The Making of a Great Company
How Spectral Dynamics Came to Be

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Any company that has been serving customers for 55+ years must be doing something right. Spectral Dynamics, SD, is just such a company. The following discussion traces the history of SD from it's inception in 1961 to the present day.

Although SD continues to offer state-of-the-art systems for multi-shaker control, rotating machinery analysis and shock data capture, this story concentrates on the early days of this great company. In those early days, it seemed like every new product was unique to our industry and each one definitely gave customers a new tool which improved their operation and contributed to advancing the state-of-the-art. We were continually breaking new ground. For example, in 1966 we introduced the SD109 Co/Quad Analyzer. This unit was often used in conjunction with our SD1002 Automatic Mechanical Impedance Measuring System. The SD109 ushered in an era of modal analysis like no one had seen before. For the first time there was instrumentation to let you virtually "see" the mode shapes and literally move transducers around to find nodes and anti-nodes on your structure.

Those early days also set the tone for product integrity, applications engineering support and customer service which carry forward to this day. In today's marketplace great emphasis is placed on software and digitizing accuracy. These are both important considerations, but what often gets overlooked in the bustle is the critical role played by quality components and engineering to minimize noise, provide alias-free data and optimize data sampling. These deserve to get just as much attention, if not more, than regular software upgrades. This story traces the products and the people who contributed so much to SD's success and to the advances in vibration, shock and acoustics testing and analysis.

Figure 1. Early Spectral Dynamics employees; Paul Christopherson, (Finance); Helen Jaszczak, (Mfg.); Hugh Ness, (Eng'g.); Laurie Burrow, (President); Bud Gillies, (Chairman); and Shirley Andre, (Exec. Sec'y); (Don Hydrick, Sales, not shown).

Figure 2. SD101A Dynamic Analyzer (Tracking Filter).

In the mid 1950s Laurie R. Burrow Jr. was a test engineer working for General Dynamics (GD) in Fort Worth, Texas. Part of his job assignment was to conduct "ground vibration tests" on new aircraft designs. This is a test, often using multiple shakers, designed to check the natural frequencies (and modes) of the entire aircraft.

It's the job of the test engineers, working downstairs in the test lab, to verify the natural frequencies predicted by the structural designers. (We called the structural designers the second story guys!) Around 1957, on one particular test, which used swept sine excitation, the test engineers reported a natural frequency at 5 Hz. "That's impossible" said the structural designers. "The first mode should not be until around 10 Hz!"

When Laurie examined the response signals more closely, he realized that the large response at 5 Hz, was due to harmonic excitation of the airframe's 10 Hz mode and not strictly a 5 Hz response. Then and there he realized that in order to present correct results, he needed a way to filter out harmonics, noise and distortion, as the sine sweep progressed. Only then could he tell the designers what the true aircraft dynamics really were.

This prompted Laurie to immerse himself in the company technical library for a few weeks on end. What he came up with was a very clever combination of 2 concepts that were there for the reading, but which had never before been combined into one device. In effect he combined a broadband 90° phase shifter with a single sideband demodulator. He put these together with the necessary power supplies and circuitry and developed the first narrowband audio tracking filter (TF). This turned out to be an "inherently tuned" device which could never lose lock. As long as a (clean) reference sine signal was applied for tuning, the TF was instantly tuned to the reference frequency, anywhere from about 2 Hz to 50 kHz. This made the ground vibration survey a much more straightforward operation. Laurie applied for and received a patent for this device under the name of General Dynamics.

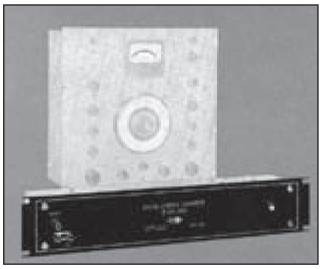


Figure 3. Model SD 11, COLA Constant Output Level Adapter with a Brüel & Kjær vibration exciter controller in the background.

In 1953/54 General Dynamics purchased Consolidated Vultee Aircraft and changed the name to Convair Aircraft which was located in San Diego. Shortly after that, Convair started work on a commercial jetliner, the 880, to compete with Boeing. Laurie and his family moved to San Diego and he got involved with performing ground vibration tests on the 880 and the 990.

Then in 1961 General Dynamics decided to stop work on the 880 and 990 jetliners. So Laurie had rwo choices: He could either move back to Fort Worth and work at General Dynamics, or he could strike out on his own. Having moved to San Diego and finding it to be a slice of paradise, the decision was pretty easy!

So Laurie got together with a mutual friend, Ken Dellinger, who took Laurie to the home of Bud Gillies (ex-VP and director at Grumman Aircraft), in San Diego. Together they visited the General Dynamics Electronics Division and on October 16, 1961 they struck a deal to buy back the tracking filter patent, the engineering data and the prototype instruments. Bud arranged some financing and Spectral Dynamics Corporation of San Diego, SD, opened for

Figure 4. SD104A-5 Sweep Oscillator.

Figure 5. SD105A Amplitude Servo/Monitor.

Figure 6. Duck Soup ad.

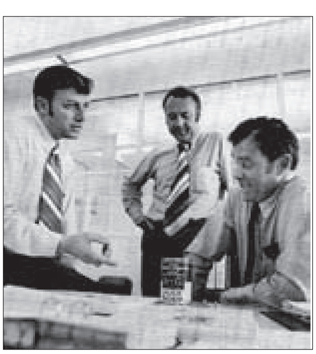


Figure 7. Tony Keller explains Duck Soup to Bill Hawkins while Bob Kerfoot looks on.

business in November, 1961. Hugh Ness, an engineer from GD and Don Hydrick, a good marketing guy, joined Laurie and Bud (Figure 1) and they moved into their first plant at 1162 Morena Blvd.

The first product, based on his patent, was the SD101, Figure 2. Although this was indeed a great tracking filter, Laurie chose to name it "Dynamic Analyzer" since it had so many applications in measurements of system structural dynamics. Based on a recommendation by Sandia National labs in Albuquerque, Bendix Corporation in Missouri placed an order with SD for a quantity of SD101s and SD was off and running. We never looked back!

Expanding Product Line

Since the Dynamic Analyzer was looking for a reference or "tuning" signal, the next four products, the SD11 COLA, Figure 3, the SD102 Dynamic Analyzer Tuner, the SD103 Dynamic Input Sine Converter and the SD104 Sweep Oscillator, all were designed to fill that need. In the early 1960s the most popular sine servo for conducting swept sine vibration tests was the Brüel & Kjær types 1018 and 1019 motor driven sine servos. They operated at an intermediate frequency (IF) of 100 kHz and produced a controlled audio drive signal for driving the shaker. But it did not have a constant level audio COLA signal. So SD developed a Constant Output Level Adapter (COLA) from the IF signals in the B&K servo. This proved to be very popular and helped sell many SD101 units.

Around 1963, SD introduced the SD104 Sweep Oscillator, Figure 4. This was an incredibly popular unit and ushered in the use of the SD101 analyzer with the SD104 Sweep Oscillator to perform "swept spectrum" PSD analysis. Customers, like White Sands Missile Range, would create a 10 second tape loop of 1 inch wide tape recordings of missile and launcher vibration. Applying this signal to the SD101A Dynamic Analyzer and sweeping the frequency from 5 Hz to 2,000 Hz, produced a calibrated PSD plot which took 22 minutes to generate! This was the state of the art at that time and your humble author spent, literally, months of his life performing this laborious task. Where was "real-time" when you needed it? Funny you should ask.

Also in 1963, the Environmental Test Lab at White Sands Missile Range, took delivery of the first "time compression" real-time analyzer west of the Pecos. This was the SIMORAMIC (Simultaneous Panoramic) analyzer built by Federal Scientific Corporation, (FSC), a small Company in New York City. Although there were some limitations to this 3 rack behemoth, the idea was incredibly exciting. You could select any 200 Hz bandwidth up to 10,000 Hz and see the spectrum content on a real-time screen. The 200 Hz bandwidth was not very practical but the whole concept was phenomenal. The concept was invented by Dr. Victor Anderson of Scripps Institute in San Diego. While working on a postdoctoral fellowship at Harvard University in 1953 and 1954 he designed and developed a digital time compression technique, using delay line time compression (DELTIC) for application to acoustic signal processing. FSC was the first company to create a commercial product from this invention.

Back in the engineering department at SD, we introduced the first "all solid state" Sine Servo Controller, the SD105, Figure 5, in mid 1965. The combination SD104 Sweep Oscillator and SD105 Sine Servo Controller, was an instant success and took over the market for this type of testing worldwide. The days of the Brüel & Kjær motor-driven sine servo ended abruptly and now Spectral Dynamics was firmly in the shaker control businesss. Speaking of "all solid state," advertising has always been an important contributor to the growth of SD and something very close to my heart. When I first joined Spectral, our advertising was done by Marty Hodes, who at the time worked for Knoth & Meads in San Diego. I was really proud of the fact that we were replacing motor-driven and Nuvistor technology with something much more modern and really pushed to have our ads say "all solid state." Marty would say "Tony, your customers don't care if their new black box is filled with cream cheese! What does it do?" Of course he was correct, so eventually I threw in the towel.

Advertising has always been an important and fun part of selling Spectral Dynamics products. And when our real-time products took hold, everyone was relieved that measurements that used to be so time consuming, now seemed so fast and easy. (Careful now, that could be the lead-in to creating a lot of bad data very quickly!) So Marty and Verne Granere, a hard-working application engineer, got together and created an advertising campaign to show how easy it was to use SD products. Why it was as easy as "duck soup," Figure 6. This turned into a very popular and fun campaign, but nearly got us in trouble. We were going to fill the cans with tap water. But that would have been against the food safety regulations. So, instead, we filled them with smog-free San Diego air, Figure 7.

With the success of our Duck Soup campaign, we looked for other ways to describe how simple it was to use SD products. So we followed up with "A Piece of Cake" and "Falling off a Log!" But neither of these had the impact or staying power of our "Duck Soup."

Still More Expansion

SD now had the SD101, SD102, SD103, SD104 and the SD105. Logically, the SD106 would be next. Unfortunately, the SD106 and SD107 nomenclature were assigned to two products that were promoted internally, but never made the cut! In fact they are now so far back in the dustbin of history, that a real description of these two "babies" is just not available. About this time, analog systems were a very important part of Spectral Dynamics' business. The SD108 Phase Servo/Monitor, Figure 8, was an interesting part of this "analog system" era and was the first effort, around 1967, of SD doing multi-shaker, multiple input/multiple output, MIMO, control!

With the advent of the Saturn missile and other ever-larger missile and weapons systems, there was a desire to use multiple shakers during a controlled sine test, so that more force could be applied than was available with a single exciter. Always on the lookout

Figure 8. SD108 Phase Servo Monitor.

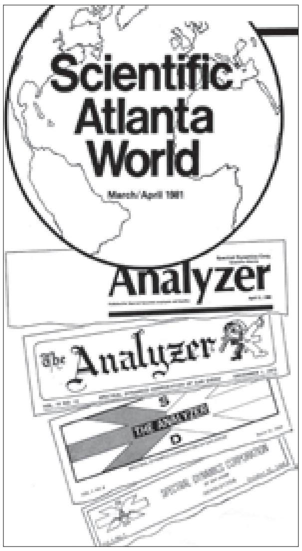


Figure 9. SD Newsletters over the years.

for new and improved testing and analysis ideas, SD eagerly developed the SD108 Phase Servo. Perhaps the ultimate multi-shaker test of that era was contracted by Wyle Test Labs, with NASA, for doing a swept sine test on a quarter scale model of a Saturn attachment ring at their lab in Huntsville, Alabama. They employed eight Hydrashakers, each rated at 50,000 pounds force, to create an amazing amount of test energy. A control accelerometer was mounted at each of the eight shaker attachment points and an 8-channel Phase/Amplitude Servo system from SD was installed. Since, at that time, pretty much everyone was new to the use of multiple shakers attached to the same test article, ideas such as "cross coupling" may have been understood, but, unfortunately, there was no way to compensate for this evil phenomena when it appeared! A paper written by Dick Arone and Paul Brock of Wyle Labs and delivered at the Shock and Vibration Symposium in 1967 gives the background of this test. A swept sine test from about 10 Hz to about 150 Hz was envisioned. In those days, when a resonance was encountered, with either single or multiple shakers, the only solution was to decrease the Drive of the controller exciting the shaker. In the case of eight shakers and eight controllers, trying to create a controlled test of 1 g peak at all eight control locations simultaneously, there was only one thing to do. As a control point began to exceed 1 g, that corresponding shaker was reduced in level, or shut off entirely. When the first mode of this Saturn ring was reached, most of the control points began to exceed 1 g. So the corresponding shakers were shut down one by one. (Hugh Ness and I were down in the pit and feeling pretty helpless!) Finally, there was only one shaker still being driven and it's control looked pretty good. However, the other seven control locations were all exceeding 1 g! The test was deemed only a partial success. We did get some good modal data.

Newsletters

Many companies around the world have found different ways to tell their story and keep employees up to date on the latest developments. Today, much of this is done on the web or thru other electronic means. But, starting back in 1968, SD was committed to putting out a written company newsletter every month. This continued right up to our merger with Scientific-Atlanta (SA) in 1978 when the San Diego operation of SA became part of the corporate newsletter. Some examples of our evolving mastheads are shown in Figure 9.

At one point in the mid '70s we also produced a quarterly newsletter about our products for customers. This eventually went out to over 33,000 folks every quarter until it just became too much. Part of that time I was the editor of that newsletter. As anyone knows, who has tried to produce a regular marketing document, you can continually ask for newsletter contributions and still end up writing 90+% of the material yourself!

Charging Into Modal Analysis

In 1966 we introduced the Model SD109. This was a 2-channel "analyzer" which came into being for a completely different function than that with which it eventually served us so well.

Figure 10. SD109A Co/QUAD Analyzer.

Let me explain. At that time power spectral density (PSD) was still being measured and displayed the hard way, with a 22 minute analysis per plot. Also, since we were measuring "g squared per Hz," we were potentially required to perform an analog squaring function, electronically, which was very inefficient and quite limited in dynamic range. So Laurie Burrow, ever the creative genius, went back into the library and studied up on stationary, Gaussian or non-Gaussian noise and in particular the effect that would result when this noise was put through a narrowband filter, such as that in the SD101A Dynamic Analyzer. What he found was a treatise by S.O. Rice, in the *Bell systems Technical Journal* on "Mathematical analysis of random Noise" published in July, 1944. The key thing he took away from this, which already seemed somewhat intuitive to him, was the effect a narrowband filter has on steady state noise. Whether or not the probability density function of the signal going into the narrowband filter was Gaussian, the distribution of the filter output was definitely Gaussian! So we knew the relationship between the average and RMS values of these filter output signals.

