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TECHNICAL INFORMATION FROM THE -hp- LABORATORIES

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Our Preparations at Hewlett-Packard for the Instrumentation of Tomorrow

To –hp– Journal readers:

Twenty-five years ago, when Dave Packard and I began to design and manufacture electronic measuring instruments, we resolved on two prime objectives. One was to produce instruments that constituted true technical contributions. The second was to produce instruments that embodied quality at moderate cost.

As we now look back and determine the extent to which these objectives have been achieved, we feel a certain sense of gratification. Many major contributions to the measurement art have been originated and introduced by Hewlett-Packard, while at the same time our objective of 'inexpensive quality' has been realized with good success.

Nevertheless, there is always room for improvement and there is always a need for progress as the future unfolds. We felt that our preparations at –hp– for meeting our objectives in the future would be of interest to you, so we have asked our **Journal** editor to write this account. We intend that –hp– instruments will maintain and even improve on the standard set in the past.

—Wm. R. Hewlett

Fig. 1. *Special –hp– designed meter-calibrating machine automatically calibrates indicating meters to ¼% accuracy. Meter being calibrated faces inward on front of machine.*

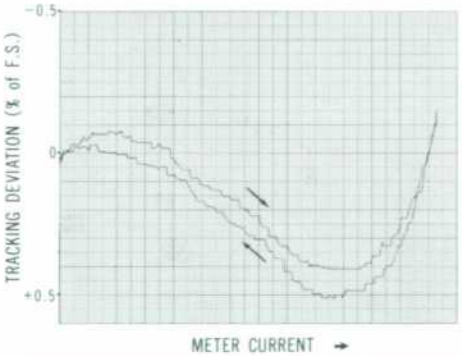


Fig. 2. *Typical meter-performance curve (tracking deviation characteristic) measured by –hp– meter calibrator (Fig. 1). Slightness of loop opening shows freedom of calibrated meter from pivot friction; lack of large anomalies in curve shows freedom from stickiness.*

THIS spring, the Hewlett-Packard Company completed its twenty-fifth year as a designer and maker of electronic measuring instruments. During these twenty-five years, the electronics field has developed and matured almost beyond belief, as everyone knows. Twenty-five years ago, for example, television and radar were in their infancy and transistors were not yet born — nor were many of the sophisticated devices that are now commonplace. And, of course, microwave equipment and practice were essentially nonexistent, one hundred megacycles or so being the upper limit for the 'advanced' tubes and techniques of the times.

The development of the electronics field as a whole in these twenty-five years has been matched by similar progress in the field of electronic measurements and measuring instruments. During all of this time the practice and policy of the Hewlett-Packard Company has been and continues to be to bring into being only instruments that improve the practice and art of measurement through advances in accuracy, range, concept or convenience. Hence, instruments of our manufacture have, it is fair to say, had a responsible place in the technological progress of our country. Such past Hewlett-Packard instruments as the high-speed frequency counter, the resistance-capacitance test oscillator, the 700-megacycle voltmeter, and numerous others (see box) have greatly contributed to prog-

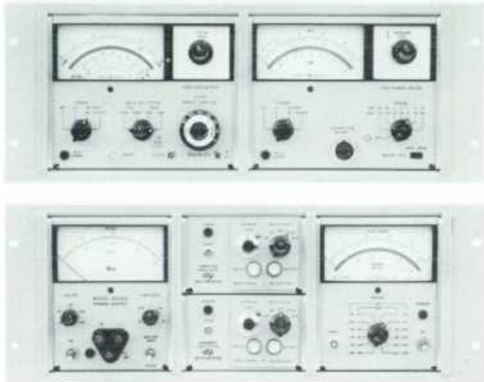


Fig. 3. *Combinations of recent –hp– instruments showing flexibility of modular enclosure system designed and now used by –hp–. Enclosures are 1/3, 1/2 and full EIA rack width, are suited to bench, rack or, with special carrying covers, to field use.*

ress in the electronics field. Today, it is an ordinary and simple matter to measure frequencies up to several thousand megacycles with Hewlett-Packard frequency counters. It is an ordinary and simple matter to observe this same range of frequencies, or its counterpart in fast waveforms, at sensitivities of a thousandth of a volt on Hewlett-Packard oscilloscopes. It is equally simple to make automatic swept-frequency recordings in the microwave range with Hewlett-Packard microwave equipment. And, incidentally, it was to communicate developments such as these to the combined electronics and electrical engineering professions that this *Journal* was begun by Hewlett-Packard some fifteen years ago. During that time –hp– engineers have published herein a number of important and well-known papers, as exemplified by the accompanying listing.

