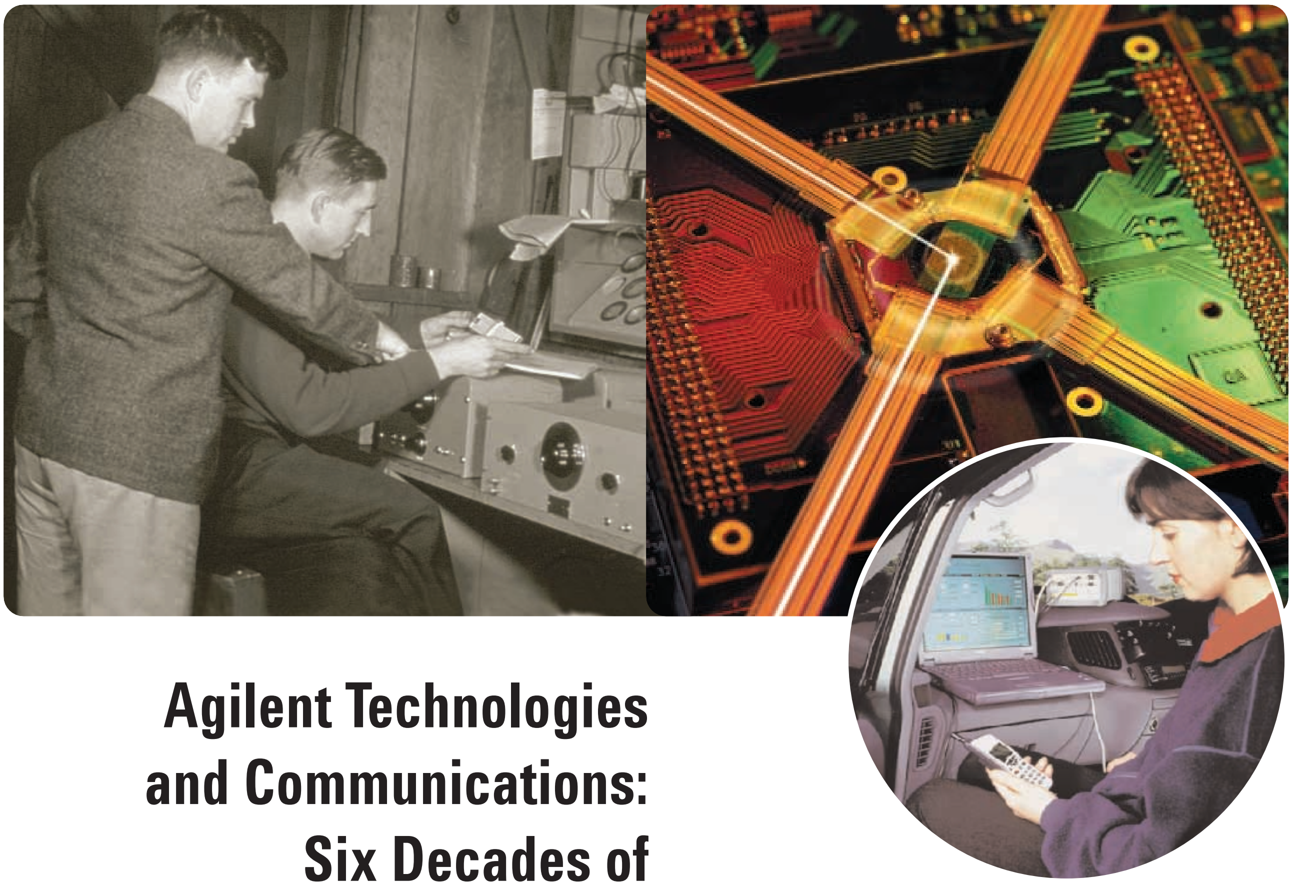

Agilent Technologies and Communications: Six Decades of Measurement Contributions

Agilent Technologies
Innovating the HP Way

Contents

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It can be reasonably argued that Agilent Technologies—which incorporates the former test and measurement sector of Hewlett-Packard Company—has been making measurement contributions to the communications industry ever since Dave Packard and Bill Hewlett assembled their first product, an audio oscillator, in 1939 in a Palo Alto, California, garage.

That product was the HP 200A audio oscillator, and its most famous sale was to the Walt Disney Company for use in making the movie *Fantasia*. But it also was used widely in the design of transmission components, including amplifiers, transformers, and filters, for the twisted-pair wireline telephony systems of that era.

With the outbreak of World War II, communications technology became the focus of intense R&D efforts as a strategy for winning the war. The results of those efforts revolutionized the world. Agilent, through its HP heritage, has played a significant and continuing role in the communications revolution, making hundreds of test and measurement contributions in nearly every sector of the industry.

Bill Hewlett and Dave Packard.

In this document, we'll take a journey through the development of 20th century communications and Agilent's test and measurement contributions. Although we discuss technologies up to the end of the century, our focus is on the historical achievements rather than present-day trends.

The early days

The 200A audio oscillator was Hewlett-Packard's first commercial success.

In the earliest analog telephone technology, open-wire telephone lines dominated the outside plant. Then came twisted-pair wires bundled into underground cables. In the U.S., these formed the backbone of the communications system well into the 1940s. Some of us still have images of telephone poles along country roads, with multiple cross-arms and dozens of green-glass insulators supporting open wires that went on for hundreds of miles. The technology of communicating in those days was heroic, and it seemed that the only way to let more people communicate was through brute force design, by adding more wires over head or more cables under ground.

Hewlett-Packard's original audio oscillator, used with the 400A vacuum tube voltmeter (ca. 1941) that boasted a 1 megacycle bandwidth, allowed the characterization of frequency-response parameters of a variety of system components, including amplifiers, transformers, filters, line-loading components, and switches. One of Hewlett and Packard's objectives was to provide "inexpensive quality," and the audio oscillator was a good example. Originally advertised for $71.50 in the Institute of Radio Engineer's Proceedings of 1939, the oscillator caught the attention of the Chief Engineer at Walt Disney Company, who needed a number of audio sources for sound effects in *Fantasia*. The competing oscillator of the day was a "beat-frequency" oscillator that cost ten times as much. Disney's Chief Engineer bought eight of the HP models.

The clever circuitry of the 200A audio oscillator was the subject of Bill Hewlett's Electronic Engineering thesis at Stanford University. In a slim document of less than 20 pages, he presented a circuitry that was the essence of simplicity. It used a tunable resistance-capacitance network to provide the 180-degree feedback phase shift needed for oscillation; an inexpensive tunable radio capacitor for the two ganged capacitors; switched resistors to achieve the tuning range; and an innovative amplitude-stabilizing function made by inserting a positive-coefficient resistance—a common 7.5 watt lamp bulb—into the cathode circuit of the oscillator vacuum tube.

The 3550A frequency response test set could qualify and troubleshoot twisted-pair cables.

With the introduction of the 300A audio analyzer (ca. 1941), engineers could analyze signal distortion in the audio components used in telephony. Testing was still in its early days. One HP engineer recalled as a college student being assigned to arrive at the engineering lab early in the morning to turn on the instrument so that its vacuum-tube drift would stabilize for lab use later in the day.

In the telecommunications infrastructure, the underground wire-pair plant served local distribution needs for decades, and HP continued to introduce new test products to improve its efficiency. In 1959, the 302A wave analyzer (20 Hz – 50 kHz) brought powerful low-frequency (LF) spectrum analysis to component and signal design. This analyzer was just the second HP product with an all-transistor design—the first being 1958's 721A power supply.

In 1962, HP introduced the 3550A portable frequency response test set for installation qualification and troubleshooting of twisted pair cables. This product was followed by the 3555A telephone test set. These instruments were called Transmission Measuring Sets (TMS), distinguishing them from the familiar Transmission Impairment Measuring Sets (TIMS) of today.

Cable multiplex communications

As the 1940s' wireline technology reached its limits, particularly in the underground cabling of twisted pairs of wires that served urban areas, new technology was needed. One answer was to exploit the broadband carrying capacity of coaxial cable, and as a result, AT&T's research labs rolled out their first cable multiplex systems, the L-1 through L-5.

Cable multiplexing grouped dozens of individual telephone conversations together using a technology called frequency domain multiplex (FDM). Each conversation occupied 3 kHz of channel width and was spaced 1 kHz from its neighbors. Twelve audio channels were single-sideband-modulated into a group; five groups were combined to form a super group; and ten super groups were combined into a master group. The key to this technology was perfect linearity in the amplification and all other circuitry. Slight non-linearities showed up as intermodulation, which resulted in degraded background noise and cross-talk.

Amplitude flatness across the many multiplexed channels was measured over the 1.5 MHz band by HP's 310A wave analyzer (ca. 1963). A wave analyzer is essentially a calibrated superheterodyne receiver, and this one featured a selectable output bandwidth, which allowed the detected audio modulation to be measured.

The 312A wave analyzer and 313A tracking oscillator were diagnostic tools for multiplexed cable.

As cable multiplex technology progressed, AT&T added more and broader channels to their cables, pushing the technology to its limits by installing an underground cable system across the U.S. from New York to Los Angeles. Cable systems also began to provide the broadband links required between the 7000 telephone central offices around the country. The AT&T L-systems ultimately reached 65 MHz per cable.

The 312A wave analyzer (ca. 1966) was a powerful diagnostic tool for multiplexed cable because it covered the 18 MHz range, was fully programmable, and featured many user improvements such as automatic frequency control. Outside the U.S., the 3745A selective level measuring set (ca. 1975) offered system engineers following the CCITT-standards precise measurements of FDM telephone equipment with as many as 3600 channels. This 25 MHz superheterodyne receiver measured down as low as -125 dBm with synthesizer precision. In 1978, the 90 MHz 3747A selective level measuring set was targeted at the new generation of 60 MHz cable that handled 13,000 channels.

The 3586A/B/C selective level meters followed in 1980 for FDM applications to 32.5 MHz. And companion 3336A/B/C synthesizer/level generators teamed with the selective level meter products to characterize transmission components for both North American and CCITT signal formats.

Pulse-coded modulation

In a real sense, most of the spectacular communication technologies of the late 20th century were based on a simple analog-to-digital concept. In the 1960s, when it became economically and technically feasible to digitize analog waveforms on a massive scale, everything in communications got better. Using a well-known sampling theory and an 8-bit digital word to express amplitude samples taken at 8 kHz, each 3 kHz audio voice bandwidth was converted into a 64 kb/s digital data stream. Twenty-four streams were interleaved into the 1.544 Mbit/s signal called T-1 in the U.S. This modulation format was described as time-division multiplex (TDM).

Amazingly, this T-1 signal could be transmitted on those same ordinary twisted pairs, which vastly increased capacity without laying a single foot of additional cabling beneath the streets. Now AT&T developed their T-systems, with a hierarchy of data rates up to T-4 (274 Mbit/s), running over coaxial cable. Similar standards were developed outside the U.S., where the CCITT hierarchy packed 30 voice channels into a 2.048 Mbit stream.

The digital data streams revolutionized telephone voice quality. As transmission distances had increased, the analog signals were subject to gradually increasing noise. When amplifiers were used to build up the analog signal for another cable hop, they added noise in each hop. In contrast, digital pulse regeneration sent brand new pulses into the next cable hop, eliminating the audio noise and distortion that came with distance. So the low noise and clarity we often attribute to fiber optics in reality began with the first digital technology of the 1960s.

HP’s digital instrumentation developed across a broad front to help speed the digital revolution. The 4940A transmission impairment measuring set (ca. 1974) met an urgent need as telephone companies began widespread installation of data modems to send data over voice circuits. This TIMS was designed to measure the analog parameters of wire lines that affect data transmission, and it was used widely as a verification tool for line quality and performance testing. The 3770A amplitude/delay analyzer made similar measurements for CCITT standards.

Logic test and the digital revolution

An emulator for the Motorola 146805G2 microcomputer added new capability to HP's 64000 logic development system.

It wasn't long after time-division multiplexing invaded the analog domain that computer-to-computer data communications arrived with a major demand for transmission bandwidth. The term datacom first came into use to define such computer-data traffic. PCM technology became the modulation format of choice for serial data on cable and for digital radio in terrestrial and satellite applications. Digital techniques began to influence every facet of communications technology. And underpinning this new datacom technology were logic circuits.

Logic designers looked for diagnostic measuring tools to help characterize their new digital circuits. HP, with its large engineering departments, quickly became a pioneer—not only by developing new techniques, but by having an immediate forum in which to try out bright new ideas. Bill Hewlett coined the term "next-bench-syndrome" to describe how a product idea could gain quick acceptance when neighboring engineers immediately asked to borrow the inventor's new measurement tool.