Why was this important? For several reasons. First, there was a competitive company at that time called Technical Products Corporation, run by Bob Moody. They had a product which did direct analog squaring, in order to produce a PSD plot. This product was advertised as "true PSD!" Laurie felt SD needed to counteract that. So we introduced the SD109 Dual Channel Squaring Analyzer. Secondly, Laurie took the direct engineering approach with just the SD101 and SD104 connected to a plotter, which says that the log of g squared is twice the log of g. So we could use an average detector, with it's inherently greater dynamic range, and simply "double the log" by scaling the plotter correctly.

After many comparisons between "true PSD" and Laurie's method, it was agreed by all that the SD answer was correct and also got better dynamic range! (There was a double bonus here however. Technical Products Corporation was running into hard times. So we hired Bob Moody to oversee and run our training seminar program, which was now growing and becoming quite popular.)

However, just to cover all bases, we built the SD109 squaring device and I took it on the road for some demos. One of the first places I took it was to Sikorsky Aircraft in Stratford, Connecticut.

THIS DEMO CHANGED MY LIFE! The engineer I showed it to, Ed Cholakian, suggested that we think of a different application for this instrument. He was involved with modal analysis and suggested we make a simple change to our product. Instead of measuring A^2 and B^2 he suggested we use our multipliers to measure AB Cosϕ and AB Sinϕ.

He also explained their use in modal analysis and suggested I check out two papers on the subject. One by Clyde Stahle and another by Kennedy and Pancu. When I returned back to San Diego, I studied both papers and presented my findings to Laurie and our engineers. It was agreed that this was a great idea and a perfect accompaniment to our SD1002E Mechanical Impedance Measuring System. So the SD109A Co/Quad analyzer, Figure 10, was born. I then made it my job to introduce this concept all over the world and the reaction was wonderful! It suddenly made the measurement of mode shapes more personal in that you could not only clearly see nodes and anti-nodes, but you could actually move transducers around in almost real-time. (In those days, our chief engineer was Bob Davis. It seemed that every one of our new products always delivered more than the requirements laid out

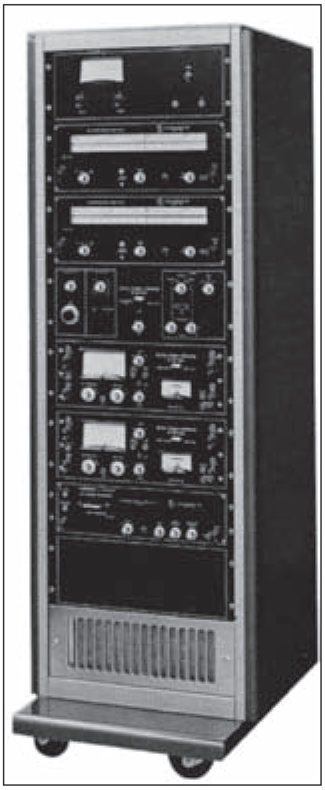


Figure 11. SD1002A Automatic Mechanical Impedance Measuring System.

by marketing. I called these special features "the Bob Davis touch" and it was really great getting to see, and anticipate, the total performance of each new product. Thanks, Bob.)

One of the customers for the SD109A was the University of Cincinnati (UC) Mechanical Engineering Department. I'll never forget going to UC to help train a young graduate student named Al Klosterman on how to use the SD109A. Al later got his doctorate, developed the building block approach to structural dynamics (SABBA), and went on to become the chief scientist for Structural Dynamics Research Corporation, SDRC. I think that introducing the vector approach to modal analysis on a commercial system and teaching this through seminars and demos was a significant advance in the state of the modal analysis art at that time. Also around this time there was a lot of consulting in structural dynamics problems being done by the faculty, especially Dr. Jason (Jack) Lemon, and graduate students at UC's ME department.

Eventually, the president of UC suggested that Dr. Lemon separate those activities from the teaching curriculum at the University. So with some financial support by SD, Structural Dynamics Research Corporation, SDRC, was formed in Cincinnati. Dr. Lemon was president and Laurie Burrow was the first board chairman. In addition to working together, Laurie and Jack became very good friends for many years and put on seminars all over the globe. One of the first tools purchased at SDRC was the SD1002A Automatic Mechanical Impedance Measuring System, Figure 11. This system had incredible dynamic range and was first developed around 1963. The story goes that one time when Jack was consulting at Cincinnati Milling, he and Laurie had a brainstorm in the company cafeteria. Later Laurie said there were four people and many napkins at the table. In later years, at least 10 people swore to me that they were at that table! This system concept deserves a more thorough explanation.

Analog Magic

The correct measurement of structural frequency response functions (FRFs) has always been a challenge, for many reasons. Not the least of these is getting signals above the surrounding noise floor and creating enough dynamic range to really see the structure's response, free from noise and distortion. To get the total picture you need accurate phase and magnitude of the FRF, $H(f)$. Because of the wide dynamic range of real structures, the magnitude is typically displayed on a log-log scale. So what Laurie and Jack came up with was truly brilliant. They found a log converter made by Houston Instruments, the HLVC-150.

This instrument used an electromechanical slide wire to show the amplitude of the measured signal input. An internal power supply provided a variable DC (reference) voltage to match the level of the incoming signal. When the reference level equaled the input level, balance was achieved and the slider stopped at the correct readout, in this case the average value. But inside the converter, at the "balance point" the signal level was always 1 V RMS. Since the only excitation available to excite large machine tools and other structures, was a swept sine signal, typically from the SD104 Sweep Oscillator, and a small shaker, it made sense to use tracking filters as part of the measurement loop to be sure only the fundamental forcing frequency was used in the measurement. So now Laurie injected an SD101A Tracking Filter into each of the log converters at the balance point. We were now reading the filtered fundamental value, even over a very wide dynamic range. But the next question is measuring accurate phase which is a real challenge if signal amplitudes are varying widely. No problem! With the tracking filters at the balance point, the level available on both channels was 1 V RMS. And since the SD101A was a heterodyned analyzer with an IF of 100 kHz, the signals available for phase measurements were a piece of cake, or as we liked to say, "Duck Soup!" All we had to do was present to the phase meter two signals which were always 100 kHz and always 1 V RMS, but which had the same phase as the audio inputs of the tracking filters. Never has a phase measurement over such a wide amplitude and frequency range been so easy, or so accurate.

Since the dynamic range of each log converter was about 80 dB, the measured FRF ratios could easily achieve 150 dB. And this was 1963! This turned out to be both a blessing and a curse! Because our dynamic range was so great, it caused us to delay our entrance into computer-based systems.

A Side Story

With any successful company that has been doing business for decades, there are bound to be some interesting stories buried somewhere. At Spectral Dynamics we certainly have our share.

One of my favorites is the following: The year was around 1974 and Bob Davis was at the San Francisco International Airport, on his way to a meeting in New Jersey. He had a few hours to spare, so like any good SD employee he was reading some company mail which he had brought along.

A man approached him and asked if Bob could keep an eye on his bag as he had to confirm his seat on the flight to New Jersey. Bob agreed and went back to reading his mail.

A short time later he was aware that the fellow had returned and had glanced over Bob's shoulder at what he was reading. "Oh, you work for Spectral Dynamics" the man said. "What does your company do?" Bob went on to explain that we made shaker control systems, spectrum analyzers and sonar processing systems. The man replied that he was writing a book on digital signal processing. Bob thought to himself "Oh no. everybody and his cousin seems to be writing a book now on DSP!" The man went on to explain; "Yes, I don't really know that much about DSP but I work with some really smart people and they're helping me to write this book!" Yikes thought Bob. But to be polite he asked "Where do you work?"

The man replied "Well this summer I've been teaching a class at the Navy Post Graduate School in Monterey." BING and a small flash went off. "I work at Bell Telephone Laboratories in New Jersey." BANG, a larger flash went off! Then he said "My name is Richard Hamming". BOOM! Bob nearly jumped out of his seat!

"Are you THE Richard Hamming?" stammered Bob. "Well I don't know about THE, but yes, that's my name." Bob quickly responded "I'm sorry but we don't use your Window!" Mr. Hamming laughed and said "Oh, that's OK. There are plenty of good weighting functions out there. Which one do you use?" When Bob replied: "Quite often we use the Kaiser-Bessel window" Hamming replied: "Oh, that's great. I work with John Kaiser and he's been a great help with my book!"

As a final note Bob says they sat next to each other on the flight and he had a really fascinating conversation.

A Word About Customer Service

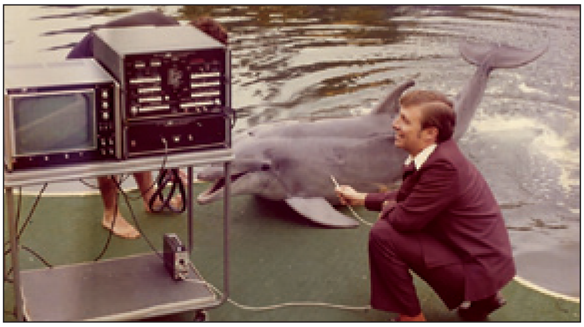
From the very beginning, servicing the products we sell has always been very high up on SD's priority list. Our first full-time service manager, Pete Gillies in 1963, was on our board of directors and made sure service got more than its share of company resources. From our simple tracking filter, to our computer-based

Talk to Me Cindy

Every year, hundreds of thousands of visitors, schoolchildren, vacationers and locals visit Sea World in San Diego. They typically have a fun, and sometimes wet, experience at some of the live shows. What many people do not realize is the incredible amount of animal research which goes on at Sea World, behind the scenes, at Hubbs Research Institute. Many years ago we were approached by Hubbs to see if we could help them with their communication with dolphins. Naturally we agreed.

Dolphins "speak" at a frequency much higher than the human hearing range. Typically, much of their communication is as high as 80 kHz. At the time, we had an excellent analyzer, the SD360, which could analyze up to 100 kHz. We also had a B&K microphone which was good to 80 kHz. So I volunteered to analyze some of a conversation with Cindy, one of their "keenest" dolphins.

We put the SD360 and display on a small floating platform near to the shoreline in one of their large pools. The trainer, shown behind the instrumentation, used his special whistle to give Cindy the command to approach the platform. What I did not expect was that Cindy was about to jump up right on the platform! The first time she did this, the platform tilted and the cart with my precious SD360 started heading for the drink! Luckily we grabbed the cart in time, Cindy temporarily went back in the water, and we saved my job. Then we locked down the cart, and did it again. The photo shows Cindy happily chatting up a storm and me taking some good dolphin speak. It was a fun day.



control systems, our service engineers and technicians have always treated our customers with the respect they deserve and given the kind of service that makes customers want to stick with SD if at all possible.

Many of our products are used to control, analyze or monitor very important and expensive tests. So if there is a problem, or a suspected problem, how we respond can have a huge effect on not only the success of our customers, but also possibly their very livelihood. As we'll see later on, this can be especially important in a large refinery, where the "failure" of a single piece of turbomachinery, can have multi-million dollar repercussions very quickly.

As our products get more complex and more sophisticated, (think multi-shaker, MIMO, control for example), the type of support required now becomes more technical. This is not a problem, but it may now take an engineer with an advanced degree to furnish the necessary assistance. Customer training, especially for computer-based systems which are heavily mathematically oriented, continues to be an issue and an opportunity.

Four of our best and longest-running customer service managers, Pete Gillies, Ken Baxter, Dave Ficker and Paul Hawk, really understood their roles. They knew that they were the last line of defense in solving the customer's problem and never passed the buck. They busted their whatchamacallit until the problem was solved!

The Real-Time Era Begins

When I first joined Spectral Dynamics in November, 1965, I may have been the only employee familiar with Federal Scientific Corporation (FSC) and the only one to have actually run a "real-time analyzer." When I had worked at White Sands Missile Range, we had purchased a 3-rack "Simoramic" time compression analyzer from FSC. This was not lost on Laurie. He was fascinated by the idea. (Remember, the FFT was just introduced in 1965 and still some years ahead of being generally integrated into real products.) Laurie had an uncanny ability to explain even complicated concepts to just about anybody, once he had a firm grasp on the concept himself. So it seems like for almost the first six months of my new job at SD, Laurie would call me into his office every day and start the conversation with something like "so tell me again about how a real-time analyzer works?" Then a funny thing happened. I got a call from Reinhold Vogel, the Chief engineer at Federal Scientific. I had met Reinhold when he would sometimes come out to White Sands to perform the semi-annual maintenance that was part of our Simoramic purchase contract. He started the conversation with "Hi Tony. I understand you make sweep oscillators. I may want to buy a hundred or more!" Now he had my attention.

Well, it turned out he wanted to sweep between 18 and 23 Megahertz. I explained that we considered anything above 100 kHz to be "RF" and not of interest. But this opened up a line of communication between SD and FSC. Before long Laurie and Henry Bickel, the President of FSC were on very friendly speaking terms. At that point SD had a solid reputation as a company who had good manufacturing capability and produced clean, reliable products. (All true!) FSC had a good reputation as a fine engineering company, with close ties to Columbia University and other academia. The result of several conversations was that we would consider signing a manufacturing contract with FSC to build their new line of real-time analyzers. First they would bring one of their prototypes out to our factory and we would evaluate its "manufacturability." Needless to say, Laurie and I and our engineers were wowed by the real-time results, even though there was limited dynamic range. At that time either 8- or 9-bit A/D converters were the standard device available but we reported a few other issues to Henry. He asked us to send the unit back to NYC and he would return with an improved and updated model. Sure enough, a few months later he returned to San Diego with a newer version of the UA-7, Ubiquitous Analyzer, and the product manager, Art Citrin. The upshot was that there were still some problems, which may well have been hidden from Henry. So the unit went back with Henry and Art and no further cooperation between SD and FSC took place. We never signed a license agreement with FSC!

