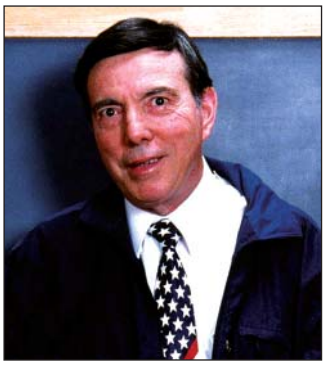
The 'Real' History of Real-Time Spectrum Analyzers

A 50-Year Trip Down Memory Lane

Joe Deery, AIM & C, Newfoundland, New Jersey



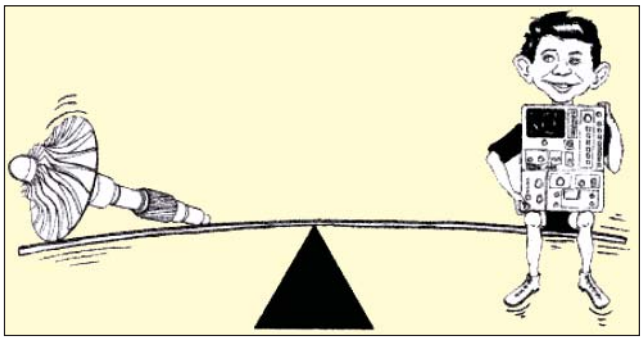
Joe Deery began his technical career in the U.S. Navy, achieving the rate of E6 as an electronics technician in four years. He was the lead technician on a ship that controlled troop landings with millions of dollars of equipment. Double Bachelor's Degrees (in Electrical Engineering and Chemistry) followed the Navy experience. After eight years as a Calibration Engineer at General Electric and one year as a Systems Engineer with RCA on the Ballistic Missile Early Warning System (BMEWS) program, he decided to make a career change.

In his own words – "I began a life of selling sophisticated dynamic measurement instrumentation, this included RTAs as a rep with Scientific Devices and J. E. Cuesta & Co. in the Pennsylvania-New Jersey area. Subsequent sales management positions included the sunny days as Sales Manager at Pulse Dynamics, VP of Sales at Nicolet Scientific, Sales Manager at Ballantine Labs, General & Sales Manager at Noise Unlimited and Sales Manager at LeCroy. The sun's brilliance then diminished; I joined the dark side and became a Regional Sales Manager for Data Physics."

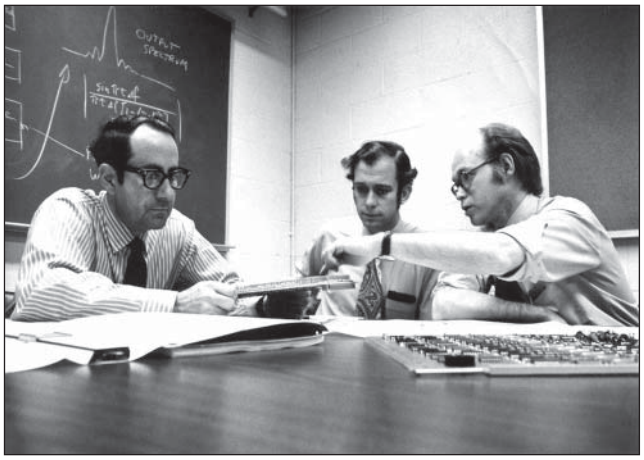
"Today, my rep company, AIM&C (www.aimcrescentbay.com), sells dynamic testing systems, instrumentation and transducers to the test and measurement community. We also sell thermal oxidizers, tanks, valves, piping, reactors and more to the chemical processing industry."

Real-time spectrum analysis is used to predict and analyze mechanical faults and failures in rotating machinery to analyze vibratory motions of components, systems and structures; to analyze the noise constituents in these systems; and for many other purposes. Real-time spectrum analyzer (RTA) development has a 50-year history that involves overcoming numerous technical barriers, challenging measurement techniques and physical obstacles. This article travels down memory lane from the earliest days in the development of these instruments at the Applied Research Laboratories of Columbia University to some of the latest product offerings. The many individuals that have contributed to this history and their accomplishments are chronicled.

