



## Broadband, Solid-State Amplifiers

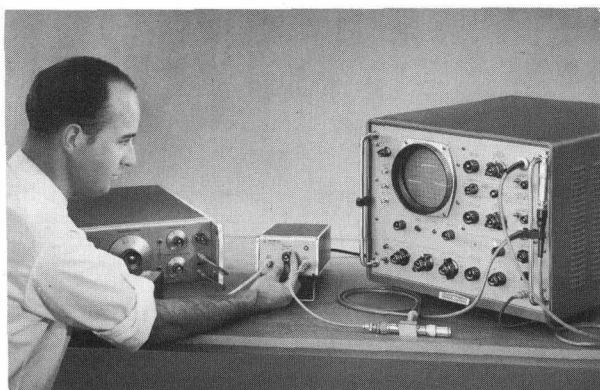
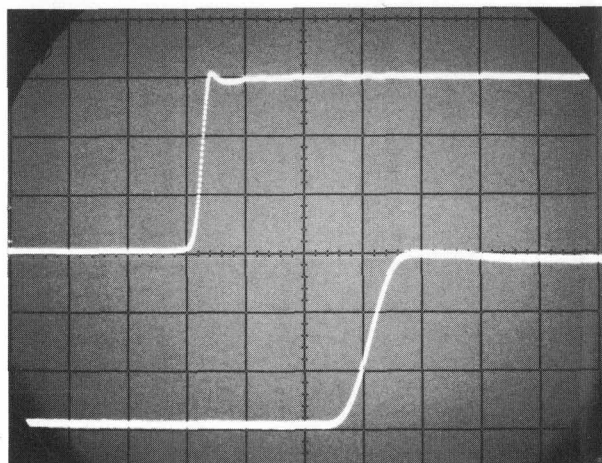


Fig. 1. New broadband, solid-state amplifier is built in two versions. Model 462A Pulse Amplifier, shown here, has frequency response characteristics optimized for best transient response. Model 461A has flat frequency response that places  $-3$  db points at 1 kc and 150 Mc.



(a)

Fig. 2. Dual trace scope photo (a) shows fast rise and freedom from overshoot of -hp- Model 462A Amplifier step response in lower trace. (Sweep speed: 5nsec/cm.) Upper trace shows input step. Graphs (b) show fre-

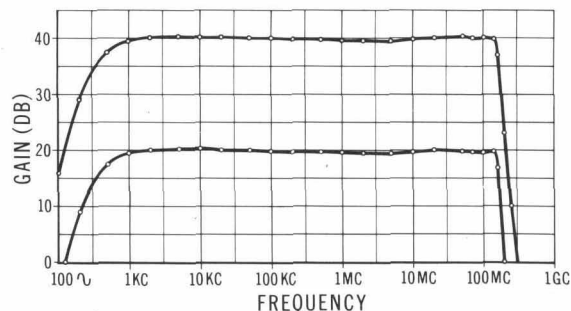
AMPLIFIERS that have a wide bandwidth or the capability of fast transient response are useful in many electronics and physics applications. Whenever low level, high-frequency signals are encountered, a broadband amplifier is indispensable for increasing signals for electronic counters, for example, or for such purposes as measurement by conventional voltmeters and oscilloscopes.

For this reason a new, general-purpose amplifier is now offered by Hewlett-Packard. Two versions of this amplifier have been designed. One version, the -hp- Model 461A, is optimized for flattest amplitude response over the widest possible bandwidth. This amplifier has a gain of 40 db and the frequency range between 3 db points extends from 1 kc to 150 Mc (a switched 20 db attenuator is included for those situations not requiring full amplifier gain).

The other version of the amplifier, -hp- Model 462A, is also a wideband unit but the passband

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New Standard Broadcast Schedules, p. 4  
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(b)

quency response of -hp- 461A Wide Band Amplifier, which is optimized for flattest response over wide frequency range. Model 461A and 462A differ with respect to shape of response curve but otherwise are identical.

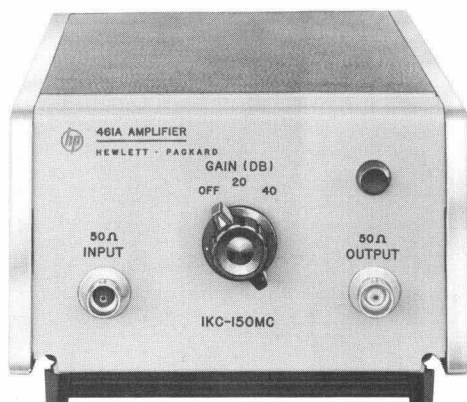


Fig. 3. Model 461A amplifier provides either 40 db (100  $\times$ ) or 20 db (10  $\times$ ) of broadband gain. Input and output impedances are both 50 ohms.

is shaped for fastest possible rise-time with minimum overshoot and ringing. Risettime of this amplifier is better than 4 nsec while overshoot is less than 5%. This amplifier likewise has a maximum gain of 40 db and a switched attenuator for reducing the gain to 20 db.