But now we'd had a taste of real-time and in 1968/69 the future rapidly came into focus. So SD hired some new engineers and one of them, Carl Dubois, hired in 1967, took to the idea of a new analyzer operating in real-time with much gusto. Before long we had laid out a plan, found some outside consultants for key pieces, and were on our way to designing the SD301, our first, time-compression real-time analyzer. (Your friendly editor is not going to believe this, but the SD301 did not steal a thing, except the big picture, from the UA-7. And, remember it was Victor Anderson's patent anyway.) Carl Dubois and his team made some real improvements in the SD301. Instead of magnetostrictive delay lines, for example, we developed crystal and then another type of delay line. And for an averager, our SD302 was 3.5 inches high and weighed less than 20 pounds. This was about 60 pounds lighter than the Fabritek averager used by FSC! A new high speed D/A design, supplied by an ex-IBM engineer in Vermont, also improved the performance of the SD301. As may be expected, the introduction of the SD301, Figure 12, in the fall of 1969 signaled the beginning of a long competition between SD and FSC. (Sometime later, when your friendly editor joined FSC, the competition with your humble writer sometimes grew to EPIC, or maybe silly, proportions!)

The introduction of a real-time analyzer (RTA) to the customers of Spectral Dynamics, has to rank up there with the greatest improvements to the state-of-the-art, ever! Our PSD measurements now went from 22 minutes per analysis to just a few seconds. That's an improvement of over 330 to 1 and made the decision by our aerospace customers to buy one a simple choice. But it also opened up many new markets to SD which we had previously

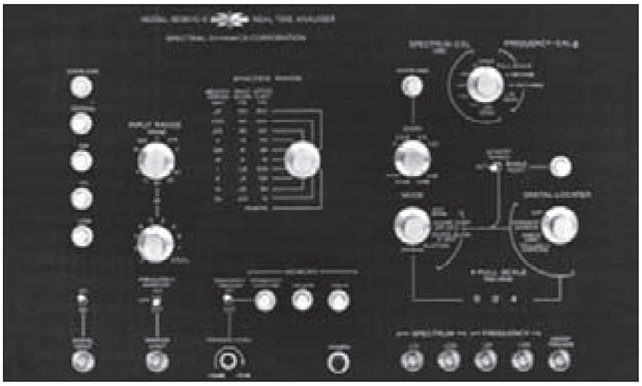


Figure 12. SD301C-C Real Time Analyzer.

Figure 13. SD25-80-1 3-D Display Adapter.

Figure 14. Some of the add-on accessories to the SD301 Real Time Analyzers. The accessories expanded the applications for the RTAs to acoustics, rotating machinery, sonar studies and much more.

How Many Splices?

The year was around 1975. One of the 3-letter "alphabet" government agencies in DC called with an exciting "offer you can't refuse". They had an interesting application and if we could solve their problem, they would buy not one but two of our newest analyzer, the SD360 Digital Signal Processor! The offer was too good to pass up, so I tucked an SD360 under my arm and flew back to DC.

I was set up in a small conference room and then they explained the problem to me: They had made a cassette tape recording of a "situation". The original tape had been processed and had "several" physical splices in it. They had a copy of the spliced tape, but with no physical splices to be seen. If I could tell them how many splices there were on the original tape, the deal would be done; They would purchase two SD360 Analyzers. They gave me a cassette playback unit with the tape inserted. That's it!

I was left alone in the conference room with some BNC cables, a monitor for my SD360 and my thoughts. What to do? My thought process went something like this: The recorder was probably not very expensive, since it might have to be used in some unsavory locations. Many of the recorders of the day used small 3,600 RPM motors. So there was a good chance that there was a 60 Hz component, somewhere in the signal.

I played back the tape and sure enough there was a pretty consistent, low level 60 Hz present. So I popped my head out of the conference room and asked for an audio function generator. They quickly supplied me with one. Then I connected the function generator to Channel B Input and the tape output to Channel A Input. The function generator was set to sine output and the frequency set, as closely as possible, to 60 Hz. On the SD360 I selected Cross Spectrum as the analysis function and displayed the cross spectrum phase on the monitor. The cursor was set to 60 Hz.As I started the analyzer the phase display was pretty random, everywhere but at 60 Hz.

At 60 Hz there was a "flat" spot a few FFT bins wide. (I think I selected the Kaiser-Bessel window to get the widest possible FFT bin. The harris flattop would have been even better but it was not developed until a few years later.) Sure enough the flat spot was "rolling" through 360 degrees over and over since the function generator was not perfectly "synced" to the 60 Hz component on the tape. I fiddled with the frequency setting on the generator until the "roll" of the cross spectrum phase display slowed way down.

Then I played the tape from the beginning and counted the number of times the smooth phase roll "jiggled." When I was convinced I had the right number, I asked my hosts to step back into the conference room. With a voice as calm as possible, (my heart was racing so I'm not sure how calm my voice sounded), I proclaimed "there were seven splices on the original tape!"

You could hear a pin drop. My two hosts stared at each other and then broke into wide grins. How did you . . . ? Since they were going to buy two units, (sorry Omniferous), I explained the technique which I had employed. Truth be told, this was one of the most exciting demos I ever did, and it had a good result.

not considered. Universities, who had previously been using our mechanical impedance systems, now had many new applications for measurements in mechanical and civil engineering as well as physics. Tape recorder manufacturers could now investigate wow and flutter in real-time. Refineries and jet engine manufacturers tripped over themselves to get these new devices. And along the way, SD kept developing new accessories for the RTA, such as the SD25-80-1, 3-D Display Adapter, Figure 13. This device was used in conjunction with a Tektronix Model 611 Storage Oscilloscope and created a 3-dimensional display of amplitude vs. frequency vs. time from the SD301 Real-Time Analyzer. This became very popular for rotating machinery analysis, RMA, as well as for sonar studies and helped sell many analyzers.

In response to customer requests, we were continuously adding neat features to our real-time analyzer product line. But in those (pre-software) days, when you added an option it meant that you added another black box! Soon it took a six foot instrumentation rack to hold all of the neat options, Figure 14.

Around this time, one of our customers in the LA area, Dwight Brown at Hughes, Fullerton, came to us with an unusual request. He was in the market for a real-time analyzer. It came down to either SD or FSC. Someone (no names will be revealed!) had told him that the UA-6 from FSC could also do shock spectrum analysis (SRS) in addition to spectrum analysis. He wanted us to comment on that before he made his choice.

We asked him if he could hold up his purchase for a few months while we delved into it and he agreed. My own thinking was that you needed to introduce damping into any SRS computation and

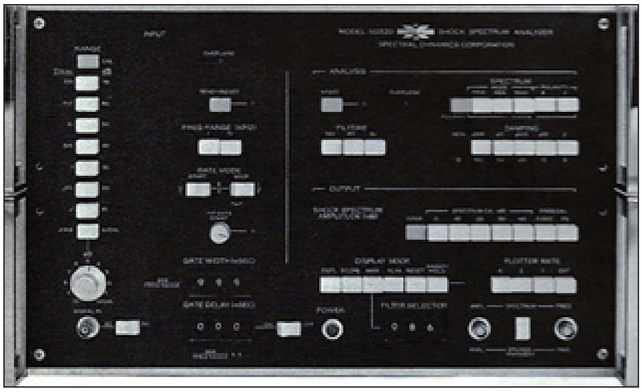


Figure 15. The first ever standalone Shock Spectrum Analyzer became a lab standard for over 20 years.

Figure 16 . The first RTA with built-in averaging and display in a single chassis.

I did not think that either the SD301 or the UA-6 had any way to do that.

So we assigned Bill Pollard to perform an engineer's "dream job." "Bill, go into the back room and don't come out until you can show us absolutely, that an RTA can or cannot perform shock response spectrum analysis!" Bill dutifully disappeared for several months and finally came out with a big smile on his face. He not only showed that it was not possible for the RTA to do an SRS analysis, but he had developed, on paper, a way to do this correctly in a standalone SRS analyzer. And he had the complete LaPlace transform analysis to prove it!

Then rwo things happened: We called Dwight Brown to give him the news; And we began development of the SD320 shock spectrum analyzer. Dwight immediately gave us an order for an SD301/302 analyzer and averager and asked to be #1 in line for our new SD320 when it became available. It took the better part of a year to bring the SD320 to the marketplace and it was introduced in 1970, Figure 15. It was an immediate success and became the standard for aerospace shock response spectrum measurements for nearly 20 years. It didn't hurt that Ken Baxter, who would end up running our customer service department years later, was one of the most knowledgeable people in the world about the shock response spectrum. And he could explain it to anyone, so that they could understand it. His SRS presentations at our training seminars always got rave reviews.

Then, in about 1971 we introduced our SD330 Spectrascope™ real-time analyzer. To my knowledge, this was the first analyzer to combine analysis and averaging with a built-in display, Figure 16. It was much, much smaller and lighter than the SD301 plus averager plus display so it was an instant success, even though it had half the resolution, 250 lines, of its big brother.

The Way it Was

Back in early to mid-1970s, Spectral Dynamics experienced a "precipitous" decline in incoming orders in May and June. (Not even an optimistic bookings forecast by Bob Kerfoot was much help!) In those days our fiscal year ended on June 30th. Here is an excerpt from our FY1971 Annual Report: "To survive through that period, the number of personnel on our payroll and all expenses were kept to a minimum. For several months last summer our factory worked with a 10% reduction in hours and all salaried personnel took a 10% cut in salary while continuing to work full time. We cannot overemphasize the appreciation we feel – and we are sure we speak for all our stockholders – toward each and every one of our employees for the outstanding performance they have given to our overall team effort."

This message from Bud Gillies and Laurie Burrow indicated the ultimate team spirit at SD. No one lost their job, and after about four months things had improved enough that we all recovered our 10% salary reductions. The numbers in that time frame tell the story. Our FY70 revenue represented a 32% increase over our FY69 revenue. However, our FY71 revenue was just 1.2% higher than that of FY70. After that things got back to normal with FY72 and FY73 showing revenue increases of 48% and 44.6% respectively. In those days, in addition to great team spirit, the philosophy of having both "commercial" and "government" customers proved to be an excellent way to weather most storms in the worldwide economy.

Figure 17. Some, but not all, key Secretaries in the early Spectral Dynamics days; clockwise from upper left: Pauline McKinley, Joan Steffan, Claudine Pierson, Joanne Moyer, Mary Lou Tussey and Joy Scott Smith, shown with her Boss.

A Word About Secretaries

One of the biggest changes that has occurred over the past 50 years is the way that the term "secretarial help" has changed definition. Today, the availability of a personal secretary to a staff member, happens about as often as you encounter live switchboard operators. Fortunately for me, I started my Spectral Dynamics career blessed with two great secretaries, each one of them assigned to me for consecutive 10-year periods. Since there were no personal computers, dictation machines were bulky and yuk, and I couldn't type, Pauline McKinley was a godsend. She could take dictation at my New York pace without missing a beat! We worked very, very well together until she retired. Then Joy (Scott) Smith took over for another great 10 years. Joy was initially nervous about keeping up with my speed taking shorthand, but a new set of small tape recorders solved that problem very nicely. When it was time for Joy to move on it was necessary for me to crank up my Apple McIntosh, but somehow I survived. A few of the early, wonderful, secretaries we had at SD are shown in Figure 17. A special thanks to Eileen Albrecht Hodes who has furnished all of SD with great marketing material for many decades

The Next BIG Step

Being located in San Diego, we were very close to a lot of U.S. Navy activity. And as word of the SD301 and its application for looking at sonar signals got around, we were always having visits from Navy personnel. One very adventurous submarine commander, even walked in our front door accompanied by some seamen carrying part of his forward bow plane! "I think this plane

Figure 18. Spectrogram Display Control – the first "digital waterfall."

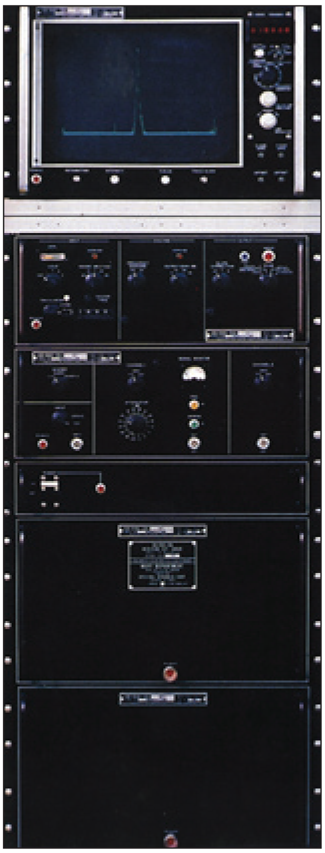


Figure 19. AN/BQR-22A Sonar Receiving Set.

is making too much "noise" at certain speeds" he said. "Can you please do a modal survey on this and tell which natural frequencies may be getting excited?" So we set up our small Wilcoxon F1 shaker and a few accelerometers and proceeded to give him the data he wanted. I'm not sure whatever happened with that data but he went away happy.

But then came, perhaps, the most important demo ever done by SD. In early 1970, we were visited by a group of managers from several "3-letter alphabet agencies" in Washington, D.C. They knew about our 3-D waterfall display using the Tektronix memory scope. They wanted to see a demonstration. So some of our managers, engineers and applications engineers set up a demo in our conference room. We thought the demo was a success. But then they said; "Look, our sonar operators may be tracking a target for many hours. We cannot suddenly give them a blank screen!" (With a memory 'scope you had to erase the whole display to start a new one.) After a few minutes of discussion about this, Carl DuBois spoke up and said: "Could you possibly all return in about six weeks?" None of us new what Carl had in mind so there were a lot of blank stares at Carl! After Carl said that he would make it worth their while, they all agreed to return in six weeks.

After they left, someone in a rather excited voice said "What exactly do you have in mind?" Carl went on to explain that he'd been thinking about a way to create a "raster scan" of spectral lines from data stored in a digital memory and to show this on a standard X-Y large screen display. Many of us were not sure exactly what this meant, but it sure sounded promising. Sure enough, in six weeks the group returned. This time the demo was not in a conference room but in the engineering lab. Carl had created the longest "breadboard" I had ever seen. It had to be 40 ft. in length! There were chips and wires going every which way.

But at the end of the bench was a large HP monitor displaying 64 lines of a very attractive, changing waterfall display. As an added bonus, Carl included a switch so the waterfall could scroll DOWN or UP! Zowie! There were nothing but smiles all around.

After this, several things happened. Carl headed up the development of the Model 13151 Spectrogram Display Control Figure 18. We were encouraged by Navy customers to go further into

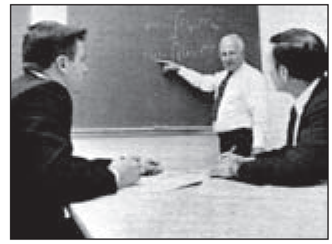


Figure 20. Bob Moody explains the Fourier integral to Tony Keller and Dennis Dinga.

sonar analysis. We hired some ex-Navy sonar technicians and in late 1970 we created a new Government Products Division which was then housed in its own building. We developed and sold tons of sonar systems to the U.S. Navy, including the AN/BQR-22A shown in Figure 19.

