The Short Saga of a Long Journey

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This issue marks the beginning of the second year of the 21st Century and the 36th year of *Sound and Vibration* publication. 420 issues of this magazine have preceded this one, each attempting to capture the pulse of our business environment with clarity and integrity. The world has changed profoundly during this interval, but our dedication to this mission has remained steadfast. S&V is proud to have presented the technical fabric of our community in an even-handed manner for the past 35 years. I want to personally thank our advertisers for their unwavering support of this policy and our contributing authors for their adherence to it.

I must apologize to our overseas readers for a personal shortcoming. I am proudly an American and view the World from that perspective. We at S&V serve a worldwide community, and strive to be good citizens of that international brotherhood. Yet, our story is uniquely American and I feel compelled to tell it from that perspective.

The World Around Us

Sound and Vibration was born on a kitchen table in January of 1967. Lyndon Baines Johnson inhabited the White House and Hubert Humphrey was the Vice President. The Beatles dominated pop music and more than 500,000 Americans were ensconced in Viet Nam doing battle. This Texan's Great Society accomplished much for the betterment of man including the Civil Rights Act of 1964 and Voting Rights Act of 1965 but is also remembered for the Watts riots and the assassinations of Malcolm X, Martin Luther King and Robert F. Kennedy.

1969 saw the inauguration of Richard Milhouse Nixon and running mate Spiro Agnew. We witnessed Neil Armstrong's "one small step for man, one giant leap for mankind" upon the surface of the moon on live television. A month later, a happening closer to home occurred: the concert at Woodstock. That fall saw the birth of Sesame Street. 1970 brought us the shame of Kent State with National Guardsmen shooting students protesting the war and the syndicated joy of Monday Night Football with Cosell, Jackson and Meredith. Nixon "opened the door" to diplomatic relations with mainland China by his 1972 visit and Detente policy. Later that same year, he signed the first SALT treaty in Moscow, giving some hope that nuclear Armageddon might be avoided. Our Vice President disgraced himself regarding income tax filings and resigned under fire in 1973 being replaced by Gerald Ford. A small problem with hotel burglary and large problem with personal integrity led to Mr. Nixon's downfall in 1974. The House Judiciary Committee approved three articles of impeachment relating to Watergate; the President resigned before being brought to trial.

Gerald Rudolph Ford became the 38th President in August of 1974, the first man ever appointed rather than elected to that office. Nelson A. Rockefeller was named to the Vice Presidency. Issuing a full and unconditional pardon to his predecessor proved unpopular. The press enjoyed emphasizing President Ford's awkward moments, both verbal and physical. Mr. Ford's luck with women soured in 1975, two of them tried to shoot him. Lynette 'Squeaky' Fromme never got off a shot and Sara Jane Moore proved a poor marksperson seventeen days later. 1976 was our bicentennial year. Viking I landed on Mars, Legionnaire's disease erupted in Philadelphia, Pol Pot became Prime Minister of Cambodia and Israeli commandos raided Entebbe (Uganda) airport to free 130 hostages of an airline highjacking.

James Earl Carter and running mate Walter Mondale took office in 1977. A soft-spoken former Georgia peanut farmer, Annapolis graduate and nuclear submarine Engineering Officer, Jimmy Carter was an 'outsider' in Washington. Some have rated his Presidency ineffective. His tireless effort to achieve the Camp Davis Accords was a real step towards peace in the mid-East, terminating in a handshake between Anwar el-Sadat and Menachem Begin. His attempt to extract 52 hostages from Tehran after Islamic revolutionaries led by Ayahtollah Ruhollah Khomeini toppled Shah Pahlevi's Iranian government was less successful. Diplomacy failed as did a helicopter rescue raid; eight soldiers died. Mr. Carter withdrew his SALT II proposal when the Soviets invaded Afghanistan in December of 1979. He halted US grain shipments to Russia and organized an international boycott of the 1980 Olympic games in Moscow. We watched Roots, Studio 54 became the "in place." Elvis died, the Apple II computer was launched, Three Mile Island nuclear plant had a little trouble with its plumbing, Miami suffered major race riots following the Arthur McDuffie beating and singer John Lennon was shot to death outside his New York apartment.

In 1981 Ronald Reagan entered the White House with George Bush as his number two. The ailing economy appeared to do an amazing recovery under 'Reaganomics.' Later we would recognize this repair as severe deficit spending. The Gipper became known as "The Great Communicator" and enjoyed immense personal popularity during both of his terms. (But not with John Hinckley who shot and wounded the President and three others in March of 1981.) His second term was marred by the Iran-Contra scandal that introduced us to the "mute Marine," Oliver North. MTV was born and we all began watching music, Sony and Phillips launched the audio CD, AIDS entered our vocabulary, space shuttle Challenger slipped the surly bonds of Earth and exploded before our eyes, Ivan Boesky paid a $100,000 fine for insider trading, the stock market hit an all-time high then two months later dropped over 500 points in a day, we settled back to read *The Bonfire of the Vanities*.

