was a latter-day member of that band of individual American inventors that includes Edison, Bell and Edwin Armstrong, the man responsible for FM mark one. From an early age, Hammond was an inveterate tinkerer, winning the first of his 110 US patents - for an improved barometer - when he was just 16.

Hammond was a mechanical engineer by education (at Cornell University). Having fought with the US forces in France during World War I, he returned to take up a position as chief engineer with a small Detroit firm of marine engine makers. But Hammond was not cut out to be a company man -- at least, not unless it was his own company. In 1920, annoyed by the noise made by the spring mechanism of a clock, he invented a "tick-less" clock enclosed in a soundproof box. Selling this idea enabled him to set himself up with his own laboratory in New York City. It was there, the following year, that he came up with his core invention -- a synchronous motor that would run in phase with the 60-cycles-a-second alternating current power supply that was then becoming standard. The significance of this was that it made Hammond's motor run very efficiently -- even in miniature form.

Hammond investigated several applications for his invention, including projectors for the first 3-D movies. But it was not until years later that he would tie his two inventions together to create a tick-less electric clock driven by the synchronous motor. In 1928, he moved back to Evanston to establish the Hammond Electric Clock Company in premises above a local grocery store. For a few years the company prospered, but by the early '30s the clock market was saturated and the depression was at hand. Clearly, if he was to remain in business, Hammond would have to come up with a new product. And come up with one he did, unveiling in 1932 ... an automated bridge table, equipped with a synchronous motor driven mechanism that would shuffle a pack of cards, then deal out four hands. Though the table was a success, selling some 14,000 units at $25 each in the run-up to Christmas that year, it was obviously only a stop-gap.

Once again Hammond went back to his work bench. Employees soon began to hear strange noises emanating from his laboratory, some of them loud enough to shake the building to its foundations. Then one day, passersby heard the sound of flute floating out the laboratory window. The source of this wonder was an invention that came to be known as a tone wheel. This was a disk of iron about the size of a silver dollar, from the edge of which protruded cog-like bumps. Spinning the wheel in front of a coil-wound magnet would induce an electric current in the coil which, amplified and sent to a loudspeaker, could be translated into sound. Hammond and his researchers discovered that by lining up 91 tone wheels on shafts driven by his magic motor, and using precision gears to change the speed of rotation, they could reproduce all the sounds made by a conventional pipe organ -- and then some.

On the organ that they built, each key was connected to a bunch of switches. The switches, in turn, were connected to each other by a system of metal strips called drawbars. The organ contained 1,500 switches equipped with long-lasting platinum contacts, hooked up via some eight and a half miles of wire. When a key was pressed, a combination of switches would close, forming a sound generating circuit in much the same way as the electromechanical relays of contemporary telephone exchanges would connect to complete a call. In January 1934, Hammond packed his prototype into a box and shipped it directly to the US Patent Office in Washington DC, where it was set up in the basement of the building. On August 24 that year, in almost record time, Hammond was granted a patent on his organ.

The Hammond organ was an overnight success. Among the company's first customers were George Gershwin and Henry Ford. But priced at $1,250, the Hammond was cheap enough for regular folk to afford, too. One organ nut who just had to have a Hammond in his living room was a young man called Don Leslie from Pasadena, California. Leslie didn't buy a speaker to go with his purchase, figuring that it would be cheaper to build one himself, which he proceeded to do. To his great disappointment, the result didn't sound nearly as good as what he'd heard in the music shop. But then the shop had a long, high-ceilinged showroom, ideal for producing the reverberations that are crucial for sonic richness. How to compensate for lack of reverberation in his living room? Leslie came up with the idea of revolving the speaker inside its cabinet. He built a prototype and ... it sounded great! In the first flush of his enthusiasm, Leslie figured that Hammond might be interested in his idea, so he arranged a demo and invited the Hammond brass.

Leslie's hopes were dashed: the Hammond people turned up their noses at his invention. Worse, when Leslie went into business making speaker cabinets on his own, Hammond declared war. Leslie speakers were not to be used with Hammond organs in stores; Hammond dealers were prohibited from handling Leslie products (so they sold them on the side: organ buyers were asked if they would like to step into the back room, or the basement, where salesmen would demo the speakers on the sly).

Hammond's feud with Leslie reveals much about the firm's attitude toward innovation. If it was not invented by Hammond, then Hammond didn't want to know, even to the extent of cutting off his nose to spite his face. Hammond the company would eventually acquire Leslie, but not until 1980, long after Hammond the man's death in 1973, having missed out on four decades' worth of speaker cabinet revenues.

Laurens Hammond retired as chairman of his company in 1960 and went to live in Cornwell, Connecticut. The official story is that in his retirement, Hammond devoted himself to research. In fact, says Doug Jackson, a veteran Wisconsin-based Hammond dealer, Hammond acted as "a puppeteer from afar -- he was a very strong character and anything he didn't want done didn't get done." So it is not unreasonable to assume that Hammond's negative attitude toward innovation from the outside would have continued to prevail at the firm even after his retirement.

By 1971, when Nils Reimer of Stanford's licensing office got in touch, Hammond was, in Jackson's words, "a very stodgy company -- they were very set in their ways, they were resting on their laurels and had been for years." The trouble was that, by the early 1970s, tone wheel technology was verging on obsolete. The company could not afford to go on much longer producing such an archaic system, with all its miles of wire and thousands of switches. And its engineers were undoubtedly aware that the emerging microchip technology had the potential to create new sounds in less space and for lower cost.

Perhaps it was a sense of urgency that caused Hammond to despatch almost its entire engineering staff to the West Coast for a look-see. Reimers recalls that they also brought along a virtuoso organist with them. When this musician heard Chowning's FM tapes, he was enthusiastic about the technique's potential. The engineers, however, just didn't get it. Chowning recalls "they kept asking me things like, how many pins will it need? Well, I didn't know anything about pins, chips or analog circuitry at all, so I couldn't answer them. I said, 'Look, it's an algorithm, and here's the code'." By this time, he had confirmed that the technique was indeed frequency modulation, so he was able to explain the principle to the Hammond people. But they couldn't see how it connected with what they did. "It was simply not part of their world," Chowning concludes.