Another way of looking at this would be – being very close to potential Navy customers, thanks to our great San Diego location, has its plusses and minuses. We had a steady flow of Naval officers and petty officers coming through our plant to see the real-time analyzers in action. Some would say "You know, many of my operators are not trained engineers and these analyzers have a ton of knobs. Could you please move this knob over there and remove these three knobs?" After a few months of this our general manager had had enough. He said something like "You, you and you. Put these #%$@$# knobs anywhere you want, but don't do it on my commercial assembly line! I've leased a building down the street. Take these units and knobs down there and get the job done!" That was the inauspicious beginning of our Government Products Division!

A Word About Training

Spectral Dynamics began with a group of engineers and technicians coming from an aerospace background, with experience in design and environmental testing. Most of our initial products found their way into vibration and acoustics testing facilities. Although the products were not difficult to use, they lent themselves to many different applications and the more you knew about the products the more benefit you could derive from their use. Also, during product demonstrations, we often found ourselves giving "mini-lectures or mini-seminars". So at least 3 things became immediately obvious: 1) All products needed a well written User's Manual; 2) We could help everyone with a series of interesting applications Notes and 3) Our customers were begging for some formalized training.

Fortunately, thanks to some imaginative tech writers and illustrators, like Bob McCoy, we already had some great manuals. Also we had a few applications engineers who liked to write, so a steady stream of applications notes and tech papers were produced. We had also hired Bob Moody, Figure 20, who was very well versed in measurement and analysis theory. So together with a "traveling demonstrator", we were putting on a series of paid seminars all over the country. Pretty soon Bob decided he was ready for retirement. So we hired Mike Walter, a semi-full fledged Brit, to organize and lecture at our training seminars full time. After a few years, Mike wanted to get involved strictly with our machinery maintenance products, so we hired Bob Kiefer, an Ohio State ME graduate, to run our seminar program. Bob did this very professionally for many years and named our program the "Spectral Institute." That put us in the training limelight for many years as we ran a very, very successful program for 25 years! We held seminars every month, most of them in San Diego where everyone loved to visit, including our "Dynamic Analysis Workshop" every fall. This was a hands-on five day seminar, where every student performed experiments and operated the latest SD equipment. This seminar was always a sellout and limited in attendance only by the "largesse" of the manufacturing manager in allowing us to tie up a large percentage of his shippable inventory! This was also our most expensive seminar, both in terms of tuition charged, equipment on hand and number of SD engineers tied up for a week. The workshop always got rave reviews. The Spectral Institute was a genuine learning experience and not just a demonstration of SD equipment. A heavy set of training course notes came with it and the classes earned Continuing Education Units, CEUs. Over the life of our seminar program, I estimate that we took in over $6,000,000 in tuition fees. Of course it probably cost us close to $5,999,995 to put them on. Even if we just broke even, the goodwill which was generated and

My Greatest Demo Ever?

Once again the year was around 1976. I received a call from our Rep, Northeast Engineering, about a requirement at Pratt & Whitney in E. Hartford, CT. They needed some help and wanted to see a demo of our SD360. (Gosh I really loved that box!)

So I took the SD360 and flew to Hartford. They set me up in a conference room with plenty of power and a tape recorder with their data of interest. There were about 22 engineers and managers in the room, plus one casual observer, way in the back of the room. The situation was this: They had been running a new engine in a test cell in W. Palm Beach, FL. Suddenly the engine, while it was running, came loose from the support arm to which it was attached. The recorder got this data during the whole episode. They knew the frequency response function (FRF) of the support arm. They wanted me to somehow remove the effects of the resonance of the arm from the recorder running vibration data!

I was looking at a real-time exercise in linear system theory and wishing I had fred harris there with me. So here's what we did:

A. The SD360 had a joystick cursor which permitted you to draw in a function in either the time or the frequency domain and then perform analysis functions on it.

B. They gave me the support arm FRF and I drew in its inverse shape vs. frequency

C. I then did an inverse FFT on this and stored the resulting impulse response, $h(t)$, in Memory B

D. We then applied the tape recorded signal to Input A and did a running convolution between A and B.

E. The result was a time history with, hopefully, the effects of the support arm removed.

F. We then did a forward FFT on this time history and saw the running spectrum of the measured vibration, with no more effects of the support arm.

I was stunned. The results were phenomenal! The 22 engineers and managers leaped to their feet and filled the room with applause and cheers! Only the casual observer in the back of the room remained calm. Hmmmmm. When I left P&W that day I was virtually walking on air. I knew we had done something that no other competitive analyzer of the day could do. (Take that, Omniferous!)

A few days later, I found out that the casual observer in the back of the room was the one with the purse strings, and his choice was for the Federal Scientific Analyzer, even before the demo! (Chalk one up for Omniferous.)

Figure 21. Some of our applications engineers; clockwise from top left: Bob Kerfoot, Jon Palm, Tom Fielder, Ed Andress, John Deutsch, Verne Granere (with Wife Kay), Lane Hauck. Roger Koch, Pete Neild, Leon Corcoran, Scotty Milne. Inset, Jim Schott.

the technical training which took place, made this program a winner for all concerned. As you might expect, there are many great stories associated with these seminars, one involving the Tijuana jail. But that will have to wait for Volume 2!

Early in the program, against the good advice of Laurie, I decided to make this a real "teaching experience." So at one seminar I fashioned a 25 question "final exam" to be taken on Friday afternoon, before the Completion Certificates were distributed. YIKES! I don't know who was more distressed with the results, me or the students? The questions covered only material which, I swear, was presented during the week. The average grade will not be reported here, nor was it reported to the supervisors of the students! But this convinced me to make the test a take-home quiz, with the correct answers (no peeking) included at the back. The feedback that we've gotten over the years is that the Spectral Institute was a great success and certainly contributed to the positive rapport between our customers and SD. (Feedback from customers also indicated that our competitors were quite envious of our seminar's success.)

Application Engineers

In my mind, one of the greatest jobs anyone can have is as an applications engineer for a reputable company. You get to help customers, you can get into some really unusual and exciting places or situations, and you have a chance to both learn and teach. What's not to like?

Figure 22. Dave Kadushin.

Over the years SD has been very fortunate to have hired some truly great applications engineers. Many of them came from or had worked in aerospace testing labs, so the language and the general concepts of transducers and controlling a vibration or acoustics test were already part of their psyche. One of the first and one of the best applications engineers we hired was Leon Corcoran. Leon came to us from a shaker background and immediately took to the culture and pace at SD. Leon was liked by everyone, could cover the world with ease and could always say something interesting when you handed him a piece of chalk! And the jokes?

The Los Angeles aerospace community was a great breeding ground for good, energetic applications guys. In quick succession it gave us Jon Palm, Tom Fielder, Verne Granere, Lane Hauck and Ed Andress, an experienced manager and shaker guy. It also staffed our service department with Ken Baxter and Dave Ficker, two very knowledgeable and helpful guys who both ended up running vibration test labs in the LA area in the latter part of their careers. Lane was the first one to join us with a real acoustics background, learned at Lockheed, Rye Canyon. This served us well as our product line expanded. Some of these apps guys are seen in Figure 21.

Selling Our Products in the US

As our company grew, we also started moving from sales reps to direct offices in key locations. Joe Ballasch and Dennis Dinga worked in the "aerospace heaven" that was greater Los Angeles. Jerry Smith took over the Northern California Bay area. But when we introduced real time analyzers, far and away our most successful salesman was Dick Merrill in our Detroit office. Dick joined us in 1973 and his grasp of customer's situations and great sense of humor served him very well. Before he retired, Dick sold nearly 500 analyzers in his territory!

For many years Dick was the undisputed leading salesman in terms of dollars booked. He was quite shocked when one year Bill

Whaddaya Mean the World's Unlinear?

The year was around 1976. Our SD360 Digital Signal Processor was in full swing. I was invited to Martin Marietta in Florida to demonstrate our SD360 and see if it could help their design efforts. Alex Pettit, the project manager for this particular effort, introduced me to the situation.

They were designing the control fins for a new missile system and needed to get a good handle on the frequency response function of the Control loop for these "steering" fins. As with many special functions or measurements, we had an option for this kind of measurement which I thought would be perfect. I'll never forget the number. It was the SD25-144 Synchronous Excitation module. (In the analog and time compression real time analyzer days, an option usually meant another small "black box" which you would add to the system. See Figure 14 for an example of some of these options. By the time of the SD360, these options usually meant adding some firmware or software, not another small instrument.)In this case, the -144 option created a Drive signal which was a pseudo-random waveform matched to the frequency range and number of FFT bins which you selected. It produced a phase randomized signal which created an excitation at each FFT line. For a linear system you could get a great FRF measurement in one block!

We set up the SD360 to excite the Control loop of the fin system. I proudly explained to Alex what I was going to do. His first comment was "It's not going to work!" I didn't know whether to faint or cry, but I gamely soldiered on. Sure enough after only a few averages, we had a pretty clean looking FRF. I felt great. Alex said "It's not right!" What? What's wrong with that? He explained that we were looking at about a 35 dB FRF, but it did not clearly show the "null" in the FRF, which was very important to the design team. Then he suggested: "Look, this is a very fast processor. Let's just use a sine wave generator as the excitation and manually sweep the Control loop with that oscillator?"

So we used an HP oscillator sitting on the bench and the result was amazing. The control loop null showed up very clearly and the measurement dynamic range about doubled! "See, Tony, that hydraulic control loop is highly non linear," said Alex. Anyway, the result was so good they bought the SD360 and got some very good results in the years that followed. And I learned that when trying to analyze a non-linear system, the use of a pseudo random signal, which only excites certain frequencies, is not the ideal excitation source. Rather, a sweeping (not stepping!) sine signal, or a true random signal is more optimum, since they will excite all frequencies within the test range.

Now, considering that my absolutely favorite class in graduate school was "Analysis of Linear Systems," and that I try to consider the world as lumped, linear, finite and bilateral, this has been a tough pill to swallow. But in later years, Dr. Marcos Underwood of SD has continued my training by showing that multi-shaker control often runs into non-linear systems, and that only adaptive Control with real sine and random signals can be counted on for accurate results. Oh well . . .

Figure 23. Some of our early direct US Salesmen; clockwise from top left: Dick Merrill, Bruce Lent, Dick Strickler, Phil Copp, Bill Knapp, Steve Suarez, Dennis Dinga, Joe Ballasch, Jerry Smith, John Anderson (with Joy); missing: Bob Thorpe, Barry Fogel, Ken Geary, Tim Weaver, Don Wheeler.

Knapp in our Indiana office swept by him for first place. It was a "friendly" competition, but Dick was back on top the next year!

Moving East, Bruce Lent opened an office in Cleveland and competed heavily with Federal Scientific for years, often with good success. In the greater New York City area, John Anderson opened our New Jersey office and added both good business and some savvy sales management to the region. This was also the area of two of our longest running and most successful sales representative organizations. In upper New York State, where the roads can be narrow and the snow very deep, Dave Kadushin and Ben Aulde, the D and the B in DB Associates, seemed to know where all the customers were, what they were doing and what they needed. They even built their own specialized measuring systems for customers like GE in Schenectady. Eventually Dave joined Spectral Dynamics in San Diego and proved something that I had always suspected. He was too smart and too educated to be an instrument salesman. He should have been a professor at an engineering school! Dave is seen in Figure 22.

A little further East and North from DB was the longest running sales representative organization in the history of Spectral Dynamics. Northeast engineering with Tom Walker and Walt Dommers covered all of New England. Tom actually started selling our tracking filters before Spectral Dynamics was officially a California Company. But he did it all legally!

One area that has always been very important to the success of Spectral Dynamics was and is Washington D.C. Not only is this the source of much of the critical funding which is needed, but it is literally awash in agencies, contractors and military customers who are very well served by our products. Early on we established the Washington Area District Office, WADO, headed up by Ken Geary. Before long he had Jay Hurley running a very appreciated service group, Barry Fogel calling on customers and Scotty Milne giving applications help all over the territory. When our sonar business took off, this office could often become the home base for a special group of sonar technicians who might disappear for extended periods.

In the Atlanta area, Bob Thorpe brought us a unique perspective. Not only did he contribute very well to our sales goals, but Bob brought a smile to everyone he contacted, near or far. Remember, this was in the days of live receptionists in every lobby. As soon as Bob walked in, perhaps with his applications engineer in tow, the whole lobby lit up and our targeted customer was always quickly made available!

Moving over to Texas, many interesting things have taken place over the course of our history. Ken Zerbe, of Carey-Wolf & Associates, was probably the most energetic rep of all time. Ken seemed to operate on 10 cylinders and never slowed down operating out of Houston. Houston also became "ground zero" for our rotating machinery specialists and a whole new division. Steve Suarez, Dick Strickler and a host of other excellent Houston-based people contributed mightily to our machinery monitoring and analysis success. Some of these direct, early salesmen are shown in Figure 23.

Our sales force, consisting of both direct employees and sales reps, recognized the power of having a factory applications engineer at their side for a demo or presentation. This was especially true when the product being demonstrated was a computer-based system. When our shaker control systems became computer-based, (covered in a later section), we definitely had a very quiet super star in our midst. salesmen all over the world told me that when they brought Tom Fielder in with them for a demo and/or discussion, their "kill rate" was over 90%! That means that with serious, funded customers, they booked the order 90% of the time or more, when Tom was with them for the main presentation. That is truly phenomenal. Customers just gravitated towards Tom for his warmth and knowledge.

Selling Our Products Worldwide

As our product advertising took hold and international visitors

Is He Awake?

In the late 1960s Tom Walker, our New England rep for the Boston area, got to know some doctors at Massachusetts General Hospital. They worked in anesthesiology and had what they thought was a serious problem. During intense surgery, with the patient being administered a serious anesthetic, there was no foolproof way to know whether or not the patient was really asleep. This could have serious implications, on several levels, if they thought the patient was unconscious, but he was actually awake.

So they devised a plan to hire local college students to simulate a patient under anesthesia. At the time, Mass. General (MG) was known for its forward thinking in many areas and they hoped to make this one more. The idea was to pay these students to sleep on the job! They would be administered a varying dosage of anesthetic, from substantial to none at all and the MG staff would try to determine their level of "wakefulness." The students thought it was a great way to earn beer money. The staff were looking for a foolproof way to determine the "wakefulness quotient," WQ. Enter the SD109A.