In 1957 the US Air Force accepted delivery of a real-time spectrum analyzer with a *Coherent Memory Filter* system from researchers at Columbia University. This instrument simulated a bank of parallel filter/detectors, providing the constant-bandwidth spectrum of an applied analog input signal. This first RTA was implemented using glass acoustic delay lines and provided real-time processing from less than 1 Hz to 40 kHz. A commercial enterprise, Federal Scientific Corporation, was spun off to develop this exciting new technology. It was founded by Henry Bickel, Reinhold Vogel, Joe Flink, Art Citrin, Mike Laviola and Bill Brookner and located at 615 West 131st Street in New York City. They obtained a patent on the "Time-Compression" methodology that allowed a single filter and heterodyning electronics to produce a spectrum in real time.



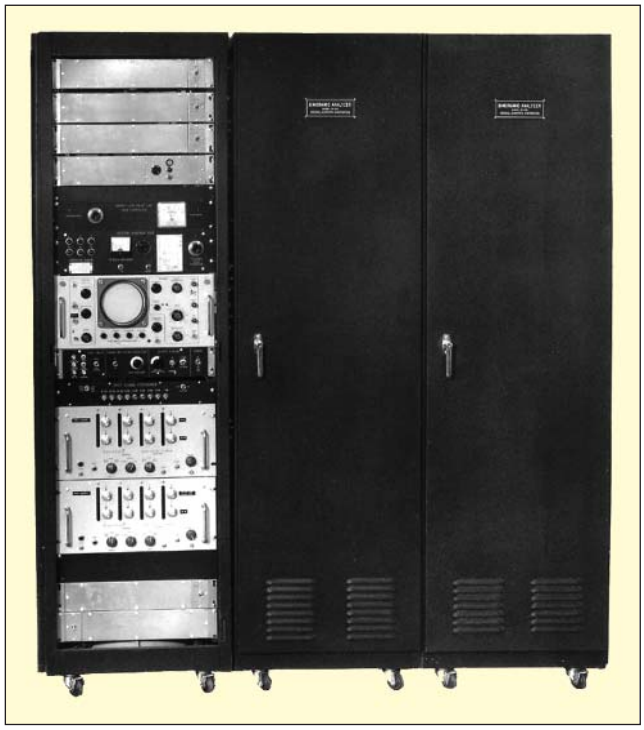
Artwork from "Nicolet Application Note 11: How to Balance with your Real-Time Analyzer" drawn by Lee Bjong in 1977.



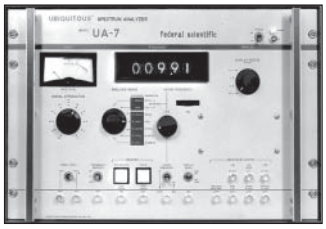
Three wise men of the East: Henry Bickel, Arthur Pini, Reinhold Vogel.

A wise man of the West: Tony Keller, early USAF White Sands Federal Simoramic user, eventual Vice President of Spectral Dynamics.

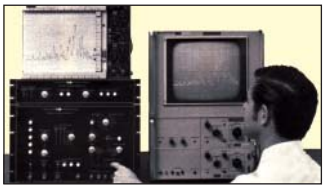
The name Coherent Memory Filter gave way to "Simoramic" and eventually to the familiar trademark, *Ubiquitous* (thank you, Dick Rothschild). Early Federal Scientific employees developed and refined the time-compression or 'deltic' RTA.



The Simoramic Analyzer.



Federal Scientific UA-7.



Spectral Dynamics SD301.

1960s Developments

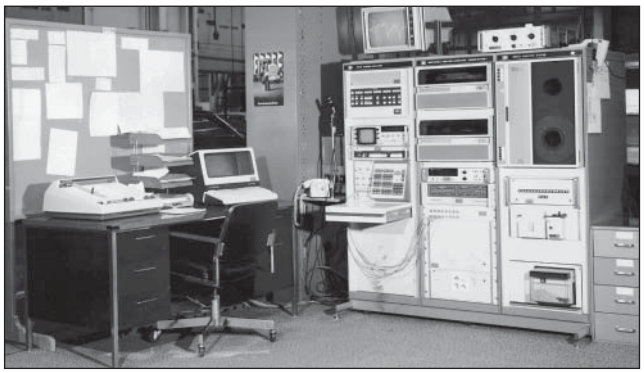
The first commercial RTA from Federal Scientific was the UA-7 *Ubiquitous*® Spectrum Analyzer. The engineering team had blinders on when it came to mechanical applications and they only projected the sale of about 100 sets to Electronic Warfare and military customers.