Other US organ and piano companies that Stanford contacted - including Allen, Baldwin, Lowrie - were likewise unable to make the connection. But rather than give up, Reimers assigned a graduate at the university's business school to do some research into electric instrument makers, to see if there was anyone else who might conceivably be interested in FM. It did not take long to come up with the name of Yamaha, which, although at that time virtually unknown in the US, turned out to be the largest maker of electric organs and pianos in the world.

Yamaha had an office in Los Angeles. In January 1972, Reimers called and told them that there was an interesting new technology up for license. A 34-year-old engineer called Kazukiyo Ishimura happened to be visiting from Japan, and he flew up to San Francisco, rented a car and drove down to Palo Alto to meet Chowning at the AI lab. Chowning played Ishimura a few examples and explained what he was doing. It took Ishimura all of ten minutes to grasp the concept. Why was he so quick? Two reasons: One was that as a student he had majored in communications technology at Tokyo's prestigious Waseda University, so he knew exactly what frequency modulation was. The other was that Yamaha had already been working on the development of digital instruments for the past five years.

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Yamaha, this huge company that no-one seemed to have heard of, owes its origins to a chance encounter between Torakatsu Yamaha, a 36-year-old medical equipment repairman, and a bellows-driven Mason & Hamlin reed organ. The encounter took place in 1887 in the Pacific coast port of Hamamatsu, a small town located midway between Tokyo and Osaka, known mainly in those days, if it was known at all, for its local delicacy -- broiled eels. But the town evidently did not see itself as a backwater, or at least had ambitions of upward mobility, witness the purchase of an expensive imported American organ - a symbol of modernity - for the local school. Then the blasted thing went wrong, and Yamaha - who fixed equipment in the local hospital - was sent for to put it right.

When Torakatsu Yamaha was born in 1851, the third son of a prominent samurai, there were no Western instruments in Japan, nor Western music, nor Western anything for that matter. The country was closed to foreigners and all things foreign, and had been for the best part of 400 years. Two years later, when Commodore Matthew Perry and his fleet of black ships sailed into Tokyo Bay, he brought a naval brass band with him. For Japan, the modern age begins with Perry stepping ashore to the accompaniment of martial fanfares and oompahs.

Aged 20, Yamaha left home for the southern city of Nagasaki, where for several years he was apprenticed to a British watchmaker. Then, after a failed attempt to make watches on his own account, he turned to repairing medical equipment, landed a job with an Osaka-based firm of suppliers, and was assigned Hamamatsu as part of his territory.

Yamaha was evidently fascinated by the organ. After fixing it, he went over the instrument with a fine tooth comb, drawing elaborate diagrams and taking copious notes. By the time he had completed this early instance of would later be known as reverse-engineering, Yamaha was confident he could build one himself. Which he proceeded to do, improvising with local materials like tortoise-shell for the key coverings in place of unobtainable ivory. Though crude, his prototype organ worked persuasively enough for him to recruit a workforce of seven and ¥30,000 (approximately $10,000) in capital from local Hamamatsu investors. The year was 1888 and Yamaha was in business.

Others would soon follow Torakatsu's example, as Western-style music became part of Japan's national school curriculum and the market for instruments blossomed. By 1895, the year of Laurens Hammond's birth, a dozen Japanese manufacturers were producing approximately 10,000 reed organs a year. Yamaha, with an annual production of 2,000 units was unquestionably the leader. The company continued to flourish, making a timely transition around the turn of the century to the new upright pianos, which from then on would be the keyboard instrument of choice for the home market in place of the more expensive organ.

In 1916, Torakatsu Yamaha died suddenly at the age of 64. The next decade was not a happy time for the company he had founded. Beset by a series of disasters - fires, earthquakes, and strikes - Yamaha lurched to the brink of bankruptcy. The firm was saved by a remarkable man. Kaichi Kawakami was Hamamatsu-born but destined, or so it seemed, for great things elsewhere. He graduated top of his class in physics at Tokyo University, then joined Sumitomo Wire, the electrical machinery wing of one of Japan's biggest industrial *zaibatsu* conglomerates. The company put Kawakami onto the fast track, sending him abroad for two years on a study tour of the US, England and Germany. In May 1927, when Yamaha's harried board of directors offered him the chief executive's job, Kawakami was 42 years old. Much to the horror of his family and friends, he accepted. Perhaps rescuing a moribund musical instrument maker was more of a challenge for him than playing corporate politics at Sumitomo.

Kawakami made three invaluable contributions to Yamaha. One was his knowledge of modern management techniques, which he immediately set about applying. The second was some desperately-needed investment from Sumitomo. Over the next half century and beyond, the Sumitomo connection would continue to provide Yamaha with financial backing, underwriting the company's subsequent forays into new businesses. In the early 1990s, group companies including Sumitomo Bank, Sumitomo Marine & Fire Insurance and Sumitomo Life Insurance would between them own almost 14% of Yamaha's stock, the single largest shareholding. Kaichi's third contribution was his son, Gen'ichi, who took over the presidency of the company in 1950, when a stroke incapacitated his father.

* * *

In 1956, the year before computer music was born at Bell Laboratories, a most unusual job interview took place in Hamamatsu. The interviewee was a 29-year-old live-wire electrical engineer called Yasunori Mochida; the interviewer, Gen'ichi Kawakami, fourth president of Yamaha. What made the interview unusual was that it took place in Kawakami's bedroom, with the chief executive lying flat on his back.

Kawakami was laid up because he had broken his leg falling off one of the 125cc motorcycles that Yamaha had recently started making. What was Yamaha, a manufacturer of musical instruments, a company whose stock in trade was pianos, organs, harmonicas and accordions doing in the motorbike business? The answer is that Gen'ichi Kawakami liked to try his hand at new things. And once started, there was seldom any stopping him.