One of us figured out (I'm not sure if it was Tom or me or an MG staffer), that the SD109A could measure the complex, averaged cross spectrum between two signals and, to an extent, determine if the two signals were related. The staff had determined that if they set up a strobe light in front of the "patient" and measured the response from a patch, carefully applied on the scalp, they could see the relationship between the two, if the patient was awake. The SD109A had three measurement modes: SQUARE for PSD; MULTIPLY for CROSS SPECTRUM and RATIO for FREQUENCY RESPONSE FUNCTION. In this case the MULTIPLY mode was deemed to be near perfect.

The outputs of the SD109A were meant to drive an X-Y plotter. What we found out was that there were basically two states or conditions of the patient, with many sub-states of each. If the patient was at all awake, the product of the two signals would be coherent to a degree. Depending on the wakefulness, the real (coincident) and imaginary (quadrature) components would drive the X-Y plotter to a position, such as 75°, around a 360° polar circle, indicating a wakeful phase lag. If the patient was truly asleep, the two components would have no measurable relationship and the plotter pen would go all over the place, making random chicken scratches. The experiment was deemed a great success and it's a good thing. I swear I must have scored about 5% on my visual observations. Each time I thought "wow, that guy is really asleep", the plotter would inform me otherwise. And if I thought he was awake, more often than not, it was zonk city!

This story has only a semi-happy ending. We proved that the concept was valid and could do a good job. But the instrumentation required two tracking filters, the Co/Quad Analyzer and a sweep oscillator. This added up to approximately $15,000 and made it kind of impractical to implement in every operating theatre. But the Boston beer was great!

saw our products at trade shows, we were encouraged to expand our sales efforts beyond the US. So Laurie journeyed to Europe and Japan. Before long we had established representatives in France, Germany, Great Britain and Tokyo, Japan.

Our first representative in England was related to Pye-Ling, a company also selling shakers made by Ling Electronics in Anaheim, CA. (This was not surprising since many of our first US representatives were also the reps for Ling Electronics.) Pretty quickly we saw the tremendous potential for business in the UK. With a lot of schmoozing and a bit of luck, we convinced Jack Greenfield, in 1971, to open up a Spectral Dynamics subsidiary in Royston, Hertfordshire.

Soon Jack had a growing staff of salesmen, applications specialists and service engineers. Before long SDUK was contributing several million dollars a year to SD's growing revenue. Over the years Jack was such a strong, honest contributor and yet such a great example of a "Brit" at his best, that I often thought he should have been Knighted! See Figure 24.

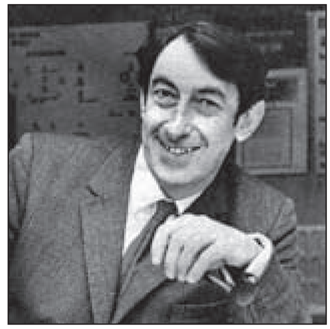


Figure 24. Jack Greenfield.

In France, our representative who introduced real-time analyzers to his market was Roger Dart, who was working for a company called IMEX. After a suitable period of time, Roger agreed to open our French subsidiary just outside of Paris, in 1972. They quickly became a sizeable sales entity, especially working with jet engine manufacturers and the French Navy.

In Munich, Germany, Hans Pospich first took hold of our products. We later opened our own office with Peter Schmidt, Irene Rappold and an excellent service group. In later years this office was successfully mentored by Rainer Konstandt and Dr. Werner Kuitsch.

For a time we also had a direct office in Rome, Italy, headed up by Domenico Concezzi. Domenico, now retired along with the office, was a very popular and effective salesman.

With some initial training by Laurie Burrow, our representative in Tokyo, Toyo Trading Company was off and running, Figure 25. They soon became a very important contributor to our total revenue. And we saw some very interesting developments while working with them.

For example in the early '70s we were excited about a nice order we received from GM for a complete mechanical impedance analysis system. This went into their engineering group for work on future products. But shortly after that, we received an order from Toyota Motors for five such systems! One for engineering, two for manufacturing and two for quality control. That really made us stop and think for quite some time. Sure enough, the quality of Toyota products were on a noticeable upswing some time after that order.

Performing Acoustic Analysis

As mentioned elsewhere regarding our experience at the USN in Quonset Point, many of our customers who are involved with vibration measurements, are also often tasked with analyzing noise. So almost from our start, we have been requested to perform acoustic analysis and providing 1/3rd octave band displays. While we were still selling our swept filter analysis tools, Bob Kerfoot and I would be asked many, many times if we could combine octave band displays at the same time as our narrowband plots. Finally we convinced management that this really was an untapped market and engineering began the development of the SD201 Universal Audio Analyzer, Figure 26. The project engineer for the SD201 was Norm Stellman. Norm was a stickler for accuracy and calibrateability. So the SD201 could be calibrated to a gnat's eyebrow! But it had over 80 adjustable potentiometers and it took the patience of a saint to

Figure 25. Toyo Sales Engineers with some early real-time analyzers they sold.

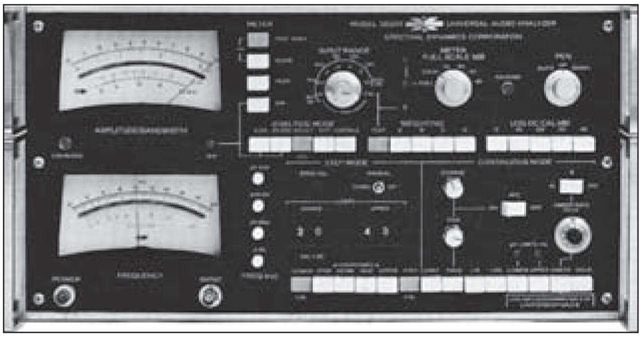


Figure 26. SD201 Universal Audio Analyzer.

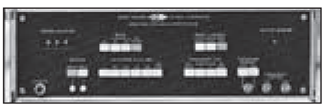


Figure 27. SD305A Octave Converter.

perform this calibration! This was a really nice analyzer, but by the time it was introduced it was being overshadowed by real-time products.

Many of the customers for our real-time analyzers were also interested in doing 1/3 octave band studies. So among the many, many accessories to the SD301, we developed the SD305 Octave Band Converter, Figure 27. This worked with the SD301 to take the narrowband "lines" from the RTA and group them into accurate 1/3 octave band values. This was done, as closely as possible, to ANSI Standard S1.11-1958. But this became so popular, we decided to build a "true 1/3 octave real time analyzer."

So in the spring of 1976 Spectral Dynamics introduced the SD312 Octave Band Real Time Analyzer, Figure 28. This was a solid engineering approach to measuring sound and we employed filters developed by SD to very accurately provide true ANSI S1.11 filter shapes and definitions. We had many customers, especially U.S. Navy customers, clamoring to see this box.

Then, scarcely three months after we popped our buttons with the SD312, Brüel & Kjær announced their Model 2131 Digital Frequency Analyzer. Kaboom! They stole the market!

Rotating Machinery Analysis

As stated earlier, rotating machinery analysis has always been of great interest to Spectral Dynamics. After all, if a motor or compressor or engine vibrates, and they all do, we want to analyze it. This began back in our tracking filter days, even before real-time came to be. We could tape record, for example, jet engine vibration, or try to analyze a turbine while it was holding steady at "one speed." We did this by applying the vibration signal to our tracking filter and sweeping the frequency along with our sweep oscillator and recording the filter output to an X-Y plotter. If the engine speed was indeed steady, this worked very well.

In one "famous" application, we agreed, in about 1967, to help the U.S. Navy analyze noise from a fighter aircraft jet engine. This took place at Quonset Point in Rhode Island. One of our applications engineers, Jim Schott, volunteered to take this on, just when the weather was turning rotten. He was taking live microphone data into our SD101A Tracking Filter and sweeping the filter across a predetermined frequency range with the SD104A Sweep Oscillator. Half of the time this was pretty good, or so we thought. But a lot of the time when Jim was expecting a spectrum peak at 8,000 RPM, for example, he would get there only to find nothing! It turned out that the engine speed was not at all constant. So just when he got to 133 Hz, the engine slowed down and he missed the peak altogether. Jim was there, fighting this phenomena, for over six weeks. Besides being very frustrated, it nearly cost him his marriage!

When he came back we had an "all hands" meeting with engineering and applications. After pounding the table in frustration, Jim finally got the idea across that the filter "tuning" signal had to, somehow, be related to the engine speed! engineering jumped on this and a whole new concept "signature ratio" was born. Now our sweep oscillator could accept a tachometer input and vary it's sweep accordingly. This was a great concept, which worked very well, but this time we used tape recordings from Quonset Point!

Figure 28. SD312 1/3 Octave (real-time) Analyzer.

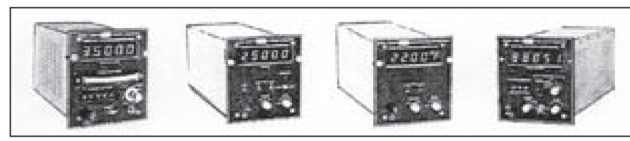


Figure 29. Early test cell instrumentation (much of it sold thru Space Corporation).

Figure 30. SD119B Trim Balance Analyzer.

This concept was later applied to our real-time analyzers, was a real success, and gave us a short-term marketing advantage.

But SD's connection to machinery monitoring and analysis goes back much further than that. Almost to our very beginning. Shortly after SD began operations, around late 1962, Hugh Ness responded to a "request for bid" from Kelly Air Base near San Antonio. They wanted to update the instrumentation in their engine test cells used for overhauling and repairing engines from the F-5 and F-100 fighter aircraft among others. With our engineering skills, together with a lot of hard work and Imagination, Hugh and Bob Davis came up with a whole room (or test cell) full of instruments and plug-in modules to exactly fit the bill. With this initial order, and follow-on business (that lasted for nearly 20 years!!), this became a multi-million dollar product line that was also one of our best-kept secrets, Figure 29. This eventually became part of our "Special Contracts" Division which later became our Government Products Division.

Domestic U.S. Airlines and jet engine manufacturers were some of SDs first customers. It was recognized that jet engines can vibrate for a variety of reasons. Often a primary reason was unbalance of the engine itself. At certain speeds this could cause, at best, uncomfortable noise and vibration in the cruising aircraft. At worst, it could be disastrous. So, at the request of American Airlines and others, we developed a stand-alone instrument to measure and display engine speed in RPM, unbalance amplitude in mils, and phase in degrees. This single instrument, the SD119, Figure 30, replaced much larger measurement sets and became instantly popular. At SD we sold literally thousands of these instruments and although they have been out of production for over three decades, we still, today, get requests for this instrument!

When we first started showing our real-time analyzers to petro-

These Demos Can Be Dangerous!

A chainsaw manufacturer in Connecticut was building some of the nicest gas-driven chain saws on the market. One of his best customers was a distributor in Japan. However, some of the users were complaining about "white finger" syndrome. So the manufacturer needed to do some vibration analysis to see if they could reduce the motion by a few gs.

I brought an SD301 Real-Time Analyzer and an SD304 Signature Ratio Adapter to their test cell and set them up. The customer was using red oak logs to cut through since that was one of the harder locally available wood supplies and they wanted to get at least 10 seconds of vibration data as they sawed through the log. The test cell was about 20 feet square and had about a 9 foot ceiling.

We attached an accelerometer to the saw and they started cutting. (It's amazing how fast sawdust can build up in an enclosed area during this kind of operation.) Sure enough the speed of the saw was varying all over the place as it met various hardness in the red oak. They asked if we could compensate for speed changes and I proudly introduced our Signature Ratio Adapter. "But I'll need a tach signal from your saw. At least 1 V." No problem they assured me and we hooked up their tach cable. Immediately our analyzer went bonkers! I said "What level is your tach signal?" They responded that they were giving me about 25,000 V right off the spark plug! After we filtered this signal down to a reasonable level, things got much better. So we started cutting through logs like crazy. You could actually see the sawdust pile growing in real-time! And the vibration "orders" were nicely stationary on the screen, just as planned. We had the saw operating close to 10,000 RPM.

Suddenly someone yelled "DUCK!!" We all hit the deck in a blizzard of sawdust as the chain, which had snapped, whizzed around off the walls like a frenzied demon! Luckily no one was injured. And the demo was considered a success. I think we all headed to the nearest pub.

chemical plants and oil refineries, the customer would typically say: "What does Charlie Jackson think about this?" After we said "Charlie who?" for about the 10th time, we decided to invite Charlie, who was with Monsanto, to one of our training courses in San Diego. He brought about four or five of his cohorts from various Texas refineries with him. By the end of the week we had made believers of all of them, but it wasn't easy! Jon Palm became their instant "hero" by managing to keep them out of jail, partly because of their "Texas driving!" (At that time we offered a "general" course, full of PSD and SRS and FRFs; It wasn't until the third day that we got around to rotating machinery analysis!) After that we started doing many more demos and got orders from users and manufacturers of large turbomachinery from all over the USA and around the world.

In late 1969, Laurie did a real-time analyzer demo at GE Steam Turbines, in Schenectady, New York. There he was introduced to the works of Dr. Wilfred Campbell, who had pioneered a 3-dimensional display to help diagnose vibration in steam turbines during runup. The display shows speed in RPM vs. response frequency in Hz, with vibration amplitude shown as increasing diameter circles on the graph, Figure 31. Laurie came back and immediately got our "computer systems engineering team," of which he was an honorary member, to work programming our system computer to work with an RTA and produce true Campbell diagrams. The result was truly wonderful and SD produced the first "real-time Campbell diagram system" in 1970. When we showed it to GE in Schenectady they immediately purchased one. The system would acquire the vibration and speed data during a run up or coast down, and within 10 seconds of finishing the run, a real Campbell diagram would appear on the screen! A real breakthrough.

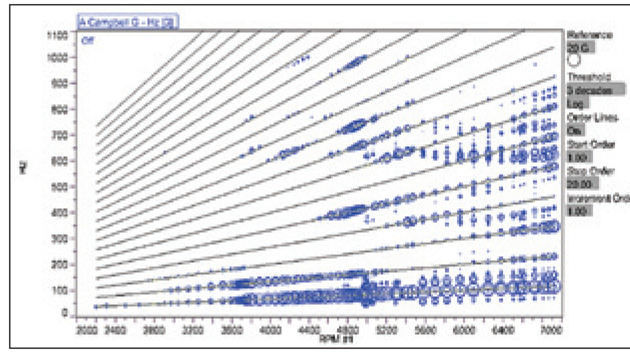


Figure 31. True Campbell diagram.

