

# BENCH BRIEFS

SERVICE INFORMATION FROM HEWLETT-PACKARD

MAY-OCTOBER 1978

## PHASE-LOCKED LOOPS

Jim Bechtold  
Editor

### INTRODUCTION

Signal sources can be classified into two distinct types. One is the fundamental type of signal generator where a single oscillator is tuned to generate the output frequency. The oscillator is usually (but not always) mechanically tuned.

The other type signal source is the synthesizer. A synthesizer uses a high stability reference oscillator operating at a fixed frequency and then translates this fixed frequency to generate the output frequency. The output frequency then has the same accuracy and stability as the reference oscillator. There are basically two techniques used to translate the frequency: direct and indirect (or phase-locked) synthesis. A simplified example shown in Figure 1 compares the two methods by using a 1 MHz reference and translating the frequency to the 20 to 30 MHz band with 1 MHz steps.

The direct method passes the 1 MHz reference through a harmonic generator to generate a comb of output signals in 1 MHz increments. These signals pass through a bank of bandpass filters tuned in 1 MHz increments. The desired frequency is selected by switching to the filter with the appropriate output.

The indirect or phase-locked method uses a sampling phase detector to compare the appropriate harmonic of the 1 MHz reference with the output of a voltage-tuned oscillator which has

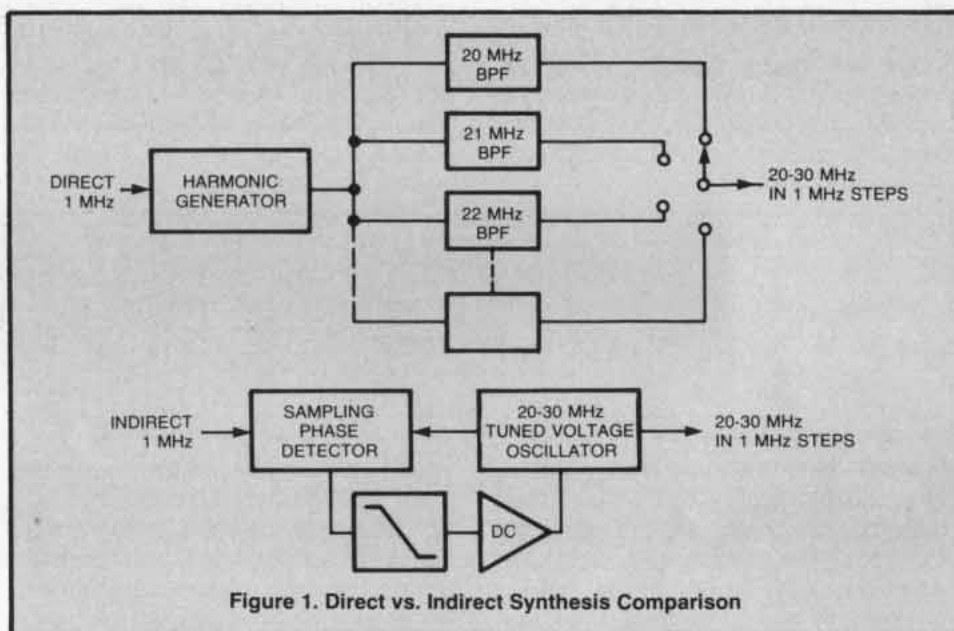


Figure 1. Direct vs. Indirect Synthesis Comparison

been coarse-tuned to the desired frequency. The error output from the phase detector is passed through a feedback network to tune and lock the voltage-tuned oscillator to the exact frequency desired.

Comparing the two methods, direct synthesis is more expensive and bulky than indirect synthesis due to the need for many filters. Also extensive shielding is needed as many frequencies exist in the direct synthesizer at the same time. Finally, the switch isolation must be good enough to reduce the possibility of spurious outputs. The advantage of direct synthesis is switching speed (i.e., speed in changing frequency) which is on the order of 20  $\mu$ s.

On the other hand, due to the extensive use of IC's in phase-locked designs, indirect synthesis is generally smaller and less expensive than direct

synthesis. Also the possibility of spurious outputs is less as there is only one frequency at a time generated in each phase-locked loop. However, switching speed is slower in indirect synthesis as you must break lock, retune the oscillator, capture and relock to change frequency. Typically it's on the order of 1 to 2 ms.

### IN THIS ISSUE

NEW APPLICATION NOTES  
BLUE TAG REPAIR  
LOGIC SYMBOLOGY  
SAFETY SERVICE NOTES

## PHASE-LOCKED LOOP PRINCIPLE

Now that you understand the why of phase-locked loops, let's examine the how. The classic definition of a phase-locked loop (PLL) is a feedback system whose function is to force a voltage-controlled oscillator (VCO) to be coherent with a certain frequency. By "coherent", we mean highly correlated in both frequency and phase.

There are many variations of phase-locked loops, but an elementary loop consists of a phase detector, low-pass filter and voltage-controlled oscillator shown in Figure 2.

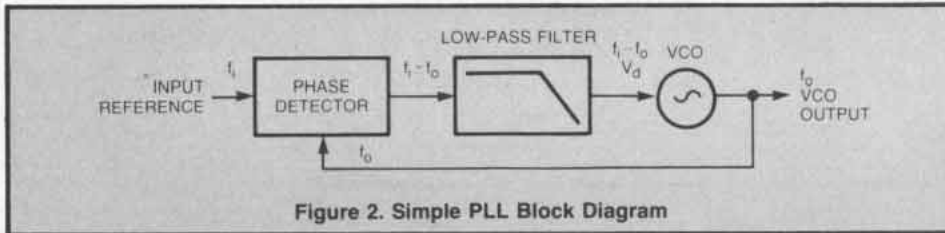


Figure 2. Simple PLL Block Diagram

**LOOP OPERATION** — The frequency at which the VCO oscillates is determined by the control voltage applied to its input. The frequency range over which the VCO can be tuned and the relationship between control voltage and output frequency are determined by the design of the VCO. The phase detector compares the phase difference between the input reference signal and the output of the VCO, then generates a voltage (or current) proportional to the error. The phase error voltage is passed through a low-pass filter which suppresses noise and any high frequency signal components. If the phase changes, indicating the incoming frequency is changing, the phase detector output voltage increases or decreases just enough to keep the oscillator frequency the same as the incoming frequency. The action of the loop then, is to slew the frequency of the VCO until the phase error is at a steady dc value and the two frequencies "track."

Looking a little closer at the action of the loop, assume that the input reference is a 10 MHz signal from a very stable source. We want to produce a 10 MHz signal which is the same frequency as the 10 MHz reference. With the loop connected as in Figure 2 but

with no reference signal input, the VCO will oscillate at a fixed frequency determined by the design of the loop ( $f_c$ ). This is an important point to note: the VCO will produce an output even if the loop isn't locked. If the 10 MHz signal is now applied to the phase detector's reference input in our example, and the VCO is leading in phase relative to the reference input, the phase detector/loop filter will respond by supplying a voltage to the VCO such that the VCO's output frequency will decrease. As the VCO's frequency lowers, the phase lag between the reference input and the VCO will decrease until the PLL is locked. This is

shown more clearly in the timing diagram of Figure 3. Once in lock, the VCO frequency is identical to the input signal except for a finite phase difference. This net phase difference is necessary to generate the corrective error voltage ( $V_d$ ) to shift the VCO frequency from its free-running value to the input signal frequency ( $f_i$ ) and, thus, keep the PLL in lock. This self-correcting ability of the system also allows the PLL to track the frequency changes of the input signal once it is

locked. In fact, the low-pass filter voltage is the demodulated output when the incoming signal is frequency modulated (provided the controlled oscillator has a linear voltage-to-frequency transfer characteristic). The synchronous reception of radio signals using PLL techniques was described in the early thirties as the "homodyne" receiver.

