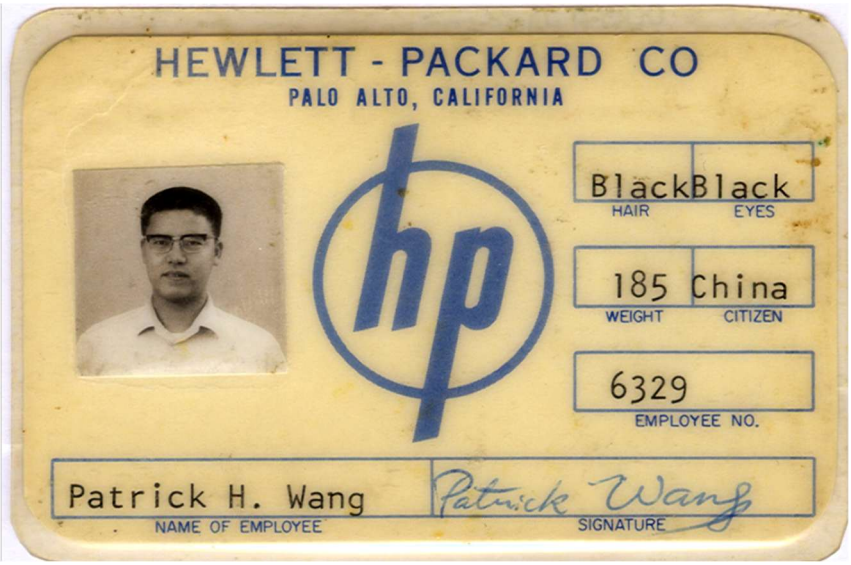
Pat Wang Tech Center Memoirs

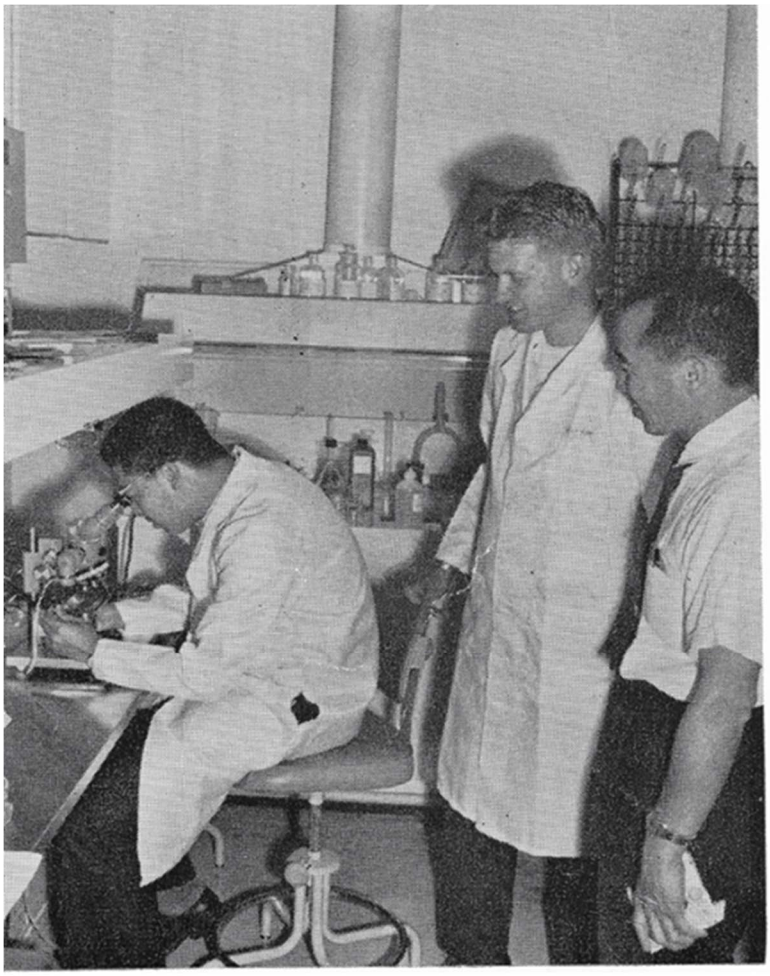
"While I was at HP's Palo Alto office, under the guidance of Art Fong, I converted a janitor's closet into a thin-film laboratory (as shown in the second image).

