cover story

Garage Gives Birth To Measurement Giant

The story of Hewlett-Packard Co., and subsequently Agilent Technologies, is a capsule history of test-and-measurement techniques and equipment for the microwave industry.

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Beginning in 1939 with only $538—an amount that today barely covers a month's electric bill in Palo Alto, CA—Bill Hewlett and Dave Packard started a company in the garage behind the home they shared at 367 Addison Rd. These two Stanford University graduates were responsible not only for starting a test-and-measurement technological revolution, but for a business philosophy that has been taken to heart by Silicon Valley's most accomplished companies.

And it is comforting to remember that RF and microwave technology was HP's primary driver for more than 25 years, and that this technology and the HP philosophy live on today, in the form of Agilent Technologies.

The story of HP's foray into microwave technology, and the development of its RF and microwave products have been chronicled less frequently than the story of how Walt Disney provided the company with its first big boost by ordering eight of its model 200B audio oscillators for use in the film *Fantasia*. Or the story of how Packard created "management by walking around," or even the story of the role played by Stanford professor Frederick Terman in shaping the "HP Way" and his vision of an electronics industry knowledge center in the Valley. Nevertheless, that foray and its subsequent developments were every bit as important for the US economy, for the tens of thousands of people who participated in them, and for what the microwave industry has become today.

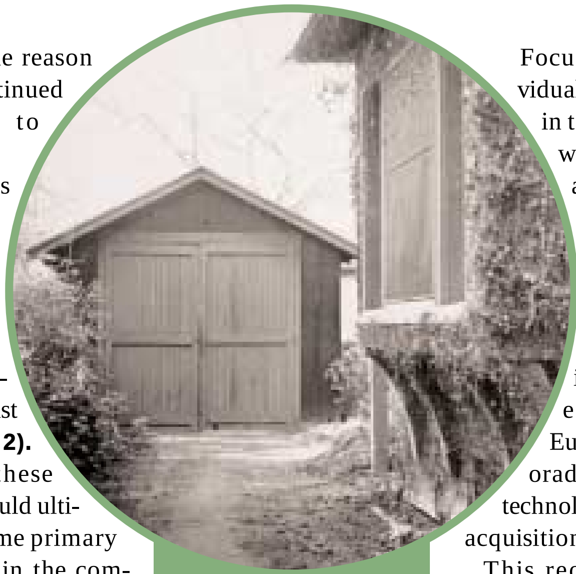
The company's entry into the RF and microwave instrumentation marketplace came about gradually. Soon after the company's founding in 1939 **(Fig. 1),** Hewlett entered the US Army Signal Corps for technical assignments in radar at Ft. Monmouth, NJ. Packard remained in Palo Alto, managing the fledgling company and its wartime production operation. The company's entire product line consisted of the 200A audio oscillator, the 400A voltmeter, an audio signal analyzer, and some crystal-stabilized frequency standards.

The company produced its first RF measurement product in 1943. The Model A signal generator covered 500 to 1350 MHz, and was designed for the US Navy. A commercial version, the 610A ultra-high-frequency (UHF) signal generator, was introduced in 1948. In the late 1940s, Varian Associates, founded in Palo Alto by Russell and Sigurd Varian, inventors of the klystron tube, offered HP a small line of waveguide test equipment. The Varian brothers felt that development of the line would detract from their tube business. The product line consisted of some waveguide slotted lines and other components such as directional couplers.

In the same period, the US Naval Research Laboratory contracted with HP to design klystron signal generators, which led to a commercial product, the 616A signal generator, with coverage to 4.2 GHz. It was followed by generators working to 21 GHz.

By 1950, the product line had grown to include the 430A power meter and a double-tuned 475 bolometer sensor. Other innovations expanded the HP line of coaxial equipment, such as the 805A "parallel-slab" slotted line, which cleverly constrained the RF fields mostly at the side walls, and effectively made the 3/4-in. (1.91-cm) open-slot function as a slot only a few thousands of an inch wide.

