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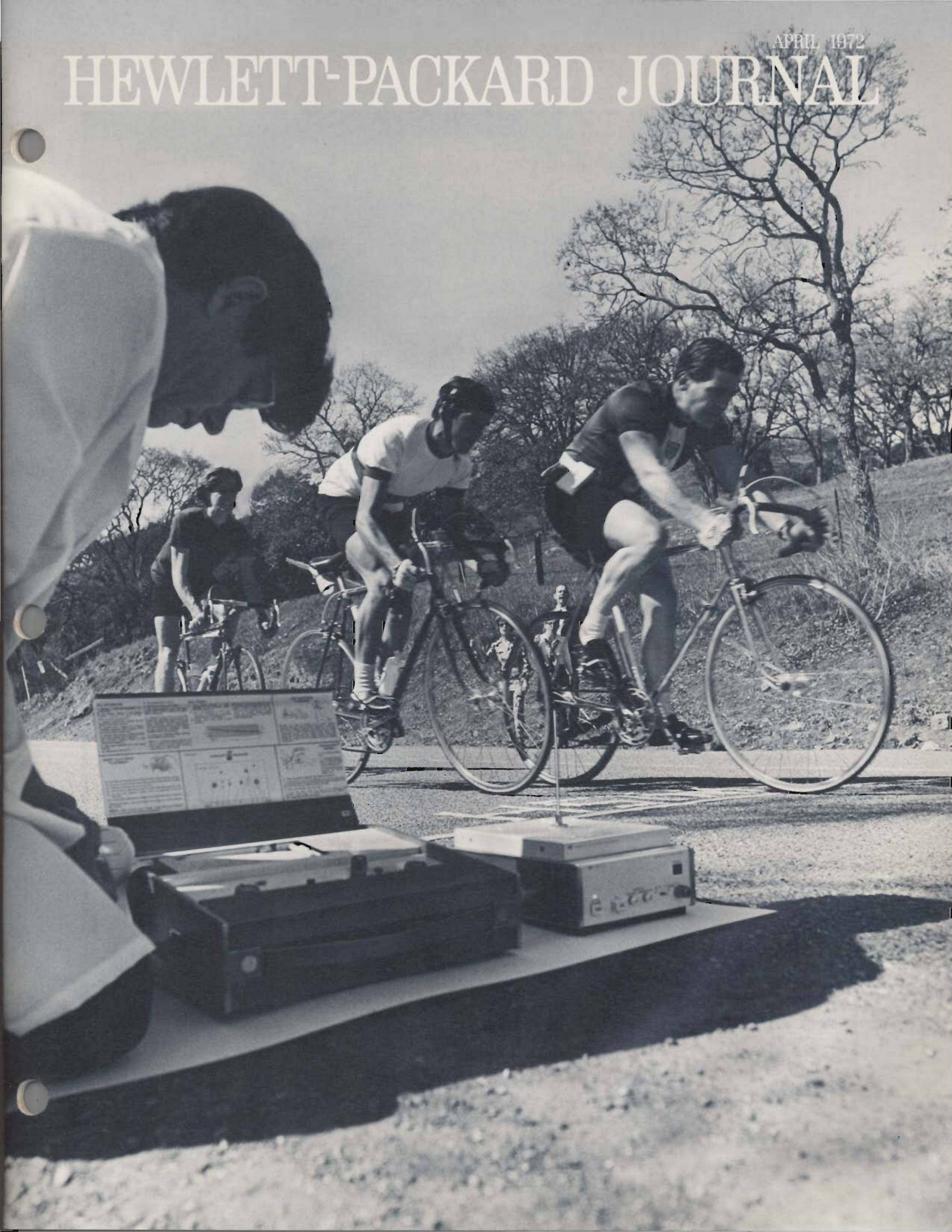


An Agile Graphic Display Device

Display area of 11 x 15 inches, 0.02 inch spot size, 50 ft-L brightness, less than 1 μs large-step jump and settling time—until now no display device could simultaneously meet all these requirements, requirements that are needed as designers strive to cram more information into computer-generated graphic displays. The new Graphic Displays described here do indeed fulfill these requirements while adding some attractive features as a bonus: reduced bulk, lighter weight, lower power consumption and lower cost.