George Bush took the reins as our 41st President in 1989 and Dan Quayle took up Vice Presidential residence at the Naval Observatory. President Bush exhibited a quiet and polished demeanor, reflecting the roots of his New England upbringing (bathed in Texas oil). President Bush was left-handed, a decorated war hero, a true horseshoe aficionado, a former state Representative, a broccoli hater, US Ambassador to the UN and past CIA Director. He was the first sitting VP ever elected to the Presidency. He weathered the 1989 Savings-and-Loan Scandal and committed 166 billion public dollars to pay off depositors of failed institutions. His "read my lips – no new taxes" pledge was broken when Congress insisted on starting to pay down the national deficit. Mr. Bush led us during the Persian Gulf War of 1991. We watched Operation Desert Storm from opening act to finale in "real-time" on our television sets. The Exxon Valdez was holed off the coast of Alaska, a 7.1 Richter earthquake struck San Francisco destroying bridges and roads, some of us watched The Civil War, others The Simpsons, devoutly heterosexual Earvin 'Magic' Johnson announced he was HIV positive.

William Jefferson Clinton and Alfred Gore (and Tipper, too!) came to Washington in 1993. We were introduced to the short-lived expression, Copresident, while Hillary Rodham Clinton made an unsuccessful bid to rectify the shortcomings of our national medical care system. "Don't ask, don't tell" entered the Federal lexicon regarding gays in the military. The Israeli-Palestinian Accord was signed and war erupted in the Balkans.

Sarajevo, Bosnia, Croatia, Kosovo and Chechnya became familiar places in the news. US Embassies in Kenya and Tanzania suffered terrorist bombings. Retaliatory cruise missile strikes were made against Afghanistan and the Sudan. India detonated three nuclear weapons despite international protest and the US crime rate fell for the seventh consecutive year. Taliban Muslims captured Kabul. Mr. Clinton championed the North American Free Trade Agreement (NFTA) between the U.S., Mexico and Canada in 1993, followed by the General Agreement on Tariffs and Trade (GATT) of 1994. He ran afoul of his own glands, Dr. Lewinsky's daughter and Ken Starr leading to the indignity of becoming the second President ever impeached (the first was 17th President Andrew Johnson). Muslim extremists bombed the World Trade Center in February 1993, US astronauts successfully repaired the Hubble Space Telescope in place, O. J. Simpson was found not guilty of murder and Timothy McVeigh was sentenced to death for the Oklahoma City bombing, Boris Yeltzin was reelected, Mother Teresa, Princess Diana, King Hussein, Joe Dimaggio and JFK junior died. The Columbine High School shooting claimed 15, Unabomber Ted Kaczynski was sentenced to four life terms, Dr. Jack Kevorkian was convicted of 2nd degree murder, Ramazi Ahmed Yousof received a life sentence for his role in the 1993 WTC bombing and the FDA approved Viagra.

2001 saw George W. Bush inaugurated as the 43rd President with Richard Cheney as his Vice President, following the most contested and protracted ballot count in American history. (If I never see another "bent chad" nor hear another lawyer giving arithmetic lessons, it will be too soon!) While he entered office with a questionable mandate, our new President has earned high approval scores for his firm and considered response to terrorist threats against the nation. We continue to live in "the most interesting of times," like it or not.

What Happened in Our World?

Our technical methods and "tools of the trade" advanced significantly during the 1967 -2001 era. However, it is safe to say that the most significant contributions to our art were not the direct result of our actions. The astounding growth made in the electronics industry far overshadows the most profound contribution of any sound or vibration practitioner on the way we do our business today. Advertisements in our first issue spoke of modern fully transistorized measurement equipment. We had just broken free of the vacuum tube!

Silicon Valley then gave birth to the integrated circuit merging multiple transistors on a single silicon substrate to build entire functional modules in a small plastic package. Initial offerings were analog components starting with the operational amplifier. These were rapidly followed by families of logic "chips" performing simple Boolean operations such as AND and OR and single-bit storage in a flip-flop. Analog ICs evolved to perform major "building block" functions such as filters, demodulators and phase-locked loops. Logic ICs spawned the microprocessor and computer support functions including byte and word-width memory, read-only memory for fixed information and an endless variety of device controllers and interface components. Standard IC packaging forms evolved, giving the earliest evidence of the value of "open architecture."