Because of the importance of measuring instruments and of the information they convey, the Hewlett-Packard Company has always assumed a deep responsibility for the integrity of –hp– instruments. Thus it is that much care is taken at –hp– to ascertain that –hp– instruments operate within specifications, even to the point that environmental tests approaching those of military equipment are followed for all new instruments. And thus it is that –hp– engineers assume a responsibility for the measuring instruments that are their handiwork.

When looking to the future, all can see that scientific and technical efforts will continue to play an important part in human society. As these efforts progress and enter into areas presently undeveloped or unexplored, more sophisticated approaches, techniques and instrumentation are certain to be required. All past experience shows that instrumentation has been fundamental to technical progress, and the role of instrumentation will continue to be no less important in the future.

When an instrument-maker looks to the future in the light of his responsibilities as well as in the light of ordinary prudence, it is obvious that he must make serious and well-founded preparations for discharging these responsibilities. Preparations must be made, for example, such that an engineering staff of suitable competence and diversifi-

Fig. 4. *Assembly area in* –hp– Associates *manufacturing facility.* –hpa– *was established in recent years to produce special semiconductor devices for –hp– and for industry.*

cation is devoting its effort toward designing the instrumentation required for tomorrow. It must then be possible to manufacture such advanced instrumentation. Since this will undoubtedly require new and imaginative manufacturing techniques, it becomes necessary that the manufacturing staff be prepared and qualified to apply and, if need be, generate such techniques. And, thirdly, steps must be taken so that the knowledge and application of this instrumentation can be adequately disseminated by a sales engineering staff to those in the technical and scientific field who are dependent on instrumentation for quantitative information.

–hp– RESEARCH AND DEVELOPMENT

At Hewlett-Packard the engineering program has always been guided by a philosophy that has two points of interest here. One is that the engineering work has been strongly product-oriented. The second is that *–hp–* engineering has been conducted while maintaining a close liaison between design engineers and the *–hp–* field engineers who have the normal day-to-day contact with instrument users. This arrangement has the important advantage that open channels of communication are maintained between those who use instruments and those who design them. As a result, *–hp–* design engineers have always had a high degree of awareness of the needs of instrument users. Emphasis has thus been maintained on the end products, resulting in instruments that are flexible in purpose and suited to the user's needs.

The design effort at *–hp–* has traditionally been divided along product lines, but several years ago as the design groups became larger the grouping was done in a more formal way. Related groups were formed into laboratories that were each wholly composed of generic instrument design groups. Such an arrangement achieved greater engineering depth since the design engineers achieve a degree of specialization on a particular type of instrument. They are thus better equipped to contribute to instrument development. The arrangement has proved effective and is expected to continue into the future. Hewlett-Packard frequency synthesizers, sampling oscilloscopes, high-frequency converters and many others are examples of contributions made by these consolidated groups in recent times.

With the passage of time and a progressive growth in the *–hp–* engineering effort, considerable support engineering in the nature of advanced work groups has now been