This lab, measuring only 3 by 3 meters, was used to develop the latest microwave thin-film integrated circuits, designed to replace bulky and costly microwave equipment. This work was featured in HP's internal publications

And the research was documented in a paper and published in the proceedings of the American Institute of Engineers, also was mentioned in the HP's 1970 annual report."



Above Pictrue I：My HP employee ID in PALO ALTO, California.

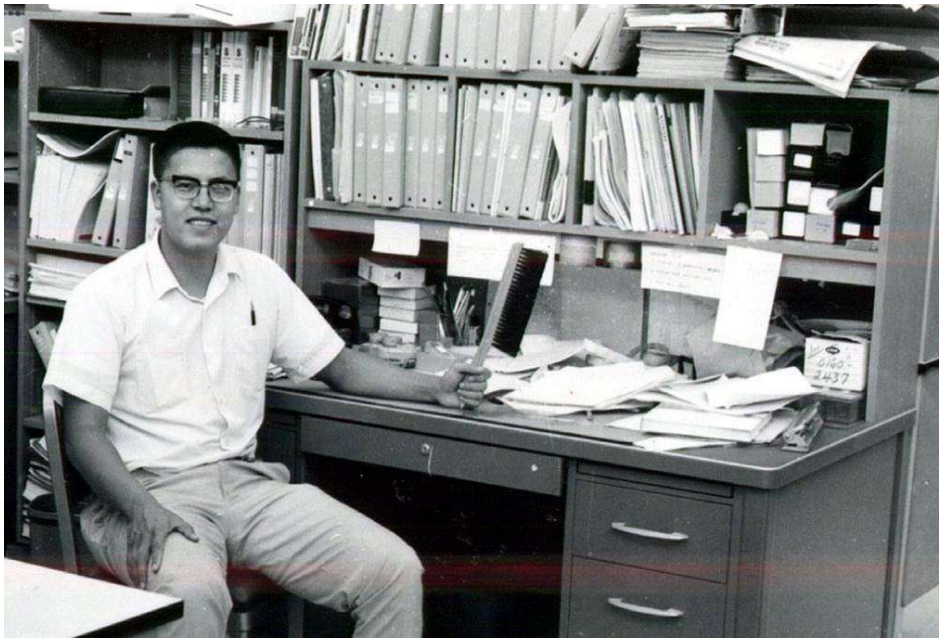


DAVE WOOLF (center, Microwave 5U) recently won an Honorabl Mention award in Eta Kappa Nu' (electrical engineering honors so ciety) program to name the Out standing Electrical Engineering Stu dent in the U.S.A. He will receiv an award at a Wescon luncheo August 25. Dave is working in thi film microcircuits at HP for th summer, and will return to Car negie Tech to continue work tc wards his Master's degree.

PAT WONG (left), who joined H in July, recently received his Mas ter's degree from Stanford. AR FONG (right) is head of thin filr microcircuit R&D for the Micrc wave Division.

Above Picture II：The Film CKT, After joining HP in 1966, I (left) and Dave Woolf (center) established this ultra-miniature thin-film processing laboratory under the guidance of Art Fong.

Above picture：Photographed in HP PALO ALTO office in 1967.In 1967, HP used many bulky instruments to test the samples they produced.



Above picture：Photographed in HP PALO ALTO office in 1967.

Above picture：Photographed with Lab assistants in HP office in 1970.

The microwaves of the future

Jewel-like microcircuits are helping to change whole concept of instrument building. HP has a unique combination of experience and capability in this new microelectronics field . . .