Another way of describing the operation of the PLL is to observe that the phase detector is actually a mixer circuit that mixes the input signal with the VCO signal. This mix produces the sum and difference frequencies ( $f_i \pm f_o$ ) shown in Figure 2. When the loop is in lock, the VCO duplicates the input frequency so that the difference frequency component ( $f_i - f_o$ ) is zero, and the output of the phase comparator is a dc value proportionate to the phase difference. The low-pass filter removes the sum frequency component ( $f_i + f_o$ ), but passes the dc component which is fed to the VCO.

**LOCK AND CAPTURE** — The range of frequencies over which the PLL can track an input signal is defined as the "lock range" of the system (refer to Figure 4). The band of frequencies over which the PLL can acquire lock with an incoming signal is known as the "capture range" of the system is never greater than the lock range. Stated another way, the PLL can track or maintain lock on an input signal beyond the capture range. Note that the

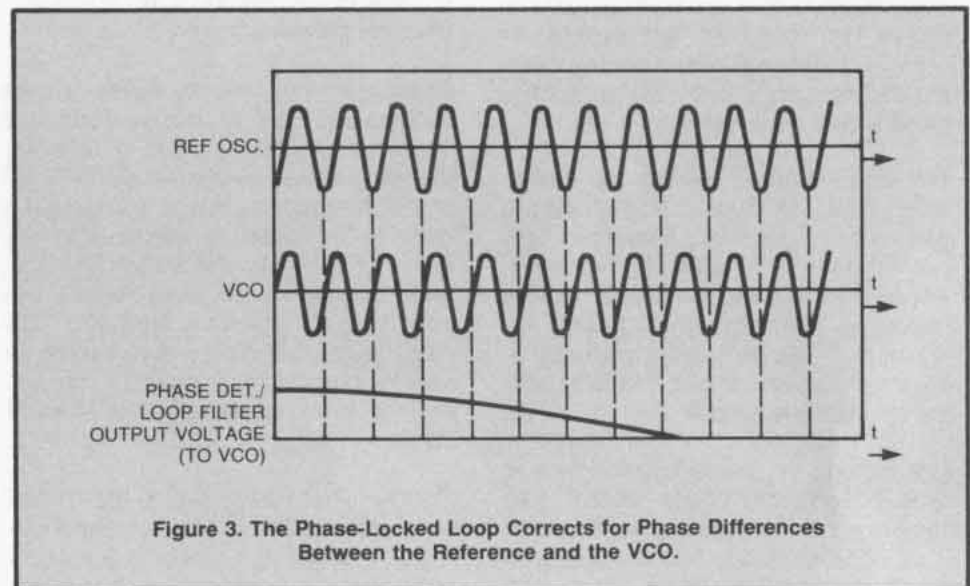


Figure 3. The Phase-Locked Loop Corrects for Phase Differences Between the Reference and the VCO.

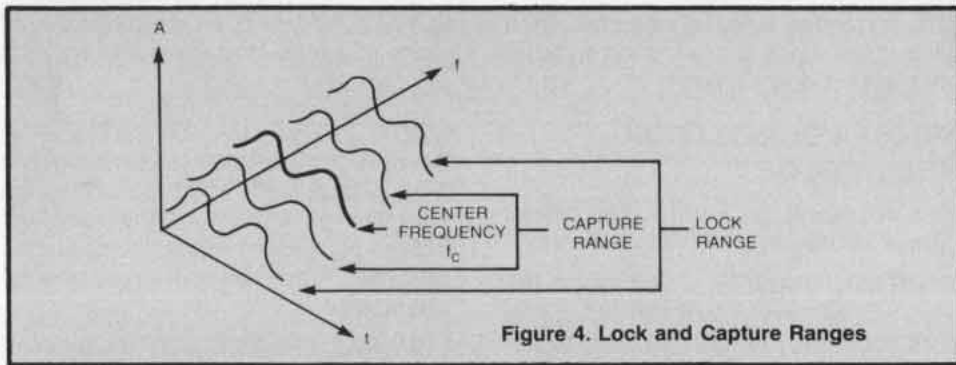


Figure 4. Lock and Capture Ranges

low-pass filter primarily determines the capture range along with the design of the loop.

Consider the case where the loop is not yet in lock. The phase detector mixes the input and VCO signals to produce sum and difference frequency components. However, the difference component falls outside the band edge of the low-pass filter and is removed along with the sum frequency component. In this case, no information is transmitted around the loop and the VCO remains at its initial free-running frequency. As the input frequency approaches that of the VCO, the frequency of the difference component decreases and approaches the band edge of the low-pass filter. Now some of the difference component is passed, which tends to drive the VCO towards the frequency of the input signal. This, in turn, decreases the frequency of the difference component and allows more information to be transmitted through the low-pass filter to the VCO. This is essentially a positive feedback mechanism which causes the VCO to snap into lock with the input signal. With this mechanism in mind, the term "capture range" is defined as "the frequency range centered about the VCO initial free-running frequency over which the loop can acquire lock with the input signal." The capture range is a measure of how close the input signal must be in frequency to that of the VCO to acquire lock. The capture range can assume any value within the lock range and depends primarily upon the band edge of the low-pass filter together with the closed-loop gain of the system. It is this signal-capturing phenomenon which gives the loop its frequency selective properties.

It is important to distinguish capture range from the lock range. "Lock range" is defined as "the frequency range centered about the VCO initial free-running frequency over which the loop can track the input signal once lock has been achieved."

When the loop is in lock, the difference frequency component at the output of the phase detector (error voltage) is dc and will always be passed by the low-pass filter. Thus, the lock range is limited by the range of error voltage that can be generated and the corresponding VCO frequency deviation produced. The lock range is essentially a dc parameter and is not affected by the band edge of the low-pass filter.

**ONWARD TO SYNTHESIZERS**

Thus far, only an ideal phase-locked loop of the tracking filter-type has been discussed. While this type of loop makes an excellent example to demonstrate how the loop works, its applications are rather specialized and of narrow scope, since the input and output frequencies are the same. The more common case, especially at microwave frequencies, is one where it is desired to lock the frequency of an oscillator to an offset frequency from another signal. It may, for example, be necessary to stabilize a YIG oscillator to a fixed offset from a standard cavity oscillator, or to force two sweepers to

track with a fixed (or programmable) offset, or to stabilize a receiver's local oscillator (LO) to some standard crystal oscillator.

Phase detectors can be designed to compare the reference signal with a VCO signal which is a harmonic of the reference. For example, if the reference is 10 MHz and the VCO operates close to 100 MHz, the loop can tune the VCO to exactly 10 times the reference. However, the capture range of the loop must contain only one harmonic of the reference or the loop could lock on the wrong harmonic.