Except for the differing passband characteristics, the amplifiers are identical. Both are designed with input and output impedances that match the widely-used 50-ohm coaxial cable systems. Both are all solid-state, permitting the units to be small with low power consumption, cool operation, and hence good stability and reliability.

The broadband 461A has a maximum output of  $\frac{1}{2}$  v rms and the 462A pulse amplifier has an output

capability of 1 v peak-to-peak. Where higher outputs are required, the new amplifiers may be cascaded with the *-hp-* 460 series broadband amplifiers, using a plug-in transformer (*-hp-* 11038A) to match the 50-ohm impedance to the 200-ohm impedance of the 460 series. Broadband outputs up to 125 volts are available with this combination and it thus becomes possible to drive cathode-ray tubes directly with the cascaded amplifiers to achieve exceptionally wideband scope performance.

#### CIRCUIT DETAILS

The amplifier performance is realized with only five cascaded stages of amplification. This design has been made possible through use of new type NPN silicon high-speed switching transistors, obviating the need for the more expensive distributed amplifier configuration.

Each of the five amplifying stages achieves stability as well as broad bandwidth by using both series (emitter degeneration) and shunt (collector-to-base) feedback. Flat response is maintained without an overall feedback loop.

The amplifier stages are in a common-emitter configuration as far as the ac signal is concerned. For dc, however, the transistors operate essentially in the common-base configuration with emitters biased through large resistors to a negative bus and bases tied to ground through low value resistors for best dc stability. Each stage has a gain of 8.4 db but 2 db is lost in the input and output emitter-followers so that the overall gain is 40 db. Fig. 4 shows the good linearity obtained with this design.

A block diagram is shown in Fig. 5. The input, either straight through or by way of the 10:1 attenuator, is terminated at the first emitter-follower. The input to this stage is paralleled by a 59-ohm resistor in series with a small compensating inductance so that the effective input impedance is 50 ohms over a broad band of frequencies, as shown in Fig. 6.

The output emitter-follower is designed to drive a 50-ohm load. For those cases where the amplifier is to be used with a high-impedance load, a feed-through termination is available. The termination provides the proper load for the amplifier

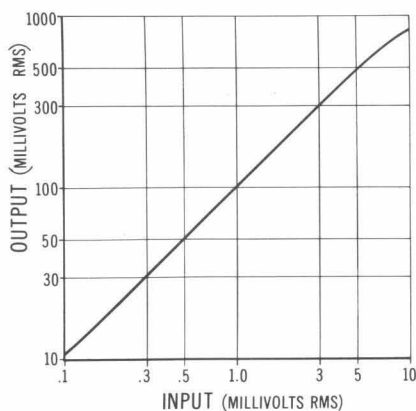


Fig. 4. Transfer characteristics show linearity typical of *-hp-* Model 461A amplifier.

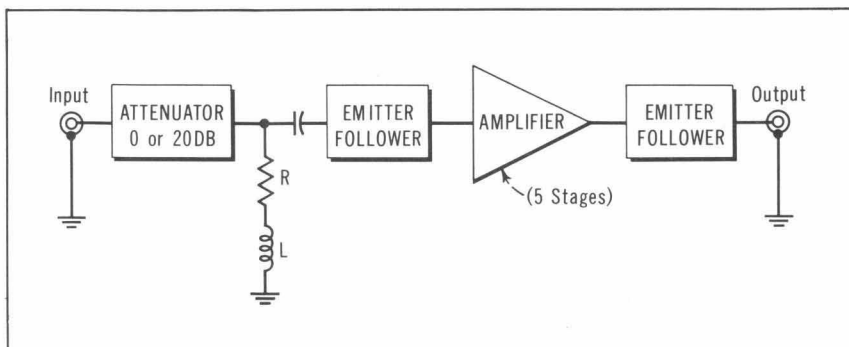


Fig. 5. Elemental block diagram of 461A/462A amplifiers.

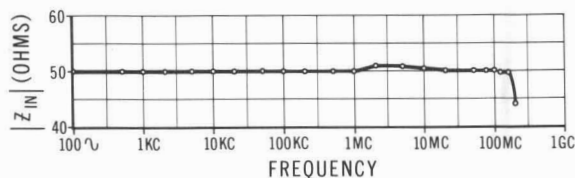


Fig. 6. Measured input impedance of 461A/462A amplifiers as a function of frequency. Compensated input network has practically uniform impedance throughout frequency range of amplifier.

output while making available a cable coupling for external circuits (Fig. 7).