Part of the reason for HP's continued attention to microwave research was Hewlett's recruiting of several engineers from wartime research facilities on the East Coast **(Fig. 2).** Several of these engineers would ultimately become primary participants in the company's future. Bruce Wholey, who later advanced to Microwave Division Manager in 1962, came from Terman's Radio Research Lab at Harvard, working in electronics countermeasures. Art Fong had been working in radar at MIT's Radiation Lab.



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1. The starting place for a multibillion-dollar international company was a simple garage in Palo Alto.

From the early days of thermistor power sensors, HP heeded the cry for a thermistor sensor that would not respond to the warmth of the human hand, introducing the 431A temperature-compensated power meter in 1961.

When Hewlett was setting up European distribution for this product, he bought the patent rights to a novel noise-figure measurement concept from the Swedish company Magnetic AB. This led, in 1958, to the 340A noise-figure meter. Later, the 524B frequency counter, with its plug-in versatility, launched HP into the frequency and time business.

By the mid 1950s, the proliferation of product lines was creating problems in managing different product and business strategies. To provide more specialization, the corporate research-and-development (R&D) lab was divided in 1958 into four product groups: audio-video, frequency and time, microwave, and oscilloscopes. Total worldwide business in 1959 was $47.7 million, and HP's 165-page catalog that year boasted 150 products.

Focusing on individual product lines in the design labs worked well, and by 1962 the company's sales had grown to $109 million. Manufacturing operations expanded to Europe and Colorado, and several technology-company acquisitions were made.

This reorganization continued in 1962, as the four major product lines became full operating divisions, of which the microwave division was one. Bruce Wholey was named general manager, but soon acquired other responsibilities.

In 1964, John Young became division manager of the microwave division, and filled out his management team with John Doyle in manufacturing and Paul Ely in R&D. John Minck became marketing manager. Ely was already known for his microwave management experience at Sperry Microwave in Florida. Young managed the Microwave Division for approximately six years, and then progressed through various vice-presidential positions to become the company's CEO in the 1980s.

The Microwave Division hit its stride in the 1960s, and its new product lines changed the face of microwave measurements. In 1964, the Model 8551 spectrum analyzer put HP into the spectrum-analyzer market and, in the process, expanded the market five-fold, since it made measurements in ranges that previous analyzers could not reach.

In 1968, the 8410 vector-network-analyzer (VNA) product line revolutionized microwave-component design with the concept of characterizing the scattering parameters of test devices. The project's slogan was "stamp out slotted lines." Major accomplishments

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were also made in signal generators, sweepers, power meters, and measurement components.

A crucial element of HP's success was a management innovation started by the Microwave Division in the mid-1960s. This was the now well-accepted "triad" management concept, which focused three-person teams from marketing, R&D, and production-on-product planning. Those product teams, consisting of young engineers, devised product strategies based on their combined knowledge of the market, applications, and technology, and then presented the strategy to division management for approval.

This approach contrasted with the strategy of many companies of that time, which created product plans from a central planning group. The genius of the arrangement was that the best creative ability of all team members was used, while also employing the insight of the company's marketing and business upper management during the reviews. Many of those young team members of the 1960s went on to become division and executive managers throughout the corporation.

HP has contributed heavily to the development of new technologies, most of which have found their way into the company's products. The step-recovery diode was one of HP's more important contributions to signal synthesis. In the early 1960s, engineer Frank Boff was working on harmonic-comb generators to extend the range of counter frequency converters. One circuit showed nonintuitive results, with high-frequency harmonics that were more powerful than what seemed theoretically possible from a nonlinear resistive device such as a diode.

To investigate further, he borrowed an early lab prototype of the HP sampling oscilloscope to display a time-domain picture of what was producing such rich signals in the frequency-domain. When Boff finally got the fuzzy picture focused, he did not see the expected chopped-off top of a sine wave produced by a diode, but rather, he saw a sine wave that rose smoothly to approximately full amplitude, then suddenly crashed to near-zero amplitude.