Imagine, if you will, the inside of an HP instrument
he future: small glittering components fashioned of sap-
e and rare earths, burnished with gold, laced with gos-
er gold thread and adorned with gem-like wafers bearing
roscopic circuits of designs inspired by Mondrian. Don't
se your head. That jewelled kind of product package is
ady with us — here, today, in production. What's more
ortant, to quite a few knowledgeable people it looks like
wave of the future for a wide range of other instruments
components.

Microwave integrated circuitry — or microelectronics
short — does in fact hold the promise of becoming a very
-growing segment of the company's business. Today ap-
ximately 170 people are employed by Microwave Divi-
n directly in the design and manufacture of the new-style
uits which currently range in selling price from $150 to
500. In addition, a large and growing number of engi-
rs working on next-generation instruments now are de-
ning microcircuits for use in instruments that will be
aller, lighter and more reliable. Looking ahead, if con-
rvative projections are fulfilled, microcircuitry will require
e services of more than 1,000 people within five years.

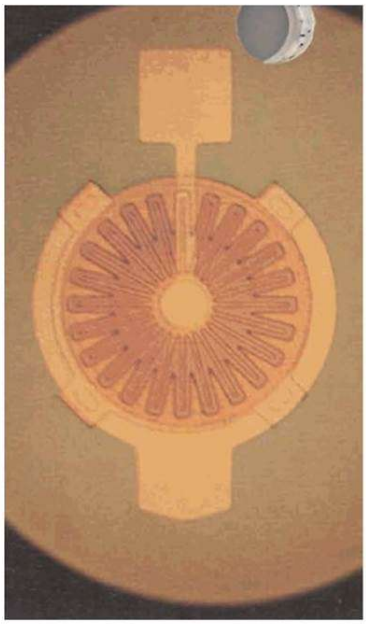
What kinds of products are involved? The present line
nsists mainly of watch-size amplifiers and oscillators that
come parts of complex radio frequency systems such as
P signal generators and spectrum analyzers, or microwave
lephone links and community-antenna television networks.

It's a David-versus-Goliath mismatch: HP's tiny 35005A microcir-cuited wideband amplifier easily outperforms its much bigger competitor. Front-cover photograph shows a variety of the new jewel-like microelectronic products now being produced by Microwave Division.

Above picture III：In 1969, I presented my first research paper at the International Microwave Symposium in the United States. The paper focused on the technical design of a solid-state broadband power amplifier, which had a bandwidth ranging from 10 MHz to 2000 MHz, entirely built using silicon semiconductors. The design software for this project was co-developed by me and my HP colleagues Luiz Peregrino and Ralph Eschen-bach.

1970
HEWLETT-PACKARD COMPANY ANNUAL REPORT

William R. Hewlett



Above Picture：My article and photo from the International Microwave Symposium were also featured in the 1970 HP Annual Report. Advanced microcircuit technology enables HP to reduce the size and cost of instruments, at the same time increasing their reliability and usefulness.

The following information is recorded in HP's 1970 annual report.

Sophisticated solid-state devices, integrated circuits and hybrid microcircuits are the elemental building blocks of complex electronic instrumentation. They have made possible today's compact, economical and extremely reliable measuring and data processing instruments.

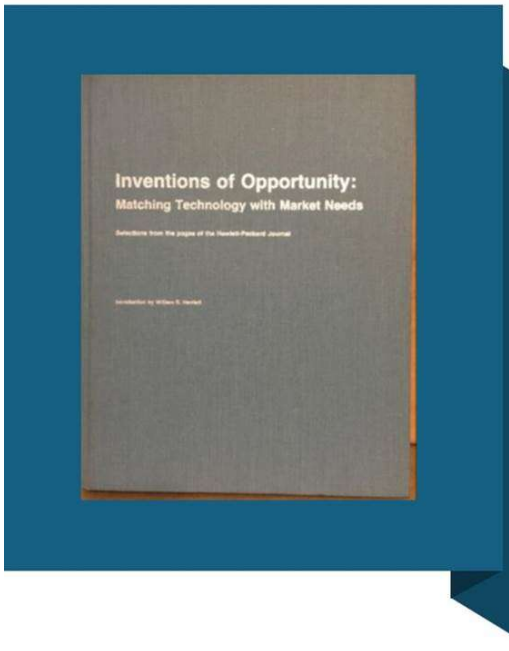
Increasingly, to fill its needs, Hewlett-Packard is designing and manufacturing its own highly engineered components. By doing so, the company is able to exercise additional controls in the design and development of its instruments and systems.