Spectral Dynamics, under the direction of Laurie Burrows and Hugh Ness, realized the breakthrough that Federal Scientific had made and entered into a license agreement to produce a product equivalent to the UA-7, which ultimately became the SD 301. These early RTAs processed data up to 20 kHz through a single filter that acted as 500 filters in 50 msec. These systems had street sale prices in the $35,000 range.

While it licensed the UA-7 to Spectral, Federal had an improved model under development. This was introduced (interestingly) as the UA-6 and featured a greater frequency range to 40 kHz. Spectral was furious about this new product offering from Federal, and a legal battle ensued. Spectral placed the highest level of engineering technology on developing RTAs for the environmental testing, rotating machinery, automotive and related markets. Federal/Spectral sales arguments included debating the benefit of 'dithering' the ADC with random noise and a 2 dB difference in dynamic range (48 to 50 dB).

Other scientists who performed work with the group at Columbia University started Saicor, which was ultimately acquired by Honeywell. Another company, EMR Hatboro, introduced an analyzer that held a spot on the stage into the '70s for about four to five years. Multiple window functions were its claim to glory. Princeton Applied Research, which was known for its "boxcar integrators," branched out and developed an RTA as well.

At this time, 85% of the RTA commercial market was divided between Spectral Dynamics and Nicolet Scientific, which purchased Federal Scientific. The lion's share of sales was registered by Spectral. Spectral made a major breakthrough for the U.S. Navy. They

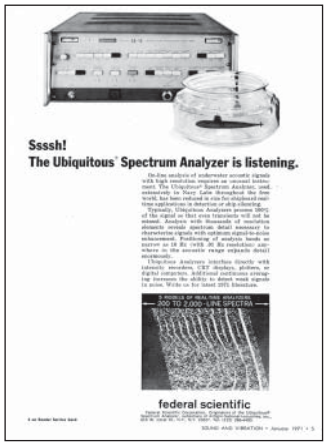


HP 5451C System used by Dave Formenti at the GM Proving Ground Noise and Vibration Laboratory. The NVL also simultaneously employed other unsavory characters including Don Kientzey, Ken Ramsey, George Fox Lang and (trust us on this) Michael Nyquist!

integrated an RTA and special *waterfall display* hardware with passive sonar to produce the AN/BQR-20 system. This sonar analysis system (and its successors) became standard tactical equipment on all U.S. submarines. Spectral sold many hundreds over a ten to fifteen year period. The SD13151 waterfall display was designed by Carl Dubois for sonar applications.

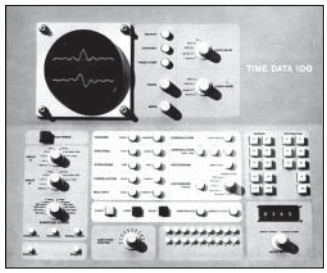
Elements of the AN/BQR-20: Spectral SD301 analyzer, SD13151 Spectrogram Display Control.

Federal made a half-hearted effort to get into the submarine sonar business with little success. Their 'fish-bowl' advertisement raised the Navy's ire and had to be quickly withdrawn to preserve good working relationships with the many Navy laboratories Federal serviced. However, they did contribute directly to the submarine sonar effort by innovating a new instrument called a *Frequency Translator*. The Frequency Translator was an accessory for an RTA. It used analog up/down heterodyning to accomplish what is now called *Zoom* spectral analysis. The translator allowed the RTA to analyze a narrow frequency band with very high resolution.



The infamous Federal fish bowl advertisement.