During the World War II, Hamamatsu had been razed to the ground by American firebombs. Some of these were no doubt intended for Yamaha's factories, which had been converted for the duration to the production of airplane parts like propellors - including all the wooden propellors installed on Imperial Army aircraft - and fuel tanks. By 1950, however, Yamaha was back in its usual business, cranking out pianos and organs. It would have been easy for Kawakami, like so many second-generation chief executives, to coast along on the momentum that his father had generated. But Gen'ichi Kawakami was not the sort of man to coast. The way Kawakami saw it, the role of a manager was not just to look after current business, it was also to find and explore new business opportunities.

Strongly-held convictions were one thing that made Kawakami different from most Japanese males. Another was an intense dislike of wearing neck-ties -- polo-neck shirts would become his trademark. One factor that separated Kawakami from fellow-countrymen was his experience: unlike all but a few Japanese in the 1950s, Kawakami had seen the world -- and been inspired by it. On a three-month round-the-world trip in 1953 (a trip which, by coincidence, Sony's Akio Morita would make that same year), he had visited the United States where he was astonished by the range and variety of products on offer, and by the sophistication of the techniques that Americans used to manufacture them. After visiting modern US facilities like the Baldwin piano factory in Cincinnati, Kawakami realized how primitive Yamaha was by comparison. For the moment, his dreams of exports were shattered.

Kawakami returned to Japan determined to modernize every facet of Yamaha's operations. He ploughed company profits into upgrading manufacturing processes, installing newfangled equipment like conveyor belts and woodworking machinery. But his biggest investment came in 1956, in a huge automated kiln used to dry wood for making pianos. It was characteristic of Kawakami to think on a grand scale. At a time when Yamaha's annual production was just 15,000 pianos, the kiln could hold enough wood for 50,000. Kawakami was widely criticized for this apparent extravagance. But as status-hungry, culture-starved Japanese consumers began buying pianos in record numbers, Kawakami's vision of the future market turned out to be right on the money. Within ten years Yamaha's output had increased to 100,000 units a year, making the company the largest producer of pianos in the world.

Kawakami was also intensely competitive. By the early 1950s, Hamamatsu had become Motorbike City, Japan, serving as headquarters for both Suzuki and a brash new start-up called Honda Motor. Kawakami was determined to get into this market too, and the metal-working tools that Yamaha had used to make airplane parts during the war gave him an effective means of entry.

Another competitive spur was the knowledge that entirely new markets were opening up. With characteristic foresight, Kawakami had obtained for Yamaha the sole agency to sell through its chain of music shops tape recorders made by Tokyo Telecommunication Engineering, which in 1955 began using the easier-to-recognize name "Sony" on its products. Sony's success in introducing electronic products presented the ambitious Kawakami with a new challenge. But it was a challenge that he felt more than qualified to meet. "Ibuka-san [Sony's first president] is a talented person," he is reported to have said at the time, "but I am a genius."

This time, however, Kawakami had no existing resources to throw at the problem. There was not even a single electrical engineer on Yamaha's payroll. Which explains why on that momentous day in 1956, broken-legged and swell-headed, Kawakami summoned young Yasunori Mochida to his bedroom for an interview.

* * *

Mochida was born in the provincial northwestern Japanese city of Kanazawa in 1927. His father was a professional soldier, but more importantly, he was a man with an inquisitive mind who loved new gadgets like radios and single lens reflex cameras. Mochida junior was very much a chip off the old block. Young Yasunori grew up in a household surrounded by gadgets that his father had bought. He was evidently one those insatiably curious kids who just have to know how things work, taking them apart then putting them back together again. Aged 14 or 15 he built himself a radio out of vacuum tubes. Above all, the youngster loved finding new things to do. Though obviously bright - math and physics were his favorite subjects - Mochida hated the rote learning that was (and is) such a dominant feature of the Japanese education system. To their credit, his parents put no pressure on him to cram to get into a good school. The end of the war found Mochida old enough to go to university, but he opted instead to enter a local technical college, where he would be able to pick up more practical skills.

After graduating, the 20-year-old Mochida came to Tokyo to work for Denon, a subsidiary of Nihon Columbia, which made phonograph records and recording equipment. His boss there was a classmate of Sony's Ibuka, and the two used to meet regularly and discuss tape recorders, which were Sony's first successful products. As a result, Mochida was assigned to develop a tape recorder, his specific responsibility being the electronics. The project was successful, but late. Sony had already captured the lion's share of the audio market for tape recorders, forcing Denon's management to look elsewhere for customers. They found a niche selling their products as data recorders to power companies for monitoring lightning strikes on their high-voltage transmission lines and seismologists for tracking earthquakes. This early exposure to both audio and data processing would later stand Mochida in good stead when it came to developing digital musical instruments at Yamaha. For the moment, however, his practical experience in developing tape recorders was the reason for Kawakami's interest in him.

What did Mochida and Kawakami make of each other on this first meeting? Mochida recalls little about it other than that Kawakami was testing him, finding out what the younger man was made of, what his attitude was. One thing, however, sticks in his mind: Kawakami revealed a burning ambition to make his mark in the world, to do something that no-one else was doing, something completely new and different. Mochida was (and is) a man whose passion is doing new things. The two men were thus on the same wavelength: the one would become the instrument for fulfilling the dreams of the other. While working at Yamaha Mochida would be conscious of a resonance between himself and Kawakami, a sort of kindred spirithood that for him would develop into close personal identification. "My feeling was that I myself was president," he laughs, "and that there was another Kawakami-san who was the real president."

Mochida joined the company with a brief to open up new business areas for the company to mine. Which is precisely what he proceeded to do. During his first few years at Yamaha, Mochida developed a range of alloys of magnetic metal for use as the record and playback heads of tape recorders. Having succeeded in metals, Mochida characteristically lost interest and started looking around for something else to do. Kawakami assigned him the most important job in the company -- coming up with an electronic organ that could compete against organs made by the US firm, Hammond, that by the late 50s were just beginning to penetrate the Japanese market.