The two amplifiers have the same dynamic range and gain capabilities. It has been shown, however, that a high frequency roll-off that follows a curve similar to the normal probability or gaussian curve provides minimum overshoot and ringing. The 462A pulse amplifier frequency response follows such a curve above 30 Mc, limiting overshoot to less than 5% with practically no ringing, even though a rise-time of less than 4 nsec is achieved.

The noise spectrum of the 461A is shown in Fig. 8. Although the amplifier is rated to have less than 40  $\mu\text{V}$  rms of broadband noise, referred to the input, this curve is more meaningful for those many applications where only the noise in a particular frequency range needs to be taken into account.

#### OTHER APPLICATIONS

The usefulness of laboratory equipment is enhanced by addition

of one of these amplifiers. For example, sources of radio frequency interference generated by high frequency or fast pulse circuits can be located and identified with the *-hp-* Model 185A/B Sampling Oscilloscopes and a 461A or 462A amplifier. An exploring loop of two or three turns of wire attached to the amplifier input cable serves as a convenient probe. The amplifier provides sufficient gain to drive the sync input of the sampling scope while also feeding one of the scope input channels through a probe tee on the amplifier output cable, as shown in Fig. 9.

Measurements of the noise figure of individual low-level circuits, while the circuits are still in the breadboard stage, are possible with the 461A as a preamplifier for the *-hp-* Models 340B and 342A Noise Figure Meters (the noise figure meters were designed to work at the output of complete IF strips that have 40 db or more gain).

When the 461A or 462A are used as preamplifiers in noise measure-

ments, the final reading must be adjusted to account for the noise figure of the amplifier, of course, using this formula for cascaded noise sources:

$$F_{\text{total}} = F_1 + \frac{F_2 - 1}{G_1} + \dots,$$

$$\text{or, } F_1 = F_{\text{total}} - \frac{F_2 - 1}{G_1}$$

In this case,  $F_1$  and  $G_1$  are the noise figure and power gain of the tested circuit, and  $F_2$  is the noise figure of the 461A or 462A. The 40  $\mu\text{V}$  RMS noise level of these amplifiers means that their noise figure is:

$$F_2 = \frac{\text{Total output noise power (referred to input)}}{\text{Noise power of } 50 \Omega \text{ input resistance}}$$

$$= \frac{(40 \mu\text{V})^2 / R_{\text{in}}}{(10 \mu\text{V})^2 / R_{\text{in}}} \approx 16$$

(In db, this would be 10 log 16, or  $\approx 12$  db).

The 50-ohm impedance of the new amplifiers is well-matched for



Fig. 7. Accessory feed-through termination has built-in 50-ohm resistance for terminating amplifier output while providing an output connection for external high impedance circuits.

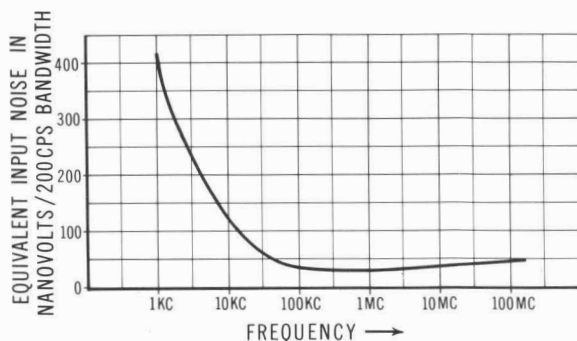


Fig. 8. Plot of noise spectrum of 461A amplifier is useful for estimating noise contribution of amplifier when filters limit signal bandwidth. Logarithmic frequency scale shown here exaggerates importance of transistor 1/f noise at low end of scale, which actually contributes less than 1% of total noise.

#### PAPERS SOUGHT FOR CONFERENCE ON AUTOMOTIVE ELECTRONICS

In view of the fact that advances in automobile design will require developments in electrical and electronic equipment, the First National Conference on Automotive Electrical and Electronics Engineering will take place in Detroit this fall (Sept. 22 and 23).

Sponsored by the Southeastern Michigan Section of the IEEE, the PTG-IECI, and four universities (Michigan, Michigan State, Wayne State, and Detroit), the conference seeks original papers on vehicle control, communication and signalling, energy conversion, and test instrumentation, among other subjects. Prospective authors are urged to get further information from Papers Committee Chairman, E. A. Hanyasz, G. M. Research Labs, G. M. Tech. Center, Warren, Michigan.

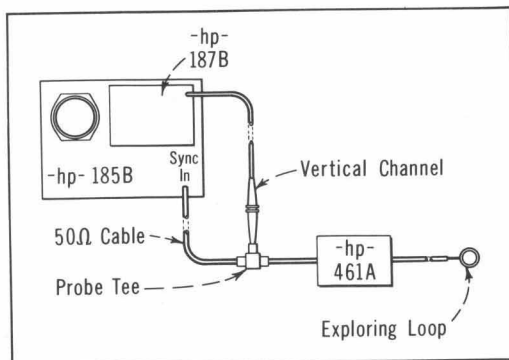


Fig. 9. Block diagram shows use of amplifier with search coil and oscilloscope to probe for RF radiation sources.

use with the -hp- 355 series attenuators when incremental levels of stable gain are desired along with broadband performance.