At that point, serendipity entered the scene. Boff remembered seeing a paper in the *IEEE Proceedings* which theorized that this waveform might exist if a device exhibited a nonlinear charge-versus-voltage curve instead of the nonlinear current-versus-voltage curve that defined a diode. Boff reviewed the article, looked again at the strange wave shape, and proclaimed that what he had taken to be a nonlinear resistor or diode was actually a nonlinear capacitor under certain conditions.

What he had developed was a variation of the well-known P-N diode that enhanced the stored carrier phenomenon and achieved an abrupt transition from reverse-storage conduction to cutoff. The device was able to switch tens of volts or hundreds of milliamps in less than a nanosecond. The result was the ability to generate milliwatts of harmonic power at 10 GHz from stable oscillators running at 200 MHz. The device was called the "Boff diode" for a number of years, and later changed to the more generic "step-recovery-diode."

HP capitalized on this new capability. HP counters used the harmonic-comb signals to downconvert test signals for counter coverage to 18 GHz. The 8410 series network analyzer used a two-channel version to downconvert microwave signals for characterizing S-parameters to 18 GHz. Sampling oscilloscopes used the diode to generate the large sampling impulses needed to measure transitions in the picosecond range. A generation of HP signal generators and sweepers used those harmonics to stabilize microwave signals, via indirect frequency synthesis.

HP also became the world leader in exploiting a family of sophisticated feedback loops, using synthesis techniques such as programmable "divide-by-N" loops. Not only did they discipline microwave oscillators and reduce their phase noise, they provided exact and programmable output frequencies.

Another variation of the P-N diode was the PIN version, which acted at low frequencies like a regular diode, but at RF/microwave frequencies similar to a programmable microwave resistor. This became the centerpoint for broadband control of signal amplitudes for leveling loops, and for a pulse generator with nanosecond rise and fall times.

HP also pioneered the development of sophisticated phase-locked loops (PLLs), which were optimized for fast switching, high stability, and spectral purity for extremely-low single-sideband (SSB) phase noise. It was a never-ending quest, and HP later designed specific instruments for characterizing SSB phase noise, as well as analysis of loop gain and stability.

2. The founders of Hewlett-Packard Co., Dave Packard (seated) and Bill Hewlett, worked with very little operating capital but quickly built a giant test and measurement business.

The 40-year history of *Microwaves & RF* magazine coincides with a period of enormous advancement in test and measurement. The contributions of HP were large and broad, as were the contributions of the people who brought them to fruition.

The distinction between signal generators, sources, and sweepers (or swept-signal generators) always seemed to confuse customers. Signal generators were intended for signal simulation, carrying modulation such as amplitude modulation (AM)/frequency modulation (FM)/pulse, and later phase and digital modulation. Later, in wireless test sets, the modulation would include the entire system of handshakes, protocols, and other functions. In contrast, sources were pure continuous-wave (CW) oscillators, generally without modulation, used for general-purpose and bridge drivers. Sweepers allowed the signal to be swept over a range of frequencies, and have been dominant in component design. In recent decades, with the power of microprocessors, the distinction between the basic types blurred as instruments were created that could perform multiple tasks.

Probably the most popular signal generator of the 1950s and 1960s was the 608C/D family. HP built tens of thousands of these very-high-frequency (VHF) instruments, and their vacuum-tube oscillators and power amplifiers (PAs) provided superior spectral purity and stability. Their semiconductor replacements, the 8640A/B of 1973, had cavity purity, with phase locking and a frequency counter.

What went unsaid was the superiority of vacuum tubes, including klystrons, for signal generation. The oscillator voltages of those tuned tank circuits or cavities provided outstanding signal-to-noise characteristics that took years for solid-state generators to match. Yet, the operating advantages of microwave transistors and yttrium-iron-garnet (YIG)-tuned oscillators in reliability and size were too much to resist, and after much development, methods such as phase-locking greatly improved spectral purity.

In its transition into synthesizer technology, HP found a way to stabilize PLLs with a VHF instrument, the 8708A. It was used to discipline and add narrowband FM to the 608E/F. However, the first integrated indirect synthesized signal generator was the 8660A unveiled in 1971, with versatile plug-ins that allowed its owner to choose from many modulation formats and frequency bands to 2.6 GHz. It was also programmable. The microwave synthesizer that revolutionized automated test systems with its general-purpose -interface-bus (GPIB) programming bus was the 8672A. Introduced in 1977, it covered 2 to 18 GHz.