Yamaha's first attempts to build an electronic organ had been based on vacuum tubes. But by the time Mochida took up his new assignment, transistors had begun to replace tubes. Transistors were attractive because they were smaller and, in theory at least, more reliable. But the methods used to produce transistors in those days were crude by modern standards, and the devices caused Yamaha no end of trouble. Nonetheless, Mochida succeeded in his task. In 1959, he and his staff of two assistants unveiled Yamaha's first electronic product, the D-1, which was launched onto the Japanese market under the prosaic brand name Electone.

Like many first-generation products, the D-1 was expensive, and it was not a great success commercially. Kawakami, however, was delighted: he had seen the future and it worked. He increased Mochida's staff and built an electronics R&D center for them to work in. Yamaha's next step was to switch from using individual transistors to chips that integrated lots of transistors on the same tiny piece of silicon.

The logic of the integrated circuit was inexorable, as the American Apollo space program would clearly demonstrate. The more features you want to include, the more transistors you need. But he more individual transistors you use, the more likely you were to have a dud one. By integrating 100 transistors onto a chip, you could increase reliability by 100 times. For a company like Yamaha that had been plagued by consistency problems, chips were a godsend. They placed orders with domestic makers like NEC. This was in the mid 1960s, around the time when chips were also starting to be used in calculators. Sales of electronic organs and calculators took off together, much to the delight of both chip suppliers and customers. But these early chips were merely miniaturized versions of circuits that had formerly been made out of transistors. The next step would be to use the unique potential of chips to create something entirely new -- just as Kawakami had hoped.

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Around 1962, while Yamaha was still wrestling with the reliability problems that plagued its first electric organs, before John Chowning had even begun messing about with algorithms, a radical change was taking place in the design of keyboard instruments, one that would have huge consequences for the musical instrument industry. In San Francisco, a young composer called Don Buchla had gotten fed up with the rigmarole of recording tones then chopping and splicing the tapes. Instead of having to beg time off broadcast studios, he reasoned, wouldn't it be neat if you could have an inexpensive instrument in your home that you could use to compose on?

Meanwhile, over on the East Coast, Bob Moog was finishing up his PhD at Cornell, building and selling theremins in his spare time. (Theremins are the granddaddy of all electronic instruments: they produce the eerie wailing sound familiar to most of us via old horror movie soundtracks and the Beach Boys' classic *Good Vibrations*.) This hobby led to contacts with composers of electronic music, which in turn stimulated Moog to start building audio oscillators and amplifiers whose output could be controlled using a voltage to produce tonally complex results.

It was Buchla that came up with a name for this new category of instrument: he called it the synthesizer. "The reason was because we started with elements of sound," Buchla explains, "building sound from basic elements like pitch, timbre, amplitude and a few other things." But it was Moog whose name would stick in the public mind as the father of the synthesizer. One reason was the huge success in 1968 of *Switched-On Bach*, by Wendy (né Walter) Carlos, a million-selling record that made the sound of the Moog synthesizer world famous.

For about ten years, from roughly the mid '60s to the mid '70s, the small but rapidly growing market for synthesizers was dominated by tiny US start-ups, most notably Moog and ARP (a Massachusetts-based firm perhaps best remembered for the synthesizer used to communicate with the aliens in the movie *Close Encounters of the Third Kind*). "People were going apeshit over these funny electronic sounds," Moog recalled in an interview with *Keyboard Magazine*'s Mark Vail.

The trouble was that the most of these firms suffered from bad management and chronic underfinancing: "We were always in the red," says Moog, "we had no capital. None. Zero." They would stumble along from one National Association of Music Manufacturers show (where instrument dealers come to place orders) to the next. If you didn't have a hit at one year's show, then you had better have one at the next, or you were dead.

A second problem was quality. According to Moog, "In the late '60s and early '70s, you could put five pounds of shit in a box, and if it made a sound you could sell it." In addition to poor manufacturing, another recurrent vexation was the inherently unstable nature of these early, analog synthesizers. The oscillators that generated the sound were controlled by electrical voltages. To boost an oscillator's pitch up an octave took a commensurate increase in voltage. The trouble was that the bloody things wouldn't stay in tune, their pitch was notorious for drifting. A ripple in the power supply, a change in temperature as the room heated up or as the components themselves became hotter -- almost anything was enough to set them adrift, necessitating a re-tune.

An expanding market, undercapitalized firms, poor manufacturing and unreliable components -- this was a scenario that was virtually tailor-made for the Japanese, with their deep pockets, superb production skills and long-term commitment, to enter and exploit. Japanese firms began to make their presence felt in the synthesizer market from the mid-70s on. Initially, it was the smaller outfits - Korg and Roland - that made most of the running. Lagging behind came Yamaha.

This tardiness was not for want of trying. But Yamaha had chosen a hard row to hoe. By 1966, Mochida had concluded that only way to produce consistent, high-quality sound was via digital rather than analog means. Converting continuously varying analog waveforms into digital ones and zeroes would be a cumbersome process, but once accomplished, it would offer some compelling features, most notably error checking and correction. Programming a digital oscillator to stay in tune would be simply a matter of defining numerically what "in tune" was, then instituting a continuous checking routine on the oscillator's output. If during the previous microsecond, the output value had drifted a smidgeon off spec, then it could be instantaneously caught and brought back into line. Et voilá: high reliability!

Digital was wonderful in theory, but implementing it in practice required digital chips. And not just any chips, either: off-the-shelf integrated circuits would not do. Yamaha would need custom chips fast enough to produce sound in real time -- in other words, the instant a musician pressed a key. And, if the chips were to be applicable to consumer products, they would also have to be cheap. But who would make such chips for them?

"We went to our semiconductor suppliers," Mochida recalls, "and asked them if they would be prepared to produce digital chips to our specifications." But everywhere they went, it was the same story: "They told us to stop thinking about something so difficult ... They said 'It'd be a nuisance to make chips specially for you, why don't you use what's available? ... What you're talking about is what they do in computers, but you make consumer products, so it'd too expensive for you, it'd never become a business.' We tried to persuade them to help us. But at that time, in the late '60s, the calculator boom had begun, and it was obvious that electronic instruments would never grow as quickly, so we weren't such good customers anymore."