#### ACKNOWLEDGMENTS

The 461A and 462A were designed at the Loveland Division of the Hewlett-Packard Company. The

electrical design and development was done by John Boatwright and the undersigned, while Darrell Coble helped with the mechanical layout. The valuable ideas and suggestions made by many individuals at the Loveland Division are greatly appreciated.

—Alfred F. Gort

#### SPECIFICATIONS

##### -hp- MODEL 461A BROADBAND AMPLIFIER

**FREQUENCY RANGE:** 1 kc to 150 Mc.  
**FREQUENCY RESPONSE:**  $\pm 1$  db when operating into a 50 ohm resistive load (500 kc reference).  
**GAIN AT 500 KC:** Selected by front panel switch: 20 or 40 db  $\pm 0.5$  db.  
**INPUT IMPEDANCE:** Nominally 50 ohms.  
**OUTPUT:**  $\frac{1}{2}$  volt RMS into 50 ohm resistive load.  
**EQUIVALENT WIDEBAND INPUT NOISE LEVEL:** Less than 40  $\mu$ v in 40 db position.  
**DISTORTION:** Less than 5% at maximum output and rated load.  
**OVERLOAD RECOVERY:** Less than 1  $\mu$ sec for 10 times overload.  
**PRICE:** \$325.00.

##### -hp- MODEL 462A PULSE AMPLIFIER

**PULSE RESPONSE:**  
**LEADING EDGE AND TRAILING EDGE:**  
**RISE TIME:** Less than 4 nanosec.  
**OVERSHOOT:** Less than 5%.  
**PULSE OVERLOAD RECOVERY:** Less than 1  $\mu$ sec for 10 times overload.  
**PULSE DURATION FOR 10% DROOP:** 30  $\mu$ sec.  
**EQUIVALENT INPUT NOISE LEVEL:** Less than 40  $\mu$ v in 40 db position.  
**INPUT IMPEDANCE:** Nominally 50 ohms.  
**GAIN:** 20 or 40 db selected by front panel switch.  
**OUTPUT:** 1 volt p-p into 50 ohm resistive load.  
**PRICE:** \$325.00.

#### GENERAL

**DIMENSIONS:** Nominally  $3\frac{1}{2}$ " high x  $5\frac{1}{8}$ " wide x 11" long.  
**WEIGHT:** Net 4 lbs., shipping: 6 lbs.  
**POWER SUPPLY:** 115 or 230 v  $\pm 10\%$ , 50 to 1000 cycles, 5 watts.  
**CONNECTORS:** BNC female.

#### ACCESSORIES AVAILABLE:

-hp- 11038A 50 to 200 ohm transformer, \$27.50.  
 -hp- 11048A 50-ohm feed-thru termination, \$10.00.  
 -hp- 1051 (\$78.00) or 1052 (\$82.00) Combining Cases (holds six -hp- 461A/462A amplifiers).

##### -hp- MODEL 11038A MATCHING TRANSFORMER

**IMPEDANCE:** 50 ohms to 200 ohms.  
**RISE TIME:** Less than 2 nanoseconds with negligible overshoot and ringing when properly terminated.

**FREQUENCY RESPONSE:** <100 kc to >200 Mc at 3-db points.  
**ET CONSTANT** ( $\int e dt$ ): >15 v- $\mu$ sec on 200 $\Omega$  winding for unidirectional pulses.  
**INSERTION LOSS:** <0.25 db at 10 Mc; <0.4 db at 100 Mc.  
**CONNECTOR:** Type N to -hp- 460.  
**PRICE:** 11038A, \$27.50.

Prices f.o.b. factory.

Data subject to change without notice.

## MODIFICATIONS IN NBS STANDARD FREQUENCY AND TIME BROADCASTS

### Geophysical alerts

A new schedule for the Geophysical Alerts broadcast by NBS radio stations WWV and WWVH becomes effective on 1 April 64. Symbols for the Alerts, broadcast in Morse code at 7 wpm, are listed here:

GEO-MMMMM (Magnetic storm)  
 GEO-NNNNN (Magnetic quiet)  
 GEO-CCCCC (Cosmic ray event)  
 GEO-SSSSS (Solar activity)  
 GEO-QQQQQ (Solar quiet)  
 GEO-WWWWW (Stratospheric warming)  
 GEO-EEEE (No Geolert issued)

The Alerts are broadcast during the first half of the 19th minute of each hour on WWV, and during the first half of the 49th minute of each hour on WWVH.