The concepts of logic test started small. The 10525A logic probe (ca. 1969) traced logic states in TTL and DTL integrated circuits with a simple probe tip and associated LED indicator. The 10528A logic clip (ca. 1970) and 10529A logic comparator were little, handheld diagnostic tools that simply clipped onto IC packages and gave the user immediate feedback through an array of LED lights.

Complete instruments were soon on the way. The 5000A logic analyzer (ca. 1973) featured a two-line display of 32 LEDs, each of which captured a pulse stream and displayed the pulse sequence. The instrument was a sort of specialized oscilloscope with sophisticated pulse conditioning and capture processes.

Next the 1600L logic state analyzer (ca. 1974) was built into an oscilloscope configuration that displayed 16 consecutive logic states of 12-bit words. This instrument had complex triggering modes for capturing specific sequences of pulses from ICs and ROMs. The 1645A data error analyzer that followed analyzed bit error rates and other transmission parameters.

The 1600A logic state analyzer (ca. 1975) was able to analyze 32 data streams at 20 MHz. Its innovative "data-map" display could locate digital words on a two-dimensional map, which also displayed a vector for tracing the digital direction from word to word. An associated multichannel word generator, the 8016A word generator, supplied 32-bit words at 50 MHz. Such instruments were invaluable in the fast-moving world of microprocessor development.

In 1973, HP introduced one of the earliest high-speed bit-error-rate testers, consisting of the 3760A data generator and the 3761A error detector. By stimulating circuits under test using pseudo-random pulse sequences selectable from 7- to 32K-bit lengths, the system operated with bit rates up to 150 Mb/s.

The later 71603/612A Gb/s testers analyzed data-error performance all the way to 12 Gb/s, and are used today by many laboratories around the world for developing high-speed optical transmission systems.

In 1980, with the introduction of the 64000-series logic development systems, design engineers began to take control of the burgeoning field of complex logic design for microprocessors. Then came tools to simulate VLSI circuit design and graphical aids to provide better insight into layout processes.

More recently, HP/Agilent logic analysis and emulation tools are almost too numerous to list, ranging from PC-hosted to highly integrated units with basic timing analysis to cross-domain measurements. Hardware solutions are integrated with software solutions for microprocessor and bus support.

HP/Agilent semiconductor test systems have also contributed in this area, by providing fast and comprehensive characterization for VLSI, digital, memory/logic, mixed-signal RF, and semiconductor parametric applications. These systems use powerful software and modeling routines to speed the design iterations of those chip engineers in the communications industry who must deal with rapid deployment and fast turnaround of design cycles.

Datacom testing

Over the years, an important general-purpose instrument for digital communications has been the pulse generator. HP introduced the 8015 and 8011A pulse generators in 1973 and 1974. These were followed by the 8016A word generator of 1975, which supplied 8 simultaneous 32-bit words at 50 MHz for communications applications. In the following decades, HP introduced ever-higher data rates and complex pulse formats for measurement and diagnostic applications. On datacom R&D benches and production lines, pulse generators have served with the same importance and ubiquity as oscilloscopes.

After system engineers tested the serial data transmission—to ensure that pulse levels, data rates, and backup logic techniques such as parity and redundancy bits were getting to their destinations—they turned to the next-higher level of moving messages, the protocol level. There, they needed to make sure that the handshake, start-message, end message, and all transmission “rules” took place in the right order.

The 37900A signaling test set sped troubleshooting of SS7 networks.

Protocol analysis first appeared about 1984, with the 4951/53/55A protocol analyzers. Data communication was getting to be serious business, and these instruments were designed to assist digital network designers, data centers, and field maintenance organizations. They were powerful machines, covering the major protocols of the day: X.25, HDLC, BSC, SDLC, SNA, DDCMP, X.21, and CCITT No. 7. They featured highly flexible triggering and speeds to 72 kb/s.

The portable Internet Advisor (now Agilent Advisor) introduced internetworking test capability for LAN, WAN, and ATM networks.

The introduction of the 4972A LAN protocol analyzer in 1989 targeted Ethernet and StarLAN networks, and the 4974S/A MAP protocol analyzer supported IEEE 802.4, 802.2, ISO, ACSE, FTAM, and more. HP was able to contribute much to datacom testing because it was itself a large user of the technologies. Agilent today carries on that tradition.

A typical example of a product family today is the Agilent Advisor, a modular protocol analyzer that provides powerful diagnostic and analysis functions for testing multiple data technologies such as LAN, WAN, ATM, and emerging voice over IP (VoIP) and fax protocols. Agilent’s LAN Analyzer product family today provides hardware and software to manage and maintain 10/100/1000 Ethernet LANs and 4/16 Token Ring networks. The family includes the company’s first software analyzer that runs on a notebook PC.

The emergence in the late 1980s of the CCITT No. 7 Common Channel Signaling protocol (SS7) revolutionized the control of message switching. Earlier strategies called for message routing information to be sent down the same channel as the voice or data, leading to fraudulent exploitation of the network by so-called “blue boxes,” which could simulate switching-control signals. By moving all message-routing instructions onto a separate, dedicated channel, system operators could centralize operational control of their networks. From this came a powerful ability to monitor and measure all kinds of signaling system parameters. The 37900A signaling test set (ca. 1989) helped install and maintain these signaling systems. And it led directly to the acceSS7 network monitoring system (described under **Superstars**) and the current signaling advisor test sets, which non-intrusively monitor the SS7 network, displaying real-time analysis of signaling data, loading levels, and error rates, and providing statistical reports of message types and more.

Digital transmission testers

The fundamental measure of performance or quality in digital systems is the probability of any transmitted bit being received in error. This is the purpose of digital pattern generators and error detectors, often referred to as bit error rate testers or BERTs. HP's long tradition of offering the highest performing instruments in this class is carried on by Agilent today.

The 86130A 3.6 Gb/s BitAlyzer is a serial BER tester with power error analysis capability and a friendly user interface. As described earlier, the 71612A error performance analyzer addresses digital testing to 12 Gb/s. The ParBERT 81250 parallel BER tester generates pseudo random word sequences (PRWS) and standard PRBS on parallel lines up to 2.67 Gb/s, making it ideal for multiplexer and demultiplexer testing. The E7580A ProBER is a handheld tester for 2 Mb/s and 64 kb/s digital-circuit testing.

Beginning in the 1990s, HP's SONET and SDH analyzers performed accurate, reliable tests on network equipment and transmission services. Portable units were used to troubleshoot SONET and SDH equipment at rates up to 2.5 Mb/s. Modular, VXI-based instrumentation could be easily integrated into R&D, production-line, or ATE systems for testing both SONET and SDH standards up to 10 Gb/s.

Agilent 's tablet-based Service Advisor, part of the Telecom Toolkit, reflects the industry's increasing desire for modular, handheld, multi-format test instruments.

Today the Agilent OmniBER family of communications performance analyzers offers a range of one-box, field-portable testers for installation, maintenance, commissioning, and manufacture of transport networks and network equipment. Optical 1310nm and 1550nm interfaces are supported, as well as electrical interfaces at all the commonly used telecom rates. The testers can be configured to include DSn, PDH, SDH, SONET, ATM, DWDM, and jitter generation and measurement. They perform non-instrusive monitoring of live traffic or test network protection switching mechanisms, out-of-service BER measurements, and other important parametric tests.

The Agilent SpectralBER test solutions offer flexible and versatile SDH/SONET functional test capability from 155 Mb/s to 10 Gb/s.

With the acquisition of CERJAC, a manufacturer of portable telecommunications test equipment, HP expanded the breadth of its field-service test products in the early 1990s. Portable and handheld instruments for field-service testing included the CERJAC 156ATM test set as well as products for T-carrier testing. Those product lines have evolved to the Agilent Telecom Toolkit, which includes the modular, flexible Service Advisor portable test tablet platform with a growing family of plug-in modules for ADSL, HDSL, ATM, SONET, SDH, PDH, and TDR testing; the portable T1 and E1 Advisor families, and the aurora series of handheld testers for DSL, ISDN, frame relay, and ATM testers.

Broadband communications

The early 1990s saw the rise of broadband communications, which has been spurred by the phenomenal growth of the Internet and the "fast packet" revolution. One of the first robust technologies developed to deliver high bandwidth services was asynchronous transfer mode (ATM). HP was a leader in developing ATM test technology, and the introduction of the Broadband Series Test System (BSTS) in 1994 quickly became the industry standard for ATM testing. Today the BSTS continues to offer the industry's most comprehensive solution for ATM Forum traffic management compliance and for ATM signaling test. With the evolution of wire-speed switch-routers from enterprise networks to carrier data networks, the BSTS has expanded to include new standards such as packet-over-SONET (POS). As ATM is a key technology for multiplexing voice, data, and signaling between fixed network elements, the BSTS added third-generation (3G) wireless test capability in 1999 for testing new wireless data technology.

The Broadband Series Test System has been the industry's platform of choice for testing ATM technology since 1994.

Terrestrial microwave communications

In the early 1950s, AT&T exploited the earlier, wartime development of microwave signal sources such as klystrons and began installing a cross-country radio link system known as the TD system, which operated in the 3.7 to 4.2 GHz band. A 30-MHz bandwidth was devoted to each of the system's FM-modulated channels, which carried 1800 (later 2700) conversations.

Soon microwave antenna towers began appearing on the flatlands of northern Indiana and the mountaintops of Nevada and California. The system was extremely complex for that time, since the coast-to-coast span required perhaps 150 radio line-of-sight hops. Because the system was all analog, all its links operated in series, thereby placing specifications of unprecedented tightness on amplifier flatness, group delay, and intermodulation.

Microwave communication links moved into north-south systems, and one well-known link from Chicago to St. Louis became the founding asset of Microwave Communication Inc. (later MCI Corp. and now MCI WorldCom), the first direct competitor to industry-giant AT&T. Terrestrial microwave technology was the first technical solution for transmitting broadband signals nationwide, and it also helped launch today's network television.

To help microwave communication companies install and maintain their microwave radio links, HP developed the 623/24A microwave test sets (ca. 1952), which offered three functions: supplied test power with calibrated output to -100 dBm for testing the system receiver, power measurement of the system transmitter, and frequency measurement of the system transmitter. The test sets were available for the 4, 6, and later 11-GHz communications bands.

The 3708A gave engineers an accurate way to assess the performance of microwave radio and satellite modem systems.

As the technology progressed, one of the key instruments that measured and verified amplitude flatness and tight group delay on system components was the 3702B/3710A microwave link analyzer (ca. 1972). By presenting the phase deviations from linearity on an oscilloscope, the analyzer allowed designers and technicians to tune components and antennas into specification. The 3730A down converter and the 8605A microwave upconverter were used to translate the analyzer's measurement capability into the microwave carrier bands.

The 3792A microwave link analyzer (ca. 1975) and later the 3711/12A IF/BB transmitter/receiver (ca. 1979) were able to handle systems with intermediate frequencies of 140 MHz, designed for 2700 telephone channels. Such dense multiplexing required precise control of distortions such as AM-to-PM conversions and amplitude linearity and group delay.

After AT&T's microwave link system had been in use for many years, the U.S. Federal Communications Commission (FCC) allowed AT&T to relax earlier rules requiring 2 of the 12 channels to be reserved for "hot-standby." AT&T instantly increased their channel capacity, and the only penalty was the need to install an HP 83001A agile microwave radio (ca. 1974) at each repeater station. The 83001A could be tuned to any of the operational channels, so it could replace an out-of-service channel during maintenance.

Since much of the circuitry of microwave radio is analog, new diagnostic equipment was needed when digital modulation formats began to invade microwave radio applications. The 3709A constellation display (ca. 1987) provided valuable insights into commonly used modulation formats such as QPSK, 9QPR, 16QAM, and 64QAM. The companion 3708A noise and interference test set helped engineers quantify the all-important relationship between signal-to-noise and bit-error-rate.

In 1987, HP's signal generators began to feature the complex digital modulation formats that were being used by communication system designers. The 8780A vector signal generator provided 150 Mb/s data rates for digital phase modulations such as BPSK, QPSK, and 16- and 64-QAM at carrier frequencies up to 3 GHz. This generator was the first to accept data lines, rather than analog signals, for modulation.

A companion analysis tool, the 8980A vector analyzer, was able to display high-speed vector diagrams, magnitude-phase versus time, and constellation diagrams. It also presented time-domain eye diagrams of complex, high-data-rate modulations intended for terrestrial and satellite applications. The first users were startled to see a 3-dimensional image of a digitally modulated data stream that looked like a spiral spring extending out of the CRT.