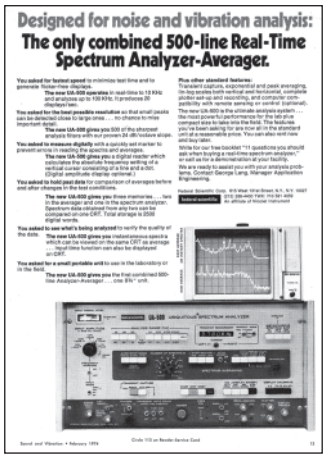
In 1965, Cooley and Tukey at Princeton University published their historic paper on the computation of the FFT. This development allowed a 1024 point FFT transform (512 lines) to be processed in one one-hundredth of the time previously required. It required 50% less memory to complete the computation.



Control panel of Time/Data 100.

Time Data, a California company resulting from the creative engineering efforts of Ed Sloan and Bruce McKeever and the creativity of Charlie Heismann and others, designed the first commercially available FFT system in 1967. Their Model 100 system, which was housed in two 6-ft racks, set the stage for the FFT analyzers that are available today. It processed a 1024 point transform in 1 sec. Time Data followed with the Model 90, which provided a speedup of the transform computation in a minicomputer. Later, in '72, Time Data introduced its model 1923 based on a PDP-11

Nicolet OF-400B Dual-Channel FFT Analyzer.



Federal Scientific UA-500.

Spectral Dynamics SD 330.

Nicolet Scientific 440A Mini-Ubiquitous FFT analyzer.

DEC minicomputer.

The U.S. Air Force took delivery of the first Time Data 100 system. A later Time Data 100 was delivered to FAA/NAFEC facility; its acceptance was based upon matching spectra with a Federal Scientific RTA Model UA-14, a 400-line *MINI_UBIQ* analyzer. IRD marketed the Federal Scientific UA-14 behind a 'green' front panel. The General Radio Company subsequently purchased Time Data and continued sales and engineering development.

The Hewlett Packard DSA Division in Santa Clara, CA under the leadership of Ron Potter, Ago Kiss and Pete Roth followed with the 5450/5451. These systems enjoyed fantastic sales success. Bill Cosby promoted the Model 5451 in automotive TV ads that showed structural vibration patterns. HP also sold hundreds of the Vibration Control System Model 5427 based on its FFT analyzer development.

1970s Developments

In 1974 Nicolet launched the *OF-400 Omniferous*® dual-channel FFT analyzer with another Rothschild-invented trade name. It had a bandwidth of DC to 100 kHz, a 10 kHz real-time rate, phase and amplitude-matched 120 dB/Octave analog anti-aliasing filters, 12-bit digitizers and a dynamic range of 72 dB. The real-time rate in the single channel mode was 20 kHz; the system processed a 2048 point transform in 30 msec. The OF-400 was 'portable' since it was in four boxes with a power supply that alone weighed at least 85 pounds and a total system weight of 220 pounds. Spectral Dynamics had a similar solution under development, but lost the race to the market. The SD 360 was a very capable and competitive FFT analyzer.

In the mid-'70s the RTAs continued to sell in decent numbers in the marketplace. Both Nicolet and Spectral developed analyzers that helped enhance the RTA's impact. First Nicolet developed the UA 500, a 500-line RTA with 100 kHz bandwidth and 10 kHz real-time rate. The instrument was smaller than the UA6/301 analyzers and included the averager. It offered digital outputs to graphing calculators available at that time.

Spectral developed the SD 330, whose specifications were not equivalent to the UA 500, but it had a built-in display with a significant benefit in size and weight reduction. This analyzer became a 'workhorse' in rotating machinery applications.

Boy with toy: George Fox Lang with Nicolet 660 FFT.

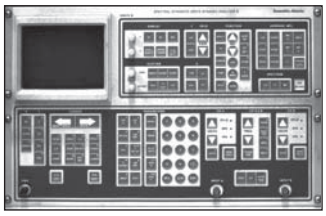
Nicolet rocked the market in 1975 with the first truly portable (30-lb) single-channel FFT analyzer. The 440A Mini Ubiquitous® had 400-lines with a built-in display. For a period of approximately seven years, Nicolet delivered 30 to 45 of the 440, 444 and 446 analyzers per month. The average cost was $13,500/system.