SOME MAJOR –hp– INSTRUMENT DESIGNS

- Resistance-Capacity Test Oscillator (1939)
- 1-Mc Sensitive Voltmeter (1941)
- Portable Frequency Standard (1943)
- 700-Mc Voltmeter (1946)
- Continuous-Coverage Audio Distortion Analyzer (1946)
- FM Monitor (1947)
- 1800-4000 Mc Direct-reading Signal Generator (1947)
- 10 cps-10 Mc Test Oscillator (1948)
- Milli-Microsecond Pulse Amplifier (1949)
- Parallel-Plane Slotted Line (1949)
- .07-10 Microsecond Pulse Generator (1950)
- 10-500 Mc Signal Generator (1950)
- VHF Impedance Bridge (1950)
- High-Speed Frequency Counter (1951)
- Interchangeable-Section Waveguide Slotted Line (1951)
- Low-Frequency Function Generator (1951)
- Precision Multi-Hole Directional Coupler (1952)
- 100-Mc Frequency Converter (1953)
- Precision Waveguide Attenuator (1953)
- 4-Mc Sensitive Voltmeter (1954)
- Microwave Reflectometers (1954)
- High-Frequency Transfer Oscillator (1955)
- High-Directivity Coaxial Directional Couplers (1955)
- The Balanced Resistance-Capacitance Oscillator (1955)
- Fast Digital Recorder (1956)
- Microwave Sweep Oscillator (1957)
- Automatic Noise Figure Meter (1958)
- Digital Delay Generator (1958)
- Dc Micro Volt-Ammeter (1958)
- Current-Limiting Transistorized Power Supply (1958)
- Clip-On Dc Milliammeter (1958)
- Automatic Dc-Microwave Calorimetric Power Meter (1958)
- Voltage-to-Frequency Converter (1958)
- Automatic-Ranging Dc Digital Voltmeter (1959)
- 50 Kc-65 Mc Signal Generator (1959)
- Wide-Range Clip-On Ac Current Probe (1959)
- 20 cps-50 kc High-Selectivity Wave Analyzer (1959)
- VHF Sampling Oscilloscope (1960)
- High-Precision Frequency/Time Standard (1961)
- Noise-Rejecting Dc Digital Voltmeter (1961)
- RMS-Responding 10-Mc Voltmeter (1963)
- Nanosecond Oscilloscope (1964)
- 0-50 Mc Frequency Synthesizer (1964)
- 3000 Mc Frequency Converter (1964)
- Microwave Spectrum Analyzer (1964)

Fig. 5. *Assembly area in –hp–'s Loveland, Colorado, plant for taut-band meters now being used in some –hp– instruments.*

added to the overall –*hp*– engineering program. The support groups can be divided into two general classes, one consisting of laboratories that perform work common to two or more of the product-design groups or work of a nature required only occasionally by the product groups. Several such common-support laboratories exist at Hewlett-Packard and range from several chemistry laboratories through specialized electrical groups to special physics groups.

The second support effort performs long-range development on concepts which may not be applicable to a specific instrument group or on which the development time or development outlook may not be suited to a product group. Coherent optics, beam tubes, and electro-acoustics are examples of this support effort.

With a view toward the future and toward the potential application of semiconductor and related sciences, a facility was established at –*hp*– some ten years ago to develop and produce the specialized semiconductor devices that were beginning to appear promising for instrumentation. Three years ago, as the number of devices developed in this facility became larger and as some of the devices began to find application by outside groups, the facility was expanded into a much broader effort in the form of –*hp's*– affiliate, –*hp*– ASSOCIATES. Today, the –*hpa*– solid-state development facility comprises several superbly-equipped advanced laboratory groups which have demonstrated proficiency in solid-state technology.

The complete –*hp*– research and development effort presently includes some twenty-five different laboratories which provide the specialized work needed in developing the instrumentation of today and the immediate future. The work of these groups embraces a broad section of technical disciplines ranging from the development of circuits to the development of complicated systems, from the development of neon lamps to the development of electro-luminescent devices, and from the development of basic transducers to the development of advanced solid-state devices.

ENGINEER DEVELOPMENT

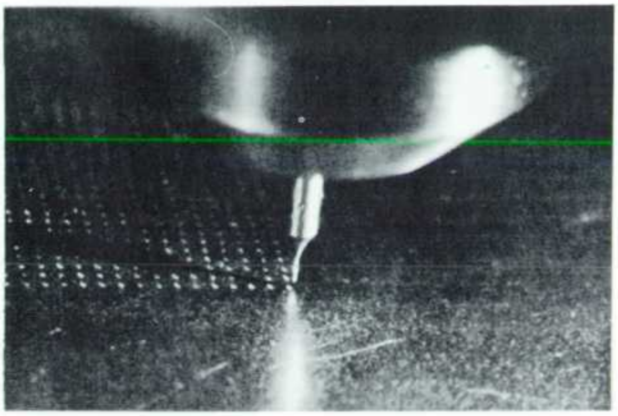
Any plan of preparedness for the future must include a program for the development of engineering personnel and this has not been overlooked. Ten years ago a program was established with Stanford University whereby qualified graduate engineers employed at –*hp*– could advance their education on a part-time basis. Under this plan –*hp*– allows time off for class attendance and reimburses the 'student' for one-half his tuition and book charges upon completion of the course.