Mochida contemplated the problem, and he decided that if Yamaha wanted to get integrated circuits made, then they would have to make the circuits themselves. At a time when giant electronics firms like Mitsubishi and Toshiba had yet to enter the chip business, this was an extraordinarily ambitious decision to make. But it was made out of sheer necessity: "It wasn't as though we had several choices and picked one -- the only way left was that we had to do it ourselves."

Having decided that Yamaha had to go it alone, Mochida then had to persuade the company's management to take the plunge. A board meeting chaired by Kawakami was held to discuss the matter. Aware that his proposal was unlikely to be well-received by his fellow directors, Mochida outlined his plans hesitantly. Not surprisingly, the reaction of his colleagues was overwhelmingly negative. Mochida must be mad, they complained, to propose something as risky and expensive as entering the semiconductor business. Especially since the firm had no prior experience of producing semiconductors, nor any qualified staff.

After a while Kawakami, who had been listening to them in silence, suddenly exploded. "Why are you all ganging up against one?" he thundered angrily, "I'm not going sit here all day trying to make sense of your arguments -- I'm the boss, and I stick up for the underdog." And then he rounded on Mochida and shouted at him, "And as for you -- if you're so sure that your idea is correct, how come you're so hesitant about it? You should speak more clearly." Then, having given both sides a piece of his mind, Kawakami gave Mochida the go-ahead.

"If we can make the best musical instruments in the world," the Yamaha president is reported to have declaimed, in true jaw-jutting samurai style, "then no matter how difficult is is, no matter how much money it takes -- we'll do it." And perhaps he did say this, or something like it. The Japanese do have a penchant for the melodramatic. What matters is that Yamaha did make the investment in semiconductor production facilities, and it was a huge sum of money, the initial amount invested being approximately equivalent to the company's paid-in capital at that time. But, as with the giant automated wood drying kiln, Kawakami had the vision - and the guts - to make such a big decision.

When a Western company elects to go into a new business, the usual approach is to go out and hire people with the requisite experience. But in neo-feudal Japan, hiring mid-career staff is extremely difficult to do. In addition to which, ever beguiled by the challenge of the new, Mochida was against the idea of bringing in outsiders. For some years, at Kawakami's instigation, Yamaha had been recruiting young graduates from top Japanese universities. Here was a chance to make use of their talent. The semiconductor industry was itself still only a few years old -- surely it was possible to catch up? So in 1969, Mochida and a hand-picked team of six bright young graduates, all of them in their twenties or early 30s, set out to learn how to make semiconductors from scratch.

They adopted a two-pronged strategy. Basic science would come from sending engineers for instruction at Tohoku University (whence Mochida had received his correspondence-course PhD) at the feet of Jun-ichi Nishizawa, one of Japan's leading authorities on semiconductors. Meanwhile, basic manufacturing technology would be transfered under license from the US firm Philco, a subsidiary of Ford (which would quit the microelectronics business shortly thereafter). Within 18 months, Yamaha's engineers had designed their first digital integrated circuit. In April 1971, they began producing chips in volume in a factory at the company's main Hamamatsu plant.

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These first efforts were simple circuits, not what Mochida needed to build digital instruments. At that time, Yamaha had two candidate designs for a digital system. Both of them required chips which would work at 3MHz, that is, would be able to accomplish three million instruction cycles a second (the speed at which a digital circuit operates is governed by the frequency at which its crystal clock ticks). Japanese semiconductor manufacturers had demonstrated their reluctance to attempt anything so advanced, but perhaps some US companies would have the capability? In January 1972, Mochida's sidekick Kazukiyo Ishimura was dispatched to the US to find out. And that is why he happened to be in Los Angeles when the call came through from Niels Reimers of Stanford University's Technology Licensing Office.

And what was Mochida's reaction when an enthusiastic Ishida phoned to tell him about FM? Did he hop on the next plane to San Francisco to sign a contract? Well, actually, no, he didn't. Mochida would not make the "pilgrimage" - his word - to Stanford until December 1972, eleven months later. The reason for the delay was that, in early 1972 he was concentrating on an idea of his own. This was a hybrid system which fudged the speed barrier by implementing control of the instrument's keyboard in digital while using conventional analog means to generate the sound. Marketed as PASS, for pulse analog synthesis system, this instrument bombed in the marketplace.

Mochida was sufficiently humble to admit the possibility that there might be better ideas out there somewhere, so in late 1972 he set off on a tour of music departments at US universities, one of which was Stanford. As it happened, Chowning was not there at the time. Having taught at the university for the required seven years, the composer had applied for an important promotion -- tenure, the academic equivalent of a full-time job. To this end, he had submitted a paper describing FM, together with *Turenas* and another piece written using his system. And, to their great discredit (and subsequent embarrassment), the stuffy Stanford review board had turned his application down. So the now-jobless Chowning had been forced to leave Stanford for Berlin, where he spent an impoverished year, as he puts it, "in exile".

It was left to AI lab director John McCarthy and Niels Reimers to demonstrate Chowning's FM samples to Mochida. The impetuous Mochida was so impressed that he decided to license the technology on the spot. "As an engineer, you are very lucky if you ever encounter a simple and elegant solution to a complex problem," he would tell an interviewer from *Music Trades* magazine. "FM was such a solution, and it captured my imagination. The problems of implementing it were immense ... but I knew in my heart it would eventually work."

Mochida also knew that there was no way FM synthesis would work using existing technology. Reimers, however, insisted that the contract stipulate that Yamaha would make products using FM within a given time limit (understandably so: without products to sell, there would be no royalties for the university). And having once again persuaded a reluctant Yamaha board that the company should go ahead and develop this extremely difficult technology, Mochida kept his promise -- just.