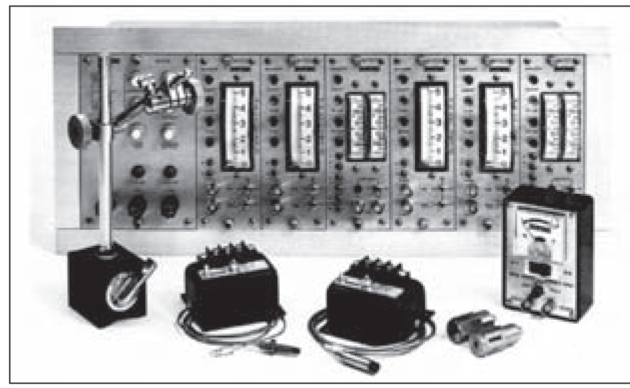


Figure 32. Early DYMAC products.

About this time, in the early '70s, we hired some experienced field service and sales engineers who had previously worked for Bentley-Nevada, so they already knew many of our customers. With the goodwill generated by our real-time analyzers, together with the good service and training that came with them, our new "machinery specialists" were quickly accepted into the "machinery fraternity." All of a sudden they were being encouraged to develop products that did machinery monitoring as well as our analysis products. This same encouragement also came from our office in the Netherlands, where large refineries were becoming better and better customers. We thought we were doing very well when we received a nice order for a real-time analysis system. When it was pointed out that the monitoring system in the same refinery cost 10 to 50 times more than our analyzer, a few bells started ringing!

Enter the DYMAC Division

So in November of 1973, our new DYMAC Division was formed in San Diego. In much the same manner as the start of our Special Contracts (Government Products) Division – "You, you and you, we've leased a building down the street, go there and monitor to your heart's content!" So some of our best designers, engineers, draftsmen and assemblers, left "the original Spectral Dynamics" and moved into a new world, with Hugh Ness smiling all the way.

Whereas SD's traditional instruments are normally used in laboratories or for portable troubleshooting assignments, DYMAC units were installed permanently on processing or marine propulsion


Figure 33. Computerized Machinery Monitoring System, M7000.


Figure 34. DYMAC monitors in an ammonia plant.

machinery for continuous detection and measurement of vibration conditions. The DYMAC product line expanded to include many different types of monitoring modules and some of the best eddy current probes ever produced, Figure 32.

Also about this time Dan Bozich of Spectral Dynamics/DYMAC was working on a very large and very complex multi-channel machinery monitoring system, the M7000. This system was eventually finished and delivered to the satisfaction of many customers in Alaska, Texas, Louisiana and around the world, Figure 33. Although this system possessed many unique and powerful features, it also became apparent that "one-off" complex, high value systems were not really compatible with the goals, and products of DYMAC, and this type of business was no longer pursued. Nevertheless DYMAC continued to thrive and grow, with standard monitors, Figure 34, transducers and analyzers, under the leadership of Bob Davis.

Computer-Based Control Systems

Since our real-time analyzers were very, very popular, they took us into many places where potential customers wanted to see them in action. At the time of our SD301, we were successfully selling many SD104/SD105 swept sine Controllers into vibration testing labs, with tracking filters accompanying many of these orders. With many labs also doing random vibration testing, it was natural for them to want to speed up their PSD measurements and plotting using a real-time analyzer (RTA). So we began to get many orders from these labs for RTAs. Remember that in the early days of random vibration Testing, from about 1963 and onward, most of the random "control systems" were of the multiple filter slide wire type made famous by Ling Electronics and MB.

Since Spectral Dynamics had a good reputation in these labs, we were often encouraged by customers to "close the loop." By that they meant that since we had an excellent measurement of what was happening at the shaker, by using our RTA, why not tie the RTA to a computer? Then all we would need is a "little bit of software" and a D/A converter and we could replace those expensive parallel filter slide wire "controllers!" (And of course Time Data was also selling controllers by that time too.) We must have heard this hundreds of times before Laurie said: "Enough already, let's give it a go."

So we purchased a few PDP-11s from Digital Equipment Corporation and started writing software. Our first random control system was based on using the SD301, 500 line analyzer as the "front end," so that was the de-facto control resolution.

To get really started in this endeavor, Laurie convinced Ago Kiss to join SD and work on our first computer-based control system. Ago was a legend at HP for the work he had done in helping them to develop their Fourier analyzers and first random control systems. When he came to SD he was joined by Lane Hauck, Terry Sorenson and Laurie himself in developing our first control system, the SD1009. Laurie spent many, many hours in "the back room" with headphones on, listening to our "digitally produced" random noise. Being an old lab guy, he was not going to sign off on any SD random control system that didn't produce a Drive signal that really sounded like pure analog noise! Our Control systems continued to evolve, using at first the latest real-time analyzer in our product line, Figure 35.

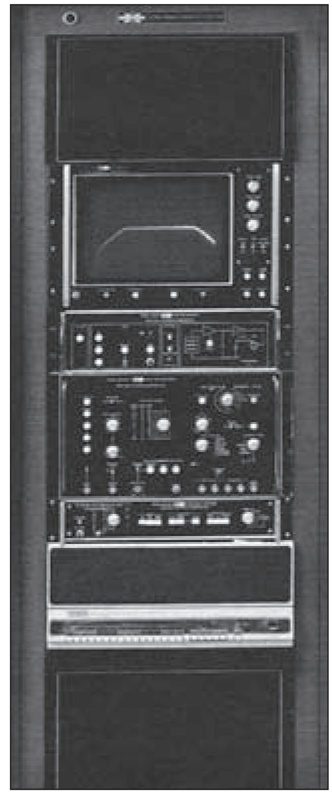


Figure 35. First SD1009A Digital Vibration Control System fed by paper tape

Finally in the mid '70s we produced our first high speed, two channel FFT analyzer, the SD360. So home-bred FFT processors replaced our time compression RTAs as our prime spectrum analyzers and as the front end of our control systems. Many of our control systems were unique for their time. For example in the mid '70s a lot of attention was being directed towards stress screening and the use of NAVMAT-9491. To make it more cost-effective to perform random vibration screening on multiple shakers simultaneously, SD developed the SD1200B Control System. With this system, you could have up to 10 shakers all running independent random tests, but all under the oversight of a single computer. This proved to be a very cost-effective approach.

Also in the late '70s Dr. Marcos Underwood used some of his acoustic testing experience with Rockwell International to develop our SD1600 Acoustic Control System. This proved to be a very successful system for controlling the sound pressure level and spectrum shape in reverberant control rooms. One of my fondest (and almost unbelieving) memories of this era is a test we did at the huge reverberant chamber at Lockheed in Sunnyvale, California. We were challenged to drive the sound generators of this large chamber, while a plate with several accelerometers was mounted in the chamber. The purpose of the test was to control the PSD on the plate through acoustic excitation. This turned out to work very well, much to the disbelief of some very well known mathematicians of the day! And the system was almost before its time with some really neat features. Such as doing accurate narrowband control while reporting the SPL in terms of ANSI-compliant *N*th octave filter bands; compensating for room delay times; producing multiple drives; and permitting some microphones to "drop out" but still completing the test with corrected averaging values. (These features have been carried over into our MIMO acoustic control systems of today.)

A Word About Our SD360 Digital Signal Processor

When it became obvious that improvements in microprocessors and computer hardware were making time compression products irrelevant, SD, sort of reluctantly, jumped into our first FFT based analyzer with both feet. (After selling literally, thousands of RTAs this was a hard but inevitable decision.)

But rather than start with something simple, we knew we needed

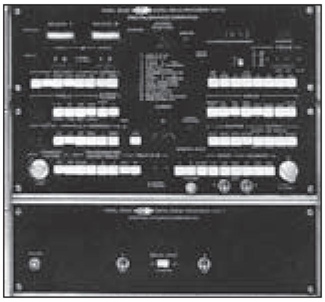


Figure 36. SD360 Digital Signal Processor.

to be able to measure frequency response functions digitally. So our first FFT device was a "do everything" beauty we called the SD360. The engineering team of Glen Madsen, Art Aylott, Carl Dubois and Dick Manning did most of the "heavy lifting" on this product. We are also very fortunate to have nearby Dr. fred harris, who teaches in the E.E. department at San Diego State University. He was of enormous help during the SD360 development. Little did we know that in addition to being a very fast 2-channel analyzer, it would become one of the greatest teaching tools ever created! And fred really liked that. Since he is one of the very best practitioners of understanding and designing weighting functions for digital signal analysis, in the world, we took full advantage of that. Soon Blackman-harris, Kaiser-Bessel and Gaussian windows were all over SD.

A funny thing happened when we introduced the SD360. fred and I soon were traveling far and wide putting on seminars with the SD360, Figure 36. He would introduce all the appropriate math and I would run the demos. But soon we were both fighting for the chalk! He usually won.

The SD360 also became an integral part of our first computer-based modal analysis system, the SD2001DM, Figure 37. When this system was introduced, it worked with modal analysis software from SDRC, called MAP (Modal Analysis Processor) running on a PDP-11 with the large RK-05 hard drives. This was a very successful system and proved to be very competitive with current offerings from HP, at that time. One of the really popular features of our modal system was it's ability to expand into running SABBA (Structural Analysis using the Building Block Approach), developed by Dr. Al Klosterman of SDRC. This permitted practitioners to take apart a structure, test each subassembly individually and put the system back together analytically with SABBA as well as physically. At the time, it was the ultimate "what if" game and it was not available with the HP system. Shortly thereafter, the four engineers responsible for the HP modal analysis software left HP and formed SMS, Structural Measurement Systems. So Mark Richardson, Ken Ramsey, Dave Formenti and Don Kientzy developed STAR modal software to run on a PC under Windows™. Eventually SD began to use this software and today it is part of the SD product line in much newer versions such as STAR V.7, Figure 38.

With so much engineering effort being invested in the SD360 development, we needed to look after the larger market for a small single channel analyzer, based on the newer technology. So as some would say, we went from the "sublime" (SD360) to the "ridiculous" (SD340), a very simple and light FFT analyzer with a built-in display, Figure 39. Not only was this popular, but it got manufacturing customers thinking about using this on a production line to create go/no go criteria.

This led to the creation of the SD210 Spectratester, Figure 40. The SD210 was a "smart" version of the SD340, which embodied five individual "windows" which could be set independently. Each window created an adjustable frequency and amplitude range which examined the response of a transducer, typically an accelerometer, mounted on the product running down the line. If any of the windows were exceeded, (high, low, left or right), an alarm would sound. This proved to be very popular in many applications, some of which we had not anticipated!

The Scientific-Atlanta Era

Spectral Dynamics first became a publicly traded corporation in November, 1967. Like many small electronic companies, our stock price varied with the market and with our financial results and ranged from about $5 to $24 per share over a period of years. In late 1977 and early 1978, Scientific-Atlanta (SA) became interested in purchasing Spectral Dynamics. SA was founded in 1952 by several engineers from Georgia Tech University. At the time of their

Figure 37. SD2001DM Modal Analysis System.

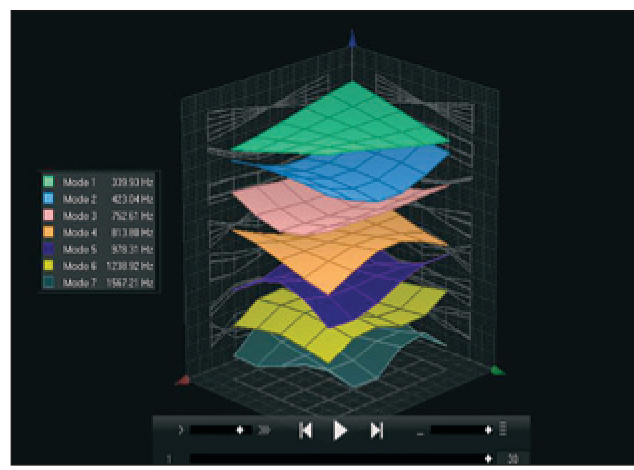


Figure 38. STAR modal display of 7 modes simultaneously animating.

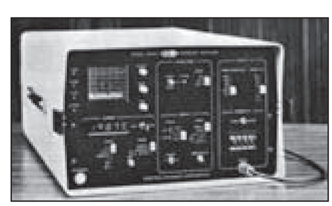


Figure 39. SD340 Micro FFT Analyzer.

interest in purchasing SD, their main business was making and selling "set top converters" for the burgeoning cable television industry. They manufactured and sold thousands of these a day. But the gross margin (GM) from selling these products was quite low. They were intrigued by the higher GM which Spectral Dynamics was able to command from our innovative products. So an equitable deal was struck and – bingo! – we were now part of a larger company.

We wanted to maintain the close-knit "family" atmosphere of our San Diego operations but suddenly there was a lot more sales reporting and forecasting necessary. East coast companies had always accused SD of being of a laid-back "surfer" mentality, not consistent with the frenetic pace of many Eastern establishments. hmmm, could that be true . . . ?

Anyway, SA was one of the few Fortune 500 companies with a CEO that came up through sales. Sid Topol was a salesman's salesman and knew when a sales forecast was a lot of hooey. This made for some very pressure packed meetings. But with the help of Doug Key in accounting, all the merger documents and monthly reporting figures worked out to everyone's satisfaction. And sales continued to grow. (At one point in the mid-'80s, the Spectral Dynamics operation in San Diego, encompassing three Divisions, had over 450 employees.)

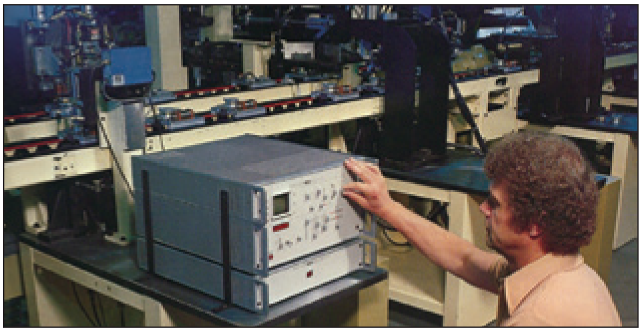


Figure 40. SD210A Spectratester on a production line.