The 11736A I/Q Tutor (ca. 1986) was a clever little computer-training model that taught the fundamentals of digital microwave radio using a PC. The I/Q Tutor modeled a system block diagram from the audio on one end to the audio on the other. At each of the diagram's stages—analog-to-digital converter, map to I/Q, filtering, mix to IF, upconvert to RF, power amplifier to antenna, and back again to audio—the model scrolled down to typical waveforms and eye diagrams, allowing users to set filter factors, data rates, modulation types, and signal-to-noise ratios.

Testing was essential for terrestrial radio links, which experience multipath fading due to signal reflections from mountain and ground effects. The 11758T digital radio test system (ca. 1990) combined measurement of eight different test parameters, so that design engineers could verify that their signal equalizers minimized fading, and so that installation engineers could meet FCC qualification requirements. The system included a microwave spectrum analyzer to create a powerful test instrument.

Satellite communications

In the 1960s, technical visionaries saw the potential for using satellites to carry massive amounts of communication traffic all around the globe. The first commercial applications were made by the Comsat Corporation, a U.S. business-and-government alliance that funded the early technology. Designers had to manage complex multiplexing technology and achieve reliability of their systems in the harsh environment of space. Since repair and service to an in-orbit bird was impossible, the designers had to incorporate multi-path and redundant circuits and components.

These "switchboards in the sky" were so complex that they ushered in a new era of automated test instrumentation. HP was there with the 8540A automatic network analyzer (circa 1969). Controlled by the 2116A instrumentation computer, the system enabled assembly and all-up-around checkout tests of the complex signal paths inside the satellite. The 8540A was based on the 8410A vector network analyzer (VAN), which we'll describe later.

Signal-switching matrix switches routed signals to and from the satellite under test, and provided powerful test routines and complex signal data processing. Error correction accounted for cable losses and signal degradation. Signal-stability performance had been a key ingredient of satellite payload design from the beginning. Thus, synthesizer-stabilized generators became the technology of choice for transceiver designers.

In orbit, satellites needed to have their channels loaded properly, because the transponders were linear systems. Signals needed to be distributed evenly so that peak power wouldn't be distorted and cause intermodulation effects. The 8580A automatic spectrum analyzer (ca. 1971) was perfect for such a job. Consisting of an HP 2116A computer and an 8552A or 8553A-type spectrum analyzer, which was modified for computer control and programmed for long-term signal monitoring, the system could gather data continuously and aid in managing the signal traffic in satellite communications.


The 8580A automatic spectrum analyzer gathered data for managing satellite communications.

Phase-locking technology of the mid-1960s led HP to develop new applications for high-stability signals by phase-locking the venerable 608D VHF signal generator and converting it to the 608F. By designing a varactor into the oscillator circuit, the 8708A frequency synchronizer (ca. 1966), with its crystal-controlled, phase-locked source, eliminated the drift and cleaned up the phase noise.

The 8660A/B synthesized signal generator (ca.1971) was one of the first examples of totally integrated, indirect signal synthesis. The instrument had plug-ins for both modulation and output control, and it provided 0.01 to 110 MHz, and later 2600 MHz, with excellent signal performance.

In the 1960s, the era of the U.S. Apollo Space Program, which successfully put men on the moon, communications technology did not have components with the integrated circuits and LSI and VLSI that we know today. Yet a system such as the integrated S-band communications link used in the big Saturn rockets produced magnificent results. Here was a system in the 2350 MHz band that carried the entire telemetry traffic used to monitor hundreds of parameters in the propulsion systems and the operational subsystems; the voice traffic to and from the crew; medical telemetry; and finally, the most exciting communications innovation of all, the video cameras. These cameras put us earthbound viewers right in the cockpit–and out on the lunar rover, the little "golf cart" that carried its own camera onto the moon's surface and brought the world along with it. With a fixed camera left at the landing site, we were able to see the final liftoff from the moon, which rippled the American flag standing on its pole, a testament of that great venture. HP's signal generators and spectrum analyzers served in the design and test of those incredible communications systems.

In later decades, NASA ventured into interplanetary scientific travel. Unmanned spacecraft now could use exquisite integrated circuits for powerful functional control and measurement of the far solar planets. Cameras and scientific payloads gathered massive amounts of data from our solar neighbors and advanced the world's knowledge of the creation of the universe. The sophisticated communications links and the massive earth antennas such as the Goldstone dish in the Mojave Desert testified to an ongoing tradition of innovation. How far technology had advanced is illustrated by the fact that the 300 foot diameter Goldstone receiver could obtain useful data from received signals at levels as low as one photon per square meter per second.

Indirect frequency synthesis became the main feature of future synthesized generators and sweepers. In 1977, the 8672A microwave signal generator delivered 2 to 18 GHz signals with 15 ms programmable carrier agility. This instrument became the core of a wide variety of automated satellite test systems.

The 8673A microwave signal generator (ca. 1983) produced 26 GHz test signals. It was followed by a family of synthesized microwave sweepers that could serve as highly stable sources for network analyzers, which required error corrections at specific frequencies. In order to speed network measurements, these synthesized sweepers used a modified sweep called "lock-and-roll." Now two categories of product were now available: synthesized signal generators that could modulate signals and sweep, and lock-and-roll sweepers that could be synthesized.

The 8660B signal generator is an early example of the use of totally integrated, indirect signal synthesis.

In the 1990s, the 83731/32B signal sources upgraded the performance of AM, FM, and pulse modulation with excellent phase noise and harmonics to 20 GHz. Today, Agilent's 83550A millimeter-wave sources supply signal power in multiple waveguide bands from 26 to 110 GHz. They are increasingly useful as military, satellite, and commercial applications move above the traditional microwave communications bands.

Site-surveillance applications became important when satellite ground stations were first planned. Because those systems had to receive tiny signals from space, earthbound interference could not be tolerated. The 8582A automatic spectrum analyzer (ca. 1980) was ideal for testing these systems. Outfitted with broadband antennas, this analyzer could sit in a mobile van for days and weeks, monitoring the local signals and other man-made electromagnetic interference and preparing statistical-occurrence data packages.

Mobile-radio communications

By the time WWII began, mobile radio communications technology had already progressed and was typified by FM-modulated radio links that served the public and some commercial sectors. The transceivers used for police, fire, and forestry applications were bulky and cumbersome, but still effective. Transceiver circuitry employed vacuum tubes, which depended on B+ supply voltages of perhaps 125 Vdc, obtained through use of a vibrating contact that chopped the 6 Vdc auto battery supply into a step-up transformer and a high-voltage-rectifier vacuum tube.

Modular printed circuit boards could be inserted and removed from the 8405A vector voltmeter for RF performance testing.

Exploiting WWII tactical radio technology, postwar applications in mobile telephony grew rapidly, particularly after the introduction of the transistor in 1948. Low-voltage and rugged, transistorized devices quickly replaced the bulky vacuum tube technology. However, frequency-spectrum assignments severely limited mobile phone users because only one subscriber could use each telephone channel at a time. Moreover, base stations were spaced quite far apart, significantly restricting frequency reuse.

Frequency counters, power meters, and signal generators were the instruments of choice for designing, testing, and maintaining mobile transceivers. The 803A impedance bridge (ca. 1950) featured a novel application of the slotted- line technique that allowed a 500 MHz measurement range in a very compact device. This bridge and the 805A slotted line (ca. 1951) were used for impedance measurements on RF and antenna sections.

A variety of signal generators served the mobile FM market, including several models acquired by acquisition of the Boonton Radio Company in 1960. The 202H (Boonton) FM signal generator was widely used in production and service facilities. Later AM-FM generators such as the 8654B signal generator (ca. 1976) and the 8642A/B signal generator (ca. 1985) featured expanded precision, capability, and programmability for mobile test. The 8642 generators were notable because they used surface-acoustic-wave technology to improve signal-to-noise performance of the programmable oscillators, even over cavity-tuned models.

A brand new concept for RF voltmeters was introduced in 1966 when the 8405A vector voltmeter was launched. The use of impulse sampling technology (described later) made this voltmeter unique. By applying the technology to two independent but synchronous channels, both channels of RF voltage could be measured to 1000 MHz, and the phase difference between the two could be measured, as well. This remarkable capability offered the RF mobile design engineer new insights into RF printed-circuitry performance.

By adding signal-separation direction couplers or RF bridges, the meter could be transformed into a sweeping impedance meter. This two-channel concept led directly to development of the blockbuster 18 GHz 8410A network analyzer, introduced in 1968. (We cover this in the **Superstars** section.)

About 1977, HP began to focus on all-round testing of mobile transceivers. By combining a desktop computer, signal generator, counter, power meter, various modulation sources, power supplies, and switching, the 8950A transceiver test system was born. It provided all the signal and measurement capability necessary to completely characterize an FM mobile transceiver. Affectionately called “Bigfoot,” it began to define testing strategies for the rapidly growing manufacture of huge quantities of mobile radios.

HP had traditionally supplied general-purpose instruments for transceiver measurements. But starting in about 1979, the 8901A modulation analyzer directly targeted the mobile transmitter test market. The analyzer was essentially a 1000 MHz, calibrated receiver that accurately and precisely measured the AM, FM, and phase modulation of mobile transmitters.

By combining the 8901A with the 8662A microwave synthesizer (ca. 1962) and 8903A audio modulation analyzer (ca. 1980), along with some signal switching, specialized test systems such as the 8957S cellular radio test system (ca. 1985) were created.

Modern wireless communications

By the 1980s, the frequency-spectrum overload in mobile telephony was becoming obvious. And one dramatic solution was waiting in the wings–the concept of cellular frequency-reuse, which envisioned a dense population of base stations at regular (cellular) intervals, and a complex control system that would "hand off" a travelling transceiver as it moved from one base station cell to another. The idea was revolutionary, but new microprocessor technologies made it possible and economically viable.

We can only pity those early radio designers who had to create RF front ends for mobile radios that encountered some of the worst signal degradation imaginable. The radio had to capture and retain the base-station signal, while a car, traveling at high speed, exhibited a considerable Doppler effect in frequency shift. At the same time, multipath effects caused by mountains, buildings, or atmospheric conditions might be causing the signal strength to fade into black holes with 70 or 80 dB attenuation. Enter the 11752A multipath fading generator (ca. 1985), which simulated up to six multipaths with individually programmable amplitude effects, all to stress-test the circuitry of the mobile radio's signal processing.

In 1992, HP launched a family of compact, portable cellular test sets, many of which are still in use today. The 8920A RF communications test set combined measurements of 22 instruments for transceiver testing of land-mobile and cellular applications. Variations were developed to meet new system formats. The 8920DT focused on digital systems such as PDC. The 8921A cell site test system covered cellular base station testing. Yet another system, the 8924C, targeted CDMA. Test sets were customized for GSM/DCS/PCM applications, for DECT (Digital European Cordless Telecommunications), and even for pagers. Today, base station testing is accomplished with the 8935 series base station test sets for CDMA and TDMA technologies.

In recent years, the company has focused attention on the evolving needs of mobile manufacturers for complex test equipment customized to exact modulation formats and signal performance. Before that, equipment was designed primarily for general-purpose use. But system designers now want test equipment that anticipates sophisticated new technologies. As we can see from the three dozen pages of wireless test equipment in the 2000 Test and Measurement Catalog, Agilent has learned this lesson well.

Mobile systems now evolve so quickly that the key to success is agility. Test equipment suppliers must be quick to respond to customer needs. So, for example, because spectrum analyzers are often the most critical piece of test equipment on the design bench, the 8590-series spectrum analyzers (ca. 1988) were given plug-in firmware "personalities," each of which customized the measuring routines to specific jobs. Numerous and inventive test routines have been offered for testing cable and broadcast TV, noise figure or EMC, and a multitude of wireless formats, including GSM, CT2-CAI, NADC-TDMA, ODC, DCS1800, DECT, CDMA, PHS, and microwave digital radio. Today's ESA series spectrum analyzers carry on the trend with evolving personalities for CDMA and GSM.

The ESG-series RF signal generators (ca. 1995) have provided flexible digital modulation for an exceptional range of RF communication applications to 4 GHz. These include GSM, CDMA, TDMA, DECT, EDGE, and broadband I/Q modulation. In addition, an internal arbitrary waveform generator can play back virtually any mathematically generated waveform–an amazing signal simulator in a traditional RF signal generator package.