Many of the instrument manufacturers were feverishly developing 'portable' two-channel FFTs with the 5420 from HP leading the pack. Nicolet followed with the Model 660 and about 12 months later Spectral delivered the SD 375. Spectral sold many of the SD 375 analyzers, as they had with time compression, to the mechanical and military markets. All in all, HP sold more two-channel analyzers than its competitors combined.

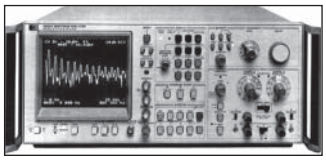
Ono Sokki, Takeda Riken and other foreign suppliers entered the market in the '70's with imitations of the SD, Nicolet and HP products. Hewlett Packard introduced the world's first dedicated modal analysis instrument, the HP 5423.

Last of a series, the Nicolet 446A.

HP 5420A FFT Analyzer.



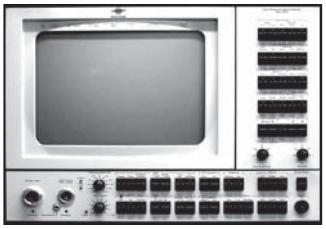
SD 375 FFT Analyzer.



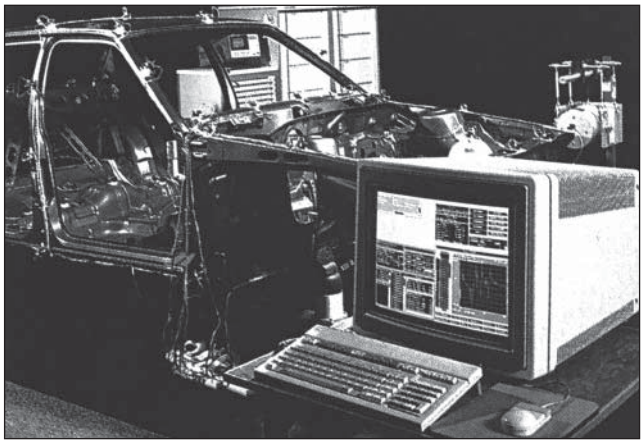
HP 3582A.

1980s Developments

The real shock came from HP in the early '80s, with a product offered from the Loveland Division. The HP 3582 was a compact two-channel analyzer with zoom and a bandwidth to 20 kHz for a price under $11K. The HP 3582 used four HP-manufactured SOS chips to perform zoom analysis; competitive instruments used 250 to 300 ICs for the same function. Limited memory and reduced processing speed produced slower 250 line



B&K 2032.



Hewlett Packard 3565S Paragon system.

HP VXI modules.

Data Physics DP 420.

transforms than competitive systems. This did not impede sales, and HP sold four times more than any other company offering FFT analyzers.

The 'box' business carried the market through the mid 80's. Emergence of application-specific analyzers for modal testing and acoustics (B&K 2032 for example), signature analysis of rotating machinery and shaker control dominated the market. The B&K 2032 was the first to incorporate a large buffer memory allowing for the re-analysis of captured data.

General Radio, renamed GenRad in the '70s, introduced the first FFT analyzer to use a raster-scan display. Employees Dick Benson, Paul Mennen, Loren Enochson and George Smith wanted to build a PC-based FFT analyzer/vibration controller. GenRad did not approve the project, believing that PCs would not be accepted in the test and measurement world.

The team left to form SIGnology, and the era of PC-based instrumentation was born when the SP-20 FFT analyzer was introduced in 1985. Tektronix got into the FFT analyzer business when it purchased SIGnology in 1987 and relabeled the SP-20 as the 2630. Tek followed with the 2624A, a 200 kHz bandwidth FFT analyzer.

In Europe, LMS was formed in Belgium. Government support allowed a group of professors to spin-off from the Katholieke Universiteit Leuven (KUL) and form a commercial business focused upon modal analysis. They developed and marketed systems based upon their software, measurement hardware made in Holland by DIFA, and HP 1000 mini-computers running Unix.