Figure 41. Jeanette Thomas at work in the HUBBS-Sea World Research Institute acoustic lab – one of the most sophisticated of its kind in the country. Below her left hand is one of the lab's key instruments – an SD345 Spectrascope III.

Figure 42. SD375 Dual Channel Analyzer.

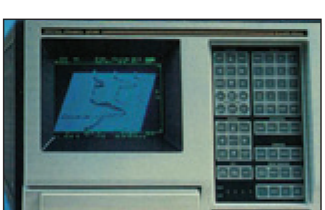


Figure 43. SD380 "Saturn" Analyzer with color display.

An Amazing Coincidence

For many years Spectral Dynamics has been supplying systems to measure the dynamic characteristics of structures. Our SD1002 Mechanical Impedance System was the first of many such systems. These systems were based on the principle that $f = ma$. We typically were measuring force and acceleration or force and velocity, so to calibrate the system was very straightforward if you had a known mass.

For the purposes of development, installation and seminars we manufactured three or four steel blocks of known mass. These were rectangular in shape and weighed about 1.2 pounds. We would connect these to a small shaker through a force transducer and attach an accelerometer to the mass. This gave us one known point on our mechanical impedance graph and from there it was "duck soup!"

A few years after Scientific-Atlanta purchased Spectral Dynamics, I happened to be in Atlanta and was given a tour of a new compact range which was being built for radar cross-section measurements. This was an indoor range, one purpose for which was to avoid detection by satellites passing overhead.

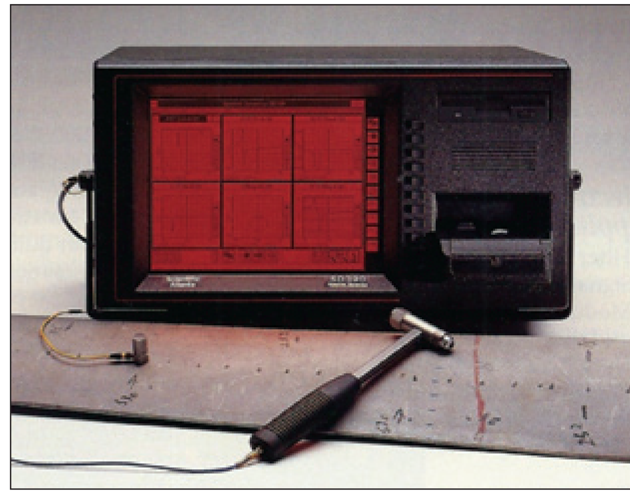


Figure 44. SD390 Signal Analyzer with built-in PC.

As I recall, the "target" in this case was nearly a hundred yards away. Being naturally curious, I asked the engineer who was showing me around, how such a system was calibrated? He laughed and said "follow me." We walked down to the other end of the range where the target structure would normally be mounted. Instead, sitting on a small fixture was a round ball of steel! It was about the same diameter as our mass calibration block. But, being more sophisticated, their calibration device was a sphere!

I told him my application story and we both had to laugh. My block of steel calibrated a measuring system which cost about $40,000. His steel sphere calibrated a measurement system which cost $1,000,000 and up. But we both got very accurate measurements.

By now we were introducing a steady stream of standalone FFT analyzers. The SD345 Single Channel, Figure 41, and SD375, Figure 42, Dual Channel Analyzers were the first in our industry to introduce "touch front panels" instead of knobs and switches. And on the SD375, engineering gave us another of their famous "special touches." At some unmarked spot on the front panel they hid a "secret switch." During a demo, when it came to be time for a short recess, our applications engineer or salesman would push this particular area of the panel and the screen would change from whatever was being displayed to show "COFFEE BREAK." This was a surefire winner with all of our customers.

Then it became time for a new analyzer and we wanted to introduce something with four channels and the ability to store data. So we developed the SD380, Figure 43. Around this time frame we began to notice that some competitive analyzers were suffering from overheating. In some cases it was because the instrument design was optimized for size. "The smaller the better." So with all the heat generated inside these analyzers, a pretty design could become a service nightmare. With this in mind, Roger Koch, who was heading up the marketing side of the SD380 development, suggested we provide plenty of cooling. The result of this decision was felt in several ways: with several large fans inside, the chassis had to be pretty large; the use of several sizeable fans created some added noise causing some people to say: "is it going to hover?" The cooling worked as designed and our failure rate was actually miniscule. And, best of all, the SD380 became the highest selling analyzer ever produced by Spectral Dynamics. (The exact number sold is available from the author for a bottle of nice wine!)

Since computer-based analysis systems were becoming very popular, we decided to do them one better. "Let's build an analyzer with the PC built-in!" So the SD390 hit the drawing board and became a real challenge. We would install the latest Windows software and we wanted a built-in mouse, so a track ball seemed like the best bet. We wanted a color display, but when we started

Figure 45. SD1700 Javelin controller on shaker controlling it's own 6 g_{rms} test as Tom Fielder looks on.

the project, built-in color displays were not available. So the SD390 with color display, hard drive, floppy drive, track ball and lots of memory, running under the latest Windows OS finally made its official debut on July 31, 1991, Figure 44. Besides built-in waterfall displays, the SD390 could actually run STAR modal in the same unit. This was another first and also proved to be very popular.

This analyzer also found a very good market in the area of rotating machinery analysis. With the help of Pete Neild a special version of the SD390 called the Balance-Pro was developed around 1994 and became very popular with airlines. This combined many features of analysis with trim balancing and became an excellent tool for aircraft engine maintenance.

Having an analyzer with a built-in PC was a super idea. But even before that many customers asked us for a "1 box" control system with a built-in host PC. This would make it easier for them to move it around the lab or even from building to building. So we developed the SD1700 "JAVELIN" controller. There was still a lot of production screening going on and Ed Andress thought we could use the JAVELIN to "spear the bad ones!"

When we introduced this controller, with a monitor and keyboard, it was an instant success. customers would put this on a cart, even a scope cart, and move it anywhere they liked. Two of these also became the controllers of choice for the 2-axis shakers made by EST.

Figure 45 shows Tom Fielder monitoring a 6 g_{rms} NAVMAT vibration test from the shaker nearby. The test article on the shaker is an SD1700 and it is controlling its own 6 g_{rms} test! I wonder how many other controllers could have done this?

Some Changes in the Corporate Structure

By the early '90s Scientific-Atlanta had decided to overhaul its corporate structure to concentrate on radar products and cable television as the primary focus. This meant that some of Spectral's products were no longer in the big picture. So the DYMAC Division was sold to SKF in 1990, with most of the operation staying in San Diego. A few years later, in 1993, PIND Testers purchased Spectral Dynamics from Scientific-Atlanta, together with the shaker control product line and changed their name from PIND Testers to Spectral Dynamics. Finally, in about 2001 the sonar and other products of the Government Products Division were sold and Scientific-Atlanta relinquished their presence in San Diego.

The New Spectral Dynamics Blossoms

Meanwhile, in other parts of California, several pertinent company restructurings were taking place. These all had an effect on today's Spectral Dynamics.

After receiving a BA in Physics from UC Irvine and an MBA from UCLA, Stewart Slykhous, Figure 46, joined Endevco Corporation in San Juan Capistrano as marketing manager of the Dunegan Division. This group was involved in acoustic emission measurements and developed products and techniques for making these measurements more accurate, yet easier to accomplish.

He was then a founding partner in Physical Acoustics and moved to New Jersey for several years while serving as vice president of marketing and sales. When Dunegan Division of Endevco was spun out, Stewart and his partner, Jim Tucker, Figure 47, acquired the division in 1988 and renamed it PIND Testers, for performing particle impact noise detection, Figure 48. Stewart moved back to Orange County to lead this new venture.

Figure 46. Stewart Slykhous, Spectral Dynamics President & CEO.

Figure 47. Jim Tucker, Spectral Dynamics Chairman.

In 1993 Stewart and Jim acquired the Spectral Dynamics shaker control product line from Scientific-Atlanta, in San Diego, and renamed their new, larger, company Spectral Dynamics, Inc., with Jim serving as board chairman and Stewart as president and CEO.

One of the first things Stewart did was hire Rick Ellis, an MSEE MIT grad, who had originally joined SD in 1988, working on analyzer design. After a few years he left to work on shaker control software elsewhere. When he rejoined SD in 1993, Rick headed up an engineering team in San Diego that developed, among other products, our PC-based PUMA control/analysis system, Figure 49. They have also developed and helped ship millions of dollars of rotating machinery analysis hardware and software to Rolls-Royce of Canada. These have been the incredibly successful turbine engine monitoring and analysis systems.

We introduced another controller in this time frame with a very specific application in mind. There was a lot of talk about mass manufacturing of electronic products and some appliances in a "lights out" factory with full automation. The concept was that some products at random would be taken off the line and undergo a quick "vibration qualification test" as a check on a particular production run. These would be tested by production personnel, not trained vibration test engineers. So we really had to make it simple to use!

What could be simpler than a controller with no keyboard, and simple pushbuttons for START and STOP? The required test parameters would be stored on a small memory card using a PC running Windows. Then the computer would be detached. The standalone control box would accept the preprogrammed test card, the operator pushes START and goes back to work. This was introduced as our SD1800 in around 1992. Then sine was added to it as the SD1815 and introduced around 1994. During development we decided that such a simple controller did not need a real-time display in a dark factory, only a hard copy when selected. That was probably a mistake.

As this was happening some of our competitors were also making very good products, but also facing difficult management decisions. The Structural Test Products, STP, division of GenRad is a prime example. Over the years they had developed some interesting and powerful controllers and analyzers. Their multi-channel Model 2515 Computer-Aided Test system was a very good product that ran SDRC MODAMS modal analysis software. At the time SD had no answer for this multi-channel beauty so the 2515 ran "unmolested" for several years in the '70s and '80s.

Then around 1984 Dr. Marcos Underwood left SD, moved North towards the Bay Area and joined GenRad. In the late '80s they developed the Model 2530, the first control system to use multiple DSP processors in parallel, Figure 50. They would do much of the "heavy lifting" for the Control functions. Then they needed a host computer to connect to this hardware box and perform data management and graphical displays. Marcos saw an excellent fit with the "MicroVax" from Digital Equipment Corporation. But

Figure 48. Typical Particle Impact Noise Detector (PIND) system.

Figure 49. 32 Channel PUMA Control/Analysis System.

Figure 50. GenRad Model 2530 Vibration Control and Analysis System.

they were not able to come to a suitable business arrangement with DEC, so they began to look around. As luck would have it there was a new computer manufacturer that had started up just a few miles away. So Marcos and his staff visited Sun Microsystems and were introduced to the Sun Sparc workstation running a Unix-based operating system called Solaris. It was clear that Sun was a company interested in building and testing robust workstations and this became the start of a long and very successful product relationship.

For a long time Marcos had been dreaming about developing a system, along mathematically "pure" lines, to accomplish true multi-shaker control. He was familiar with the early attempt by Spectral Dynamics to create and market the SD108 Phase Servo in 1967 and was convinced that with the new, more powerful, computers available, this was a good time to make a serious effort in this direction. His Ph.D. dissertation dealing with control theory had also touched on these ideas. So when he had a chance to join Synergistic Technologies Incorporated, STI, in San Jose, he just had to do it. STI had been making multi-shaker control and data acquisition systems for many years with some success. When Dr. Dick Stroud at STI had a chance to get Marcos on his team, he jumped at the chance. So in 1988 Marcos left GenRad/STP and joined STI as their chief engineer.

By incorporating his optimal control strategies together with his soon to be patented adaptive control concepts, the STI Multi-Exciter Control Systems began to see immediate improvement. Since STI was not a very large company, it used commercial off-the-shelf data acquisition, D/A and PC hardware. Marcos realized that, even though the company name suggested it, the way to achieve optimum synergy in a control system was if the same group designed and built both the hardware and the software used for the multi channel and multi shaker operations. This realization would serve him very well in the near future.

In 1989 STP had also acquired Structural Measurement Systems,

Figure 51. 98 Channel JAGUAR Control and Analysis System.

the developer of STAR modal analysis software. This was still being used with the Spectral Dynamics SD390 and many other universities and customers running stand alone Windows-based PCs.

Then in 1995 the "new" Spectral Dynamics acquired the STP Division of GenRad and with it the STAR modal products. By this time STP had developed the 2550 and 2552 control systems and was able to offer a 32 channel, single shaker controller, running on a Sun workstation. So Spectral Dynamics found itself with two strong engineering groups. One in San Diego developing controllers and analyzers to work with PCs running Windows and one in San Jose developing controllers and analyzers to work with Solaris on Sun workstations. With the emphasis of STAR running under Windows, it was logically transferred down to the San Diego operation where it has thrived under continuing development.

This also meant that Bill Grafton, an accomplished engineer, famous for helping Caterpillar solve some difficult engineering problems through GenRad in years past, would bring his modal analysis and control system design expertise to the San Diego group. This has been and continues to be a tremendous help.

Some New Product Families

When STI was purchased by Spectral Dynamics in 1996, it marked the return of Dr. Marcos Underwood to Spectral Dynamics. This was significant for many reasons. Chief among these was the fact that he now had the company commitment and the resources to begin design of his "dream" product. This would be a control/analysis system, designed with multi-shaker control capabilities in mind, where hardware and software would be designed by the same engineering team, with maximum performance the main goal! The result of this effort, first released in 1998 with single-shaker control, is the very popular JAGUAR Acquisition and Control System, Figure 51. In 2000 multi-shaker, MIMO, software was released and has continued to be developed and improved for 16 years and counting. Over this time frame SD engineers have written and presented over 30 papers on multi-shaker, MIMO, control, many of which introduced new MIMO concepts for the first time. (This group of 30+ MIMO papers is more than was published in that time frame, by all of our competitors, combined!)

The introduction of JAGUAR meant that for the first time a 98 channel real-time controller was available with a long list of unique features. For the sake of brevity, only two will be mentioned here. For decades test engineers have known that the most difficult test to run is a swept sine test. That is because the response of a test structure, as you approach resonance, can change abruptly, sometimes by several orders of magnitude in a matter of milliseconds. To compensate for that the controller must not only react incredibly fast, without overshoot, but it must also have the input channel voltage range values set correctly. If you set the input range too low, you may cause overload on one or many channels. If you set all inputs to 10 V full scale, you will probably never overload, but most of the time, your inputs will be so low as to never fully utilize the 16 or 24 bit input A/D features. Of course another choice would be to run the test once to set all the inputs correctly and then run the "real" test. But no one wants to subject their precious test

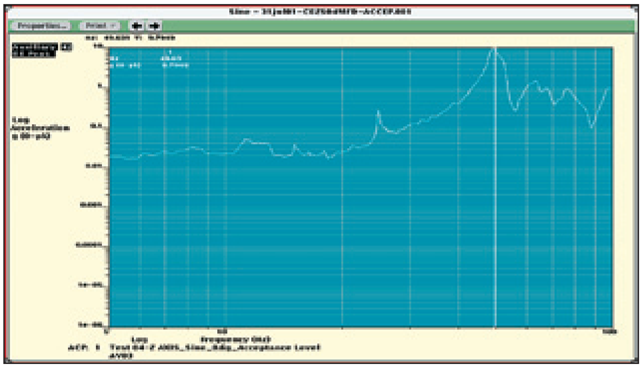


Figure 52. Broadband peak sine response with no tracking filters.