By John Riggen and Douglas Fogg

FOR DISPLAY OF COMPUTER-GENERATED DATA, the cathode-ray tube still reigns supreme. This is true for a number of reasons, chief among these being the flexibility of the cathode-ray tube —it can display an infinite variety of symbols in a variety of sizes, and it can also display graphs, curves, diagrams or anything else that can be traced by a movable dot. And, for readout of many-worded messages, it costs less on a per-symbol basis.

While brightness and resolution are excellent, there has been a limit to the number of characters or vectors a CRT can display at one time if the refresh rate is to remain above the flicker level. This is a consequence of the limited response speed of commonly-used deflection systems, which long age were pushed to practical limits. Nevertheless, there is a growing demand for faster response, as system designers strive to place more and more information on display.

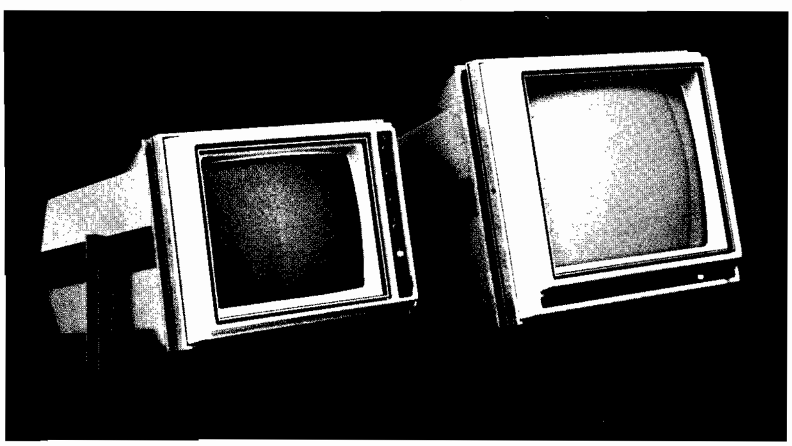


Fig. 1. *New Graphic Displays have far less bulk and weight than the usual directed-beam display, while speed of response has been increased an order of magnitude. With optional covers and stands shown here they become free-standing instruments but they are easily installed in equipment racks and consoles. Model 1310A (right) has 11 x 15 inch display area while Model 1311A (left) has 8½ x 11 inch area.*

Much faster response can be had by using electrostatic rather than magnetic deflection, but this has not been practical for large-screen displays. This is because large-screen electrostatic deflection required either a very long CRT, or impractically high deflection voltages.

All this is now changed by further refinements in CRT expansion mesh electrode techniques, refinements that make electrostatic deflection feasible in a large-screen display without sacrifice of brightness or spot size. The expansion mesh electrode technique is applied in two new Hewlett-Packard large-screen, directed-beam graphic displays (Fig. 1), intended for use in display consoles and computer terminals.

The new Displays have much faster writing capabilities than was commonly available, giving a speed of response far greater than was thought possible for large-area displays. The spot in the larger of these Displays (Model 1310A) can be moved from one corner of the 11 x 15 inch display area to the corner diagonally opposite in 1 microsecond, including the time needed to settle within 0.02 inch (0.5 mm) of its final position. Formerly, at least 10 microseconds was needed. The speed advantage is not as great for smaller deflections but even for a deflection of 0.1 inch (2.5 mm), the ratio is 0.2 μs for the new electrostatic system vs 1 μs for older ones.

As by-products of this development, weight and power consumption have been reduced significantly, features of special importance to those concerned with airborne displays. What's more, overall costs have been reduced.

Semidependent instruments

The new Graphic Displays include deflection and blanking amplifiers. They are designed for systems that have D-to-A converters and character generators that supply the analog voltages for driving the deflection systems. A 1-volt signal into the input of either the horizontal or vertical axis of these Displays drives the spot from one edge to the opposite edge. One volt into the Z-axis turns the beam from full off to full on. Spot size, comparable to a magnetically-deflected CRT, is less than 0.02 inch (0.5 mm) over 75% of the display area in the larger unit, and is less than 0.015 inch (0.4 mm) in the smaller one. The quality of the presentation is evident in the photos of displayed data on pages 12 and 13 of this issue.