### Adjustment in phase of time signals

The clocks that control the time signals broadcast by both NBS and the U. S. Naval Observatory will be retarded 100 milliseconds on 1 April 64 at zero hours UT (7 p.m. EST of 31 March). NBS stations affected will be WWV, WWVH, and WWVB; U. S. Navy stations are NBA, NPG, NPM, NPN, and NSS.

The adjustments, necessitated by changes in the speed of rotation of the earth, are made by international agreement to enable synchronization within about 1 millisecond of time signals broadcast by participating countries. Participating countries are Argentina, Australia, Canada, Czechoslovakia, Italy, Japan, South Africa, Switzerland, United Kingdom, and the United States.

### VLF schedule

Low frequency standard broadcasts from National Bureau of Standards stations WWVB and WWVL will be on a new schedule beginning 1 April 64. Both stations will broadcast continuously from 1630 UT (11:30 a.m. EST) Wednesdays to 2230 UT (5:30 p.m. EST) Fridays but on Saturdays, Sundays and Mondays, broadcasts will be from 1630 UT to 2230 UT each day. On Tuesdays, WWVB alone will be on from 1630 UT to 2230 UT one week and WWVL will be on for the same period during the next week.



## AN AIR-BEARING SPINDLE FOR HIGHLY PRECISE MACHINING

ADVANCED developments in electronics generate requirements for a concurrent sophistication in related mechanical design. As microwave techniques extend to shorter wavelengths, for instance, the tolerances permitted on the mechanical dimensions of waveguide equipment become exceptionally tight. To illustrate, a frequency meter for millimeter wavelengths requires parts that are accurate to 0.000050 inch with less than 2 microinch rms surface roughness and a companion directional coupler requires holes that are bored to an accuracy of 0.000050 inch with respect to both size and location. Unfortunately, even the highest quality machine tool spindles deviate from true round rotation to virtually the entire tolerance allowed.

A photographic mask for diode manufacture, as another example, requires 4025 holes drilled to a diameter of 0.0016 inch in 0.002 thick brass shim stock. With the finest conventional equipment, three weeks time is required to fabricate one mask, and that is done with less than acceptable hole quality.

An organization such as Hewlett-Packard that works toward the forefront of the state-of-the-art in one area often finds that it is required

to push the state-of-the-art in other areas to achieve desired goals. Such is the case with machine tools for making the parts described above. Since the dimensions required are finer than the mechanical tolerances allowed on conventional machine parts, new developments in machine-tool technology were called for. It was suggested that some of the problems would be solved by the development of a spindle using an externally-pressurized air-lubricated bearing.

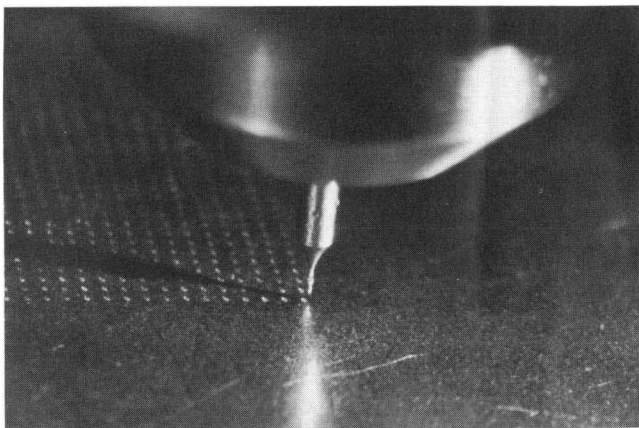


Fig. 2. View through microscope shows drill bit held in miniature chuck clamped magnetically to spindle shaft. Holes shown in square array have 0.004 inch diameter and are spaced on 0.020 inch centers.

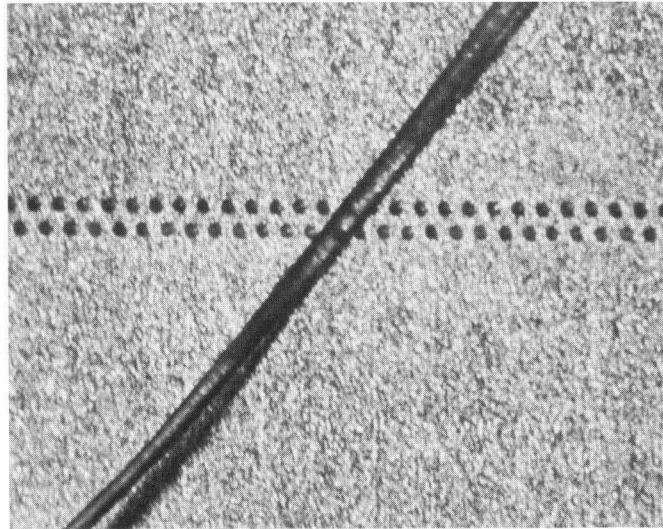


Fig. 1. Microphotograph of holes drilled by air-bearing spindle. Array consists of double row of 0.002 inch dia holes spaced on 0.004 inch centers in brass shim stock. Large "wire" is strand of human hair, shown for comparison.