The results of the engineer-development program have been significant. Nearly 50 Master of Science degrees have been granted to –*hp*– engineers. In addition, three Engineer and four Ph.D. degrees have been granted. Of these degree recipients, all but eight are still employed by –*hp*–. Currently, more than forty engineers are participating in the –*hp*– Honors Cooperative Program to further their training for the future.

MANUFACTURING AND ENGINEERING

Much of what can be achieved in an advanced field such as instrumentation is inherently interlocked with the capability to perform specialized manufacturing. To produce advanced instrumentation, a surprising number of specialized components unavailable elsewhere must not only be designed but also manufactured. Consequently, specialized manufacturing capability is presently required, and will certainly be needed for the future as well.

Over a period of time substantial effort has been expended toward establishing a capability for designing and producing specialized components. Because of this capability it has been possible to produce a number of well-known instruments not previously available. One example is the DC Micro Volt-Ammeter which measures dc voltages as small as 1 microvolt and currents as small as 1 micro-microampere through the use of special photo-conductors designed and developed in the –*hp*– laboratories. Another example is the high-frequency converters used with frequency counters to measure frequencies up to several kilomegacycles. These were made possible through the design and development in the –*hp*– laboratories of



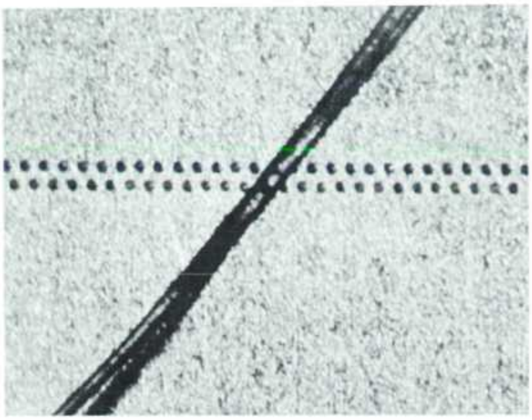


Fig. 6. *In-house developed ultraprecision air-bearing spindle has been used with numerical-control machine tools to drill complex arrays of precision miniature holes. Line across right photo is human hair strand.*

the step-recovery diode. The display storage feature first introduced on *–hp–* counters was also made possible through the development of *–hp–* photo-devices.

A fourth and most important example is the development in the *–hp–* laboratories of the servo-calibrating machine for calibrating individual meter movements with a speed and accuracy much superior to that previously known. This in-house-designed and in-house-built machine automatically calibrates meters in a few minutes' time to an accuracy of much better than 1%*. At the same time the machine produces a quality-related signal that permits previously undetectable pivot-roll or stickiness in the meter movement to be examined in very great detail. The machine is now being used to calibrate the special taut-band type meters that are presently being used in a number of *–hp–* instruments. These meters have a torsion type suspension that avoids conventional bearings altogether. As calibrated with the servo-calibrating machine, the taut-band meters make available to the engineering profession measuring equipment with meter performance and accuracy unavailable a short time ago. Accuracies of 0.1% to 0.2% for these movements are typical.

* Bernard M. Oliver "Increased Accuracy in –hp– Meters Through Servo Calibrating Methods," **Hewlett-Packard Journal,** Vol. 12, No. 7, March, 1961.

SOME NOTABLE ARTICLES PUBLISHED IN THE HEWLETT-PACKARD JOURNAL

Design Notes on the Resistance-Capacity Oscillator Circuit (1949)

The High-Speed Frequency Counter—A New Solution to Old Problems (1951)

Inexpensive Quality (1951)

Good Practice in Slotted Line Measurements (1951)

A Precision Directional Coupler Using Multi-Hole Coupling (1952)

Table of Important Transforms (1953)

The *–hp–* Microwave Reflectometers (1954)

Some Effects of Waveform on VTVM Readings (1955)

A Simple Precision System for Measuring CW and Pulsed Frequencies up to 12,400 Mc (1955)

Square Wave and Pulse Testing of Linear Systems (1955)

Sputnik's Doppler Shift Measured and Recorded (1957)

Permanent Record and Oscilloscope Techniques with the Microwave Sweep Oscillator (1957)

An Improved Method for Measuring Losses in Short Waveguide Lengths (1957)

Noise Figure and Its Measurement (1958)

The Effect of μ-Circuit Non-Linearity on the Amplitude Stability of RC Oscillators (1960)

Improved Sweep Frequency Techniques for Broadband Microwave Testing (1960)