High-density data

Now, with high-speed deflection available, the amount of displayed graphic data can be increased without reducing the refresh rate. Linear writing speed is better than 10 inches/μs (25.5 cm/μs) but the all-solid-state deflection amplifiers can move the spot at a rate greater than 100 inches/μs (255 cm/μs) when the spot does not need to be visible while moving. Because of the fast response to deflection signals, no delay is needed in the Z-axis circuit to synchronize beam unblanking with spot movement.

Capable of writing character strokes in less than 100 ns each, these Displays can refresh 4096 alphanumeric characters in less than 6 ms. Thus for a 60-Hz refresh rate, 10 ms of each refresh cycle would be available for display of other data. This makes it possible, for example, to superimpose characters on a video display. Point-plotting time for small steps is less than 200 ns per point, reducing the time needed for completing matrix type displays.

The fast response also simplifies system programming since vectors can be written in random fashion anywhere on the display, rather than necessarily in sequential order.

Loss of weight with fewer calories

The voltage drive of an electrostatic deflection system consumes much less power than the current drive of magnetic systems. Thus, overall power consumption of the new Displays is only 115 watts, as compared to 500 watts or so for others.

Lower power consumption means lighter transformers and related structural hardware. As a consequence, the new Model 1310A 11 x 15 inch (28 x 42 cm) Graphic Display, including deflection amplifiers and power supplies, weighs less than 53 pounds (24 kg) without covers, as compared to the usual 100 pounds (45 kg) or more. The Model 1311A, with a display area of 8½ x 11 inches (21.5 x 28 cm) weighs only 40 pounds (18 kg).

Framework

One of the most striking features of the new Displays is their mechanical design. The product designers made every effort to hold down costs by minimizing tooling and making it possible to assemble all units identically regardless of whether they were to be installed in a system or used freestanding.

The open frame construction shown in Fig. 2 resulted from this effort. Only two side rails, anchored firmly to the front panel, are used. These support the main deck. The circuit boards plug into a motherboard on the main deck and, as can be seen, are readily accessible for replacement. The CRT is anchored to the front panel.

The side rails can be mounted into a slide-rack mechanism or attached to a stand for freestanding applications. The covers are non-structural and can be attached or removed as needed by the intended application.

Shortening the CRT

The desired combination of speed, resolution, and brightness hinged on the development of a new cathode-ray tube. The first step was to increase beam current without increasing spot size. This was done by designing the electron gun to use an accelerating voltage of 4.5 kV, about twice that of high-performance oscilloscope CRTs.

Next came the deflection electrodes, always a compromise between sensitivity and bandwidth. Solid-state circuit developments have made a 300-volt deflection voltage practical at high frequencies, so the length and position of the deflection electrodes were designed to obtain 36° deflection with a 300-volt potential.

As the beam leaves the deflection region, it passes through the expansion mesh, a fine screen formed into a spherical surface. The mesh, held near ground potential, develops a voltage gradient in the post-accelerator region that bends the beam, the degree of bending being proportional to the amount of off-center deflection imparted by the deflection plates. The 36° maximum deflection is thus expanded to 90°.

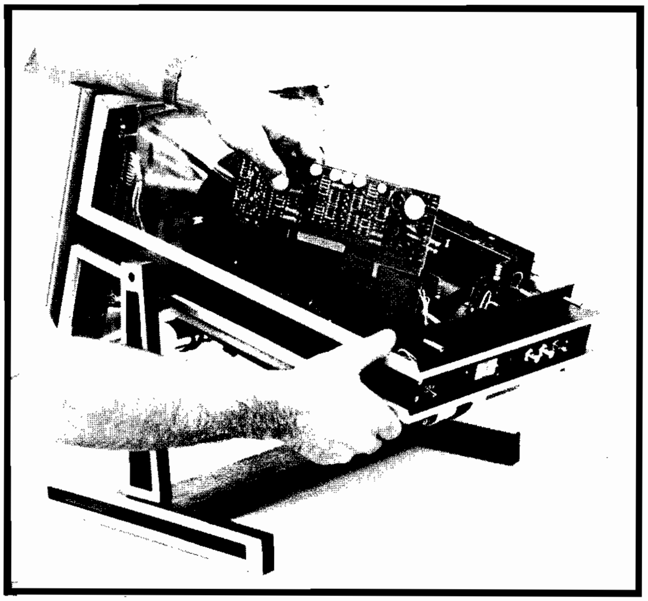


Fig. 2. *Open-frame construction provides ready access to circuits. CRT compression band anchors to front panel, which serves as structural foundation. High-voltage connector is encapsulated to CRT, protecting service personnel from 24 kV accelerating potential. Low power consumption eliminates need for cooling fan.*