With the 8960 Series 10 wireless communications test set introduced in 1999, mobile phone manufacturers could achieve breakthrough speed that could improve test throughput by up to 300% in a system designed to test multiple communications formats.

Today as third-generation (3G) and interim 2.5G digital wireless standards emerge, Agilent is launching manufacturing, field-service, and network operations test systems to help ensure the performance and quality of the next generation of wireless network equipment, digital appliances, and services.

The 8935 series base station test sets were designed to operate under varying environmental conditions.

LMDS in the last mile

In the late 1990s, the battle heated up to deliver interactive, broadband connection to homes and businesses, and the industry began to consider wireless technology alternatives (“fixed wireless”). One of the new service formats developed was the Local Multipoint Distribution System (LMDS). Allotted frequency at 30 GHz, LMDS consisted of a cellular arrangement of hub base stations that connected to homes and businesses using very small (8-inch diameter), line-of-sight antennas spaced about every 2 to 4 miles. This arrangement bypassed all the headaches of laying underground cable and required easily installed modems at the customer premises. HP developed a two-way LMDS technology for broadband, interactive connections that was sold in 1997 to Lucent Technologies.

Military communications

With vast and far-flung operations, the world's military forces rely heavily on tactical and strategic communications. Most countries want to develop the most highly sophisticated, high-performance communications technology possible to assure success in their complex military endeavors. And while the military certainly depends on large amounts of commercial communications capacity, in every decade the military has had unique needs that have pushed communications technology to the limit.

One of the earliest products developed by HP during WWII was the 100A secondary frequency standard (ca. 1941). This crystal-controlled oscillator had countdown circuits to provide precision outputs to 100 kHz and was used in certifying transmitter frequencies. In those days, frequencies were often standardized using the "Lissajous" comparison pattern on a cathode ray tube, which placed a standard frequency on the horizontal deflection, and the unknown signal on the vertical. The 500A frequency meter (100 kHz) of 1941 used an analog meter dial.

The 524 frequency counter established HP as a leader in electronic counting.

A fellowship grant made to Al Bagley, a young graduate student at Stanford University in 1948, led the development of HP's frequency counters. Hewlett and Packard personally asked Bagley to study the measurement needs of the nuclear physics industry. From that study came the requirements for a faster nuclear-pulse-counting technology that could resolve two nuclear events only 0.1 microsecond apart. Bagley determined that new, low-capacitance semiconductor diodes just coming on the market might allow faster digital circuitry. He built a prototype as part of the project—and asked for a job at HP. When he was hired, he was asked to continue the work.

Out of that work came the 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. Sadly, the 520A had only minimal commercial success. However, Hewlett envisioned a different measurement process, one that gated those scaled-down, high-speed pulses (using a selectable time base similar to that of the 100A time standard) into a slower-speed accumulator (counter). Thus the common frequency counter was born.

Frequency counters were a huge commercial success and in great demand from the 1950s onward. They were used in measuring everything from transmitter 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 (ca. 1952), which boasted a 0.01 cps to 10 "mc" measuring range. It was augmented with the 512A frequency converter to measure to 100 MHz.

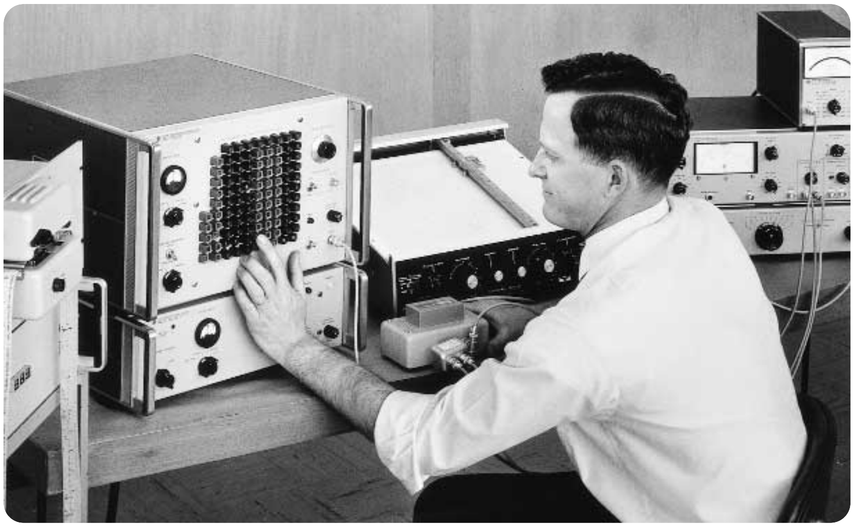
In 1954, plug-in downconverters were added and introduced as the 524B electronic counter, which became an industry standard for some years. Plug-ins eventually measured to 18 GHz, after the introduction of the step-recovery-junction diode. With this diode, HP's design engineers could create a broad comb of harmonic spectra from a crystal-stabilized frequency source in the 200 MHz region. This down-conversion technology allowed convenient measurements to 18 GHz, a real accomplishment at that time.

Development of the 5100A frequency synthesizer (ca. 1964) came about in response to the U.S. Navy's critical need for a fast-switching, direct synthesized, high resolution signal source for secure communications. The product was a marvel of the time, covering 0 to 50 MHz with a resolution of 0.01 Hz and crystal frequency stability of 1 part in 10^{10}. Its success launched HP into a long line of direct synthesizers that became faster, wider in range, and more flexible. The 5105A frequency synthesizer, offering 500 MHz direct synthesis, followed in 1967.

HP's first entry into the RF measurement sector was introduced in 1943. The Model A signal generator, a UHF (ultra-high-frequency) signal source with a 500 to 1350 MHz range, used "lighthouse" vacuum tubes for the oscillator and power amplifier. Frequency adjustment was made through ganged, tunable cavities.

To fulfill a wartime government purchase order, HP developed some sophisticated manufacturing processes that served the company well for decades. For example, the design of the Model A used moveable, contacting short-circuit “fingers” to provide the cavity resonance function for the oscillator. Those fingers were assembled and worked in with a careful burnishing process. This process smoothed the sliding metal surfaces so that electrical noise would not occur as an operator tuned the frequency across the band. The manufacturing process also ensured a long life for the cavities despite the wear from continuous movement.

A commercial version of the wartime product, the 610A UHF signal generator, was introduced in 1948. The 612A UHF signal generator (ca. 1953) found applications in UHF television, which had been opened up for broadcast communications at that time.



The 5100A frequency synthesizer answered the military’s need for a fast-switching, direct-synthesized, high-resolution signal source.

The early HP signal generators provided user features that contributed to the company’s dominance of the signal generator market for decades. These included direct readouts of the frequency, amplitude, and modulation functions—a big advance in usability. Also, the instruments incorporated mutual inductance coupling and waveguide-beyond-cutoff technology, which allowed precise attenuation of the output signal down to extremely low levels, on the order of 1 microvolt.

Klystron tubes were the power sources of early HP microwave signal generators, and the first was the 616A signal generator (1.8–4.2 GHz) of 1947. The 614-series signal generators covered frequency bands to 21 GHz and were replaced in 1962 with the 8614/16 signal generators that featured power leveling and amplitude modulation using PIN (positive-intrinsic-negative) diodes. PIN diodes made a significant contribution to microwave amplitude control. They were created by adding an intrinsic layer of silicon in the middle of a standard PN junction. A PIN diode acted like a resistor at microwave frequencies and a diode at low frequencies, thus allowing the attenuation of an array of these diodes positioned along a microwave transmission line to be programmed with a dc current.

It was not until 1982 that solid-state YIG (yttrium-iron-garnet) sources were introduced in the 8683/84A signal generators, which covered the 2.3 to 12.4 GHz range with AM/FM/pulse modulation, making them suitable for many microwave communication applications.

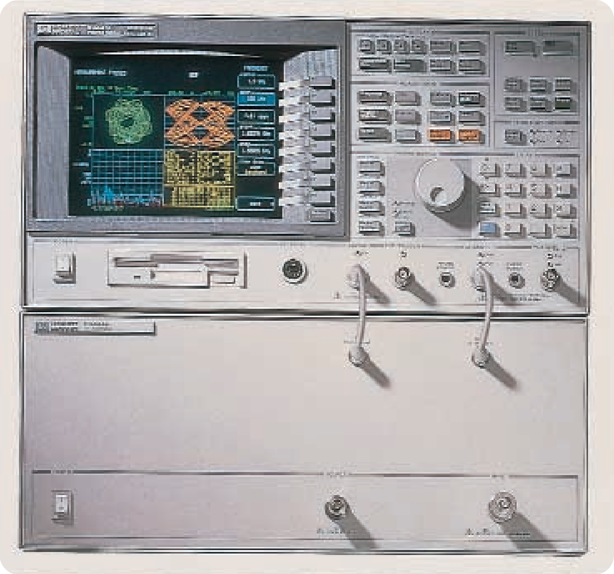
Tactical aircraft communications and navigation systems have been calibrated and maintained by a long line of signal generators, such as the 450 MHz 608A VHF signal generator (ca. 1950). The 65 MHz 606A HF signal generator (ca. 1959) was well-suited for design and testing of the ultra-long-range, single-sideband HF communications radios of the U.S. Strategic Air Command bombers.

Standard HP signal generators have served a variety of other military applications, such as tropospheric scatter communications, in which high power signals were aimed at the horizon, and receivers over the horizon had to detect the tiny amounts of signal that scattered from ionic elements in the high troposphere.

The 606A high frequency signal generator could test ultra-long-range, high-frequency radios.

The 8640B VHF signal generator (ca. 1973) represented a quantum leap in signal generation, replacing the venerable 608-series generators that were installed in thousands of radio test benches. To achieve superior phase noise in the new product, the designers used a cavity-tuned oscillator to 512 MHz. They phase-locked the oscillator for drift stability, and used a power doubler for 1024 MHz output. The digital countdown circuits went to 500 kHz, and an internal frequency counter gave user precision. The 8640B offered very high-performance AM-FM signals to military radio testing for a decade.

As high-frequency digital circuits became available, HP developed a powerful digital direct-synthesis technology for use in secure communications. The 8770A arbitrary waveform synthsizer (AWS, ca. 1988) created completely arbitrary waveforms from dc to 50 MHz by use of a super-fast, digital-to-analog converter (DAC). This circuit could plot computed-amplitude points to create totally arbitrary waveforms using 8 nanosecond-width pulses. HP's frequency-agile technology also made it possible to hop from one frequency to another in the time it took to move to a different sequence of 8 nanosecond pulses. More importantly, the design was directly focused on signal generator performance standards, and the AWS far exceeded ordinary fast (computer-style) DAC performance in signal-to-noise ratios and harmonic generation.



Vector signal analyzers such as the 89441A process highly complex, modulated signals to obtain both phase and amplitude information.

Next came fixed upconverters that could place the agile 50 MHz band into microwave application frequencies. Then in 1991, the 8791A frequency-agile signal simulator (FASS) added frequency-agile upconverters that achieved a typical 100 nanosecond agility all the way to 18 GHz. In addition to impressive carrier agility, FASS used a special waveform generation language that allowed users to program wide-bandwidth modulations of arbitrary formats such as non-linear chirps, TDMA, and CDMA. With such custom signals, operating receivers could be stress-tested using actual link traffic and congested signal environments tested with in-channel and out-of-channel interference.

Some military satellite work, such as the MILSTAR satellite program, required ultra-complex modulations and frequency-agile formats to make them secure from jamming and other mischief. Sophisticated generators such as FASS and other millimeter-wave signal source modules were introduced there.

Hybrid spectrum analyzer technology integrated frequency- and time-domain functions to process highly complex modulation signals for both phase and amplitude information. These are typified by the 89410 to 89450A vector signal analyzers (ca. 1993), which still offer unparalleled capability, from baseband to 10 MHz and from RF to 2650 MHz. Powerful signal processing software contributes useful displays of digital modulation, statistical parameters, and advanced data analysis functions. Thus the analyzers can display time patterns of digital modulation such as eye-diagrams concurrently with phase patterns such as constellation and vector diagrams. Innovative waterfall and spectogram display formats give insight to communication traffic characteristics.

The 8604B VHF signal generator featured built-in phase locking and a 550 MHz counter for high-performance AM and FM signal testing.

Environmental testing

Products built for military communications have influenced the commercial market in important ways. For example, a high standard of performance of HP and Agilent instruments has dramatically affected the ownership experience of the company's customers over the years. This performance standard was initially the result of HP's so-called "Class B" environmental qualification.

In the early years, when HP occasionally contracted to design militarized test equipment for the rugged field conditions of the armed services, the operating requirements included a wide range of thermal and mechanical stress. It was found, not surprisingly, that when those instruments were later commercialized, their failure rate and field reliability were often superior to many other ordinary designs.