Increased Accuracy in *–hp–* Meters Through Servo Calibrating Methods (1961)

The Present Attainments of Adjustable Power Supplies (1962)

Time Domain Reflectometry (1964)

A New Performance of the "Flying Clock" Experiment (1964)

A Measurement of the Zero-Field Hyperfine Splittings of Cesium 133 and Hydrogen (1964)

Fig. 7. *Aerial view of –hp–'s Stanford plant in Palo Alto, California.*

Special capabilities have also been built up for many other special-purpose components such as quartz plates, special-characteristic precision resistors, transformers, tuning capacitors, special neon lamps, special tubes, solid-state devices of a number of kinds, transducers, and others.

LOW-COST MANUFACTURING CAPABILITY

In producing precision electronic instruments, it has been essential for –hp– to be capable of producing needed special parts and components at low cost, despite the small quantities in which these parts are used. Otherwise, of course, the use of a few special components in an instrument would make the cost of the final product excessively high if not prohibitive. To achieve a low-cost manufacturing capability, an unusually wide variety of manufacturing methods have been incorporated into the –hp– manufacturing facility. Metal etching, vapor deposition, silicone-rubber molding, plastic molding, die-casting, printed-circuit fabrication, spray painting, and plating are examples of present in-house manufacturing processes.

A fabrication method of increasing importance for low-cost fabrication in the –hp– facility involves the use of 'numerical-control' machine tools. Several techniques have been explored and developed for employing these tools with other advanced equipment. This effort is probably most noticeable in the machining of castings. Considerable use is made of aluminum castings in –hp– equipment, and the use of numerical-control machining both reduces the cost of finished castings and makes their use more widespread because of lower cost.

In-house generated techniques are also being used with numerical-control tools in some cases to perform otherwise-impractical and even impossible operations. One example of this is found in the use of an –hp– developed air-bearing spindle which permits ultra-precise drilling when used on conventional mills and drill presses. This spindle, which was described in a recent issue of the *Journal*,* has a run-out or deviation from true round of only .000003". When combined with a numerical-control drill press, it has been used to drill matrices composed of 4,000 such ultra-precise miniature holes in a working day.

The numerical-control tool is widely recognized as a logical supplement in manufacturing to the digital computer in engineering work, and this combination has been used for some time at –hp– in a design-to-production relationship. Some time ago the –hp– engineering and computer-programming group worked out a general computer program for solving the problem of the contours needed for a cam to translate a nonlinear tuning characteristic into a linear dial drive system. Needless to say, such cams must be precise and machining them by conventional methods is very costly.

The existence of this computer program and the availability of numerical-control tools in the –hp– manufacturing facility has reduced both the design as well as the fabrication of such cams to a routine matter. The drive variables for an individual new design are fed to the computer which produces the numbers for the tape of the numerical-control mill in a few minutes. The cams are then machined automatically. A number of recent –hp– instruments employ drive systems using these cams and more are expected in future instruments.

PERSONNEL DEVELOPMENT

What is true about a need for the development of engineering personnel in response to an advancing technology is also true of personnel in other groups including the manufacturing group. In recognition of this, a broad program has been under way for some years for development of manufacturing personnel. In fact, at least six separate programs are available for various levels of manufacturing personnel from assemblers through middle management. In addition to programs designed to advance technical knowl-

* Edward H. Phillips, "An Air-Bearing Spindle for Highly Precise Machining," **Hewlett-Packard Journal**, Vol. 15, No. 7, March, 1964.

edge, programs exist for other development such as improving supervisory skills.

The broadest of the programs is one in which all employees at the main factory have the opportunity to attend an evening course designed for general employee development. In another program courses have been given to test engineers and technicians to improve their technical knowledge as advances have occurred in the level of electronic techniques and devices used. A four-year, 8,000-hour apprenticeship program with related junior-college level instruction for machinists and tool- and diemakers has resulted in 16 completions with nearly 40 men presently in training. An Educational Assistance Program separate from the Honors Cooperative Program mentioned earlier is available to employees for work-related subjects. And all assemblers at the main factory have recently been given refresher courses to assure a high level of understanding and workmanship.