Continuing developments yielded products such as Agilent ESG-series of digital signal generators, which generate the most complex modulation formats used in modern communications systems, including Global System for Mobile Communications (GSM), code-division multiple access (CDMA), time-division multiple access (TDMA), Digital European Cordless Telecommunications (DECT), Enhanced Data rates for Global Evolution (EDGE), as well as broadband in-phase/quadrature (I/Q) modulation.

The Model 5100A frequency synthesizer introduced in 1964 was developed in response to the US Navy's need for a fast-switching, direct-synthesized, high-resolution signal source for secure communications. The product covered DC to 50 MHz with a resolution of 0.01 Hz and crystal frequency stability of one part in 10^{10}.

The emergence of high-frequency digital circuits provided HP with the tools to create powerful digital-direct-synthesis (DDS) generator technology for use in secure communications. The Model 8770A arbitrary waveform synthesizer in 1988 created completely arbitrary waveforms from DC to 50 MHz using a fast digital-to-analog converter (DAC). This frequency-agile technology made it possible to hop from one frequency to another in 8 ns, the time that is required to move to a different sequence. Next, came fixed upconverters that could translate this 50-MHz band to microwave frequencies.

In 1991, the Model 8791A frequency-agile signal simulator (FASS) added frequency-agile upconverters that achieved a typical 100-ns agility to 18 GHz. In addition to impressive carrier agility, FASS used a special waveform-generation language that allowed users to program wide-bandwidth modulation of arbitrary formats such as nonlinear chirps, TDMA, and CDMA. These powerful simulators were able to recreate entire channels of signals, noise, and interference, providing real-life signal environments for the qualification of receivers (Rxs).

3. HP's first spectrum analyzer in 1964, Model 8551/851A, became a frequency-domain oscilloscope, indispensable for RF and microwave workbenches.

As source technology moved from the backward-wave oscillators (BWOs) of the 1960s to solid-state YIG oscillators, sweepers for the more advanced network analyzers had to be programmable, as well as frequency repeatable, so that data-correction routines could be ensured. To do this, synthesized sweepers were required.

Synthesized signal generators were also required for automatic test systems that were designed to evaluate electronic-warfare (EW) Rxs. These tests required simulated modulations and programmable test frequencies. Landmark sweepers such as the 8340A and, more recently, the Agilent 8360, packed remarkable functionality into user-friendly packages.

Wholey launched HP into the spectrum-analyzer market in 1964, partly driven by pressure from field sales engineers who were looking for a new market area. The business was dominated by the Polarad Co. (Long Island City, NY), which was a prime contractor for military analyzers. They mostly used single-band, tunable klystrons as the first local oscillator (LO), with a sweeping second LO for 100-MHz sweep width (dispersion, in the jargon of the day). The Panoramic Co., also on Long Island, was soon building a multi-band unit, capable of 2 to 12 GHz, downconverted with harmonics of the first LO.

The project engineer assigned to the HP analyzer was Fong, whose experience at MIT had involved signal generators and spectrum analyzers, including waveguide components. By designing a sweeping first LO using a BWO for the source, it was possible to provide a sweep width of 2 GHz. The BWO used a tracking, phase-locked, VHF sweeping oscillator in the narrowband mode that quieted the noise of the BWO tube.

The prototype of the first HP spectrum analyzer, the Model 8551/851A **(Fig. 3),** was first shown to key customers during the 1963 IEEE show in New York City, in a private suite in the Essex House Hotel. The unit was draped with a tablecloth to conceal the powerful fan connected to a laundry dryer hose that piped cool air to the bulky circuitry. The customers left impressed—and HP had a year before the launch date to work out any problems. One year later, production units were on display at the IEEE show in the New York Coliseum. Within the first year of production, HP sold more than 75 a month, and it soon became the company's first \$1 million-a-month product.