### AIR-LUBRICATED BEARINGS

Air-lubricated bearings have been the subject of intense study during recent years. Interest in their capabilities runs high because they have exceedingly low viscous drag and generate a minimum of noise and vibration, in addition to having accuracy, cleanliness and a potentially long life. In other technological areas they are attractive since they can operate at high or low temperatures, or in corrosive atmospheres and also because the lubricant is not susceptible to radiation damage. They are not a panacea, however. Successful operation requires that air-bearing parts be manufactured to close tolerances. Furthermore, many experimental air-lubricated bearings have been prone to instabilities, such as air "hammer" and other shaft oscillations. The

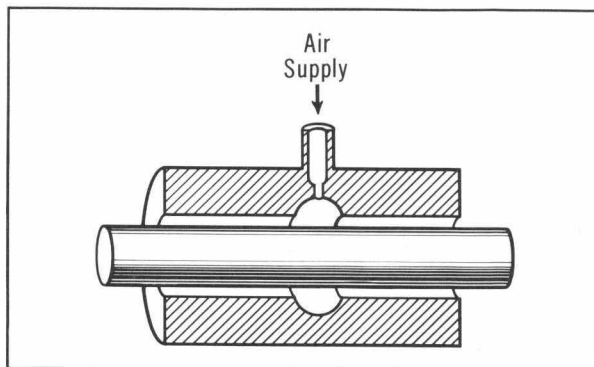


Fig. 3. One form of air-lubricated bearing in cross-section. Clearances shown here and in following drawings are exaggerated for illustration.

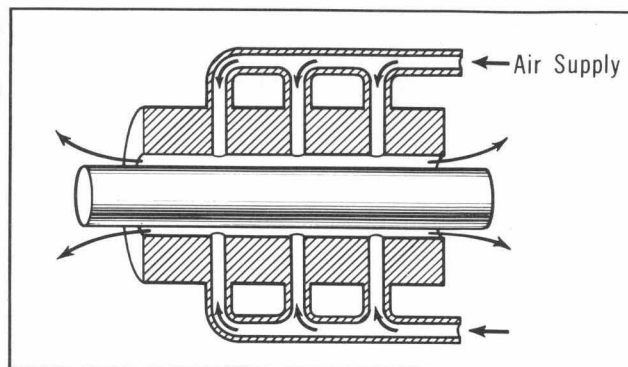


Fig. 4. Cross-section of multiple-venturi bearing.

aero-dynamics of an air-lubricated bearing are exceedingly complex and are not readily analyzed, making design difficult.

One typical configuration for an air-lubricated bearing is shown in Fig. 3. Air under pressure is introduced circumferentially around the center of the shaft and is obliged to flow out in a thin layer between shaft and housing. Any radial movement of the shaft alters the air flow pattern, causing high pressure regions to build up which tend to counteract the shaft movement. To obtain adequate "stiffness" (resistance to deflection), however, this type of bearing has to be relatively long. (Besides, it has doubtful high speed performance.)

Another type of air bearing is shown in Fig. 4. This one is a multiple application of a "school boy" experiment involving the Venturi effect, as shown in Fig. 6. In this experiment the high velocity of the air between the cardboard and spool lowers the air pressure, according to Bernoulli's law, restraining the cardboard from dropping off. In the bearing, likewise, the speed-up in air velocity as the air passes between shaft and housing reduces the air pressure. Any radial movement of the shaft squeezes off the air flow on one side so that pressure rises on that side, restoring the shaft to the center position. This type of bearing also requires considerable length to obtain adequate stiffness and it also

expends considerable quantities of air.

A third type of bearing is shown in Fig. 7. Rather than surround the bearing completely, this bearing consists of several "pads" which work in pairs on opposite sides of the bearing surface. The internal configuration differs from the bearing of Fig. 3 in that the "pockets" are relatively large, in addition to being compartmented.

To keep the shaft centered in the housing the following action occurs. An impressed force  $F_i$  on the shaft, directed downwards in the example of Fig. 7, tends to move the shaft with respect to the housing. This movement closes off the bottom gap and opens the opposite gap, altering the resistance to lubricant flow through the end of the housing. Because lubricant flow into the pockets is limited by the supply orifices, pressure drops in the upper pocket while pressure builds up within the lower pocket. The pressure difference restores the shaft to its normal position.

An electrical analog of this behavior is shown in Fig. 8. The effect of the movement of the shaft is to alter the resistances of elements  $r_{c1}$  and  $r_{c2}$ , which represent resistance to lubricant flow, creating an unbalance in the system which then develops a restoring force.

Oil-lubricated bearings such as this have been used for many years.