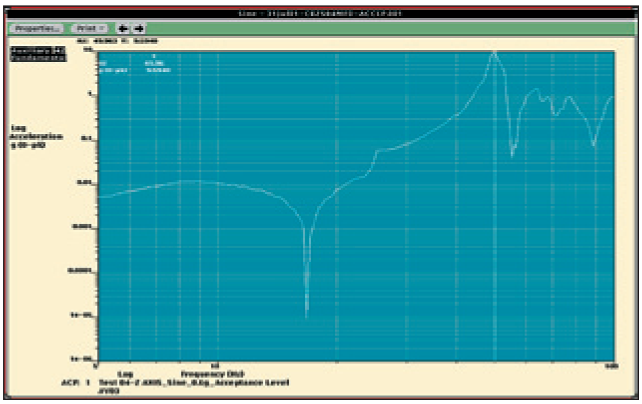


Figure 53. Same data as previous but showing tracking filtered fundamental response.

article to twice the amount of required stresses. In the JAGUAR, Dr. Underwood very neatly solved this dilemma.

Every JAGUAR contains a special "DSP" card we call an MDSP. This in fact is a complete embedded computer with it's own operating system! This function is so fast and so powerful, that it performs many functions, for all 98 input channels, in real-time. Among these are the instantaneous measurement of the RMS value of all 98 input levels simultaneously. These values are then fed back to a series of three programmable amplifiers on every input channel. The correct value for each input attenuator is then adjusted, continuously, during swept sine (and random) testing so that an optimum value is presented to the A/D converter. So the necessity to select the correct input range has been taken out of the hands of the test engineer, once and for all!

The second feature, unique to both JAGUAR and PUMA, is the ability to set up a selectable tracking filter for every input channel during swept sine testing or analysis. Since the very first product ever produced by Spectral Dynamics was a tracking filter, we have always been very aware of the benefits which high quality tracking filters offer to those performing swept sine tests and analyzing the resultant data. There are many reasons for performing vibration tests, besides being required by a test specification. One of these is to obtain "dynamic response" characteristics of the test article for the structural dynamics engineers, the infamous "2nd story guys," mentioned earlier in this article. An example from a satellite qualification test will be briefly discussed next.

A two ton satellite which was designed to measure certain earth characteristics, was undergoing its "final qualification" test. This was a sine sweep from 5 to 100 Hz at four octaves per minute, with an average level of 0.65 g peak. The satellite was mounted in the vertical direction for this test. A particular point of interest on the satellite was a bracket housing several heavy batteries. An accelerometer was mounted on this bracket in a horizontal direction and identified as location 42. About 170 measurements were made during this qualification test.

As the test was run, all 170 channels were recorded to removable hard drives with a sampling rate of 12,800 samples per second per channel. As with most satellite tests, the dynamicists were looking for their test data the minute the test was over. So hard copies were blasting forth from printers at an amazing rate. The "sine response" plot of Figure 52 shows the (broadband) peak response of Channel 42 during the single upsweep. Since I was present in the data acquisition room during this vertical test, I was able to see the results of the sine analysis coming off the printer immediately. When I saw the channel 42 peak plot, something just didn't look right. Most of the data below about 40 Hz looked more like a "random" plot, than a real sine response. Since we were playing the recorded data back from the "throughput" hard drives, I asked if I could rerun channel 42, but this time I would invoke a narrowband tracking filter in the playback sine analysis. Everyone agreed so we ran it again.

The results, as seen in Figure 53, were astounding! Suddenly you were seeing the true response of the satellite structure, free of noise, distortion and harmonics. And now you could clearly see the "notch" frequency, which helped in the validity of the mass model. The resonant frequency is the same in both displays. But the increase in effective "dynamic range" of the display was phenomenal – from less than 60 dB to 120 dB. Makes you wonder why everybody does not use tracking filters?

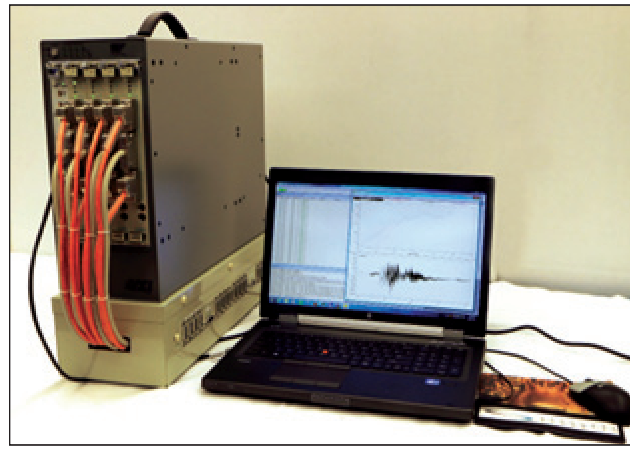


Figure 54. 32 Channel VXI Acquisition System with 5M samples/sec/channel.

Figure 55. Some current SD salesmen; clockwise from upper left; Mark Marraccini, Tony Keller, Mark Remelman, Marc Lamparelli, Gary Marraccini, Deepak Jariwala.

Another Acquisition

In 2001, Spectral Dynamics acquired DSP Technologies and with it two very meaningful product lines. One of these was the SIGLAB family of products, which included 2- and 4-channel acquisition/analysis modules that could be stacked together for up to 16 channels. This product came with a host of applications software that served many different requirements from modal analysis to servo system design. It was very popular with universities around the world and added to our customer base for over a decade.

The acquisition of DSP Technologies also brought to SD a very powerful VXI product offering for capturing transients with sampling up to 5 mega samples/second. This has proven to be the system of choice for many government agencies who need reliable, fast sampling, free from slew-rate, aliasing and other errors which can be encountered. Several excellent papers have been written about this by SD's Mark Remelman and Dr. Vesta Bateman, a respected expert and consultant in this field. An example of a 32 channel VXI system with VIDAS software is seen in Figure 54. Some of today's direct SD salesmen are shown in Figure 55.

This group has thrived under the caring, dynamic leadership of Gary Marraccini, our sales manager. He just instinctively knows the best thing to do.

Spectral Dynamics Shakers

At Spectral Dynamics, we consider our shaker controllers to be the best in the world! Based on the success of our PUMA and JAGUAR controllers, many customers agree. However, over the past decade or so many customers have chosen to bundle their shaker and controller requirements into one procurement. Several reasons may exist for this approach, one being to cut down on purchasing costs. Or to avoid any "finger-pointing" between shaker and controller suppliers should a problem arise. Whatever, in about 2009, SD made the decision to start supplying electrodynamic (ED) shakers in addition to our control systems. We wanted to be sure that any shaker with the Spectral Dynamics name could stand up in a solid, reliable way when used by our customers. So we contracted with a shaker manufacturing company in Suzhou, China, which has many years experience in all phases of ED shaker and amplifier design, quality control and manufacturing. Since SD already had several engineers on our staff with decades of shaker manufacturing and installation experience, we have been an active part of the creation and promotion of a range of excellent shakers for the U.S. and worldwide market.

The shakers made for SD by SONIC Dynamics are available in a range of sizes from about 10 pounds force to more than 50,000 pounds force. Depending on force rating they are supplied as permanent magnet, air-cooled or water-cooled designs. Our air-cooled designs go as high as 17,600 pounds force with 3 inch P-P strokes. Along with the shakers and power amplifiers we have available a complete range of head expanders, slip tables and isolation systems. And these all come with the unbeatable Spectral Dynamics service, Figure 56.

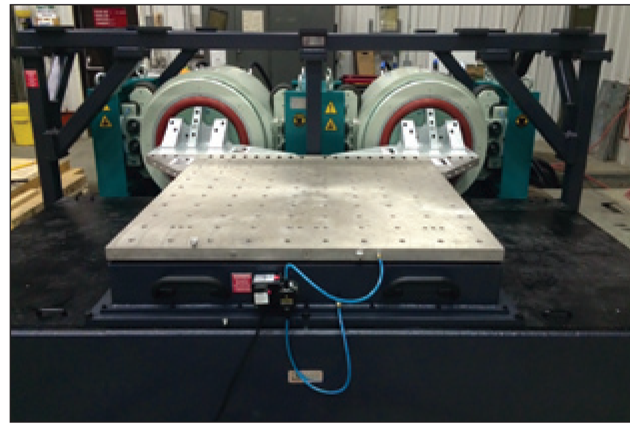


Figure 56. Dual 25,600 lb shakers with special slip table.

Figure 57. Russ Ayres standing outside the SD factory in San Jose, CA.

Figure 58. Dr. Marcos Underwood, Chairman of DTE-022.

A Peek into the Future of vibration Testing

A vast majority of vibration testing done around the world takes place because the organization doing the testing is required by law or contract to do so. Yes, there are many companies, including SD, who voluntarily submit their new products to some extreme environments in the interest of improving product quality. But, nevertheless, the vast majority of testing is done in accordance with a published specification, often based on military experience.

One of the most thorough and widely used specifications is MIL-STD-810. Now in the "G" version, MIL-STD-810G is widely respected around the world. Over many revisions "810" has encouraged practitioners to use their own "field" data if at all possible. Knowing that many organizations have no field data, "default" test specifications have usually been included to assist those who need to perform a test to acceptable criteria.

When MIL-STD-810G was first released on October 31, 2008, it was noteworthy for several reasons. Not the least of which was the fact that for the first time "810" recognized and encouraged, where practical, the use of multiple shakers for testing large and unusually shaped objects. So the introduction of Method 525, Time Waveform Replication and Method 527, Multi-Exciter Test, essentially "legitimized" these two methods that SD had been providing for nearly a decade. Some organizations that had been considering using multiple exciters for testing a single article, were now encouraged to do so. The net result of this has been an increase in the number of customers who are willing to jump into multiple shakers with MIMO control, most for the first time.

Many very good test engineers have found it difficult to make the transition from single- to multi-shaker testing. When you get to MIMO control, many of your old control concepts get turned on their head! For example when you are doing a single shaker test your focus is on controlling the structure's resonances. With MIMO it is the anti-resonances that can, literally, kill you. If your test structure with fixtures, etc. exhibits a deep frequency notch within the test range, the controller's tendency may be to pour more and more energy into that frequency region to boost its response. With multiple shakers, you can be dealing with incredible amounts of testing force, so you cannot just keep increasing the Drive(s).

When doing MIMO control, the entire control loop is typically described in terms of a matrix of the system frequency response functions. In order to calculate the required Drives, the FRF matrix must be inverted. This requires special handling and if done incorrectly you can cause severe damage to the test article, the shaker systems and possibly injury to those nearby. So I like to say that MIMO testing is "not for the faint of heart!" At SD we are very fortunate to have on our staff a registered professional engineer who has grown up with the JAGUAR system as well as its predecessors. Russ Ayres specializes in "all things JAGUAR" and has been with GenRad/SD since 1978. He works side-by-side with Dr. Marcos Underwood and has not only written several papers on MIMO control, but also conducts seminars on the subject and is a tremendous help to all JAGUAR customers.

In addition to that, Russ holds a record of great distinction; He has personally installed, worldwide, more multi-shaker control systems, in our industry, than any other person alive! That means, among other things, that Russ has pretty much seen it all in terms

Wrapping It Up

A great company is formed when smart, dedicated people work together to create innovative products which are needed by a customer base they understand. It takes enough financing, an incredible amount of hard work and, yes, some really good luck, to make this all come together. Spectral Dynamics has been truly blessed to have all these things in spades over its 55+ years of continuous operation including several company reformulations!

Thank you to all our customers and wonderful hard-working employees, past and present, who have made this happen. And thanks to you, Jackson Mowry, for having put up with me for 58 years and creating an excellent and much needed magazine for 50 years and counting!

Figuure 59. Some of the "Factory folks" who make Spectral Dynamics hum. Front row, L to R. Starting with the teal colored shirt; Minh Ha; Karen Pham, Ken Bosin, Marcos Underwood, Michelle Eisenbruck; Back row: Gloria Hernandez, Desiree` Marquez, John Arbuckle, Hung Pham, Ken Oneto, Mark van Sant, Russ Ayres, George Potter, Mu Lin, George Hamma.R

of MIMO setups; the good, the bad and the strange! So Russ, Figure 57, is available to help anyone with a question about using our JAGUAR system for single- or multiple-shaker control. One added thought: IEST Recommended Practice DTE-022 Multi-Shaker Test and Control, is worth reading if you are serious about doing MIMO testing. It offers many good tips which are not found in a test standard like MIL-STD-810G. Dr. Marcos Underwood, the Chairman of DTE-022 is seen in Figure 58.

Life at the Factory

As with any great company, Spectral Dynamics has been blessed with a series of excellent production managers. From John Atkinson to Bill Brown to John Arbuckle today, our heads of manufacturing have always had to wear many, many hats. Included in these hats is one of "parts detective!" Way back in the SD301 days, one of our suppliers delivered a quantity of mismarked parts. They were very close to the "real thing" but not quite. Sure enough after a few months of deliveries, we started getting feedback from some customers of unexplained anomalies. When we reported this to our supplier he was more than happy to replace the parts. It was up to us to replace the hurt feelings and lost productivity of our customers! Today it still takes a keen eye by John and others to avoid a repeat of problems like this.

From a sales perspective, it is always a fine line between giving a too optimistic or too pessimistic forecast to manufacturing. You want to have enough stock to make fast deliveries to deserving customers, but not so much stock that it languishes on the production line! With that in mind my sincere thanks to all the understanding that our manufacturing managers have (usually) shown to this sales dilemma. Figure 59 shows some of the folks who work hard at the factory to make SD successful, including John Arbuckle, Operations Manager, Ken Bosin, Engineering Manager and Michelle Eisenbruck, Controller. S|V

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