National Instruments entered the analysis market with plug-in FFT hardware and software as part of its LabVIEW® suite of products. National made high channel-count PC-based systems affordable.

Data Physics ACE.

Former HP employees Sri Welaratna and Dave Snyder founded Data Physics in 1983. The first Data Physics product was a DOS computer-based vibration controller. In 1989, they introduced the DP 420, which consisted of a board set in the computer to process up to 16 input channels. An advantageous benefit of the design was that the same hardware could be used for analyzers and controllers, and the software suite dictated the performance characteristics of the system.

Hewlett Packard Company entered the modular analysis business with the introduction of its HP 3565S *Paragon* system. A rack of multi-channel input and source modules was controlled by an HP-9000 workstation running HP-UX (Unix) and Vista® application software. The concept proved very popular with large organizations.

Developments in the 1990s

From the early '90s a user of FFT analyzers had choices from among a number of suppliers including HP, Stanford Research, B&K, Zonic, Tektronix, CSI, Larson Davis, Data Physics, DLI, DSP Technology, LMS, Wavetek, Rockland and others.

Hewlett Packard Company introduced modular VXI multi-channel hardware, starting with the 1432A module in 1992. The concept was expanded to span from DC-88 kHz and 8 to 1000 channels using modules of 8 or 16 inputs.

LMS acquired Skalar GMBH and DIFA Measurement Systems. They ventured with HP to provide CADA-X software support for the Hewlett Packard VXI hardware.

Wavetek acquired Rockland, and eventually Nicolet Scientific. Spectral Dynamics was purchased by Scientific Atlanta. Spectral was then repurchased by a group of people who merged it with the GenRad FFT group.

Due to internal management problems and loss of market share, Wavetek Scientific ceased production during this period. Today the product line is owned by Ballantine Laboratories, which only performs repairs on these ancient systems.

Tektronix abandoned the FFT analyzer market in 1993 to concentrate on oscilloscopes. DSP Technology was bought by MTS and its FFT analyzers sold to Spectral Dynamics.

Microsoft Windows and UNIX replaced DOS operating systems in the computers utilized to process the FFT.

Dactron, founded by James Zhuge who left Data Physics, entered the market in the late '90s with FFT analyzers and vibration controllers.

The major market entries in the mid-'90s included FFTs from B&K, HP, Dactron, 01dB, LMS, Nicolet (Madison, WS), Spectral Dynamics, Oros, Ono Sokki, Zonic, Stanford Research, Data Physics, National Instruments and others.

Data Physics introduced the ACE 2-channel PCMCIA spectrum analyzer with 100 dB of dynamic range and 20 kHz of real-time bandwidth. This FFT set the standard in price/performance capability with a complete system price of $3,950.

As the decade closed, the Hewlett Packard Company was divided into two entities. Inexplicably to old-timers, the HP name went with the new PC/commodity-hardware business while the old-line instrument business was forced to re-establish itself under the trendy new name, Agilent.

Brüel & Kjaer Pulse mainframes and modules.

Spectral Dynamics Cougar.

LDS/Dactron Focus.

LMS SCADAS Mobile.

The 21st Century

Acquisitions and mergers of RTA manufacturers continued into the 21st century. Ling Dynamic Systems (LDS) purchased Dactron and Nicolet Instrument (Madison, WS). IOtech purchased Zonic, thereby adding FFTs to its data acquisition instrumentation line. PCB purchased Larson Davis.