Many refinements can be added to the simple PLL shown in Figure 2 which would increase its versatility and usefulness to do some of the things mentioned above.

**PRETUNING** — The phase detector error voltage usually is limited in tuning the VCO over a relatively small frequency range. When the VCO must be tuned over a wide frequency range, pretuning is used. Pretuning is accomplished by summing a dc voltage, which can vary over a wide range, with the phase detector output which varies over a small range, and using the combined voltage to tune the VCO. The pretuning voltage comes from a Digital-to-Analog (D/A) converter which is programmed by digital data representing the frequency to which the VCO is to be tuned. The pretuning voltage "coarse tunes" the VCO close to the desired frequency and the phase detector then "fine tunes" the VCO to lock the loop. The phase detector keeps the loop locked by adjusting for small variations in VCO frequency. See Figure 5.

**DIVIDER IN FEEDBACK PATH (IN LOOP)** — This technique provides a way of stepping the VCO in fine increments, or of effectively setting the

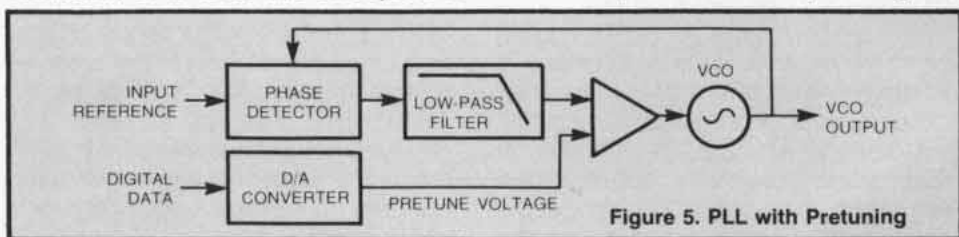


Figure 5. PLL with Pretuning



VCO to a higher multiple of the reference frequency (as shown in Figure 6). In this case the output of the VCO drives a programmable divider and the output of this divider is the input to the phase detector. The operation of this circuit can best be described by an example. The input reference signal is 100 kHz and we want the VCO to tune between 29.6 MHz and 19.8 MHz in 0.1 MHz steps. The programmable divider can divide by whole numbers from 198 through 296. The digital data input to the divider specifies the divide-by number.

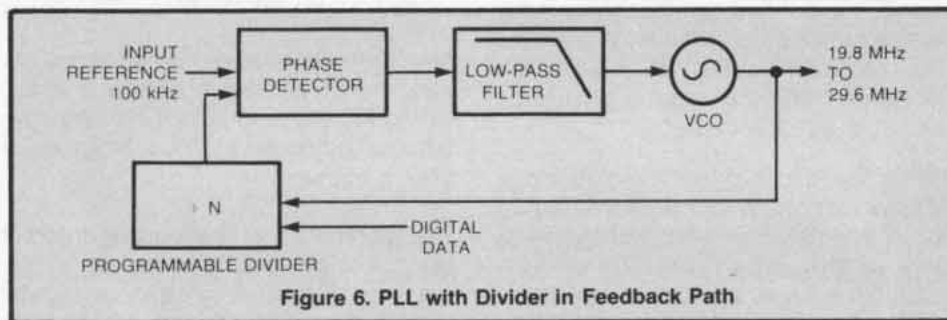


Figure 6. PLL with Divider in Feedback Path

When we want the VCO to output 20.0 MHz, the divider would be programmed to divide by 200. When the VCO reached 20.0 MHz, the output of the divider would be 100 kHz ( $20 \text{ MHz} \div 200 = 100 \text{ kHz}$ ). The phase detector would see both its inputs at 100 kHz and the loop would be locked. If the VCO were too high in frequency, the divided signal would also be too high and the phase detector would tune the VCO down in frequency until the loop locked. Increasing or decreasing the divide number by one will increase or decrease the VCO frequency by 0.1 MHz which is the minimum step size of this loop. This type of PLL is often called an N loop because of the divide-by-N method of generating output frequencies.

## TROUBLESHOOTING TIPS

A malfunctioning PLL is difficult to troubleshoot due to the fact it's a positive feedback-type loop. The most common method of troubleshooting is to open the loop and check the individual circuits. For example, about all you can do with the circuit shown in Figure 5 is ground the output of the filter, then check the VCO output at the various frequencies dictated by the

D/A converter. If that checks out, then look at the input, phase detector, filter, and associated circuitry.

## PHASE-LOCKED LOOP TERMINOLOGY

The following is a brief glossary of terms encountered in PLL literature.

**CAPTURE RANGE** — Although the loop will remain in lock throughout its lock range, it may not be able to acquire lock at the tracking range extremes (i.e., capture range is smaller than lock range). The range over

which the loop can acquire lock with the input signal is termed capture range, sometimes called the LOCK-IN RANGE. (The latter refers to how close a signal must be to the center frequency before acquisition can occur and is thus one-half the capture range.)

**CURRENT CONTROLLED OSCILLATOR (CCO)** — An oscillator similar to a VCO in which the frequency is determined by an applied current.

**DAMPING FACTOR** — The standard damping constant of a second order feedback system. In the case of the PLL, it refers to the ability of the loop to respond quickly to an input frequency step without excessive overshoot.

**FREE-RUNNING FREQUENCY** — Also called the CENTER FREQUENCY, this is the frequency at which the loop VCO operates when not locked to an input signal.

**LOCK RANGE** — The range of input frequencies over which the loop will remain in lock. It is also called the TRACKING RANGE or HOLD-IN RANGE. (The latter refers to how far the loop frequency can be deviated from the center frequency and is one-half the lock range.)

**LOOP GAIN** — The product of the dc gains of all the loop elements, in units of  $(\text{sec})^{-1}$ .

**LOOP NOISE BANDWIDTH** — A loop property related to damping and natural frequency which describes the effective bandwidth of the received signal. Noise and signal components outside this band are greatly attenuated.

**LOW-PASS FILTER** — A low-pass filter in the loop which permits only dc and low frequency voltages to travel around the loop. It controls the capture range, noise and out-band signal rejection characteristics.

**PHASE DETECTOR GAIN FACTOR** — The conversion factor between the phase detector output voltage and the phase difference between input and VCO signals in volts/radian. At low input signal amplitudes, the gain is also a function of input level.

**PHASE DETECTOR** — A circuit which compares the input and VCO signals and produces an error voltage which is dependent upon their relative phase difference. This error signal corrects the VCO frequency during tracking. Also called PHASE COMPARATOR. A MULTIPLIER or MIXER is often used as a phase detector.

**QUADRATURE PHASE DETECTOR** — A phase detector operated in quadrature ( $90^\circ$  out of phase) with the loop phase detector. It is used primarily for AM demodulation and lock detection.

**VCO CONVERSION GAIN** — The conversion factor between VCO frequency and control voltage in radians/second/volt.

**VOLTAGE CONTROLLED OSCILLATOR (VCO)** — An oscillator whose frequency is determined by an applied control voltage.

## Acknowledgments

I would like to extend a special thanks to Helmut Diener, Instrument Repair Technician on the 8660A/B, and Gary Sprader, Service Engineer on the 8660A/B, for their patience and the help they gave me in putting this article together.

## NEW APPLICATION NOTES

**Fundamentals of the Electronic Counters** (Application Note 200) discusses fundamentals of the conventional counter, the types of measurements it can perform and the important considerations that have significant impact on measurement accuracy and performance.