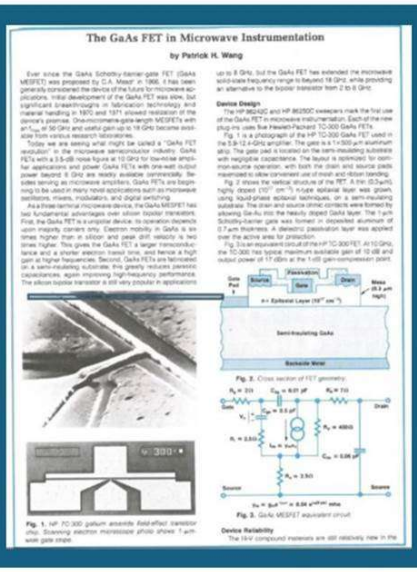
Hewlett-Packard has demonstrated industry leadership in developing solid-state photoconductor devices, step recovery and PIN diodes, MOS technology, monolithic integrated circuits and light-emitting diodes. Components such as these, developed initially for HP instruments, can now be produced to exacting quality standards-in high volume. Consequently, the company today is providing reliable solid-state devices in large quantities to outside customers- establishing itself in a new, important market.

These internal capabilities also have a synergistic effect. The creation of an integrated circuit, for example, may lead to the development of an instrument that provides more functions at lower cost, a higher degree of reliability, and a smaller, more convenient size. On the other hand, the introduction of an instrument by one division may give another the tool it needs to produce a new instrument of its own.

This structured, interactive background for technological development has also made it possible for the company to design many of the specialized tools needed during the manufacturing and testing phases of its own products. These range from highly specialized equipment used in the fabrication of component parts to automated test systems for continuous and consistent reliability checks of finished products. The systems have had an added benefit, in that their successful performance has helped establish the company as a leader in custom designed systems for outside sale.

Above Picture：George Bodway， TThe results we developed in that small thin-film research lab. And our supervisor, Dr. George Bodway to lead us in verifying a microwave integrated circuit design method based on S-parameters. The verification was highly successful, and this design generated new business for HP's microwave instruments division, earning over a billion dollars for HP.





The GaAs FET in Microwave Instrumentation

by Patrick H. Wang

Ever since the GaAs Schottky-barrier gate FET (GaAs MESFET) was proposed by C.A. Mead[1] in 1966, it has been generally considered the device of the future for microwave applications. Initial development of the GaAs FET was slow, but significant breakthroughs in fabrication technology and material handling in 1970 and 1971 showed realization of the device's promise. Submicrometer-gate-length MESFETs with f_{max} of 50 GHz and useful gain up to 18 GHz became available from various research laboratories.

Today we are seeing what might be called a "GaAs FET revolution" in the microwave semiconductor industry. GaAs FETs with a 3.5-dB noise figure at 10 GHz for low-noise amplifier applications and power GaAs FETs with one-watt output power beyond 8 GHz are readily available commercially. Besides serving as microwave amplifiers, GaAs FETs are beginning to be used in many novel applications such as microwave oscillators, mixers, modulators, and digital switching.

As a three-terminal microwave device, the GaAs MESFET has two fundamental advantages over silicon bipolar transistors. First, the GaAs FET is a unipolar device; its operation depends upon majority carriers only. Electron mobility in GaAs is six times higher than in silicon and peak drift velocity is two times higher. This gives the GaAs FET a larger transconductance and a shorter electron transit time, and hence a high gain at higher frequencies. Second, GaAs FETs are fabricated on a semi-insulating substrate; this greatly reduces parasitic capacitances, again improving high-frequency performance. The silicon bipolar transistor is still very popular in applications up to 8 GHz, but the GaAs FET has extended the microwave solid-state frequency range to beyond 18 GHz, while providing an alternative to the bipolar transistor from 2 to 8 GHz.