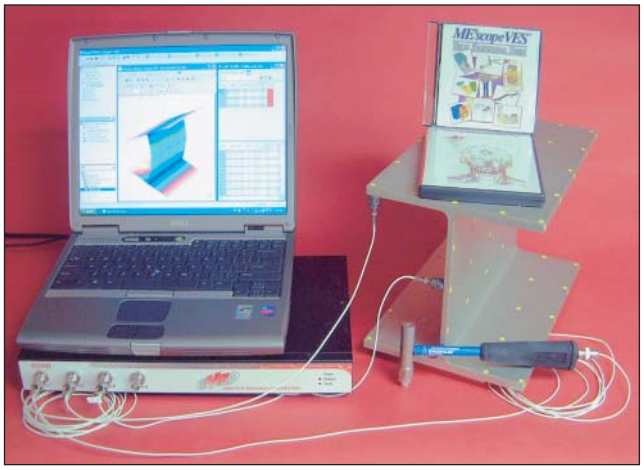
Modular multi-channel FFTs with higher real-time bandwidths (up to 100 kHz) and 24-bit digitizers supporting dynamic range of 120 dB or better dominate the market entries. Connectivity via a number of portals including USB, FireWire and Ethernet integrates computers, replacing older RS232 and IEEE488 interfaces. The inclusion of a transducer database and TEDS support for automatic entry of transducer sensitivities are also key selling features of these powerful instruments.

We have watched the progress of the PC industry refocus the RTA business. Rapid changes in popular desktop and laptop configurations have driven spectrum analyzer and vibration controller manufacturers back to the "far end of a wire." USB, Ethernet and FireWire are currently viable means of integration. ISA and PCI card formats are now antiquated and 'fat' (type III) PCMCIA modules find it hard to find a slot. In short, the instruments have been physically driven back out of the PC while the need for their tight integration with it have been enforced.

Recent software from Vibrant Technology has, perhaps, shown us where the future will really reside. Their *ME'scopeVES* application has now been outfitted with a series of acquisition options that allow hardware from 15 (list growing) different manufacturers to gather data for structural analysis. Suddenly, a broad range of equipment including signal analyzers, DAC cards, digital data recorders and vibration controllers can act as the measurement 'front-end' for modal testing and related activities. More importantly, *the operator's interface remains the same regardless of what piece of hardware is employed*. The economic implication is enormous: train your people for the application, not for the vendor's hardware selected to perform it. Wow! Look for wireless linkages to take on greater importance and plan on taking FFTs as well as pictures with your cell-phone in the not too distant future!

Personal Proclamations

The *Father of the RTA,* in my opinion, is Henry J. Bickel with strong parenting rights given to the entire Federal Scientific team. Mr. Bickel is currently the Vice President of Business Development for LeCroy Corporation.



ME'ScopeVES uses Vibration Research 8500 shaker-controller to acquire impact data.

Laurie Burrows and the crew at Spectral Dynamics had the first real insight into the role of the RTA in the mechanical testing marketplace and deserve recognition for their vision. Mr. Burrows is performing structural analysis on heaven's pearly gates and probably on a number of other heavenly bodies.

Few curmudgeons besides the author still practice in the business today. The two "old guys" I can think of who could step up to and use a time-compression real-time analyzer are Tony Keller, International Sales Manager for Spectral Dynamics and George Fox Lang, irascible Associate Editor of this magazine.

The customer group cited for recognizing the value of the RTA for solving rotating machinery problems used to gather at the E.I. Dupont Experimental Station. This since dissolved group of approximately 25 engineers included Dr. Larry Mitchell and Dave Mellon. Today, DuPont monitors the machinery signatures of its plants throughout the world in real time from Wilmington, DE. Larry Pharo and his associates at Penn State University ARL are cited for their work in submarine signature recognition and U.S. ship silencing using RTAs creatively through the '60s and '70s.

The *Capo di tutti capi* of the *Modal Mafia* will always be Dr. Dave Brown. The University of Cincinnati remains the epicenter of modal activity and Dr. Randy Allemang carries the reins of his retired associate with consummate skill.

Dr. Mark Richardson, Dave Formenti, Don Kientzy and Ken Ramsey founded Structural Measurements Systems (SMS), a company that led the way in solving structure problems by developing software supporting HP FFT analyzers. Mr. Formenti wrote the modal code for the HP 5423. Dr. Richardson invented the world's finest modal parameter curve-fitter and is currently the President of Vibrant Technology. The late Dr. Jason Lemon and Dr. Al Klosterman at SDRC are recognized for their early development of modal parameter identification utilizing swept sine methods and later with FFT-based random techniques.