Various types of measurements used in conventional counters are discussed including Frequency, Period, Frequency Ratio, Time Interval, and Totalizing. One chapter focuses on counters that use the reciprocal technique, with other chapters covering Time Interval and Microwave Counters.



**Extended Applications of Automatic Power Meters** (Application Note 64-2) goes beyond the straightforward power measurements of sources, transmitters and amplifiers. It expands the usefulness of automatic power meters — especially the HP 436A Power Meter using the HP Interface Bus (HP-IB) — by describing other important and difficult measurements. One example is the periodic recalibration of power sensors for calibration factor and effective efficiency against a traceable standard sensor. The system described in AN 64-2 measures calibration factor and

HEWLETT  PACKARD

Should one of your HP instruments need repair, the HP service organization is ready to serve you. However, you can help us serve you more effectively. When sending an instrument to HP for repair, please fill out this card and attach it to the product. Increased repair efficiency and reduced turn-around time should result.

COMPANY \_\_\_\_\_

ADDRESS \_\_\_\_\_

TECHNICAL CONTACT PERSON \_\_\_\_\_

PHONE NO. \_\_\_\_\_ EXT. \_\_\_\_\_

MODEL NO. \_\_\_\_\_ SERIAL NO. \_\_\_\_\_

P.O. NO. \_\_\_\_\_ DATE \_\_\_\_\_

Accessories returned with unit

NONE  CABLE(S)  
 POWER CABLE  ADAPTER(S)

OTHER \_\_\_\_\_

over

## BLUE TAG REPAIR

Service needed

CALIBRATION ONLY  REPAIR

OTHER \_\_\_\_\_

Observed symptoms/problems

FAILURE MODE IS:

CONSTANT  INTERMITTENT

SENSITIVE TO:

COLD  HEAT  VIBRATION

FAILURE SYMPTOMS \_\_\_\_\_

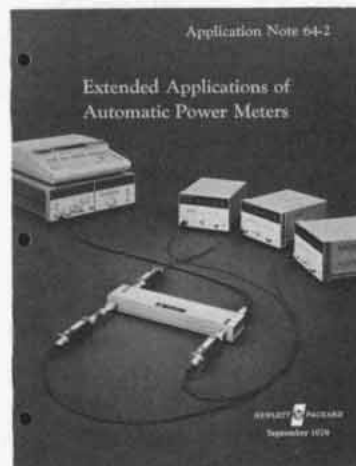
If unit is part of automatic system list model numbers of controller and other related components. \_\_\_\_\_

9320-3896

Printed in U.S.A.

Should one of your HP instruments need repair, the HP Instrument Repair Organization is always ready to serve you. Toward this end, we are promoting the use of the "Blue Repair Tag." These tags are available from your HP representative, and are filled out by

you and attached to any instrument being sent to HP for repair. Increased repair efficiency and reduced turn-around time are our goals. Please help us help you. Ask your HP representative for some of these cards today.



computes its own measurement uncertainty at each cardinal frequency by using stored calibration data for the system components.

In another example, the system is used to make high-accuracy attenuation measurements. The usual 40-50 dB of sensor dynamic range can be doubled to 80 dB by using a signal source with programmable output level. In this way, the sensor which monitors input power uses up its 40 dB range after which the 40 dB range of the output sensor is used. A broadband coupler allows both SWR and attenuation to be measured at the same time with fairly high accuracy.

## MINI GLOSSARY for STRIP CHART RECORDERS

### GENERAL TERMS

**Strip Chart Recorder:** A recorder that produces accurate records in rectangular coordinates. It automatically makes a plot of a variable versus time on graph paper. The paper is moved at a constant speed under a pen or other writing device as the variable is recorded.

**X-Y Recorder:** A recorder that plots Cartesian coordinate graphs. It automatically plots on graph paper two variables against each other, one on an X axis and the other on a Y axis. The paper, which can be of any type — linear, log-log, etc. — remains stationary, and the pen is moved across the paper in accordance with signals to the recorder's X and Y inputs.

**Axis Phasing:** A term that refers to the phase match between the axes of an X-Y recorder. Since X-Y recorders are very susceptible to normal mode noise, and since many high performance recorders are not equipped with input filters, external filters sometimes must be added. Adding a filter to one axis often causes large dynamic errors due to the resulting phase mismatch between axes. Generally, to retain axis phasing when a filter is added, an identical filter must be added to the other axis.

**Retrace:** A common term applied to a quick test used to check an X-Y recorder's general performance. An identical ramp voltage is applied to each axis causing a straight line to be drawn. The ramp is then reversed and the pen "retraces" the line. The smoothness of the lines indicates absence of mechanical binds and slide-wire nonlinearity, the opening between the lines at slow speeds indicates the amount of deadband and resettability, and the opening between the lines at faster speeds indicates the phase shift between axes.

### DYNAMIC SPECIFICATIONS

Dynamic specifications are those that relate to the motion of the pen (or other writing device); e.g., acceleration, slewing speed, etc. In other words, they define the dynamic limitations of the recorder. Errors caused by dynamic limitations must be added to those caused by static limitations.

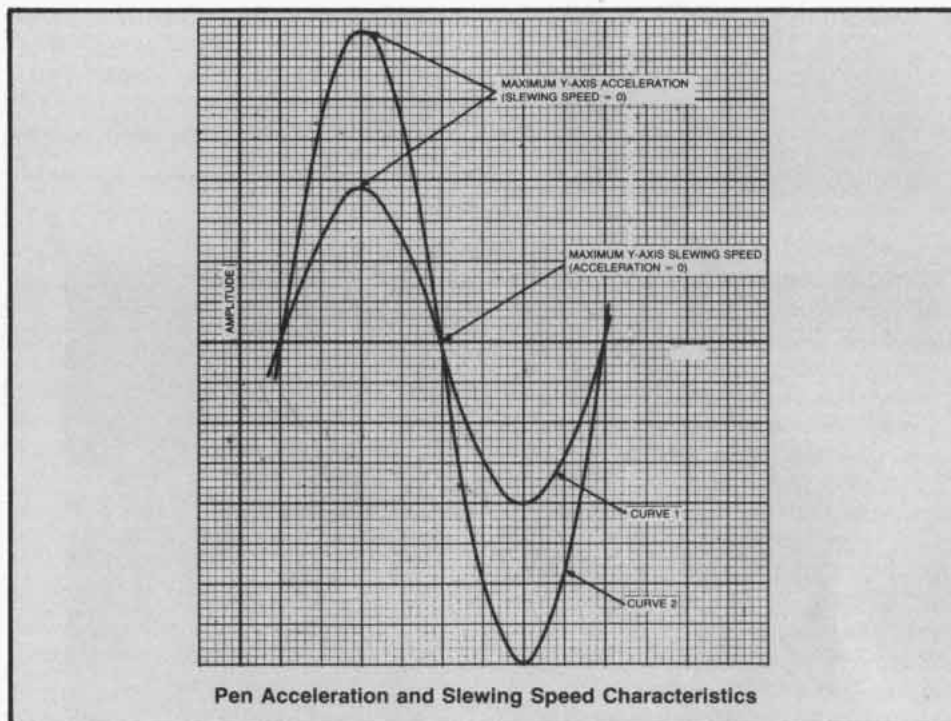
**Acceleration:** The peak pen acceleration of an X-Y recorder when the pen responds to a step input. Acceleration decreases as the pen approaches its maximum speed. Acceleration is the most significant specification in applications requiring fast dynamic response. Typical acceleration values range from about 150 to 3000 in/s<sup>2</sup>. (See *Dynamic Response*.)