Device Design

The HP 8620C and HP 86290C sweepers mark the first use of the GaAs FET in microwave instrumentation. Each of the new plug-ins uses five Hewlett-Packard TC-300 GaAs FETs.

Fig. 1 is a photograph of the HP TC-300 GaAs FET used in the 5.9-12.4-GHz amplifier. The gate is a 1 × 300-μm aluminum strip. The gate pad is located on the semi-insulating substrate with negligible capacitance. The layout is optimized for common-source operation, with both the drain and source pads maximized to allow convenient use of mesh and ribbon bonding.

Fig. 2 shows the vertical structure of the FET. A thin (0.3-μm), highly doped (10^{17} cm^{-3}) n-type epitaxial layer was grown, using liquid-phase epitaxial techniques, on a semi-insulating substrate. The drain and source ohmic contacts were formed by alloying Ge-Au into the heavily doped GaAs layer. The 1-μm Schottky-barrier gate was formed in deposited aluminum of 0.7-μm thickness. A dielectric passivation layer was applied over the active area for protection.

Fig. 3 is an equivalent circuit of the HP TC-300 FET. At 10 GHz, the TC-300 has typical maximum available gain of 10 dB and output power of 17 dBm at the 1-dB gain-compression point.

Fig. 2. Cross section of FET geometry.

Fig. 3. GaAs MESFET equivalent circuit.

Device Reliability

The III-V compound materials are still relatively new in the semiconductor industry. Therefore, many people are suspicious of GaAs FET reliability. From our extensive reliability test results and from reports from other leaders in this field[2,3], the device itself is very reliable and an MTBF (mean time between failures) of 10^6 to 10^8 hours is expected. Even though the gate is made of aluminum with fine geometry (1 μm × 0.7 μm), metal migration should not be a problem because the gate is not supposed to carry any appreciable current. Even under heavy RF driving conditions, the gate current can be reduced by a proper negative bias on the gate. However, because the GaAs FET has a very high impedance at low frequencies, it is more vulnerable to static charge or transient spike damage. Extreme care must be exercised during device handling and testing, and spike protection circuits are recommended.

Acknowledgments

GaAs FET development has taken a long time and much team effort. Many people contributed to the project during the many different phases of the program. Their combined efforts made the end product possible. Special acknowledgment should go to C. Liechti and E. Gowen of HP Laboratories for their initial device and process development; to C. Li for his continuous effort in LPE work; to M. Marcelja, R. Tillman and C.C. Chang for their final state process development work; and to A. Chu, P. Froess, P. Chen and D. Lynch for their contributions in device characterization, testing, and reliability evaluations.

References

1. C.A. Mead, "Schottky-Barrier Gate Field Effect Transistor," Proceedings of the IEEE, Vol. 54, p. 307, 1966.
2. D.A. Abbott and J.A. Turner, "Some Aspects of GaAs MESFET Reliability," IEEE Transactions on Microwave Theory and Techniques, Vol. 24, p. 317, 1976.
3. T. Ha et al., "Reliability Study of GaAs MESFETs," IEEE Transactions on Microwave Theory and Techniques, Vol. 24, p. 321, 1976.

Patrick H. Wang

Pat Wang is section manager for GaAs device technology in HP's Microwave Technology Center. With HP since 1966, he's been concerned with the development of microwave integrated circuits, microwave IC amplifiers, and microwave transistors. An IEEE member, he's authored six papers on microwave transistors for IEEE publication and conferences. Pat received his BA degree in literature from National Taiwan University in 1960 and his MSEE degree from Stanford University in 1966. He's married, has three daughters, lives in Santa Rosa, California, and is interested in photography.

Patrick Wang