The performance of this product was demonstrated by application engineer Lyle Jevons, who uncovered an interesting application at Edwards AFB, approximately 50 miles north of Los Angeles. The problem faced by the Air Force was that three long-range S-band surveillance radars operated by National Aeronautics and Space Administration (NASA), the Air Force, and the Federal Aviation Administration (FAA) that were located on mountain peaks in the area interfered with each other. The colonel's job was to sort out the signals.

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To help, Jevons, accompanied by the US Air Force colonel who was the frequency-control officer at Edwards, parked alongside a phone booth at a desert intersection north of the base, where they could monitor the signals and the colonel could call his radar technicians.

The Model 8551, with its broad 2-GHz sweep, could experience all of the signals at once, and its 60-dB dynamic range also identified the sidelobes that overlapped each other. The colonel stepped into the phone booth, called each radar technician, and quickly unsorted the signals. Jevons reported that the colonel offered him $100,000 to keep the analyzer.

It was little wonder that this instrument was soon merchandised as a "frequency-domain oscilloscope," since it could display baseband frequencies from 10 to 2000 MHz, and it became an indispensable instrument for RF and microwave engineers. In succeeding generations, smaller size, absolute amplitude calibration, and innovative features such as tracking generators made frequency-response measurements simpler. Solid-state LOs made the products more stable, reliable, and portable.

The 8566 and 8568 spectrum analyzers of the late 1970s were a new generation of instruments that took advantage of microprocessors—and each employed three. These analyzers had better frequency-tuning accuracy, narrower resolution, lower phase noise, and better phase-lock stability.

Their most impressive feature was their human interface. These were among the first instruments with a lower panel that looked like a calculator keyboard. A single rotary knob provided a selectable analog feel for tuning, but the keyboard offered digital precision. More important, they offered powerful onboard signal data computation.

A fellowship grant made to Al Bagley, a young graduate student at Stanford University in 1948, led to the development of HP's frequency-counter business. Hewlett and Packard personally asked Bagley to study the measurement needs of the nuclear-physics industry. From that study came requirements for a faster nuclear-pulse-counting technology that could resolve two nuclear events only 0.1 ms apart. Bagley determined that new, low-capacitance semiconductor diodes might enable faster digital circuitry. He built a prototype for the project—and asked for a job at HP.

From that work came the model 520A high-speed decimal scaler, which was able to condition very short nuclear pulses occurring at up to 10 MHz, and to divide down by factors of 10 or 100. Although the 520A had only minimal commercial success, Hewlett envisioned a different measurement process that gated those scaled-down, high-speed pulses into a slower-speed accumulator (counter). Thus, the frequency counter was born.

Frequency counters were a huge commercial success and in great demand from the 1950s onward. They were used to measure everything from transmitter (Tx) frequencies to the accelerometers on which ballistic missile-guidance systems were based. HP became the industry leader in electronic counting in the early 1950s with the 524A frequency counter, which boasted a 0.01-Hz-to-10-MHz measuring range.

In 1954, plug-in downconverters were introduced as the model 524B electronic counter. Plug-ins eventually extended the measurement range to 18 GHz after the introduction of the step-recovery-junction diode.

RF-interference (RFI)-measuring Rxs of the 1970s were generally mechanically tuned and cumbersome. By modifying some early spectrum analyzers, HP was able to enhance the RFI measurement technology with the addition of common antennas and probes. The 85650A quasi-peak adapter (circa 1982) was an early example of an instrument which, when added to spectrum analyzers, provided a broad electronic sweep capability and offered the designer a wide bandwidth in which to search for leakage signals. It also provided precise, calibrated data.

The earliest power-measuring techniques were primitive by today's standards. The story has been told that Russell Varian cleverly drilled a small hole at the appropriate position in the klystron cavity wall and positioned a fluorescent screen alongside it. The screw provided a gross indication that the cavity was in oscillation.

A major improvement to this measurement technology was made in 1961, when the 431A power meter, with a dual-thermistor design to reduce drift 100-fold, could measure power levels as low as 1 μW. The 478/86A line of power sensors covered 100 kHz to 40 GHz, and later to 110 GHz.