**Slewing Speed:** The maximum speed attainable along either the X or Y axis of an X-Y recorder. Slewing speed is expressed in in/s (or cm/s); a typical slewing speed ranges from about 20 to 30 in/s. Many recorder specifications include slewing speed as the only dynamic specification. A common misconception is that slewing speed is the single major contributor to good dynamic performance. In many applications, however, it is sometimes the

least important. Most applications demanding fast pen response are limited not by slewing speed but by acceleration instead. (See *Dynamic Response*.)

**Dynamic Response:** Dynamic response is a measure of an X-Y recorder's overall performance which is a combination of slewing speed and acceleration. The slewing speed's main contribution is the ability to record large amplitude, low frequency signals. Acceleration's main contribution is the ability to respond to high frequency, lower amplitude signals. As shown in the following waveforms, the highest Y-axis pen speed occurs at the point the trace crosses the X-axis. Because curve 2's amplitude is larger than curve 1, the pen has to travel a greater distance within the same time period. Therefore, larger amplitude signals require higher pen speeds. However, the pen acceleration must be high enough to allow the pen to quickly respond to a reversal of direction.

**Overshoot:** The amplitude of the first transverse of the pen or other writing device past the servo balance, or null, point. Specified as a percentage of full scale with typical values less than about 2%.





**Response Time:** The time it takes for a strip chart recorder to transverse its span, that is, to travel full scale. A typical response time is about 0.5 seconds.

## STATIC SPECIFICATIONS

Static specifications generally refer to recorder limitations that are controlled by the recorder's electrical characteristics such as sensitivity, accuracy, deadband, etc. (See *Dynamic Specifications*.) Most static specifications are generally very close to the readability limitations imposed by the human eye.

**Deadband:** Expressed as a percentage of full scale, it defines the largest input signal (within the bandwidth of the recorder) to which the pen will not respond. Typical deadband ratings range from about 0.05% to 0.25%.

**Linearity:** Can be either "terminal based" linearity or "best straight line" linearity. Terminal-based linearity is the maximum difference between the actual pen position and the theoretical position, based on the assumption that the 0 point corresponds exactly to 0 signal and that full scale point corresponds exactly to full scale signal.

Expressed as percentage of full scale, a typical figure is 0.1%. Some manufacturers use the "best straight line" definition of linearity which is less precise than terminal based linearity.

**Resettability:** The measurement of the total distance separating the final resting points of the pen when the same point is approached from different directions. It is expressed as a percentage of full scale, and a typical value is 0.1%. Resettability is only occasionally specified for strip chart recorders.

## RECORDERS, PLOTTERS AND THEIR INK SUPPLIES

Sam Gromley,  
CSC Mt. View, CA

Can you imagine trying to clean an instrument with gooey, messy, running and seeping ink coating the inner and outer surfaces? Ink that has penetrated bearings, potentiometers, and other expensive parts? Ink that has

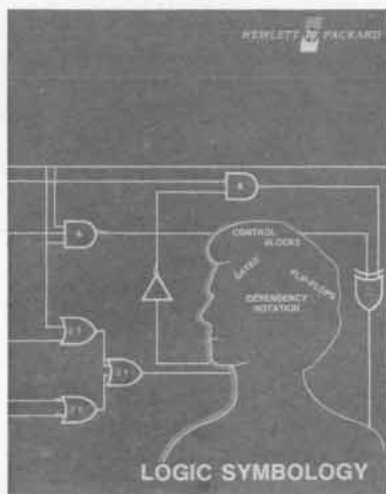
dribbled all over circuit boards coating resistors, IC's, transistors, and other components subject to leakage?

It's a dastardly job — expensive too!

Repair costs for the required clean-up (which also affects turn-around-time) can be easily saved by removing the ink supplies from **all** recorders and plotters before returning them to HP. And you will also earn "Sam's" undying gratitude.



## LOGIC SYMBOLOLOGY & WITHIN HEWLETT-PACKARD



Some time ago, Bench Briefs ran a series of articles on Logic Symbolology as defined by the ANSI Y32.14 Standard. The author, Tom Trompeter, showed some of Hewlett-Packard's first attempts at interpreting this standard — no easy task in light of the sophisticated IC circuits being used.

Now, a staff member of HP's Instrument Service Training Group has completed a Training Manual that goes quite a bit further in defining Hewlett-Packard's interpretation of ANSI Y32.14. The Logic is presented in clear concise terms with liberal examples using color for emphasis.

Several schematics from various HP instruments are also included, with color overlaid explanations describing how to interpret the Logic.

To help offset printing and distribution costs, the Logic Training Manual (HP part no. 5951-6116) has been priced at \$6.00 plus sales tax and handling charge. Also, to avoid the \$20.00 minimum order HP normally requires, a Direct Mail Order Form has been included in Bench Briefs for your convenience. Using this form also guarantees that your order will be processed within 24 hours of receipt.

## SAFETY-RELATED SERVICE NOTES

Service Notes from HP relating to personal safety and possible equipment damage are of vital importance. To make you more aware of these important notes, HP has recently modified the Safety Service Note format. The note is now printed on paper with a red border, and a "-S" suffix has been added to the note's number. In order to make you immediately aware of any potential safety problems, we are highlighting safety-related Service Notes here with a brief description of each problem. Also, in order to draw your attention to safety-related Service Notes on the Service Note order form at the rear of *Bench Briefs*, each appropriate number is highlighted by being printed in color.

### 5150A THERMAL PRINTER



Safety Service Note 5150A-3-S describes a modification that adds a shield and insulating tubing around some hazardous voltage connections inside the printer. The hazardous voltages could be touched by reaching into the cabinet through the opening behind the paper tray. This modification pertains only to instruments with serial numbers 1724A02350 and below.

### 8614A/B and 8616A/B SIGNAL GENERATORS



Some front panels on these instruments have been painted on their backside. This may result in a poor ground connection causing a hazardous voltage to appear on the shafts of the SQ WAVE and  $\Delta F$  controls should a short occur internal to their cases.

Also, a hazardous voltage may appear on the outer shell of the FM input jack if the external FM drive source is not properly grounded.

To detect and correct this problem, measure the resistance to ground of the SQ WAVE control shaft, the  $\Delta F$  control shaft, and the FM input jack outer shell. If the resistance at any point is greater than 0.1 ohm, remove the components and scrape the paint free from the area where the components seat against the backside of the front panel. For more information, refer to Safety Service Notes 8614A-18-S, 8614B-10-S, 8616A-16-S, and 8616B-10-S.

### New Internal Fuse

## ATTENTION INSTRUMENTATION TAPE RECORDER OWNERS

HP Models 3964A, 3968A, and 8868A Instrumentation Tape Recorders, with FM channels (Option 001) and HP-IB (Option 007) installed, require a higher value A24F6 fuse to handle the surge current load at turn-on. Service Notes 3964A-14 and 3968A-14/8868A-12 describe the procedure for changing the old A24F6 2.0 amp fuse to a new 2.5 amp (HP part no. 2110-0015) fuse.