Assembly of electronics became more sophisticated. Chassis and point-to-point wiring gave way to printed circuit boards that quickly evolved from phenolic to fiberglass and from single-sided artwork to two-sided. Plating processes were developed to connect the two layers using any through-hole rather than requiring a soldered component pin to accomplish this. By the 80s multi-layer laminated PCBs with ten or more layers became commonplace and completely eliminated the need for wire wrap construction, which the industry embraced temporarily for high-density applications. Component size and power requirements dropped steadily, and advances in photolithography allowed PCB line density to increase dramatically. Improved bonding and soldering techniques made surface mount components feasible, reducing the volume of ICs dramatically.

The digital computer of 1967 was a major corporate investment and was used by relatively few engineers on a routine basis. (Remember punch cards?) Most of us still relied on slide rules for personal calculation; a good desktop calculator might have a square-root key. Mini-computers evolved (remember paper tape and keying in the 'bootstrap' on switches?), better shared use of large systems came about (remember the first time you worked on a CRT instead of a teletype?) and good technical calculators came to fit our pockets (remember those RPN lectures from a proud HP-35 owner?).

A relentless and successful effort throughout the interval placed a personal computer in every office by 1980 and in everyone's home and briefcase by 2000. Add-in hardware made these affordable computers useful test tools as well as potent analysis platforms. Combining both of these capabilities in a formidable communication system has had a profoundly positive effect on the way we now work and think.

What Happened to Us?

In 1967 the Nastran manuals filled a four-foot bookshelf. Yet this formidable code was virtually useless for dynamic problems. Finite Element analysis was used exclusively for static analysis of structures. Vibration analysts spoke in matrices and concentrated on lumped-mass systems, normally without damping. Real-time simulations were run on analog computers and the digital 'wannabes' (CSMP, Mimic) ran so far out of real-time as to be impractical.

Acoustic studies were performed with swept-filter octave and 1/3 octave analyzers. The General Radio 1564 was typical. It had a big filter-tuning knob on the front of it, with a sprocket. It sat on top of a special chart recorder that put out special paper containing a log frequency axis. It connected to the analyzer via a chain and sprocket. You lined up the paper to 10 Hz, set the filter to 10 Hz, threw in the clutch, and allowed the strip chart motor to drive both the paper and the analyzer's frequency knob. It took 5 minutes to go from 10 Hz to 10 kHz.

Structural properties were measured using sinusoidal excitation (or the best approximation to this we could muster!) analyzed by tracking filters and co-quad meters. Results were typically plotted on a Mosley X-Y recorder using fluid ink on pre-gridded paper. A great test was one where the ink flowed properly for the entire (really long!) sweep duration and the control system remained stable around resonances so that ink was not 'buzzed' on everyone in the area!

Random vibration testing was used solely for environmental shake-and-bake activities. While there were "control" systems, they really weren't! Random testing was done using manually adjusted banks of "shaping filters" and the strong faith that something once done could be repeated . . . this often proved elusive!

Analysis and Test were two very disparate activities and the practitioners of one art almost seemed proud of their ignorance of the other. Mechanical and electrical engineers suffered great difficulty in simply talking to one another about problems they could readily solve in congress. Companies tended to organize their Engineering departments to emphasize this schism and universities did a poor job of producing test-oriented S&V practitioners.

Clearly, our world has changed and for the better. Modern technical education has changed profoundly. A Mechanical Engineering student is now introduced to electronic measurement techniques through meaningful laboratory experience. Digital Signal Processing has become an integral part of the mechanical curriculum. Most importantly, the fundamental need for test-verified analytic models is now stressed and demonstrated. What were once viewed as disparate activities are now taught as part of the continuum of practice. Today's graduate is better rounded and prepared, thanks to the persistent efforts of those professors, young in 1967, who waged a hard battle to revise our preparation for industry. Thanks are also due the fore-

sighted instrument industry, many members of which have financially supported this revolution through equipment donations and research support.

Clearly, the evolution of the Digital Signal Analyzer has had a profound impact on our profession and our profession has had an echoing impact on the development of the DSA. FFT analysis has aided the progress of structural understanding and design optimization. In the short lifetime of this magazine, we have learned how to measure and display animated three-dimensional mode shape 'movies' as a matter of routine. We can deduce natural frequencies, damping factors and shapes from tests using impact, random or sine excitation with equal ease. More importantly, we now use such observations to systematically update Finite Element (and other) design models. We use the 'as-tested' results to forecast the results of Structural Modification, aiding the design refinement cycle. Most of us will remember landmark offerings by Time Data, Hewlett-Packard, Spectral Dynamics, Nicolet, Brüel and Kjær, Data Physics, GenRad, SDRC and SMS.