The next big step in microwave power measurement came in 1974 with the introduction of the Model 435A power meter and its associated power-sensor family. This sensor family was a clever exploitation of a silicon (Si)-chip fabrication process that placed a broadband microwave termination on one side of a thin Si web, and a sensitive metallic thermopile on the opposite side. The meter measured the absorbed heat down to 3 μW and up to 20 mW. Since the sensor was a true heat-sensing device, it provided "square-law" linear response over its entire range.

In 1997, the latest family of power meters and sensors was introduced. The Agilent EPM-series power meters took advantage of new ultra-wide-dynamic-range sensors (the E-series power sensors), to measure from −70 to +20 dBm in a single sensor.

The 185A and 187A sampling oscilloscopes (circa 1960) were giant leaps ahead in RF and digital measurements. Using sampling technology, they permitted engineers to measure exceedingly fast transition times for repetitive, pulsed waveforms. They featured sophisticated triggering circuitry for viewing actual RF waveforms to 1 GHz.

The ability to view the time-separated reflections from a coaxial transmission structure enabled engineers to diagnose reflections from individual elements. For example, the individual attenuation elements of the model 355A VHF attenuator could be seen and each tweaked for exact 50-Ω performance. If all were lumped together in a standing-wave-ratio (SWR) measurement, no corrective adjustments could be made. The advancement helped circuit engineers working on components that relied heavily on coaxial and stripline transmission structures.

Picture a mechanical, motor-driven klystron signal source, driving two back-to-back directional couplers, two diode detectors, and a 1-kHz ratio meter. This was the state of reflectometers in 1954. Scalar parameters were considered entirely adequate for production-line test assurance, and these analyzers measured SWR and reflection coefficient, as well as transmission parameters. Systems were developed for waveguide bands from 2.6 to 40 GHz, and for most coaxial bands.

Next came the 890-series sweep oscillators, which exploited BWOs for signal generation, making the sweep electronic. This led to oscilloscope displays with calibrations grease-penciled onto the cathode-ray-tube (CRT) screen. The 1416A SWR display (circa 1966) offerd a scope plug-in with calibrated reflection and transmission data.

ABOUT THE AUTHORS

John L. Minck joined Hewlett-Packard Co. in 1958 and retired in 1995, enjoying a rich 37-year career with the company. He held technical-marketing assignments, mostly in microwave areas, and was RF and microwave marketing-communications manager for several decades. In the early 1970s, Minck managed a venture product group that designed and introduced light-emitting diodes (LEDs) to the market, contributing LEDs to HP's first Model HP-35 pocket calculator. Since 1972, Minck has been active with NCSL International, a trade association, with interest in metrology and calibration issues. He was National President of NCSLI for 1977, and since 1979 has been editor of the organization's NCSLI Newsletter. Minck lives in Palo Alto, CA, with Jane, his wife of 45 years. He has three grown children.

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Other families of sweep oscillators followed, with the 8690 series and eventually the 8620A series (circa 1970), which featured solid-state YIG oscillator sources for the first time. HP's microwave-component research labs contributed coupling microwave transistors with YIG technology to yield exceptionally stable and high-power sources. Later came the 8350- and 8340-series signal sources.

HP continued to introduce new RF and microwave scalar analyzers, starting with the 8755 frequency-response measuring system of 1972. This was a plug-in for the 180-oscilloscope family, which was specifically designed as a system for scalar parameter testing. The 8756A and 8757A scalar network analyzers followed in turn, each with more measuring capability and higher frequency ranges, ultimately reaching 60 GHz in 1985.

Following 1967's two-channel 8405A vector voltmeter, the 8410A VNA in 1968 revolutionized the characterization of microwave components from 10 MHz to 12 GHz, and soon to 18 GHz **(Fig. 4)**. With its swept microwave source and signal-separation test sets, it easily exceeded its original objective—to stamp out slotted lines. Before this, engineers had to use tedious slotted-line measurements to compute a Smith chart plot, frequency by frequency.