## 1979 APPLICATION NOTE INDEX

Hewlett-Packard Application Notes are a compilation of applications research and experience which have been written in collaboration with HP engineers and our customers.

Some notes are tutorial in nature, while others describe very specific "how to" procedures. Most copies are available at no charge from your local field engineer or sales office.

The Application Note Index abstracts the current notes available. A listing of the HP instruments for which notes have been written is included as well as a subject index.

If you wish to receive a copy, please write on your letterhead to

Pam Keck, Editor  
Hewlett-Packard Company  
Corporate Marketing Communications, 19L  
1501 Page Mill Road  
Palo Alto, CA 94303



# supplement to

## BENCH BRIEFS

### SERVICE NOTE INDEX

## NEED ANY SERVICE NOTES?

Here's the latest listing of Service Notes available for Hewlett-Packard products. To obtain information for instruments you own, remove the order form and mail it to the HP distribution center nearest you.

### GENERAL

M 59-S. Product safety service note index.

### 403B/BB PORTABLE AC VOLTMETER

403B/BB-9. Serials 0986A20520 and below. New battery replacement.  
403B/BB-10. Serials 0986A20521 to 0986A21374. Battery charging circuit improvement.  
403B/BB-11. Serials 0986A21830 and below. CR5, CR6, CR7, and CR8 diode replacements.

### 436A POWER METER

436A-2. All serials. 9825A HP-IB verification program.

### 495A MICROWAVE AMPLIFIER

495A-B. Serials 1717A and below. Modification to prevent potential arcing on A1 high voltage assembly.

### 618C SHF SIGNAL GENERATOR

618C-13. All serials. Modification to improve minimum pulse width.

### 620B SHF SIGNAL GENERATOR

620B-15. All serials. Modification to improve minimum pulse width.

### 745A AC CALIBRATOR

745A-18. All serials. A1A2 reference oven replacement instructions.

### 746A HIGH VOLTAGE AMPLIFIER

746A-10. Serials 0990A01520 to 0990A01511; 0990A01460 and below. Recommended transformer T3 replacement.

### 970A MULTIMETER

970A-4. All serials. Recommended backbone assembly replacement.

### 1740A OSCILLOSCOPE

1740A-3A. All serials. Modification instructions for state display, option 101 kit, PN 01740-69501.  
1740A-5A. Serials 1533A and below. Modifications to improve vertical amplifier balance and gain adjustments.  
1740A-8A. All serials. Modifications to improve pulse response and risetime.  
1740A-10A. All serials. Preferred replacement for A16CR4 rectifier.  
1740A-12A. Serials 1616A-01925 and below. Improved reliability of +120V power supply.  
1740A-15A. All serials. Preferred replacement for input FETS.

### 1741A OSCILLOSCOPE

1741A-1A. Serials 1624A00550 and below. Preferred replacement for A15R15 and A15R16 focus resistors.

### 3435A MULTIMETERS

3435A-2. All serials. Replacement procedures of 0.1 ohm current shunt.

### 3438A MULTIMETERS

3438A-2. All serials. Replacement procedures of 0.1 ohm current shunt.

### 3455A DIGITAL VOLTMETER

3455A-5A. All serials. Removal and replacement procedure of front panel switch.

### 3466A MULTIMETER

3466A-1. Serials 1716A01186 and below excluding options 001 and 002. Modification to prevent and restoration procedure for fully discharged battery.  
3466A-2. All serials. Replacement procedures of 0.1 ohm current shunt.

### 3495A SCANNER

3495A-4. Serials 1428A02185 and below. Power supply modification for 3495A with four accessory 44404A's or 44405A's.

### 3555B TRANSMISSION AND NOISE MEASURING SET

3555B-2C. Serials 0992A05670 and below. Improved power supply reliability.

### 3703B GROUP DELAY DETECTOR

3703B-2. All serials. Retrofit of int./ext. B.B. switch to front panel.  
3703B-3. Option 14, all serials. Recommended replacement resistors A1R141, A1R142, A1R143.  
3703B-4. All serials. Replacement procedure for A1MC1, A1MC2 (1820-0595).  
3703B-5. Serials 1326U-01309 and below. Recommended replacement resistors A1R195, A1R197, A1R199.

### 3703Z GROUP DELAY DETECTOR

3703Z-1. All serials. Recommended replacement for underrated resistors A1R141, A1R142, A1R143.  
3703Z-2. All serials. Replacement procedures for A1MC1, A1MC2 (1820-0595).

### 3710A IF/BB TRANSMITTER

3710A-17. Serials 1637U-01686 and below. Removal of +15V and -15V rectifiers from A15 PC board to reduce temperature on PC board.

### 3790A IF/BB RECEIVER

3790A-4A. All serials. Recommended replacement for A15CR23.

### 3960 TAPE RECORDER

3960-12A. Serials 1006 and below. Installation of new brakes.

### 3964A INSTRUMENTATION TAPE RECORDER

3964A-14. Serials 1715A thru 1801A. Modification to increase A246F6 fuse to 2.5 amps.

### 3968A INSTRUMENTATION TAPE RECORDERS

3968A-14/8868A-12. Serials 1715A thru 1748A. Modification to increase A24F6 fuse to 2.5 amps.

### 5004A SIGNATURE ANALYSER

5004A-1A. Serials 1736 and above. Data probe threshold voltage adjustment and compensation.

5004A-2. All serials. 5004A operational verification.

### 5045A AUTOTEST SYSTEM

5045A-7A. Installation and test procedures.  
5045A-8. All serials. 5045A operational verification.

### 5062C CESIUM BEAM FREQUENCY REFERENCE

5062C-3. All serials. List of all assemblies which require adjustments when replaced.

### 5150A THERMAL PRINTER

5150A-3-S. Serials 1724A02350 and below. Corrective action for a potential hazard.

### 5308A 75 MHz TIMER/COUNTER

5308A-3. Serials 1720A02951 and above. In-cabinet performance procedure update.

### 5312A ASCII INTERFACE

5312A-2. All serial prefixes. Operational verification using 9825A controller.

### 5328A UNIVERSAL FREQUENCY COUNTER

5328A-18. All serials (std, option 040, 041). Operational verification.

### 5342A MICROWAVE FREQUENCY COUNTER

5342A-1. All serials. HP-IB programming notes.  
5342A-2. Serials 1720A00225 and below. Addition of de-bounce capacitor to A2 display driver.  
5342A-3. All serials. Procedure for selecting A3R15.  
5342A-4. All serials. Procedure for selecting A3R16 & C10.  
5342A-5. All serials. Procedure for selecting A9R16.  
5342A-6. Serials 1720A00225 and below. Addition of A14 capacitor to fix flickering display segments.  
5342A-7. Serials 1804A00226 and above. Preferred replacements for A14 ROM's.  
5342A-8. Serials 1720A00225 and below. Increased filtering of +5V supply on standard oscillator.

### 5345A ELECTRONIC COUNTER

5345A-10. Serials 1708 and below. Resistor changes to A4 input trigger assembly (05345-60004).  
5345A-11. All serials. Modification to A7 linear regulator assembly (05345-60007) to improve +15V supply operation.