This observation led HP to implement an instrument class of environmental specifications that *all* HP commercial products had to meet. Class B instruments had to operate from -40 to +65 degrees Celsius, and perform to specifications from 0 to +55 degrees C. During the design qualification of an instrument, the entire parts list was analyzed, part by part, to determine how much derating would be used. For example, resistors were to run at only 25% of their maximum published ratings. Since heat is generally the killer of reliability, IR scans were made on chassis and printed circuit boards to identify spots of unwanted heat. It is generally accepted that these rigid programs of operating qualifications were fundamental in building the high esteem held for HP and Agilent products.

Broadcast communications

Certainly HP's early audio oscillators and distortion analyzers (such as the 330B distortion analyzer, ca. 1941) found use in the broadcast industry, which in the 1940s meant simply AM radio broadcast. As frequency modulation technology was introduced to the broadcast community, the FCC required instrumentation at the broadcast station to continuously monitor the transmitter frequency and the modulation characteristics. In 1947, HP introduced the 335B broadcast service monitor to meet these FCC broadcast rules. Other broadcast monitors followed, with the 335E TV waveform monitor in 1945 and the improved 337B FM monitor in 1950.

The early development of television took place in the late 1930s and was demonstrated at the New York World's Fair in 1941, but implementation was put aside during WWII. When postwar television rolled out, HP equipment was in demand for signal simulation and analysis. The 612A UHF signal generator (ca. 1953) became the signal source of choice because its modulation capability was specifically designed for the UHF TV modulation formats. This product was a direct descendent of the 1943 Model A signal generator.

When HP entered the oscilloscope market in 1958, various specialty markets looked promising for the new scope technology. In 1965, the 191A TV waveform oscilloscope was introduced for broadcast studios to test the quality of the video signal. Some of HP’s oscilloscope innovations, including the internal graticule for a more precise display and a flood gun for illuminating the screen, were included in the 191A. This scope also featured higher bandwidth, so it could read and display the VITS (vertical interval test signal), which was a new test signal transmitted during the TV vertical interval period for concurrent monitoring of signal distortions. These innovations were important for the emerging color technology.

The MediaStream broadcast server dramatically improved storage and playback capability for broadcast television stations.

In the 1990s, video technology underwent a dramatic conversion from analog signal format to digital. The timing was right for many reasons: picture quality was higher, precision post-production editing was available, dramatic improvements had been made in digital storage techniques, and reliability of the technology had improved over earlier digital video tape. HP was confident of the opportunities and created a division just to supply the broadcast video market.

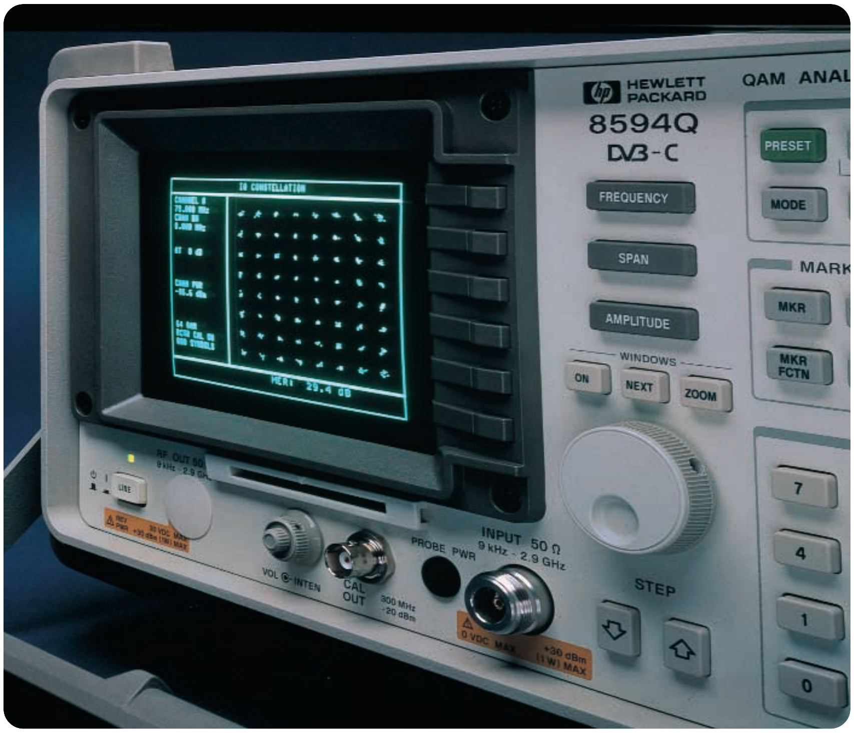
One of the first products was a novel frame-grabber-type video data processor called the VidJet-Pro video print manager (ca. 1994). It was designed for broadcast and post-production studios, which had walls full of video tape files. By processing video data from a streaming video signal, the VidJet could capture a single video frame and create the proper data map, which in turn could print the picture on a standard color page printer.

The VidJet provided other functions, such as detecting each scene change and printing story boards with 30 slide-sized thumbnail pictures on the same sheet. In this way, video news and other cassettes could be inventoried for easy access when studios needed to retrieve specific video clips. The product served an important inventory function for a few years until replaced by on-line photo shops.

Other products for the digital video market included a line of digital video recorders and video servers. In 1993, HP introduced the MediaStream broadcast server. This product’s technology offered a dramatic improvement in storage and playback capability for broadcast stations and post-production studios, first for 1 or 2 video channels and later for up to 6 channels. It offered 50 hours of video storage for advertising or spot media content. Through integration with programming computers, it made digital video instantly available, and the new medium began to replace video tape and cart machines for playback functions.

Video servers were more than just modified computer data servers, because the video data had to be constantly “streamed” to its applications, and not subjected to the data bursts typical of computer servers. HP made real contributions to the industry with the development of RAID (redundant array of independent disks) technology, which in the case of a disk-element failure allowed reconstruction of the lost video from redundant data on other surviving disks. Broadcast stations moved quickly to exploit the new disk technology. HP supplied similar digital video storage with a line of MediaStream disk recorders. These could scale up to 5 channels with storage capacity up to 18 hours.

In the test world, as analog video gave way to digital video technology, the 11759D dynamic ghost simulator (ca. 1993) stressed TV receivers with real-life signal impairments such as airplane flutter, tower sway, and mountain or building multi-paths. The 8594Q QAM analyzer (ca. 1995) targeted performance testing of digital video signals, including the 16, 64, and 256 QAM formats used for satellite distribution.



The 8594Q QAM analyzer targeted performance testing of digital video signals.

Data compression played an important role in the new digital video broadcast. One standard, developed by the Motion Picture Experts Group and called MPEG, became the main compression technology for recording and playback of digital video. The MPEG standard allowed economical data storage yet permitted editing functions and other important broadcast and post-production processes. Today Agilent's MPEGscope family of test products (ca. 1997) are used in the industry for MPEG-2 as well as DVB (digital video broadcast) and ATSC (Advanced Television Standards Committee) system development and qualification. The MPEGscopes are used to verify and debug digital TV network systems, including encoders, multiplexers/demultiplexers, set-top boxes, and video servers. In 1999, the MPEGScope was awarded an Emmy for technical contributions to the television industry.

In 1999 the MPEGscope won an Emmy award for technical contribution to the television industry.

Cable television

HP was an early contributor to the cable industry, even in cable's first incarnation as community antenna television (CATV) in the late 1940s. Often tiny local companies were built on a shoestring to bring broadcast TV "over the mountain" where direct line-of-sight signals didn't reach. Some general-purpose HP gear was used in designing the broadband amplifiers and circuit components such as signal splitters and combiners. Certain transmission testers that were used for telephony cable maintenance could be applied to cable TV installation and service, as well.

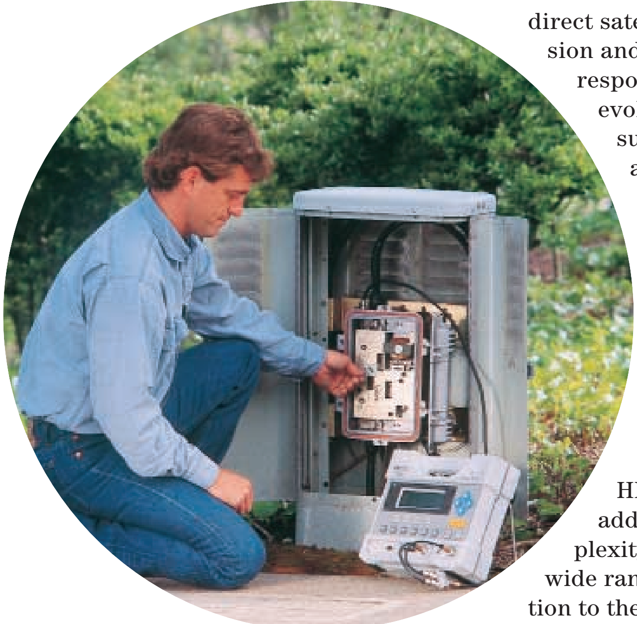
The 8591C cable TV analyzer was given a flexible hardware and software architecture that could be upgraded to keep pace with changing regulations.

Powerful yet versatile signal testing for the cable industry came about in 1991 when the innovative 8591C cable TV analyzer was introduced. This full-featured spectrum analyzer operated a measurement personality (loaded from a plug-in card) that displayed test parameters for video and carrier characterization in the units of the application. In the early 1990s HP acquired CaLan, a manufacturer of cable test equipment, which added a new array products including a sweep/ingress analyzer and signal level meters.

In recent years, the cable industry has faced intense competition from other service providers, including direct satellite system (DSS) television and telecommunications. In response, cable operators began evolving their businesses to supply more than just packaged entertainment. They began to upgrade coaxial-based facilities with fiber-optic technology and introduce digital communication services—including high speed Internet access, telephony, data, and interactive television.

HP—today as Agilent—has addressed the growing complexity of cable systems with a wide range of instruments in addition to the traditional cable TV test products. To help cable operators turn up two-way systems, the company introduced in 1998 a return path monitoring and analysis system. For telephony and converged service testing, Agilent supplies protocol analyzers with voice over IP test capability and a voice quality tester.

Fiber testing can be performed with a mini OTDR, WDM channel analyzer, and optical spectrum analyzer. Digital broadcast test equipment (described above) is also used. An advanced, automated test suite for DOCSIS verification was introduced in 1999 to assist in standard certification of new and important technologies critical to the deployment of interactive cable services.

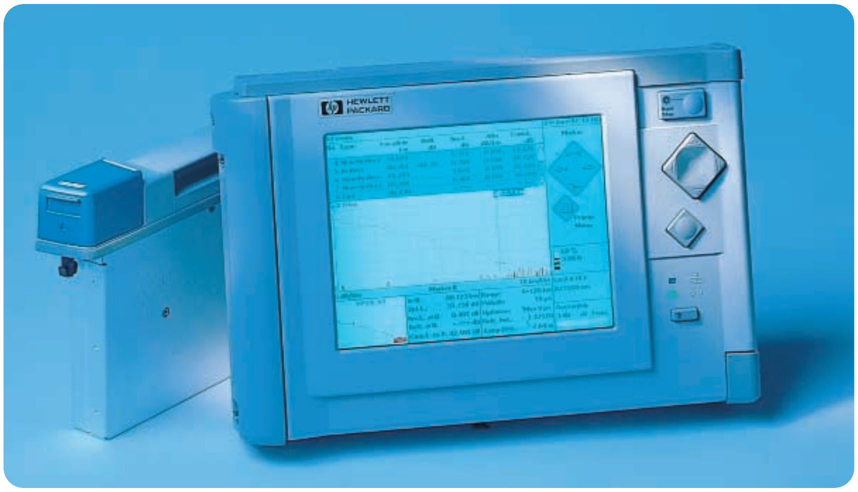


Portable cable TV test products include the 3010 series sweep/ingress analyzer.

Lightwave communications

The confluence of solid-state laser light sources invented in the 1960s and the low-loss glass fibers developed by Corning Glass Co. around 1970 fostered a communications revolution unmatched in human history. The amounts of digitized voice and data now transmitted by light across continents and under the oceans are so massive that even the greatest visionaries cannot predict where the growth will end. And the production and installation of fiber-optic technologies continue to accelerate. All these advancements have required the services of new kinds of test and measurement equipment, and fortunately HP was there.