The GS-1, the first product to use FM technology was what techies call a kludge. Introduced in 1978, instead of a single FM chip, it had over 50 chips lined up in parallel, and cost $20,000. This effectively put it out of the reach of everyone except rock stars like Keith Emerson.

In order to achieve their objective, a chip that would run fast enough to perform several million calculations a second, to produce sounds in real time (which Chowning's software-based system had not been able to do) Yamaha had continually to update their semiconductor production technology, keeping up with the state of the art. For example, Ishimura, who was in charge of this aspect of development, recalls that Yamaha was perhaps the third or fourth Japanese company to purchase a stepper, a key piece of equipment used to reproduce microscopically fine circuit patterns on silicon wafers.

At the same time, as they were transforming Chowning's algorithms to hardware, boiling them down onto ever smaller slivers of silicon, Yamaha's engineers were also developing the software that would create the actual sounds. This, as Mochida points out, also takes time to produce, because it stems from a gradual accumulation of know-how, from endless cut-and-try until Yamaha's engineers had achieved something that sounded like a regular instrument.

During those years, Chowning (now reinstated at Stanford) would make regular visits to Hamamatsu, where he would work closely with small groups of engineers on the development of prototype instruments. He came away with a lasting admiration for their dedication, their skill and inventiveness, and - interestingly - their remarkable lack of ego. "That's the Japanese way," he comments, "they express themselves anonymously through the products they make."

It took more than seven long years of effort, but eventually Yamaha came up with the goods. In 1983, the company launched the DX7, the first synthesizer to incorporate the brand-new FM chip. It was a huge commercial success, catapulting the Japanese firm to the head of the electronic keyboard industry. According to English music critic Clive Bell, "The DX7 was immensely popular because it was the first synth with a hard, sparkly sound, it was very cheap (the first models sold for around $2,000, less than half the price of a comparable contemporary US instrument like the Sequential Prophet), and it was very reliable."

Yamaha sold over 200,000 DX7s (compared with Moog's most popular synthesizer, the Minimoog, which sold around 13,000 units during its ten-year lifetime), making it by far the best-selling synthesizer ever. The instrument became part of every self-respecting keyboard player's set-up. "It was used on loads on records," comments Bell, "usually mixed with other things; particularly popular were its fluffy, flutey calliope sounds, and its fake Fender Rhodes electric piano." Interestingly, though almost everyone used it, there is no single classic DX7 track (in fact, you can argue that there is no classic track for any synthesizer: flexibility rather than distinctiveness is the characteristic of the instrument).

The DX7 was by no means the only synthesizer that was powered by FM chips. Yamaha leveraged its investment in the technology by applying it across the product range, in everything from small portable keyboards to high-end, top-of-the-line electronic organs.

After the introduction of the DX7, Mochida characteristically lost interest in musical instruments. Ever in search of new things to do, he had decided that since he now had a digital chip, and since digital chips were the stuff of computers, he would use his chip to build a home computer -- a multimedia computer, no less, complete with state-of-the-art sound and graphics. And that was where he made his first big mistake.

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Seen from the outside, Japan may appear homogeneous, a country where corporations all pull together - directed by an omniscient government - in pursuit of a common goal (domination of world markets). Inside Japan, however, it is hard not to notice how little cooperation there is between rival groups, how fierce in fact is the competition between these groups. This is particularly true of the electronics industry. Indeed, one of the main reasons why the PC revolution was so slow to get off the ground in Japan was that manufacturers simply didn't appreciate the importance of standards and the need to encourage independent software vendors. Only NEC understood this need, and walked off with a near-monopoly of the market as a result. And did other firms recognize the NEC standard, like Compaq et al had with the IBM PC and crank out clones accordingly? No, they did not. Instead, they all opted to make PCs to their own design, fragmenting the market and stunting its growth.

So in deciding that Yamaha would have to develop everything - including operating system, applications software, processors and peripherals - itself, Mochida was making a classic Japanese error. To his credit, though, he was quick to recognize it. "Within a year of commercializing the computer [ie, around 1985], I realized that we had made a mistake. So I went straight to Kawakami-san, and I told him that we should stop at once, that the more we did, the more money we would lose."

Mochida paid a stiff price for his failure: he was demoted from managing director to director, his authority was limited, he suffered a cut in salary, and most serious of all, he was re-assigned from his beloved R&D to run Yamaha's audio division. This was a job whose responsibilities included manufacturing and marketing and sales as well as development. But Mochida was not a businessman, and his last years at Yamaha would not be happy ones.

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Burned by its failure, Yamaha decided to pull out of the computer business, electing instead to pursue the less risky option of selling its chips to outside customers. Ishimura, Mochida's long-time deputy, got Kawakami's nod to run this business. Among the first customers for FM chips were arcade game companies like Sega and Bally.

The version of the chip developed for arcade game machines would subsequently find its way onto a plug-in sound board that IBM developed in 1986 to go with its new PS/2 personal computer. But this was an expensive chip, the board wound up costing $499, and back then there was little in the way of market pull for personal computer sound. "We only sold about 10,000 units," Ishimura recalls ruefully, adding with a laugh that "maybe the only people who bought them were IBM employees."

So Yamaha withdrew from the board business too, clearing the way for the entrance of a most unlikely entrepreneur from the other side of the world. Credit for the creation of the sound board market goes to Martin Prével, a soft-spoken French-Canadian professor of music at Laval University in Quebec. Prével was originally interested in the use of computers for teaching music, for training the ear to hear. In the early '80s he developed a specialized 8-bit computer and founded a company called Ad Lib to market it. This first computer was not a great success, but with the advent of more advanced personal computers, Prével decided to have another go. This time, Ad Lib designed a sound board that would plug into one the expansion slots on the IBM PC. "We were looking for a low-end technology for sound boards," Prével recalls, "and that's where we came up with the Yamaha sound chip."