### 5501A LASER TRANSDUCER

5501A-2. Serials 1712A and below. Modification to eliminate random retune problems.

### 6940B MULTIPROGRAMMER

6940B-2/6941B-1. Serials 1752A01805 and below. Modification recommendation.

### 6941B MULTIPROGRAMMER

6940B-2/6941B-1. Serials 1750A00730 and below. Modification recommendation.

### 7100 SERIES STRIP CHART RECORDERS

7100-4A/7101-4A/7127-4A/7128-4A. Recommended bearing replacement for servo and chart drive motors.

### 7221A GRAPHIC PLOTTER

7221A-5/9872A-7. Serials 00325 and below. Factory retrofit of flame-sprayed cabinet parts.

### 8444A TRACKING GENERATOR

8444A-2. Serials 1817A and below. Modification to reduce residual FM when operated at 50 Hz power mains.



## DIGITAL MULTIMETERS

### 8558B SPECTRUM ANALYZER

8558B-13. Serials 1612A and below. Two-pot gear drive tuning modification.  
 8558B-14. Serials 1707A03361 and above. Short circuit prevention for third converter transistor A9Q2.

### 8565A SPECTRUM ANALYZER

8565A-2AS. Operating and service manual change to eliminate potential shock hazard.

### 8614A/B SIGNAL GENERATOR

8614A-18-S. 8614A serials 1748A and below. Check for proper front-panel grounding.  
 8614B-10-S. 8614B, all serials. Check for proper front-panel grounding.

### 8616A/B SIGNAL GENERATOR

8616A-16-S. 8616A serials 1739A and below. Check for proper front-panel grounding.  
 8616B-10-S. 8616B, all serials. Check for proper front-panel grounding.

### 8672A SYNTHESIZED SIGNAL GENERATOR

8672A-2A. Serials 1719A and below. Preferred replacement for 1853-0050 transistor.  
 8672A-3. Serials 1733A and below. Improved preset operation.

### 8868A INSTRUMENTATION TAPE RECORDERS

3968A-14/8868A-12. Serials 1715A through 1748A. Modification to increase A24F6 fuse to 2.5 amps.

### 9872A GRAPHIC PLOTTER

7221A-5/9872A-7. Serials 01300 and below. Factory retrofit of flame-sprayed cabinet parts.

### 59500A MULTIPROGRAMMER INTERFACE

59500A-1. Serials 1809A-00784 and below. Circuit modification to improve performance.

### 63005C MODULAR DC POWER SUPPLY

63005C-2/63315D-2. Serials 1806A-01040 and below. Modification to reduce susceptibility to power line noise and brief interruptions.

### 63315D MODULAR DC POWER SUPPLY

63005C-2/63315D-2. Serials 1804A-00674 and below. Modification to reduce susceptibility to power line noise and brief interruptions.

### 69322A QUAD D/A VOLTAGE CONVERTER CARD

69322A-1. Modification to increase range of gain adjust.

### 69435A PULSE COUNTER CARD

69435A-1. Serials 1801A-01533 and below. Circuit modification to improve performance.

## DO YOU OWN ONE OF HP'S DIGITAL MULTIMETERS OR COUNTERS?

*Product Improvement Service Notes Have Been Issued for Models 970A, 3435A, 3438A and 3466A Multimeters, and 5328A and 5342A Counters.*

If you own one of the above Digital Multimeters or Counters, be sure and order the appropriate Service Notes listed in this issue of Bench Briefs.

For example, if you need a new Backbone Assembly, the 970A-4 Service Note lists a service procedure for replacing just the backbone alone and a few parts that can save you approximately 75% in repair costs.



The 3466A-1 Service Note outlines a modification procedure that eliminates further battery drain if, when on battery operation, the battery voltage goes below 5.4 volts and shuts the 3466A down.



A new verification procedure for the 5328A Universal Counter is listed in Service Note 5328A-18. The abbreviated checks in this note can be performed instead of the complete performance test, and will give a high degree of confidence that the Counter is operating properly. This operational verification is useful for incoming QA, routine maintenance, and after instrument repair.



The 5342A Microwave Frequency Counter has eight Service Notes listed that provide everything from HP-IB programming information to hints on improving performance. You can order

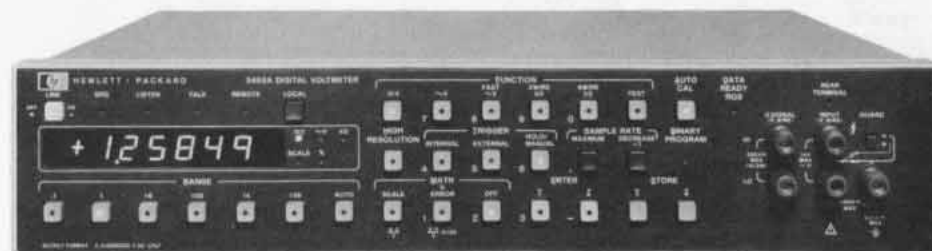
these or any notes described here by using the order form on the inside last page of Bench Briefs.

A late word on the 5342A is that the final manual is nearing release and will incorporate all the above notes. If you haven't returned the card inside the temporary manual, please do so now as it's the only way we have of sending you a new final manual.



### Servicing The 3455A

## 3455A DIGITAL VOLTMETER SERVICE BOOK



If you service your own 3455A Voltmeter, chances are you can use a new service book containing original material and supporting documentation from past 3455A Customer Service

Seminars. The book is appropriately titled "Servicing The 3455A" and can be obtained through your local HP Sales and Service Office.

If you want service notes, please check the appropriate boxes below and return this form separately to one of the following addresses:

**Hewlett-Packard**  
1820 Embarcadero Road  
Palo Alto, California 94303

For European customers (ONLY)

**Hewlett-Packard**  
Central Mailing Dept.  
P.O. Box 529  
Van Hueven Goedhartlaan 121  
AMSTELVEEN — 1134  
Netherlands