The parade of innovative measurement solutions started simply enough. As the first fiber-optic links were being developed, the fibers had generally high loss and were best suited for short distances. Fiber inventors were willing to try anything that could improve their measurements. One engineer derived a simple fiber-power-sensing thermistor mount for HP's regular line of microwave power meters. The resulting 84801A fiber optic power sensor (ca. 1981) coupled the light from the 0.004 inch fiber pigtail into a fly-speck-sized black thermistor bead (about 0.010 inch diameter), heated the bead, and metered it much like microwave power.



For field testing, today's E6000A mini-OTDR combines powerful measurement tools in a rugged, portable package.

Soon came more sophisticated optical power meters, directly suited for high-performance characterization of sources and fibers. The 8151A optical pulse power meter (ca. 1985) offered several interfaces to fibers and sources and featured a well-thought-out design with two power heads covering the 550 to 950 nm and 950 to 1750 nm ranges preferred for optical fiber applications.

At about the same time, HP introduced the 8150A optical signal source, which provided a calibrated optical power source for the short-wavelength window of 850 nm. Combined with the 81519A optical receiver and the optical power meter, these completed a test-bench layout for parametric testing of fiber technology.

Several innovations in optical-path manipulation produced continuous attenuation control and interfacing to various fiber standards of the time. By 1987, HP had introduced a new family of stimulus-and-response equipment. The 8154B LED source, 8152A optical average power meter, an optical attenuator, and an optical switch added greater versatility to the tools required by optical design engineers.

As more fiber was manufactured and installed, the 8145A optical time-domain reflectometer (ca. 1988) helped engineers characterize transmission characteristics of long lines of fiber. Since only limited peak-pulse power was achievable at that time, the OTDR exploited a very clever, correlation-based, long-pulse technique to extract reflected signals from noise and to look farther down the length of fiber.

The 8702A lightwave component analyzer (ca. 1989) was basically an optical modulation analyzer for bandwidths up to 6 GHz at 1300 nm, and 3 GHz at 1500 nm. It showed in great detail how lightwave transducers (sources and receivers) modified the information-carrying signal. It also boasted a new technique called

The 8541A OTDR helped engineers characterize lon glines of fiber.

OFDR (optical frequency-domain reflectometry). By processing the frequency-response data on a computer, the designer could determine time- or distance-related imperfections.

The 86140 series optical spectrum analyzers have the high sensitivity, wide dynamic range, and exceptional sweep time need to test the current generation of WDM components and systems.

The 71400C lightwave signal analyzer (ca. 1988) was the first piece of test equipment that could characterize the modulation of optical signals up to 22 GHz. Measurements of RIN and optical distortion were provided in a calibrated system. This innovation was followed in 1991 by the 20-GHz 8703A lightwave component analyzer, which was the first commercial product incorporating a high-speed, Lithium-Niobate Mach-Zehnder modulator, used to create the 20 GHz modulated optical signal.

The 8153A lightwave multimeter (ca. 1991) used plug-in modules to precisely measure fundamental quantities such as optical power and loss. Available plug-ins included optical power meters, fixed-wavelength laser sources, and an optical return loss module. The optical power meters became industry standards in the 90s.

In 1993 came other families of optical instruments. The 71450A optical spectrum analyzer and the 8168A tunable source (one of the first commercial tunable lasers on the market) offered designers powerful new ways to characterize their components and sources.

Portable SONET/SDH test sets measure optical rates to 2.5 Gb/s.

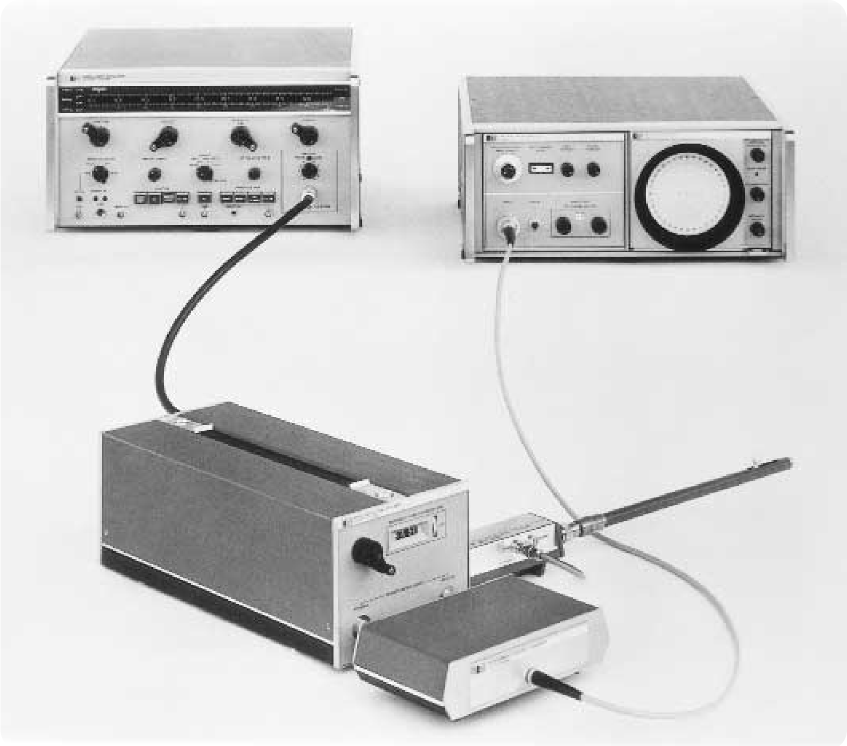
The mid-1990s saw some of the most dramatic and rapid installation ever of a new technology. Development of the ingenious Erbium-doped fiber amplifier made possible the distributed, broadband amplification of signals. Wavelength multiplexing offered up to 120 channel capacity in the same fiber. Huge capacity for digital communications was in sight—none too soon, since the Internet phenomenon was just getting underway.

As the world's transmission capacity doubled, re-doubled, and then went up by factors of 100, the Internet and the digital communications revolution gobbled up capacity. No one knows when or if the demand for high bandwidth will end, but most people recognize that without test and measurement, this communications revolution wouldn't have been possible.

Today Agilent's optical test equipment blankets the industry. For optical component testing there are sources, analysis equipment, and automatic test systems for high volume manufacturing. For field installation and maintenance there are optical TDRs (OTDRs), optical multimeters, and wavelength meters. Agilent systems test chromatic dispersion, polarization, and the unique Erbium-doped fiber amplifiers. Fiber modulation testers can analyze the digital intelligence transmitted down the lines. A family of grating-based spectrum analyzers attacks the wave-division multiplex technology that enables the remarkable 120+ channels per fiber.

Agilent's OmniBER family of communications performance analyzers are the market-leading SONET/SDH testers, testing telecommunications transport networks at optical rates to 2.5 Gb/s. The 71612A 12 Gb/s pattern generator and error detector has become the industry standard tester in labs and production lines for test of optoelectronic components and systems in the new, high-speed optical Internet operating at 10 Gb/s.

RF and microwave component design



In the late 1960s, the 8410A network analyzer ushered in a new era in component design and test.

There is a broad category of test and measurement instrumentation that serves the R&D engineers designing RF and microwave components, all crucial for high performance communications systems. These components include amplifiers, mixers, filters, combiners, antennas, couplers, oscillators, attenuators, and terminations. With many real breakthroughs, HP and Agilent have been primary contributors of R&D bench instruments for component design and test.

Vector network analyzers are important tools. As described earlier, the 8410A network analyzer of 1968 ushered in a revolution in component design and test. Multi-band sweeps of Smith Chart characterizations of components and systems arrived at just the right time for exploiting hybrid microcircuit technology for communications systems.

HP continued to dominate the vector network analyzer category for decades, with lower-frequency range as well as higher-capability products. The 8753A vector analyzer (ca. 1987) covered 3 GHz. Sometimes called the 8510's little brother, it was the first low-cost VNA operating below 3 GHz. This positioned it perfectly for cellular design and test engineers working in the 800 to 900 MHz frequency range, and later 2400 MHz range. The 8753 was also the first RF analyzer to have complete error-correction.

Along with the flashy vector network analyzers, another important (and more numerous) type of component design tool were scalar network analyzers. Scalar parameters were considered entirely adequate for production line test assurance, and these analyzers measured SWR (standing-wave-ratio) and reflection coefficient, as well as transmission parameters.

The first implementation of scalar analyzers was the reflectometer technique that HP pioneered in 1954. This technique used back-to-back waveguide directional couplers, a motor-swept klystron 670A signal source, and a 416A ratio meter to test waveguide components at all frequencies across their band. Systems were developed for waveguide bands from 2.6 to 40 GHz, and for most coaxial bands.

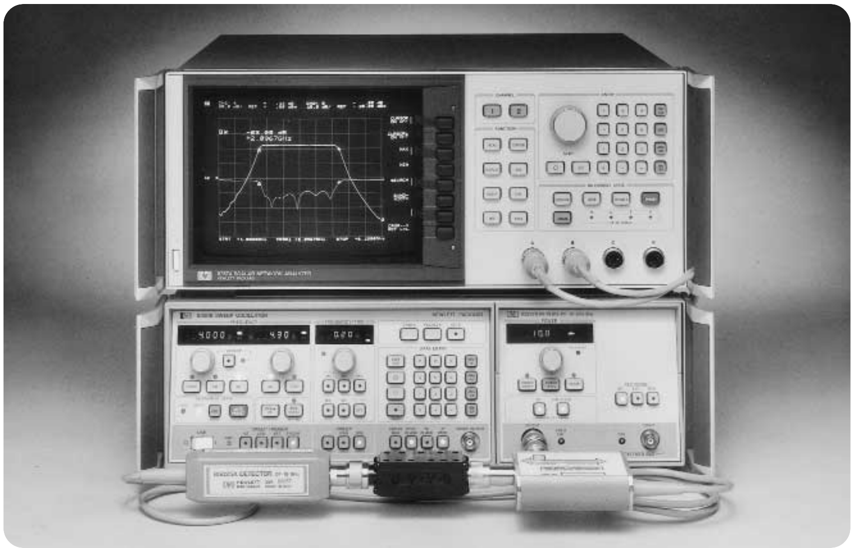
Next came the 890-series sweep oscillators, which exploited backward-wave-oscillators (BWOs) for signal generation, making the sweep electronic. This led to oscilloscope displays with calibrations grease-pencilled onto the CRT screen—not a very aesthetic solution. The 1416A SWR display (ca. 1966) solved that with a scope plug-in that provided calibrated reflection and transmission data.

Other families of sweep oscillators followed, with the 8690-series and eventually the 8620A-series (ca. 1970), which featured solid-state YIG oscillator sources for the first time. HP's microwave-component research labs contributed exceptional results coupling microwave transistors with Yttrium-iron-garnet technology to yield exceptionally stable and high-power sources.

Later came the 8350 and 8340-series signal sources. While early sweeping sources were free-running, sophisticated vector network analyzers required phase-locked stability for proper error correction. The 8340-series sweeping synthesizers were far more than just sweepers.

HP offered a continuing family of RF/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 complete system included dual directional couplers for forward and reverse signal separation, RF/microwave multiband directional bridges, and a new family of wide-dynamic range Schottky diode detectors. It used 30 kHz microwave modulation to extend stability and range.

The 8756A and 8757A scalar network analyzers followed in turn, each with more measuring capability and higher frequency ranges, with the 1985 capability at 60 GHz.



The 8757A scalar network analyzer measured scalar parameters of components to 60 GHz.

HP's 8970A noise figure meter (ca. 1983) pleased circuit designers because they could measure and display the gain and noise figure parameters of amplifiers, mixers, and converters at the same time. Since circuit designers will gladly trade off a little gain to improve the noise figure of an input amplifier, this capability proved highly popular for critical applications such as satellite receiver front end design. An earlier 340A noise figure meter (ca. 1958) measured only noise figure and not gain, so it had only limited usefulness for component work.

Design engineers of RF and microwave oscillators destined for local oscillator applications in most communications systems have particularly difficult tasks, because while their VCO (voltage-controlled-oscillator) usually must be agile to achieve channel tuning, it must at the same time have the lowest phase noise characteristic to minimize out-of-channel interference.

HP's first product to characterize microwave phase noise was the 11729A carrier noise test set (circa. 1983). By downconverting the signal under test using an exceptionally "spectrally clean" signal, the close-in noise spectra could be measured and displayed for analysis. In 1985, the 11740A phase noise measuring set combined the 3047A spectrum analyzer and the 11729B for a complete solution. The later E5500A-series phase noise measurement solutions covered oscillators to 26.5 GHz.