The chip in question was a low-priced version of FM synthesis that Yamaha had designed to provide audio for an ill-fated (Japanese government sponsored) teletext terminal project. The chip was not on the market, and when As Lib first contacted Yamaha, the Japanese company was very nervous about the idea of selling it. The reason for this reluctance was that Yamaha was concerned that FM chips might end up in cheap knock-off keyboards made by Korean or other East Asian firms. But eventually Prével persuaded Yamaha to supply him with chips, and Ad Lib's FM-based sound board made its début at the Chicago Consumer Electronics Show in June 1987.

Ad Lib was still looking primarily at the music education market. But the Canadian company's board turned out to be the solution to another, hitherto unseen problem. PC game companies like Sierra On-line were looking to add sound to their games to make them more attractive. Suddenly, there was this board that enabled the computer to generate music. Of such serendipitous match-ups are niche markets made.

Alas for Ad Lib, the sound board market would blossom into much more than a niche market, but the Canadian company would not be the beneficiary of this explosive growth. If Yamaha had been responsible for Ad Lib's success, it would also be responsible for the company's failure. Game developers were soon demanding more than music, for that merely turned their products into the equivalent of a silent film with piano accompaniment. Now what they wanted was the ability to include in their games voices and sound effects as well. For that they needed a converter that would take chunks of sound stored by the computer as digital data and turn them into analog audio. Instead of developing a chip that would do this by themselves, Ad Lib decided to work with Yamaha.

Bad decision. If you look at a map of the world, you will see that Quebec is about as far away from Japan as it is possible to get on the North American continent. In addition to the difficulties of communicating over vast geographical distances, cultural differences must also be taken into consideration. Ad Lib was a small start-up, Yamaha a big bureaucratic corporation; and in Quebec, they prefer to speak French, a language almost unknown among Japanese engineers.

It seemed like everything that could go wrong did go wrong. Ultimately, Ad Lib was 17 months late in coming to market with its second generation board. That left an opening for another unknown company from even further out of left field. Creative Technology, a Singaporean outfit run by a shy but aggressive young entrepreneur named Sim Wong Hoo, came in and grabbed the sound board market with its best-selling Sound Blaster board while Ad Lib watched helplessly from the sidelines. The Canadian firm subsequently went bankrupt.

Yamaha was not hurt by Ad Lib's demise. Happily for the Japanese, thanks to Ad Lib's early efforts, it was necessary for sound board makers to concern themselves with providing backward compatibility. Hundreds of games had been written for the Ad Lib board: if this software was to continue to run on new hardware, then that hardware had to be compatible. In effect, it meant that all future sound boards would have to be based on Yamaha's FM synthesis chip and its derivatives. By great good fortune, Yamaha had become to sound boards what Intel was to personal computers: the possessor of a de-facto monopoly.

Yamaha could conceivably have had the sound board market all to itself. Especially if the old double act of Kawakami and Mochida had still held the reins at the company. But Kawakami had retired as chairman of Yamaha in 1983, and Mochida was no longer in charge of new product development. Ishimura, now Yamaha's managing director, is philosophical about the issue: "If we had been successful in the sound board business," he says, "maybe we wouldn't have been successful in the chip business -- it's very difficult to do both."

Nonetheless, in late 1993 Yamaha's musical instruments division would attempt to enter the market with a sound board of its own. So can the company be considered to have dropped the ball? Perhaps it would be more accurate to say that Yamaha was forced to settle for a field goal, when they could have had a touchdown.

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Epilog

By early 1994, well over 25 years after John Chowning first heard his oscillators making interesting noises, FM synthesis was well on its way to becoming ubiquitous in the personal computer marketplace. That year, analysts reckoned, the sound board business would break through the billion-dollar mark; millions of boards would be sold, all but a handful of them carrying Yamaha chips. At the same time, computer makers were beginning to incorporate sound chips in their basic designs, ensuring even more business for Yamaha. Indeed, the only cloud on the horizon for the corporation's chip business was the imminent expiration (in April 1994) of Chowning's patent, hence Yamaha's exclusive license on the technology. And even this was not as bad as it sounded, for Yamaha had built up a wall of its own patents surrounding FM technology, and Ishimura was confident that these would survive challenges from other chipmakers.

Mochida's vision of a quarter of a century ago that survival as a music industry leader would require the ability to design and make chips had proved prophetic. The cream on the cake was that chipmaking had flourished into a business in its own right for Yamaha, worth over $300 million in 1993 and growing at the rate of 10% a year. And even Mochida's ill-starred venture into the computer business had not been a complete disaster. The expertise the company developed in computer graphics would stand it in good stead when a small company called Sega asked Yamaha to develop graphics and sound chips for a video game machine it was developing. In 1994, Yamaha continues to be Sega's chip supplier of choice.

Compared with well-known Japanese chipmaking giants like NEC and Toshiba, "Yamaha is not recognized," says Bernie Vonderschmitt, president of leading Silicon Valley chip design house Xilinx, "but in reality they have some of the finest [chip production] capability -- they're up with the best in Japan." And Vonderschmitt adds "it's just amazing what those people have done."

In fiscal 1993 ended March 31, Yamaha Corporation [which does not include Yamaha Motor] had total sales of over $2.8 billion. Of these, "digital musical instruments" was the single largest category, accounting for almost $600 million. Almost level with pianos in second place was a category entitled "metal products and electronic equipment", which includes semiconductors, worth $465 million. Significantly, this was the only category enjoying decent growth that year. Overall, electronics related products accounted for almost 54% of the company's sales. By any standard, Mochida's mission had been a smashing success.

And as for the man himself, Mochida left Yamaha in 1988 to join Ricoh, exchanging the world of consumer musical instruments for that of professional office equipment. It was a surprising move in a country where lifetime employment is the norm for workers in big companies. But the irrepressible Mochida is anything but a typical Japanese; rather, he is a man who sees himself as an outsider. Once again, the lure was the opportunity to do something new (in this case, to develop a recordable compact disc).

In 1992, he retired from Ricoh to take up a position as a professor in the electrical engineering department of Kogakuin University, a Tokyo-based private school. You'll find him there, in an open plan office-cum-laboratory, surrounded by young students, teaching a course in multimedia. He appears delighted with his new career.