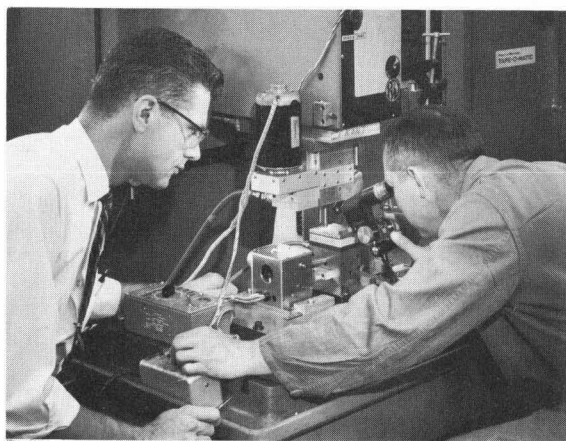


Fig. 5. Air-bearing spindle mounted on drill head of tape-controlled machine tool. Drill head serves only as fixed mount since spindle has own motor and enclosed belt drive for minimum vibration. Operator, looking at work piece, requires microscope because of small dimensions. In this application, work piece is raised by small, cam-driven table guided by flat air-bearings to achieve extremely smooth movement.

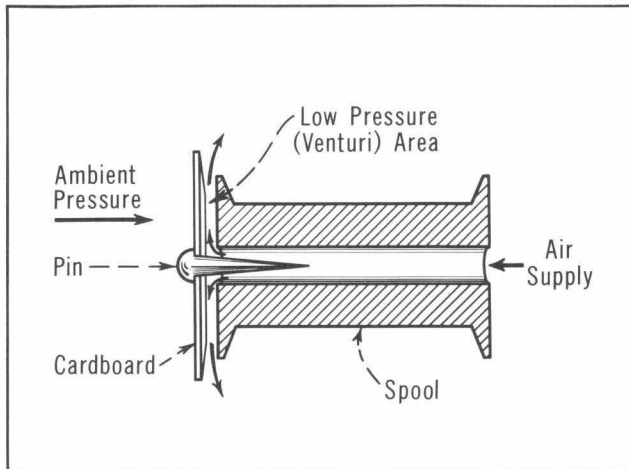


Fig. 6. In "school boy" experiment, air blown into spool fails to dislodge cardboard because of low pressure region created by high-velocity air in venturi region.

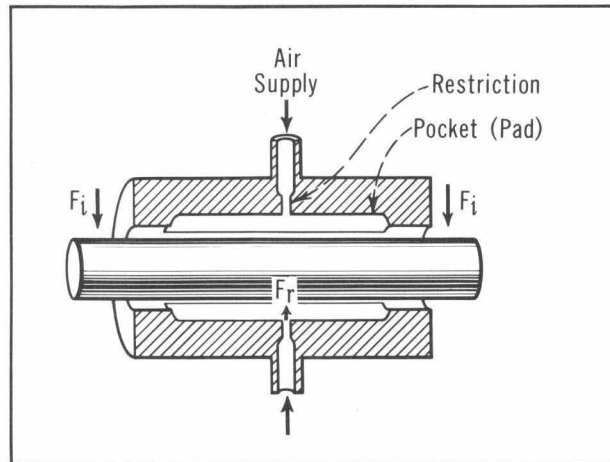


Fig. 7. Hydrostatic bearing that uses several pairs of pressure "pads" to support shaft.

Early attempts at using air lubrication, however, were not successful because of complications introduced by the compressibility of air. Capacitances  $C$ , which represent the compressibility of the air in the pockets, are added to the equivalent circuit, as in Fig. 8. The spring-mass system formed by these pneumatic capacitances and the mass of the spindle tend to make the shaft susceptible to mechanical oscillations. Also, the numerous, difficult-to-analyze non-linearities and feedback paths existing in the fluid-flow system, not shown in the simplified diagram of Fig. 8, are capable of sustaining oscillations. Early air-lubricated bearings of this type suffered from considerable dynamic instability.

Development work at Hewlett-Packard concentrated on controlling the parameters of the system to achieve an overdamped condition in the mass/air-spring system and to eliminate non-linearities by consideration of the air flow parameters. This not only included a study of air flow characteristics within the supply orifices and between shaft and housing, but also careful consideration of the shape of the pocket. A workable design has been achieved and a successful air-bearing spindle using this approach is

in operation at the Hewlett-Packard plant. The spindle is not prone to oscillations and bearing stiffness in both radial and longitudinal directions exceeds 200,000 pounds per inch. The spindle exhibits a total deviation from true round rotation of approximately 0.000003 inch.

#### RESULTS ACHIEVED

The air bearing spindle, mounted on a tape-controlled drill, has drilled the 4025 holes of the semiconductor mask with total size variations within 0.000050 inch and a hole roundness better than 0.000005 inch. This was done during one eight-hour shift and consumed only one 0.0016 inch drill bit.