MARKETING

As mentioned earlier, it has always been considered essential at *-hp-* for the development groups to be well informed not only about present but also about future needs of instrument users. In recognition of this, one of the most important field functions assigned to the *-hp-* marketing organization has always been to operate as an effective communications link between the field and the *-hp-* development groups. This is, however, but one of three major marketing-department field functions. The second is acquainting and training customers in the uses and application of new instrumentation as it is produced from the *-hp-* laboratories. The third function is maintaining a suitable program for instrument maintenance.

With these functions in mind, the Hewlett-Packard field sales-engineering staff has recently been more tightly consolidated into a single-representation group. We at *-hp-* believe this step will provide a number of benefits to *-hp-* customers. These benefits derive from the fact that the customer has available for consultation a sales-engineer whose full time is spent with *-hp-* instruments. This has the advantage that the sales-engineer becomes more intensely trained in *-hp-* instruments and is thus in a better position to advise of their application. He also acquires broader experience in the measurement problems that are in his field of expertise.

It is of interest to note that virtually every *-hp-* field sales-engineer each year attends at the factory at least a one-week course in the theory and use of *-hp-* instruments. This is, of course, over and above the training each receives when he enters the field. This training ranges from several weeks to more than six months, depending on individual circumstances.

All field sales-engineers also attend monthly training sessions given at field offices by factory personnel. Individual offices supplement this with additional training sessions of local design.

Field sales-engineering offices are now located in or near all of the industrial centers of the country — more than forty offices in all. Many of these have direct teletype lines to the main plant. Field sales-engineering offices are also located in many of the main centers in Europe.

SERVICE PREPARATIONS

All equipment manufacturers are undoubtedly aware of a responsibility to assist in minimizing equipment 'down' time, but it has always

Fig. 8. *Eastern Service Center at Rockaway Township, New Jersey, was recently established to facilitate repair and recalibration of -hp- equipment in eastern U.S.*

been Hewlett-Packard policy to assume this responsibility to the fullest. 'Same day parts shipment' has, for example, long been in effect at –hp–, and the –hp– service organization has been recognized for its effectiveness.

A major step recently taken to prepare the –hp– service organization to render even more assistance in the days to come is the inauguration of two national service centers — one in northern New Jersey*, and the second at Palo Alto, California†. These centers are equipped to perform major repairs and to recalibrate virtually any of the instruments manufactured within the –hp– organization. The existence of these centers can save the customer significant time if a major repair is required. They also shorten the delivery cycle on major repair parts since such parts are stocked at the centers.

Over and above these advanced centers are the repair offices now maintained at some 25 cities in the United States, in one city in Canada, and in several cities in Europe. These local service facilities are designed to give a more individual handling of customers' service problems, to perform emergency repairs, and to have available the more commonly used replacement parts and operating supplies. Direct teletype lines from these field repair offices in the U. S. to teletype printers located in the stockrooms of the national service centers are now used to implement the 'same day parts shipment' mentioned above.

* Hewlett-Packard Eastern Service Center, Green Pond Road, Rockaway Township, New Jersey 07866.

† Hewlett-Packard Western Service Center, 395 Page Mill Road, Palo Alto, California 94306.

GOALS

It has always been the objective at –hp– to produce instrumentation of high standards, and the present wide usage of –hp– instruments is undoubtedly a measure of how well that objective has been met. It has also been an –hp– objective to render a high standard of service. These continue to be Hewlett-Packard objectives for the future.

—*F. J. Burkhard*
Editor

HEWLETT-PACKARD COMPANY


William R. Hewlett


David Packard

–hp– was founded in 1939 when William R. Hewlett and David Packard, as candidates for the degree of Electrical Engineer from Stanford University, joined in a partnership to manufacture electronic laboratory measuring instruments. Their first product was the resistance-capacitance test oscillator which Hewlett had just invented and patented. By applying their philosophy of designing and producing only instruments that contributed an advancement to the measuring art, their firm grew until it is now recognized as a world-wide leader in the measuring instrument field. The firm is actively directed by Hewlett, as president and director, and Packard, as board chairman and chief executive officer. Both men are also active in numerous professional and business affairs. Both are holders of several patents in the measuring field and have held offices in the IEEE's forerunner, the IRE, both being fellows and Hewlett being past president. Both are trustees of Stanford University and Packard is a past board president. Both Hewlett and Packard hold a number of major directorships including, for Hewlett, the J. I. Case Co., Kern County Land Co., and The RAND Corp. Directorships held by Packard include General Dynamics Corp., Pacific Gas and Electric Co., and United States Steel Corp.