A complete test solution for voltage-controlled-oscillators (VCOs) became available in 1996 with the 4352S VCO/PLL signal test system. This unit characterized 12 different parameters of the VCOs with clever techniques to speed the tests, and they can be installed as production test equipment in high volume assembly applications.

The first simple impedance meters arrived with the acquisition of the Boonton Radio Company in 1960. The 250A (Boonton) RX meter measured reactance to 250 MHz and the unique 260A (Boonton) Q-meter (50 MHz) were industry standards on their own merits.

At about the same time (1962), HP's 4800A impedance meter (500 kHz) and 4815A impedance meter (500 MHz) were introduced. The 4815A used the brand new HP sampling technology, which downconverted the two channels and measured and displayed impedance and phase and gain characteristics. Each meter was supplied with a variety of impedance bridges (components that separated forward and reverse signals) and probing accessories. For design engineers, the insight gained about amplifiers and a wealth of circuit components speeded RF work considerably.

Component measurement technology grew to encompass many other highly important functional parameters. For example, EMC (electromagnetic compatibility) became a legal requirement just about the time digital integrated circuits came into their own. Signal leakage, which some referred to as electronic smog, could interfere with adjacent equipment or test instruments in two ways. If a piece of test equipment was operating in an environment with a high power transmitter, and the equipment's susceptibility was high, it could be jammed by the high-level signal. If its own EMC output was not designed to be low, its digital circuits and RF oscillators could leak enough level to disturb other measurements in the area.

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

With the advent of the 8540A automatic network analyzer in 1968, HP had a measuring tool which could measure the complex amplitude and phase characteristics of RF and microwave antennas. In fact, the technology led to the development of near-field antenna measuring ranges. By manipulating the near-field data of an antenna pattern, computer models could predict the far-field performance without depending on a large outside measuring range. For military communications, the ability to use a small, inside closed range offers obvious advantages.

Other developments focused on the job of totally characterizing antennas. Today the product line includes antenna measurement systems as well as a wide variety of accessories such as computer-controlled pedestals.

In the 1970’s, engineering responsibility for RF impedance measuring instruments transferred to HP’s division in Hachiogi, Japan. Soon powerful, multi-function meters rolled out, featuring many highly innovative probing stations and holding fixtures. This was not surprising, given the large amount of industrial engineering that involved printed and integrated circuit technologies being done at this time for consumer electronics.

Typical instrumentation now offered such capabilities as LCR characterization (with the 4263B LCR meter), crystal resonator measurements (with the E4915A crystal impedance meter), and dielectric and magnetic test (with the 4291B impedance meter/material analyzer). Solutions included software routines to provide design engineers with the latest measurement routines, so they would not have to spend time researching the field for new measurement techniques. For Agilent today, selling the measurement techniques has become as critical as selling the hardware.

One final type of instrumentation was the combination spectrum/network analyzer. Consider that spectrum analyzers are single-channel sweeping superheterodyne receivers and vector network analyzers are two-channel versions. By cleverly configuring a single-channel circuit so that it could also switch its measurement between two network inputs, and by exploiting microprocessor signal processing, HP gave birth to the combination 4395A network/spectrum/impedance analyzer (ca. 1997). It is especially useful for testing communications components such as amplifiers and mixers in which both network and signal characterization is required.

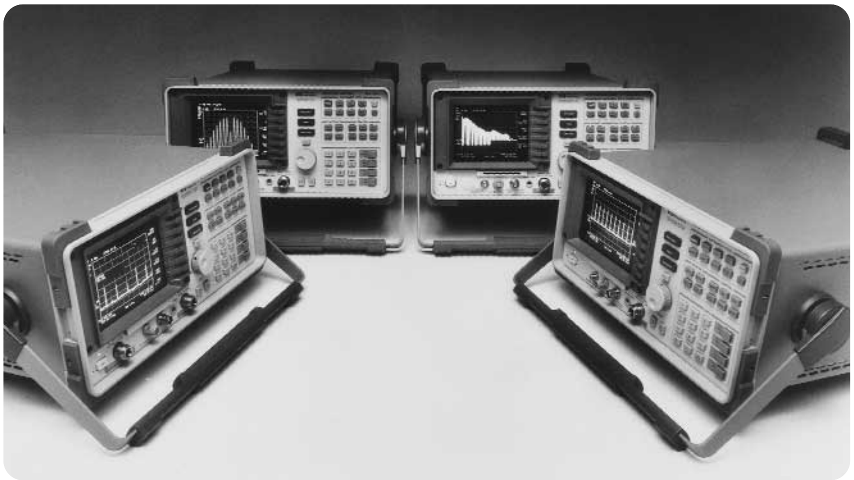
General communications applications

Some instrument types are so widely used that they could logically fit in any communication test sector. Two obvious examples are the oscilloscope and the spectrum analyzer. When HP began manufacturing scopes in 1958, the company became known for several innovations: quality, low frequency scopes (below 1000 MHz) suitable for many production applications; sampling scopes; and TDRs. HP's designs also included many convenience features, including beam finders and internal graticules on the CRTs that eliminated parallax errors in readout.

On the benches of communication engineers, spectrum analyzers are as ubiquitous as oscilloscopes. They analyze the frequency domain of signals with indispensable diagnostic power. From the first 8551/851 analyzer of 1964, HP never stopped innovating. Many spectrum analyzers became the starting point for other measuring instruments such as electromagnetic compatibility analyzers, antenna testing systems, and others.

Modern spectrum analyzers, such as the ESA series, feature digital filtering and all the advantages of the digital age. Still others have frequency ranges to 110 GHz, and measure phase noise and even noise figure. Used with tracking generators, some spectrum analyzers can incorporate measurement of scalar network parameters.

The 8590-family portable spectrum analyzer (ca. 1988) became a fruitful progenitor. By downloading a measurement "personality" from a card, users could configure the hardware and firmware of this highly compact signal analyzer to perform special applications. Cable TV, mobile radio testing of many types, noise figure tests, EMC, and a dozen more application personalities featured custom CRT display calibrations, and the analyzer had an internal card cage to accept hardware circuits for unique signal handling.



The 8590 series portable spectrum analyzers could be customized for cable TV, mobile radio, noise figure, EMC, and other applications using software measurement personalities.

HP and Agilent have dominated microwave power measurements since the first 430A power meter and associated 475A bolometer were introduced in 1950.

Microwave sensors absorb power from a transmission line and heat up. By detecting the heat-caused change in resistance of metallic or thermistor elements, the first power meters could measure and display power. The technology was useful, but frustrating for engineers who had to detect very low power, since they found that just holding a sensor in their hands was enough to make the meter drift off scale.

A major contribution was made in 1961, when the 431A power meter was introduced to take advantage of a dual-thermistor design. This design reduced drift 100-fold and also could measure down to 1 microwatt. A whole line of 478/86A sensors covered a frequency range from 100 kHz to 40 GHz and later to 110 GHz. Older engineers still fondly remember the introduction of this useful concept.

The next big step in microwave power measurement came in 1974, with the introduction of the 435A power meter and its associated 8481A power sensor family. This sensor family was a clever exploitation of a special silicon chip fabrication process that placed a broadband microwave termination on one side of a thin silicon web, and a sensitive metallic thermopile on the opposing side. The meter measured the absorbed heat down to 3 mW and up to 20 mW. Since the sensor was a true power sensing device, it was "square-law" over its entire range.

The 436A digital power meter (ca. 1975) provided important programmability for the popular HP Interface Bus and also featured a new 8484A power sensor, which used the square-law detection characteristic of a temperature-isolated diode to measure down to an amazing 100 pW. The 437A power meter and the 438A dual power meter applied microprocessors to provide more convenience and functional power to measurements.

In 1997 a new family of power meters and sensors was introduced. The 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. Such range permitted measurements right at the receive antenna of microwave radio systems.

General technology contributions

There are a few measurement contributions that do not involve instruments, yet cross all lines of communications and are worthy of recognition. This section will list a few.

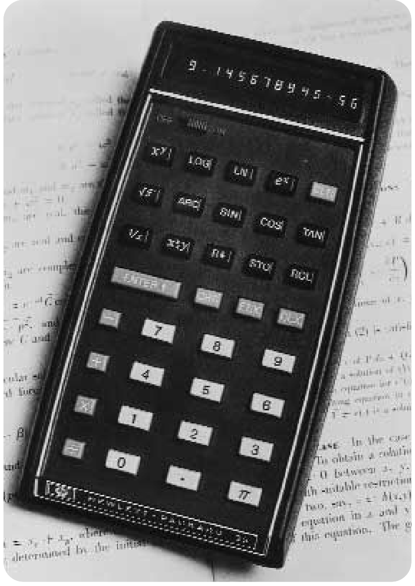
The step-recover-diode is one of these contributions. In the early 1960s, engineer Frank Boff was working on harmonic-comb generators to extend the frequency range of counter frequency converters. One circuit showed non-intuitive results, with high frequency harmonics that were more powerful than theoretically possible from a non-linear resistive device such as a diode. To investigate further, he borrowed an early lab prototype of the HP sampling scope to display a time-domain picture of what was producing such rich signals in the frequency-domain. When he finally got the fuzzy picture focused, he didn't see the expected chopped-off top of a sine wave produced by a diode, but instead saw a sine wave that rose smoothly to almost full amplitude, then suddenly crashed to near zero amplitude.

At that point, serendipity entered. Frank remembered seeing a paper in the IEEE proceedings that theorized that such a waveform might exist if a device exhibited a non-linear charge-versus-voltage curve instead of the non-linear current-versus-voltage curve that defined a diode. Frank reviewed the article, looked again at the strange wave-shape, and proclaimed that what he had taken to be a non-linear resistor, or diode, was actually a non-linear 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 milliamperes 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. Discovered by an extraordinary engineer, the device was called the "Boff diode" for a number of years. The name was later changed to the more generic "step-recovery-diode."

HP exploited this new capability in a variety of ways. HP counters used the harmonic-comb signals to downconvert test signals for counter coverage to 18 GHz. The 8410 network analyzer used a two-channel version to downconvert microwave signals for characterizing scattering parameters to 18 GHz. Sampling oscilloscopes, after prototypes were used to discover the effect, in turn used the diode to generate large sampling impulses for measurement of fast-transition test signals. A whole generation of HP signal generators and sweepers used the rich harmonics to stabilize microwave signals using the technique of indirect frequency synthesis.

HP also became the world leader in exploiting phase-lock loops for frequency control and programmable switching of microwave oscillators. Using step-recovery diodes to provide rich harmonics from stable low-frequency oscillators and using synthesis techniques such as "divide-by-n," sophisticated phase-lock loops were created to discipline microwave oscillators and reduce their phase noise. In fact, using the 312A selective voltmeter and an associated tracking generator, HP designed a new phase-loop measuring technique that produced a signal equal to and tracking with the tuned frequency of the 312A. This combination characterized the closed loop performance of feedback loops, validating the fast switching response and loop stability under wide environmental performance.



The HP 35 pocket calculator changed the way we all do math.

The HP Interface Bus (ca. 1972) was a solution pioneered by HP to provide a practical system for programming electronic instruments under computer control. By developing the system in conjunction with an IEEE/industry committee, this "open system" created a powerful design capability for applications ranging from research and design to production and support. Instruments from many manufacturers designed with the HP-IB functionality could be "daisy-chained" together to furnish stimulus test signals, and measurement data could be taken from a multitude of voltmeters, analyzers, and other measuring instruments. The resulting data could be conditioned, manipulated, and stored.

The IEEE standard became best known as the GPIB, or General Purpose Interface Bus. It was accepted by test engineers for its powerful ability to configure large or small test systems. And as an open standard, it was acceptable to all.

Fast signal sampling technology of the late 1960s enabled another powerful analysis tool to be invented. Recognition that a single electrical event, such as a pulse, contains all the mathematical information needed to define its frequency spectrum gave birth to the Fast-Fourier analyzer. The 5451A Fourier analyzer (ca. 1972) made it possible to achieve real-time spectrum analysis to 300 Hz. That made possible applications in underwater acoustics, medical instrumentation, and vibration analysis. The technology was used in later products with even more amazing results because of faster and more powerful digital computation. The FFT technique was exploited in HP's 89410-series vector spectrum analyzers, described earlier, and used for highly sophisticated communication modulations.

No listing of the company's technical contributions could be complete without mention of the design engineer's personal companion, the HP 35 pocket calculator. Introduced in 1972, this (mostly) electronic engineer's tool revolutionized calculation, replacing slide rules and desktop computers for many of the engineer's daily computations. It provided unparalleled accuracy for transcendental functions and offered many other engineering parameters—all in a package that fit into a shirt pocket. With four computing registers, reverse Polish notation format, a remarkable 200-decade computing range, and 15 digits, it was an immediate hit even at the $395 selling price.