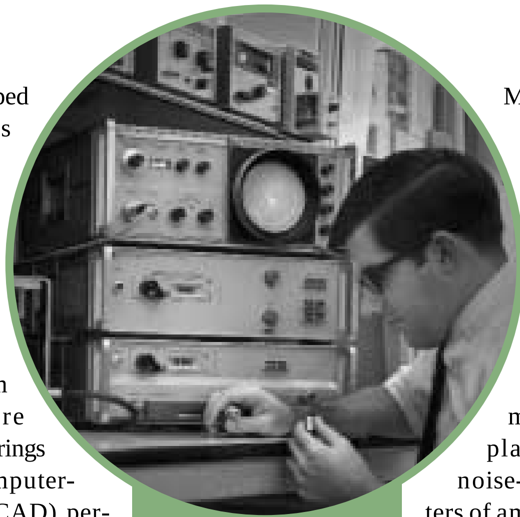
The availability of the VNA popularized the design concept of scattering parameters: characterization data in complex impedance format for two-port and N-port microwave components. Provided with actual Smith-chart oscilloscope displays or phase-gain plots versus frequency, component designers gained powerful insights into their circuitry. In the microwave semiconductor revolution of the 1970s, designers raced to develop thin-film-on-sapphire integrated-circuit (IC) technology to combine the power of microwave transistors with a variety of circuit elements, including directional couplers, filters, mixers, converters, terminations, and lumped-circuit components such as inductors and capacitors.

The 8510A network analyzer of 1985 built on the tremendous insight that component design engineers first realized with the 8410A. Combining the new power of the microprocessor with the earlier analyzer's extensive capability for characterizing components and systems, the 8510A launched a revolution. For example, it could process frequency-domain data and render a time-domain characteristic of the signal passing through a complex subsystem on a chip.

Agilent's latest network-analyzer family, the PNA series, is built on the legacy of the 8510 family. However, these are totally new products, and some of the first to truly take the integration of microprocessor and microwave instrument to its highest level. They employ the Windows 2000 Professional operating system that brings the full complement of personal-computer (PC) and networking capabilities to the world of microwave instruments, and employ powerful digital signal processing (DSP) to implement 160 digital resolution bandwidth filters.

The measurement capability provided by the 8510T network-analyzer system was combined with RF and microwave circuit-design modeling software. This process provided the verification feedback needed to confirm that circuits and fabrications worked according to the design model. EEsof (later acquired by HP) and pioneers such as Les Besser, then with Super-Compact, delivered sophisticated microwave circuit-design models that have never stopped improving. As new computing power became available, more powerful modeling followed. Agilent's Advanced Design System (ADS) software suite currently brings microwave computer-aided-design (CAD) performance and functionality to its highest level.

The 340A noise-figure meter was designed for radars, not for characterizing components, a clear need that had been mentioned by customers. Based on a 1982 landmark market-research study led by Mike Cuevas, a new noise-figure product was envisioned. The resulting 8970A noise-figure analyzer pleased circuit designers since they could measure and display the gain and noise-figure parameters of amplifiers, mixers, and converters at the same time.



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4. A young John Minck is shown with the 8410A vector network analyzer, an instrument that revoloutionized the way that microwave components were characterized.

Since circuit designers will gladly trade-off gain to improve the noise figure of an input amplifier, this capability proved popular for applications such as satellite Rx front ends. The 8970A had enough sensi-

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tivity to measure its own noise figure, and thereby compute out the error effect of its own front-end noise. Agilent's NFA series of noise-figure analyzers continue to expand the possibilities of noise-figure measurement, providing a real-time display of noise figure or gain versus frequency, easy measurement set up, built-in data storage, and printer connectivity.

In the late 1970s, HP began to focus on testing mobile transceivers. By combining a desktop computer, signal generator, frequency counter, power meter, various modulation sources, power supplies, and switching, the 8950A transceiver test system (Bigfoot) was born. It provided all of the measurement capability necessary to completely characterize an FM mobile transceiver.

HP had traditionally supplied general-purpose instruments for transceiver measurements. But starting around 1979, the 8901A modulation analyzer directly targeted the mobile Tx test market. The analyzer was essentially a 1-GHz-calibrated Rx that accurately and precisely measured the AM, FM, and phase modulation of mobile Txs.