After passing through the mesh, the electron beam is subjected to a 24-kV post-deflection accelerating voltage to give the desired brightness with small spot size. Any X-radiation resulting from the high accelerating potential is suppressed to the background level by the strontium-doped glass in the faceplate.

Since the gun and expansion mesh were designed to give 90° deflection, standard color-TV glass funnels and faceplates can be used, a big factor in keeping costs low. The steel rim band of these tubes, which places the faceplate under high edge-to-edge compression to increase the glass's resistance to implosion, performs extra duty as a device for mounting the 30-lb CRT solidly to the front panel.

Dynamic focusing

Designing a large-screen display becomes more than an exercise in scaling up small-screen parameters—little aberrations that are insignificant in a small display assume major proportions when magnified for large-screen display.

One problem is deflection defocusing, especially noticeable when wide-angle deflection is used with a low-curvature faceplate. Some defocusing results from the increased distance the beam travels to the faceplate as it is deflected away from center screen but when electrostatic deflection is used, additional defocusing is caused by the voltage gradient between the deflection plates. The electron beam has a finite diameter so, in response to a deflection voltage, electrons near the positive plate are accelerated more than those near the negative plate. Electrons on the positive side thus stay within the deflection field a shorter length of time so at off-center positions, the electrons receive unequal deflections and the beam spreads.

Defocusing from both causes is corrected in the new Displays by changing the focusing and astigmatism voltages as the beam is deflected from center screen. A diode shaping network converts the linear deflection voltages into the parabolic voltages needed for proper correction.

Burn protection

Another problem: with the high accelerating voltage and beam current density of this tube, the beam would burn the CRT if it remained stationary while turned on fully. Automatic circuits, shown in Fig. 3, reduce the possibility of this occurring. Whenever the beam moves less than ⅓ screen diameter within a 16-ms time span, a 100-megohm resistor is inserted in series with the CRT cathode. The resistor limits the beam current to less than 1 μA. The spot is still visible but it is not so bright that it would immediately burn the CRT.

Since there may be situations where users would not want the beam current limited automatically, an internal switch is provided for deactivating the protection circuits.

Transient-free remote gain control

Yet another problem: transients in step-wise deflection voltages caused by a subtle thermal effect in voltage-controlled attenuators. One objective to be met was that all operator controls should be accessible from the front. This poses no problems for those controls that work with dc currents (e.g., Intensity, Focus, Position, etc.) but there is a problem with lead length in those that pass signals, i.e., Gain. Accordingly, electronic gain control is used in this instrument so that only dc current need be brought to the control panel.

But most electronic gain controls cause small perturbations in step voltage response, and perturbations as small as 0.1% of a large positioning step voltage are visible in this display.

These perturbations result from a thermal effect. Most electronic gain controls, in actuality attenuators, work by feeding the signal current into two transistors, one that passes a portion of the signal on to succeeding amplifier stages, and one that