The 2116A instrumentation computer (ca. 1967) brought measurement and control right to the engineer's test bench. The strategy of the computer's design was to provide an accessible card cage on the bottom layer of the product, which allowed programmable instruments to be connected to the computer. Each interface card controlled one instrument, either a stimulus instrument such as a signal generator or dc power supply, or a measurement instrument such as fast a DVM, counter, or spectrum analyzer.


The modular architecture of VXI enabled development of "instruments on a card."

From today's perspective, these automatic systems seem primitive indeed, having the interface of a clacking teletype with punched paper tape. The original 2116A controller had a memory based on ferrite core technology; basic memory size was 4096 16-bit words (expandable to 8K, at $1 dollar per byte.) Storage disks arrived later, as did terminals with CRTs. The real contribution of the 2116A was that unlike business computers of the day, it didn't need to be coddled. The 2116A was designed specifically for the hostile environment of the factory floor.

The HP 9100A calculator (ca. 1968) was the first desktop computer for HP. Conceived before the availability of integrated circuits, its 32-Kbit ROM consisted of a 16-layer printed circuit board loaded with thousands of discrete diodes. It featured a CRT display with 3-display registers and Reverse Polish Notation, and it revolutionized the expectations of design engineers. It led directly to the 1972 family of 9810/20/30A programmable calculators (which would now be called desktop computers), which had HP-IB automation capability.

In addition to integrating instruments with the HP-IB, in 1987 HP led a consortium of major instrument manufacturers to devise a modular architecture, the VXI. This architecture relied on the previous popularity of the computer-industry-standard VME technology, and it initially focused on low frequency and RF. Conceived for portable applications, including military, custom measuring applications were configured into standardized modular cages. Dozens of available compatible instrument solutions from multiple suppliers are now available, and software routines can be devised to control the measurement process, many now using the modern plug-&-play concepts of hardware and software.

A similar open standard was introduced for microwave applications, the modular measurement system (MMS). It was built for higher-frequency signal performance with much more attention given to electromagnetic compatibility and RF/microwave signal routing.

Superstars

Over the decades Agilent has introduced many groundbreaking products. Picking the superstars of communications test is personal, but here are some of our favorites.

The 5060A cesium beam standard could 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 U.S. Naval Observatory time 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, designed for rugged performance and long term reliability, became the first commercial product-of-choice in industrial primary-standards labs. It and a long line of progeny came to dominate the time and frequency standards labs of the world. Since today’s communication technology relies heavily on synchronized transmission frequencies, everything from cellular base stations and broadcast television stations to satellite flying oscillators must incorporate such precise and stable standards.

The 185A/187A sampling oscilloscope (ca. 1960) was a giant leap ahead in RF and digital measurements. Using sampling technology, this scope permitted engineers to measure exceedingly fast transition times for repetitive, pulsed waveforms. It featured a sophisticated triggering circuitry for viewing actual RF waveforms to 1000 MHz. The same sampling scope technology led directly to the 1415A time domain reflectometer plug-in. The ability to view the time separation of reflections from a coaxial transmission structure enabled engineers to diagnose reflections from individual elements. For example, the individual attenuation elements of the 355A VHF attenuator could be seen and each tweaked for exact 50-ohm performance, whereas if all were lumped together in an SWR measurement, no corrective adjustments could be made. This translated into great design power for circuit engineers working on components for communication projects, which relied heavily on coaxial and stripline transmission structures.


The 185A oscilloscope was a giant leap ahead in RF and digital measurement.

Although microwave spectrum analyzers had served the communications industry since the days of WWII, they were cumbersome to use and had narrow dispersions and only modest dynamic range. In 1964, HP introduced its first spectrum analyzer and revolutionized the concept and functionality of the instrument. The 8551A/851A spectrum analyzer, with its 2000 MHz sweep width and its 10 MHz to 12 GHz (or 40 GHz with external mixers) tuning coverage was a marvel of the time. It featured a swept first local oscillator, which was a backward-wave-oscillator, to achieve a wide sweep width. For high stability in narrow sweeps, it used a new technique for phase-locking to a sweeping VHF source.

For the first time, engineers could look at a huge baseband range and characterize the performance of component and system signals for amplitude and harmonic performance. For example, an amplifier could be shown with the fundamental signals and all the signal harmonics. The instrument featured an amplitude dynamic range of 60 dB, and thereby became accepted as a “frequency-domain-oscilloscope.” Spectrum analyzers soon became as ubiquitous on microwave design benches as time-domain scopes were on the benches of low-frequency engineers.

An evolution of spectrum analysis instruments ensued. Smaller size, absolute amplitude calibration, and innovative features such as tracking generators made frequency-response measurements simpler. Solid-state local oscillators made the products more stable and reliable. Plug-in designs allowed selection of different frequency bands and conversion circuits. Eventually spectrum analyzers were integrated into automatic systems using modular construction that mimicked the versatile plug-in design of laboratory scopes.


The 5060A cesium beam standard was used to set the world's clocks.

In 1978, a new generation of spectrum analyzers took full advantage of microprocessors. In fact, these analyzers used three processors each. The HP 8568A and 8566A spectrum analyzers—affectionately known around HP as the "doomsday" machines—had better frequency-tuning accuracy, narrower resolution, lower phase noise, and better phase-lock stability. But the biggest feature was the human interface. These were among the first instruments with a lower panel that looked like a calculator keyboard. A single rotary knob gave selectable analog feel for tuning, but the keyboard offered digital precision. Powerful marker functions allowed marking and measuring of differences between traces. And powerful computation routines stored traces so that one trace could be subtracted from another. Maximum signals could be monitored and stored. Most engineers operating this machine for the first time were dazzled by the performance. The spectrum analyzer had now truly become the "frequency domain oscilloscope." And with the HP-Interface Bus (which became the IEEE-388 or GPIB), it formed a central measurement instrument for even more powerful, automatic spectrum monitoring systems.

The 851A spectrum analyzer, with its wide sweep and tuning range, was a marvel of the early 1960s.

Following 1968's two-channel 8405A vector voltmeter, the 8410A vector network analyzer (VNA) of 1968 revolutionized the characterization of microwave components from 10 MHz to 12 (soon 18) GHz. With its microwave sweeping source and the associated signal-separation test set, the network analyzer met 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 8510A network analyzer combined the power of microprocessors with extensive measurement capability to launch a revolution in component test.

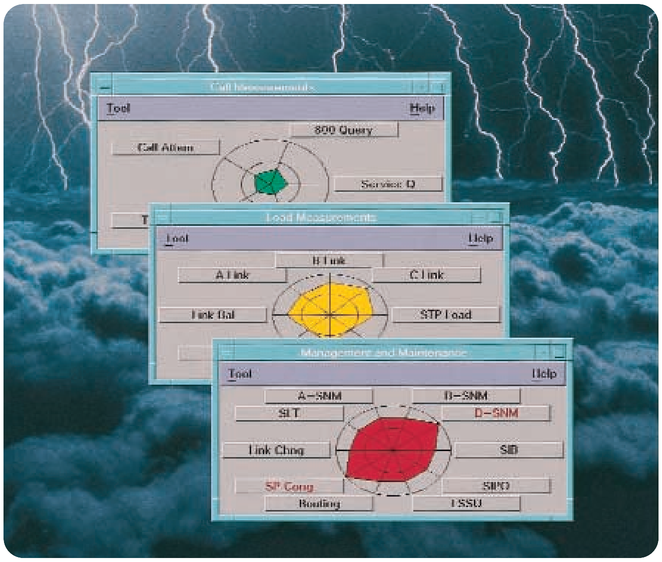
The VNA's introduction came at a propitious time, since the microwave semiconductor revolution was just gaining headway in design labs around the world. Microwave microcircuit technology shrunk the size of amplifiers and intregrated circuitry, and demanded total knowledge of the complex impedance of all the semiconductor chips and on-substrate components such as filters, couplers, and mixers.

The availability of the VNA popularized the design concept of scattering parameters, which are 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, communications 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 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 broadband network analyzer became indispensable for that role.

The 8510A network analyzer of 1985 brought full circle 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. Full of user operating features and error-correction routines, this 26.5 GHz component analyzer pushed into new application areas. For example, it was able to process frequency-domain data and render a time-domain characteristic of the signal passing through a complex sub-system on a chip.

The power of the 8510A resulted in numerous, unexpected applications. With special probing antennas and innovative software routines, dielectric characteristics of microwave materials could be measured. Micro-miniature probing stations and fixturing were developed for wafer testing. Special detection equipment and routines could measure pulsed components that could not survive CW signals.

Importantly, the powerful measuring capability provided by the 8510T network analyzer system (ca. 1987) 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. HP's EEsof Division and other companies such as Compact invented sophisticated microwave circuit-design models in their Advanced Design System software. Now the entire communications signal path could be simulated, from the data stage through microwave circuits and antennas back to the data stage.



The acceSS7 signaling network monitoring system provides network operational monitoring on a vast scale.

The acceSS7 signaling monitoring system took on the world's networks, literally, when it was introduced in 1996. Designed to provide network operational monitoring on a vast scale, it specifically targeted the world-standard CCITT SS7 common channel signaling protocol. The design grew out of the earlier 37900A/C/D signaling test sets.

Scalable and non-intrusive, the acceSS7 measures and displays real-time information on SS7 switching data activity, and provides the platform for a host of network monitoring and management and business intelligence applications. For example, it provides security and fraud operators with automatic real-time messaging status for detecting and reporting suspicious telephone activity. The acceSS7 databases gather key marketing information, such as usage vs. capacity, call duration, and unanswered calls. Such data can be used by service providers to optimize benefits and services. By keeping a constant watch over revenue-critical operations, the acceSS7 system can generate information vital to management decisions on network operations, both hardware and software. The global measurement reach it provides gives system operators advance notice before network performance deteriorates, even by small increments.

Other candidates for the communications superstar category are many:

- The 3710A microwave link analyzer family, introduced in 1967, became the industry standard for installing microwave radio links in North America and Europe.

- The 3760/61 pattern and error detector of 1973 was the world's first commercial 150 Mb/s error rate tester. It helped engineers develop the first generation of digital transmission systems. Through several generations it has led to Agilent's OmniBER family of testers, the market-leading SONET/SDH testers working to 2.5 Gb/s. In 1994, the 71612A 12 Gb/s pattern generator and error detector was introduced, and it has become the industry standard tester in labs and production lines for test of optoelectronic components and systems in the new, high-speed optical internet operating at 10 Gb/s.

- Launched in 1975, the 3745A selective level measuring set was HP's first microprocessor-controlled instrument that accelerated the testing and troubleshooting of frequency division multiplex (FDM) telephone systems by automatically tuning the receiver to the FDM frequency plan.

- A family of compact, portable cellular test sets, launched in 1992, combined measurements of many instruments for transceiver testing of land-mobile and cellular applications. Variations were developed to meet new system formats such as North American Digital Cellular (NADC), GSM, TDMA, CDMA; for DECT (Digital European Cordless Telecommunications); and even for pagers. Today Agilent's test sets for mobile phone manufacturing dominate the industry.

- In the early 1990s, HP extended its range of test for ATM (asynchronous transfer mode) and broadband applications by introducing the Broadband Series Test System. The BSTS has been on the leading edge of ATM technology for switches, routers, and network services, and it continues to support a growing number of protocols that carry voice, data and video services. These include ATM, frame relay, LAN, LAN internetworking, MPEG-2, UNI signaling, NNI signaling, W-CDMA, and more.

The legacy of innovation continues as Agilent provides the communications industry with innovative test and measurement products such as optical spectrum analyzers, a voice-controlled oscilloscope, voice over IP testers, the industry's first gigabit and terabit router testers, 3G wireless solutions, and many more products. On the frontier of new technology, Agilent has launched a family of optical switches that may lead to the realization of the much-anticipated all-optical communications network.

Agilent's wide range of communications offerings today includes breakthrough technology for optical switching, handheld instruments for field-service testing, and drive test systems for optimizing wireless networks.

Agilent's products today

For more than 60 years, Agilent Technologies has contributed to the success of communications companies, and our innovations continue to influence the industry in many areas. Today communications companies face waves of new technology, new business models, and increasing customer demand. Only those who can take advantage of the change will thrive. Agilent Technologies plays a continuing role in the success of these companies, providing the people, technology, components, and tools they need to design, deliver, and manage the next generation of communications networks and services.

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