By combining the 8901A with the 8662A microwave synthesizer and 8903A audio-modulation analyzer, along with some signal switching, specialized test systems such as the 8957S cellular-radio test system were created. In 1992, HP launched a family of compact, portable cellular test sets, many of which are still in use today. The Agilent 8920A RF communications test set combines 22 instrument functions for transceiver testing of land-mobile and cellular applications.

Yet another system, the Model 8924C, targeted CDMA. Test sets were customized for GSM/digital-communications-services(DCS)/pulse-code-modulator (PCM) DECT, and pager applications. Today, base-station testing is accomplished with the Agilent 8935-series base-station test sets for CDMA and TDMA technologies.

With the 10 wireless communications test sets of the Agilent 8960 series that were introduced in 1999, mobile-phone manufacturers could achieve breakthrough speed that improved test throughput up to 300 percent in a system designed to test multiple communications formats.

HP has always played a commanding role in the computerization of instrumentation. The 2116A instrument computer that was introduced in 1968 yielded its first major application in the 8540A automatic network analyzer. Despite an interface which used a clacking teletypewriter and programming with punched paper tape on the floor, component designers were awed at the power of data-corrected measurements, and the insight they got into their circuit performance. By coupling the 2116A to HP spectrum analyzers, the 8581 automatic spectrum monitor was born. It enhanced long-term signal characterization for satellites and antennas.

True egalitarian automation became reality with the IEEE approval of the IEEE-488 GPIB of 1962. This emerged as desktop computers were becoming popular, and priced so that every test bench could afford them. HP led development of the bus technology, and arranged for an industry committee to take over and make it an open system.

Today's communication technology relies heavily on synchronized transmission frequencies, and cellular base stations, broadcast-television stations, and GPS satellites must reference these precise and stable standards. In fact, cesium beam standards can arguably be credited with standardizing the technology clocks of the world. HP engineers undertook the first "Flying Clock" project in 1964, flying two atomic clocks to Europe to precisely compare the US Naval Observatory time and the national standards at the National Bureau of Standards (NBS) with official clocks in Switzerland.

Atomic frequency standards had been developed in many countries to serve as the basic reference based on the atomic resonance principle, unvarying and fundamental. The 5060A became the first commercial product of choice in industrial primary-standards labs.

HP celebrated its 60th birthday in 1999 in a whirlwind of change. For a quarter century of the company's history, test and measurement was its core business, and within it RF and microwave measurements played an enormous role in the company's success. Over those 60 years, HP had recorded an impressive record, including a compound annual growth rate of 18 percent.

But the marketplace, and HP's role within it, had changed. The company that dedicated itself so steadfastly to test and measurement had become a leader in many other areas of electronics technology, most notably in computing. The question for the future of HP became increasingly how to continue its success in every market area.

Agilent Technologies was the answer. In March 1999, HP announced that it would split the company, with Agilent focusing on communications and life sciences, and HP focusing on computers and imaging. Agilent CEO Ned Barnholt encapsulates the opportunity:

"The split gave us a greater strategic focus. We were a communications and life-science company trapped in the body of a computer and imaging company. We now had an opportunity to go out and tell our story, and to focus more aggressively on our markets. We felt, and I think this has been proven to be true, that we've become a lot faster and more responsive. So anything we want to change, anything we want to do differently, we can do. We decided to bring forward the best of the HP values and culture, and to look also at new ways to become more successful."

Although less than two years have passed since Agilent was formally created, the results of this line of thinking have already borne fruit—perhaps most noticeably in the area of RF and microwave instrumentation. Agilent is introducing significant new RF and microwave instruments that solve key measurement problems, at a rate much faster than when it was HP.

Agilent recently made the decision to sell its life-sciences interests. So, as it was for so long at HP, test and measurement is Agilent's primary focus. MRF

Editors note: Readers can request a copy of a 36-page Agilent brochure that reviews a broad array of HP and Agilent communication test products, starting with the model 200A by requesting literature number 5890-2090E from the website at www.agilent.com.