With the spindle mounted on a standard lathe bed, many parts have been turned to a better than one microinch rms finish with a roundness better than 0.000005 inch. These parts were made of aluminum and brass as well as of oxygen-free copper and other "gummy" materials.

#### ACKNOWLEDGMENTS

The assistance of W. E. Kincaid and Richard H. Barth, who fabricated the air-bearing spindle, and of G. Robert Kirkpatrick who designed the electrical components for operating the spindle with an automated drill press, is gratefully acknowledged.

—Edward H. Phillips

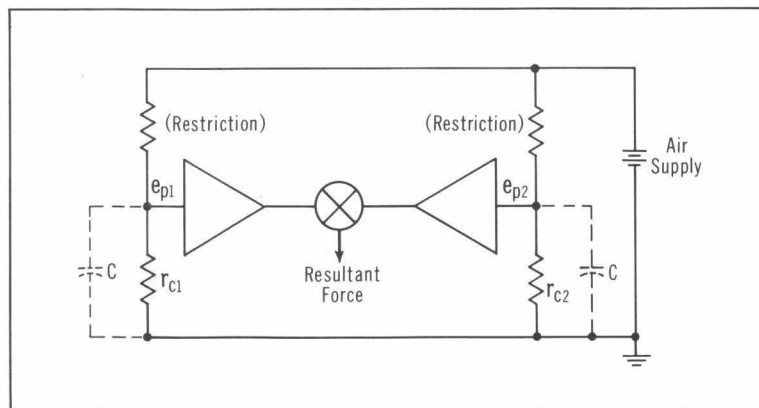


Fig. 8. Electrical analog of one pair of "pads" in multiple-pad bearing of Fig. 7. Capacitances  $C$  are added when air or other compressible fluid is used as lubricant. Voltages  $e_{p1}$  and  $e_{p2}$  represent pressure within pad.



# INTERNATIONAL SYSTEM OF UNITS

The table of units for physical quantities shown at right is reproduced here to serve as a reference for readers of the Hewlett-Packard Journal. This System of Units (designated SI for *Système International d'Unités*) was defined and given official status in a resolution of the 11th General Conference on Weights and Measures at a 1960 Paris meeting.

Only one unit is specified for each quantity but multiples and submultiples may be designated with approved prefixes (e.g., mega-, milli-, micro-\*). Four of the basic units on which the others are based are independent; that is, a definition of one does not depend on any of the others. The ampere and candela, however, involve other units in their definitions.

The National Bureau of Standards has adopted the SI for use in its publications, except where use of the units would complicate the communication of information. NBS will continue, however, to calibrate standards and measuring devices in customary U. S. units, such as inches, pounds, and gallons, when the nominal values are in those units.

\* See "New Submultiple Prefixes," Hewlett-Packard Journal, Vol. 14, No. 7-8, Mar.-Apr., 1963, for current list of prefixes adopted by the International Committee on Weights and Measures.

BASIC UNITS			
Quantity	Unit	Symbol	
Length	meter	m	
Mass	kilogram	kg	
Time	second	s	
Temperature	degree Kelvin	°K	
Electric current	ampere	A	
Luminous intensity	candela	cd	
SUPPLEMENTARY UNITS			
Plane angle	radian	rad	
Solid angle	steradian	sr	
DERIVED UNITS			
Area	square meter	m <sup>2</sup>	
Volume	cubic meter	m <sup>3</sup>	
Frequency	hertz	Hz	(s <sup>-1</sup> )
Density	kilogram per cubic meter	kg/m <sup>3</sup>	
Velocity	meter per second	m/s	
Angular velocity	radian per second	rad/s	
Acceleration	meter per sec. squared	m/s <sup>2</sup>	
Angular acceleration	radian per sec. squared	rad/s <sup>2</sup>	
Force	newton	N	(kg•m/s <sup>2</sup> )
Pressure	newton per sq. meter	N/m <sup>2</sup>	
Kinematic viscosity	sq. meter per second	m <sup>2</sup> /s	
Dynamic viscosity	newton-second per sq. meter	N•s/m <sup>2</sup>	
Work, energy, quantity of heat	joule	J	(N•m)
Power	watt	W	(J/s)
Electric charge	coulomb	C	(A•s)
Voltage, potential difference, electro-motive force	volt	V	(W/A)
Electric field strength	volt per meter	V/m	
Electric resistance	ohm	Ω	(V/A)
Electric capacitance	farad	F	(A•s/V)
Magnetic flux	weber	Wb	(V•s)
Inductance	henry	H	(V•s/A)
Magnetic flux density	tesla	T	(Wb/m <sup>2</sup> )
Magnetic field strength	ampere per meter	A/m	
Magnetomotive force	ampere	A	
Flux of light	lumen	lm	(cd•sr)
Luminance	candela per sq. meter	cd/m <sup>2</sup>	
Illumination	lux	lx	lm/m <sup>2</sup>