Financially, as is the Japanese way, Mochida received no reward for his work other than his regular salary and bonus. He is happy with his achievements, but for him, he says, "the greatest satisfaction is when the people around you are also happy ... it's not a question of 'I did that', because if you're just by yourself, no matter how hard you try, you can't succeed, you're just a small part of it. In order to produce a success, what you need to have is people with all sorts of different talents, and then you combine them to make a team."

Yamaha minus Kawakami and Mochida is a different company. Gen'ichi's son Hiroshi took over from his father as president in 1983. But the younger Kawakami did not make a success of the job and in 1992, he was obliged to resign. As Mochida points out, only a very few people possess the special blend of vision, guts and charisma needed to produce a great leader. Effort and diligence are not enough. "What you really need," he laughs, "is a gift from heaven." Or a genius, as Kawakami might have put it.

But though the company is going through a difficult patch, with many of its product lines mature or declining, it would be premature to write Yamaha off yet. For one thing, the company has recently introduced a revolutionary new line of synthesizers based on a technology licensed from ... Stanford University.

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In the seemingly endless debate that rages over whether the US is selling its birthright by licensing technology to Japan, the prevailing view is that both sides are engaged in a zero-sum game. In the case of FM synthesis at least, this is a difficult argument to sustain. Without the revenue stream that flowed from Yamaha to Stanford, there would have been no new generation of synthesizer technology, because there would have been no place to incubate it.

You could say that Yamaha was smart enough not to kill the goose that laid the golden egg. But the fact of the matter is that, this time round, the license that the Japanese firm has on the technology is non-exclusive, and there are half-a-dozen US firms jockeying to get in on the act.

After his year in exile, Chowning had been re-instated at Stanford as a professor, largely as a result of the notice that Pierre Boulez took in his work. If Chowning's algorithms were of interest to such a famous composer, a European eminence who was then conductor of the New York Philharmonic, then perhaps there was some merit in them after all .... In 1975, Chowning formed the Center for Computer Research in Music and Acoustics, a mouthful which was soon invariably known (this is California, remember) as "Karma".

Karma is a conscious attempt to carry on the great multi-disciplinary tradition as practiced by Bell Laboratories and the Stanford AI lab. The center is housed in a beautiful Spanish Gothic mansion which sits on knoll at the back of campus, giving it a panoramic view over Silicon Valley. Visitors to Karma will meet historians, roboticists, psycho-acousticians, electrical engineers, all of whom are also accomplished musicians and composers. If they are lucky, they will also meet Max Mathews, the father of computer music, who came to Karma after taking retirement from Bell Labs in 1987.

Today, the focus of the center's work is the development of new tools to aid composers and performers. Advances in electronics technology have opened up all sorts of new possibilities. One of the reasons FM synthesis was so attractive was that it was a very efficient technique, able to produce a wide variety of sounds without recourse to memory, an almost prohibitively expensive commodity back in the late '60s and early '70s. But as memory chips came whizzing down the learning curve, doubling in capacity every 18 months, a new type of synthesis became feasible. This was sampling, a technique which draws on a data base of frozen snapshots of sounds recorded from actual instruments then digitized.

But though samples sound more realistic than the approximations produced by FM, because frozen, they lack the expressiveness that composers desire. Ergo waveguides, a technique invented at Karma in 1985 by an intense young electrical engineer named Julius Orion Smith III. Waveguides are computer-generated models of strings vibrating and air resonating in tubes just like it does brass and woodwind instruments. They sound uncannily realistic and at the same time, because generated dynamically from sets of equations, they are also expressive.

Waveguides are the basis of the new range of "virtual acoustic" synthesizers that Yamaha launched, to rave reviews, in November 1993. Waveguide chips from US chip designers could appear on sound boards as early as 1994. Game developers are excited about the prospect of being able to draw on these new, more natural sounds. Can waveguides pull off the double for Stanford? Joe Koepnik, the official at the university's technology licensing office clearly thinks so. "Because of multimedia, the potential is clearly there for waveguides to eclipse FM in terms of market impact," he enthuses, "my daughter aged 8 will be playing with waveguides.

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At the 1939 World's Fair in New York, Laurens Hammond introduced his latest creation, the Novachord, an all-electronic organ that could produce all the sounds of a dance band or an orchestra. It never caught on, was way ahead of its time, and Hammond would never again attempt anything so ambitious. After 1939, says organ dealer Doug Jackson, "it was all money -- he saw he had a winner on his hands, and he rode the wave like a pro."

The last Hammond Model B-3s rolled off the company's Evanston production line in 1975. In the mid-70s, Hammond Organ was acquired by the Marmon Group. "During this high-tech era," as a history of the firm issued in 1984 to celebrate a half-century in business puts it with unconscious irony, "the advantages of being a part of a large conglomerate were realized." With advantages like these … .

In 1985, Hammond Organ was sold to Suzuki, a small Hamamatsu-based firm best known in Japan for melodicas, wind-blown keyboard instruments originally developed for kindergarten and primary school children who didn't like the metallic taste of harmonicas. Today, Hammond Suzuki produces the Super-B, an instrument which "captures that great Hammond sound and adds a whole new array of voices and playing features." Organ fanciers complain that the Super-B sounds a little too perfect. For the real B-3 sound, they say, there's no substitute for the old tone wheels.

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Sources

This chapter is based on a series of interviews, the bulk of them in person, one or two over the phone, conducted in Palo Alto, California, Tokyo, and Hamamatsu October '93 through January '94.

• Principal interviewees include:

- John Chowning
- Max Mathews
- Julius Orion Smith III
- Niels Reimers
- Joe Koepnik

- Yasunori Mochida
- Kazukiyo Ishimura
- Bob Starr (Yamaha Corp of America, San Jose)

- Martin Prével

- Doug Jackson

• Principal written sources include:

- Yamaha' First Century (Music Trades magazine, August 1987)

- Fifty Years of Musical Excellence (Hammond Organ brochure)

- Vintage Synthesizers (Keyboard magazine anthology, ed. Mark Vail)

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