Acoustic studies have progressed from pressure to power to intensity analysis. In 1967 we masked an objectionably loud structure in a semi-anechoic chamber and exposed one small area at a time while measuring the resulting sound pressure at a reference point. Eventually, the dominant radiation path was identified for subsequent treatment. Today, we simply map the vector intensity of radiated sound using dedicated probes and digital processing with real-time results in 3D color plots. The non-linear metrics of sound pressure and power are now measured routinely with full statistical reports. Octave and 1/3 octave results are easily obtained from portable equipment.

Basic sensors have improved tremendously. When *Sound and Vibration* started publishing, charge-mode piezoelectric sensors dominated the field of vibration sensing. In the late 1960s, low impedance piezoelectric vibration sensors with built-in isolation amplifiers were introduced. These sensors eliminated the need for expensive charge amplifiers and troublesome high impedance signal cables. The first of many patents issued for such devices went to David Packard of Hewlett-Packard fame. He claimed a charge generating crystal mated to an insulated-gate field effect transistor called a MOSFET. PCB and Kistler championed this technology and brought it to market dominance.

When DC acceleration response was required, a servo accelerometer was the only 1967 answer. Today we can employ inexpensive capacitance accelerometers at a fraction of the price in a smaller, more robust package. In like manner, many lower precision sound measurements may now be relegated to inexpensive electret microphones, which eliminate the high voltage source of precision capacitor microphones. The operating boundaries of precision capacitor microphone have been vastly improved and the number of NIST qualified sources has broadened.

PCB pioneered the mating of a force sensor with a hammer for modal testing and the University of Cincinnati aided them in refining the concept and championing the application. Today's modal practitioner has a variety of such impact sensors on hand, ranging from micro-tappers to small sledgehammers. Impulse testing has become the de facto approach to *in-situ* modal testing and quality hammers are offered by PCB, Kistler, Dytran and others.

Kistler draws my personal admiration for incorporating rotational accelerometers in its line of structural analysis accelerometers. It is clear that we must understand rotations as well as translations of a structure to predict its behavior with accuracy. The world still needs a driving-point sensor capable of detecting all of the moments as well as forces at a structural drive site. When we look at the 36 input/output relationships between any two points, our ability to measure angular motion has been a significant liability. The remaining big problem is to be able to properly measure moments. Once this is overcome, precise structural modification analysis will become a reality.

'Smart' sensors entered our lexicon within the interval. Initially championed by Vibrometrics, these sensors operate on a two-wire network and permit sensor addressing and information recall from an integral Transducer Electronic Data-Sheet (TEDS). Smart sensors are redefining the way we monitor in-place machinery and conduct structural examinations. Endevco, B&K and PCB all offer sensors in this arena.

Wireless transduction is on the verge of being a commercial reality. Bluetooth sensors will not be an indication of a need for a dental visit; they will be the invitation to instrument a facility without stringing cables. Once this new interface is mated with a piezo crystal's natural ability to generate a small amount of power from its dynamic environment, the dream of sprinkling sensors then harvesting their output remotely will become a reality.

The laser has become a guiding light in our business. Inexpensive coherent light allows non-contacting displacement measurement of incredible resolution without magnetic interference. It has also paved the way to field visualization of vibration patterns. We are dangerously close to owning that "magic lens" that lets you view the mode shapes of a structure in operation. This guiding light has also opened new vistas in detecting torsion vibration of operating shafts.

New sensors, new instruments and new thinking are now moving us from a scalar/vector understanding of sound and vibration phenomena to an era of three dimensional understanding involving total motion, forces, moments and waves. A six-axis motion calibrator using redundant sensors and computed spatial averaging was recently announced. Arbitrary transducer placement may now be measured using a fixed array of fast pressure sensors, a mobile spark generator and computer triangulation.

Still, we must remember that engineering is a practical business. We will always be called upon to accomplish what is just slightly out of technical reach. Those who will flourish in the S&V field will maintain a clear insight of the basic physics involved while others surrounding them will be awash in the "whiz-bang" of the latest tools. An old friend reminded me of how well we were able to do a few things in the dark ages of the late 20th Century: A 3D force transducer, with less than 1% crosstalk, was made out of a rusty horseshoe. Filling the cabin of a self-propelled howitzer with helium-filled balloons properly identified an acoustic standing mode.

My thanks to Ken McConnell, Steve Goldman, Ralph Hillquist, Raj Singh, Bob Lally, Chris Powell and Susan Hough for their help with this missive. One of the best things about my 35 years in the S&V business has been the great people I have met sharing the harness. Old friends are reliable and *Sound and Vibration* has introduced me to some of the best friends I have ever had.