NAME \_\_\_\_\_  
COMPANY NAME \_\_\_\_\_  
ADDRESS \_\_\_\_\_  
CITY \_\_\_\_\_  
STATE \_\_\_\_\_ ZIP \_\_\_\_\_

- |                                     |                                    |  |   |   |
|-------------------------------------|------------------------------------|--|---|---|
| <input type="checkbox"/> M59-S      | <input type="checkbox"/> 1740A-12A | <input type="checkbox"/> 3703Z-2           | <input type="checkbox"/> 5342A-1          | <input type="checkbox"/> 8444A-2            |
| <input type="checkbox"/> 403B/BB-9  | <input type="checkbox"/> 1740A-15A | <input type="checkbox"/> 3710A-17          | <input type="checkbox"/> 5342A-2          | <input type="checkbox"/> 8558B-13           |
| <input type="checkbox"/> 403B/BB-10 | <input type="checkbox"/> 1741A-1A  | <input type="checkbox"/> 3790A-4A          | <input type="checkbox"/> 5342A-3          | <input type="checkbox"/> 8558B-14           |
| <input type="checkbox"/> 403B/BB-11 | <input type="checkbox"/> 3435A-2   | <input type="checkbox"/> 3960-12A          | <input type="checkbox"/> 5342A-4          | <input type="checkbox"/> 8565A-2AS          |
| <input type="checkbox"/> 436A-2     | <input type="checkbox"/> 3438A-2   | <input type="checkbox"/> 3964A-14          | <input type="checkbox"/> 5342A-5          | <input type="checkbox"/> 8614A-18-S         |
| <input type="checkbox"/> 495A-8     | <input type="checkbox"/> 3455A-5A  | <input type="checkbox"/> 3968A-14/8868A-12 | <input type="checkbox"/> 5342A-6          | <input type="checkbox"/> 8614B-10-S         |
| <input type="checkbox"/> 618C-13    | <input type="checkbox"/> 3466A-1   | <input type="checkbox"/> 5004A-1A          | <input type="checkbox"/> 5342A-7          | <input type="checkbox"/> 8616A-16-S         |
| <input type="checkbox"/> 620B-15    | <input type="checkbox"/> 3466A-2   | <input type="checkbox"/> 5004A-2           | <input type="checkbox"/> 5342A-8          | <input type="checkbox"/> 8616B-10-S         |
| <input type="checkbox"/> 745A-18    | <input type="checkbox"/> 3495A-4   | <input type="checkbox"/> 5045A-7A          | <input type="checkbox"/> 5345A-10         | <input type="checkbox"/> 8672A-2A           |
| <input type="checkbox"/> 746A-10    | <input type="checkbox"/> 3555B-2C  | <input type="checkbox"/> 5045A-8           | <input type="checkbox"/> 5345A-11         | <input type="checkbox"/> 8672A-3            |
| <input type="checkbox"/> 970A-4     | <input type="checkbox"/> 3703B-2   | <input type="checkbox"/> 5062C-3           | <input type="checkbox"/> 5501A-2          | <input type="checkbox"/> 59500A-1           |
| <input type="checkbox"/> 1740A-3A   | <input type="checkbox"/> 3703B-3   | <input type="checkbox"/> 5150A-3-S         | <input type="checkbox"/> 6940B-2/6941B-1  | <input type="checkbox"/> 63005-C-2/63315D-2 |
| <input type="checkbox"/> 1740A-5A   | <input type="checkbox"/> 3703B-4   | <input type="checkbox"/> 5308A-3           | <input type="checkbox"/> 7100-4A/7101-4A/ | <input type="checkbox"/> 69322A-1           |
| <input type="checkbox"/> 1740A-8A   | <input type="checkbox"/> 3703B-5   | <input type="checkbox"/> 5312A-2           | <input type="checkbox"/> 7127-4A/7128-4A  | <input type="checkbox"/> 69435A-1           |
| <input type="checkbox"/> 1740A-10A  | <input type="checkbox"/> 3703Z-1   | <input type="checkbox"/> 5328A-18          | <input type="checkbox"/> 7221A-5/9872A-7  |   |

CUT HERE

CUT HERE

CUT HERE

**HEWLETT-PACKARD  
DIRECT MAIL ORDER FORM**

If you want the Logic Symbology Training Manual, please return this form with payment to:

**HEWLETT-PACKARD COMPANY**  
MAIL ORDER DEPARTMENT  
P.O. DRAWER #20  
MT. VIEW, CA. 94043

SHIP TO:

COMPANY \_\_\_\_\_  
NAME \_\_\_\_\_  
STREET \_\_\_\_\_  
CITY \_\_\_\_\_ STATE \_\_\_\_\_  
CUSTOMER REFERENCE # \_\_\_\_\_  
TAXABLE\* \_\_\_\_\_  
ZIP CODE \_\_\_\_\_

Item No.	Check Digit	Part No.	Qty.	Description	List Price Each	Extended Total

Special Instructions

Sub-total

\*Hewlett-Packard is registered and licensed to do business in your state, and we are required by the laws of your state to pay state and local taxes to them monthly on all shipments we make into your state. Therefore, we must pass these costs on to the consumer. Tax is verified by computer according to your ZIP CODE. If no sales tax is added, your state exemption number must be provided: # \_\_\_\_\_  
If not, your order may have to be returned.

Your State & Local  
Sales Taxes\*

Handling Charge

TOTAL

Check or Money Order, made payable to Hewlett-Packard Company, must accompany order.

Most orders are shipped within 24 hours of receipt. Shipments are made via UPS or Air Parcel Post. APO's, FPO's, PO Boxes, or destinations outside the continental 48 States will be shipped Air Parcel Post. Shipments over 25 pounds will be made via truck. No Direct Mail Order can be shipped outside the U.S.



# READERS CORNER

## LOGICAL ANSWERS TO LOGICAL QUESTIONS

Here are a series of questions submitted by the "Calibrators of Red Stone Arsenal." See how many you can get.

1. How many birth days does the average man have?
2. Divide 30 by one-half and add ten.
3. Do they have a fourth of July in England?
4. A man has two coins that total 30¢, one of which is not a quarter. What are the two coins?
5. A man built a house rectangular in shape and each side has a southern exposure. A bear came wandering by. What color is the bear?
6. Is it legal for a man to marry his widow's sister?

7. Why can't a man living in North Carolina be buried west of the Mississippi river?
8. How many outs are there in an inning of baseball?
9. If you set the alarm clock for nine o'clock in the morning at eight PM, how many hours of sleep will you get?
10. How far can a dog run into the woods?
11. A man gave a beggar 50¢. The beggar is not the man's brother, but the man is the beggar's brother. Why?

### Answers

1. One, the day he is born.
2.  $70, 30/1/2 = 60 + 10 = 70$
3. Yes, every year after the 3rd.
4. Quarter and a nickel, the nickel is not the quarter.
5. White, the house is on the north pole.

6. Not hardly, he is dead.
7. You don't bury a person that is living.
8. Six.
9. One hour before the alarm goes off.
10. Half way, then he is running out.
11. The beggar is his sister.

## PETALS ROUND A ROSE

I am sure that by now, all of you have solved the puzzle. (A special thanks to Jerome Brophy at the Institute For Sensory Research, Syracuse University, for sending his solution in.) I know that several of my co-workers had to take it home in hopes their children or their neighbor's children could show them the solution. So, for those of you who did not have access to children (remember, a child thinks pictorially, not analytically), here it is. A flower has a center where the pollen and honey are, so a *picture* of a flower has to have a dot in the center. The two-, four-, and six-spot die faces are not pictures of a rose.

The one-spot has a center but no petals. The number of petals each of the other two die faces has is left as an exercise for the reader.

Do *you* have a puzzle to contribute to our enjoyment? If so, please send it to the address shown below.

### HEWLETT-PACKARD COMPANY

1820 Embarcadero Road  
Palo Alto, California 94303

### BENCH BRIEFS

MAY-OCT 1978

Volume 18 Number 2

#### Service Information from Hewlett-Packard Company

To obtain a qualification form for a free subscription, send your request to the above address.

Reader comments or technical article contributions are welcomed. Please send them to the above address, attention Bench Briefs.

Editor: Jim Bechtold, HP, Mt. View  
California

Bulk Rate  
U.S. Postage  
PAID  
Sunnyvale, CA.  
Permit No.  
317

NORRIS ARTHUR W

COLOR SPRING

Address Correction Requested

Printed in U.S.A.

All rights are reserved. No part of Bench Briefs may be reproduced without the express consent of the Editor. The editor may be telephoned at (415) 968-9200, Extension 376.