The top factory RTA sales engineer was Jack Heeg who sold for Nicolet and B&K. Mr. Heeg lived in Ohio and sold throughout the Midwest for more than 25 years before losing his battle with cancer. The Spectrum Analyzer Museum at Ohio State University, developed under the direction of Dr. Donald Houser, cites Mr. Heeg as the inspiration for the project. Review the museum's offerings at www.spectrumanalyzer.org. Dr. Houser accepts "old RTA donations" to add to the Ohio State collection.

The legendary Lionel Swartz, sold numerous spectrum analyzers throughout the Midwest, especially in Motown. Lionel is named the top real-time analyzer sales representative. His arch opponent in the Detroit sales arena, Dick Merrill of Spectral Dynamics, is also recognized for his sales numbers. Dick, did you save Lionel's condolence cards from those lost orders?

Joe Cuesta, a legendary RTA sales representative for Spectral Dynamics, at one time received commissions for every GSA RTA

sale to Spectral from anywhere on the globe. B&K's Tony Schneider is recognized for his presentation ability; he made FFTs easy to understand with creative slide shows. His *Little Brown Book*, published by *Sound and Vibration* for the Case Alumni Association, is a classic.

A tip of the hat to Kathy Sullivan who showed the boys how to sell RTAs in the '70s. Kathy retired from A.T.&T. with the title of President. Gents, eat your hearts out!

Dean Dawson, a West Coast economist, salesman, analyzer repairman, philosopher and writer sold for many manufacturers. He is recognized for his unique sales and repair skills. Dean was one of the top sales producers of RTAs for more than 25 years and developed technical 'blarney' to a fine art.

Thumbs up to Ted Lisbon, the South's super FFT salesman from Atlanta, who has sold analyzers for more than 30 years. Ted started his career with B&K, hit his stride with Nicolet and is now president of Microspec, Inc. Ask Ted to tell you the story of his strong-arm tactics while retrieving an FFT for its rightful owner.

France's Jacques Perdriat deserves special mention for selling serial number one of almost everything built by Federal and Nicolet Scientific. Not only did Jacque sell superlatively, he personally repaired anything and everything that failed in France or Switzerland. England's Andy Campbell was the Nicolet U.K. manager and consummate "party animal." Who else regularly flew on the Concord, had a company boat (Nicolet Belle) or company-sponsored race horse? Dispite the "infamous fishbowl ad", Andy produced an unbelievable volume of orders from the U.K. Navy.

Charlie Jackson (Monsanto) is recognized for his seminar presentation skills describing complex rotating machinery problems in simple, easy-to-understand, language wrapped around some anatomy studies. Charlie, we want a repeat and a lengthy review of Slide #10 and Slide #20.

Hundreds of vibration analysis engineers and technicians owe a big 'thank-you' to one of the founders of IRD, Dr. Arthur Crawford. His free telephone help in solving numerous rotating machinery problems goes well beyond being a "good guy." Art, you are not only a good guy, you are also one great individual that I am proud and happy to know. The entire industry owes a 'thank-you' to Dr. Ron Eishelman founder of the Vibration Institute, to Henry and Sally Pusey and to Jack Frarey for their work with SAVIAC and MFPT.

Recognition is due his supreme editorship Jackson Krueger Mowry for his steadfast dedication to the industry publishing *Sound and Vibration* during four decades of this exciting period for RTA users. Hundreds of design, application and sales engineers owe a debt of gratitude to Jack.

Acknowledgements

Without the inputs and encouragement of these professionals this "trip down memory lane" would not be a true and accurate presentation.

- Dr. Don Houser – Ohio State University
- Reinhold Vogel – Retired Sr. V.P. Engineering of Federal and Nicolet Scientific
- George Fox Lang – former Nicolet Scientific V.P.
- Anton C. Keller – Permanent Chief Cook & Bottle Washer, Spectral Dynamics
- Dr. Susan Hough – Independent Consultant (Tektronix)
- Dr. Tom Miller – NU Laboratories

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S/V

Author's Note – Thoughts expressed in this article were initially presented as a featured paper at the 57th meeting of the Society for Machinery Failure Prevention Technology and as well at Vibration Institute Chapter meetings and meetings of other technical groups. The author may be contacted at: winwin@tellurian.com.