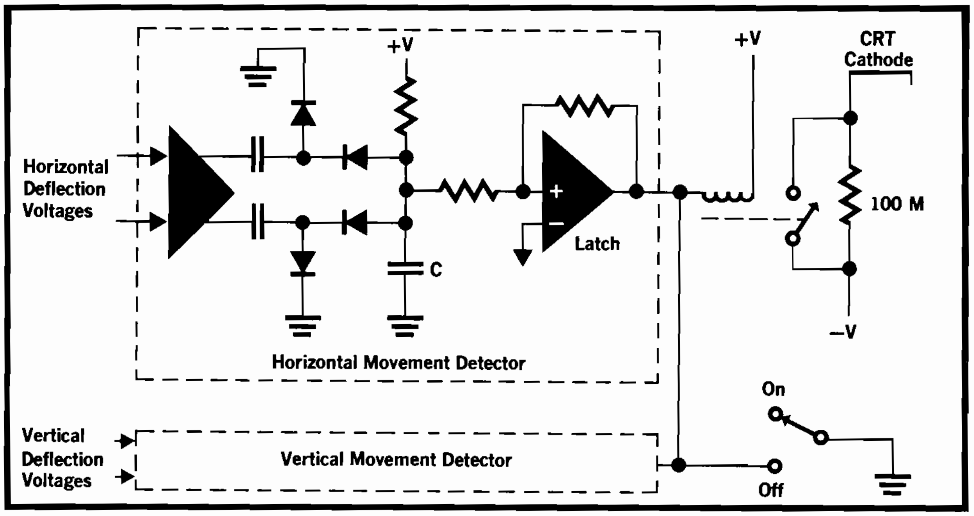


Fig. 3. *Phosphor protection circuit responds to any change in push-pull horizontal deflection voltages by charging capacitor C negatively. Whenever voltage on C falls below trip point of latch circuit, latch draws enough current to close relay, bypassing 100M resistor. Similar circuit performs same function in response to vertical deflection voltages. Hence, beam movement of sufficient magnitude and speed in any direction closes relay, removing limit on CRT current. Time constant of capacitor C and hysteresis of latch circuits hold relay closed for 16 ms after beam movement stops.*

sinks the remainder into a dummy load. Changing the base-emitter bias on one of the transistors affects the current division ratio and hence the signal attenuation. The problem is that a change in signal current, as well as a change in the bias ratio, affects the relative power dissipation in the two transistors. Thus within a few microseconds of a change in signal current, the transistor temperatures will change, causing an additional change in the current ratio. This temperature-induced change in current ratios causes perturbations in the step-voltage response of the deflection system.

This problem can be minimized if the transistors have equal power dissipation for all signal levels and for all values of attenuation. Analysis shows that this would happen if the transistor collectors were connected to sources with identical equivalents of Thevenin voltage and resistance (see Appendix). The circuit using this principle attenuates the signal over a 1.75:1 range with no loss in signal fidelity.

Deflection amplifiers

In designing the deflection amplifiers, speed of response was an important consideration but even more important was the need for deflection accuracy. The amplifiers must be able to position the CRT beam at a new location precisely, regardless of the beam's previous position. This means the amplifiers must be dc-coupled, eliminating coupling capacitors with their inherent time constants.

Considerable power economy is achieved by using an extension of an amplifier design used in other Hewlett-Packard CRT instruments: the amplifier with driven-current-source load.* The basis of this amplifier is the use of a current source as the amplifier load. By linearizing the dV/dt of distributed capacitance, a current source load speeds up the circuit's response to a step change in signal.

A fixed current source, however, must continuously supply current equal to the maximum that may ever be required to charge the distributed capacitance. But, by driving the current source load with the high-frequency components of the deflection signal, the high current needed for quickly charging the distributed capacitance during fast transitions can be made available while the steady-state current can be quite low. The amplifier shown in Fig. 5 uses this technique.

The amplifier of Fig. 5 drives one deflection plate while the opposite plate is driven by an identical amplifier. The deflection plates of the other axis are also driven by a similar pair of amplifiers.

*Originally developed by Gregory Justice of HP Labs for the Model 191A TV Waveform Monitor.

What about Storage Displays?

Cathode-ray tubes with storage capability do not need to be constantly refreshed, as do the non-storage displays described here. Since storage displays do not need refresh buffer sections in the computer's memory, their use requires far less memory. Neither do they 'steal' computer time for refreshing. Hence they are particularly useful in smaller systems that do not have discs or other large-scale memories.

The refreshed display, on the other hand, has significant advantages for most applications. For one, it can be selectively updated. This is particularly important for interactive terminals that use light pens, track balls, or other means of manually 'writing' on the display. Also, trace writing time is faster and at the present state of the art, the refreshed display is brighter than large-screen storage types, allowing it to be viewed in higher ambient light levels.

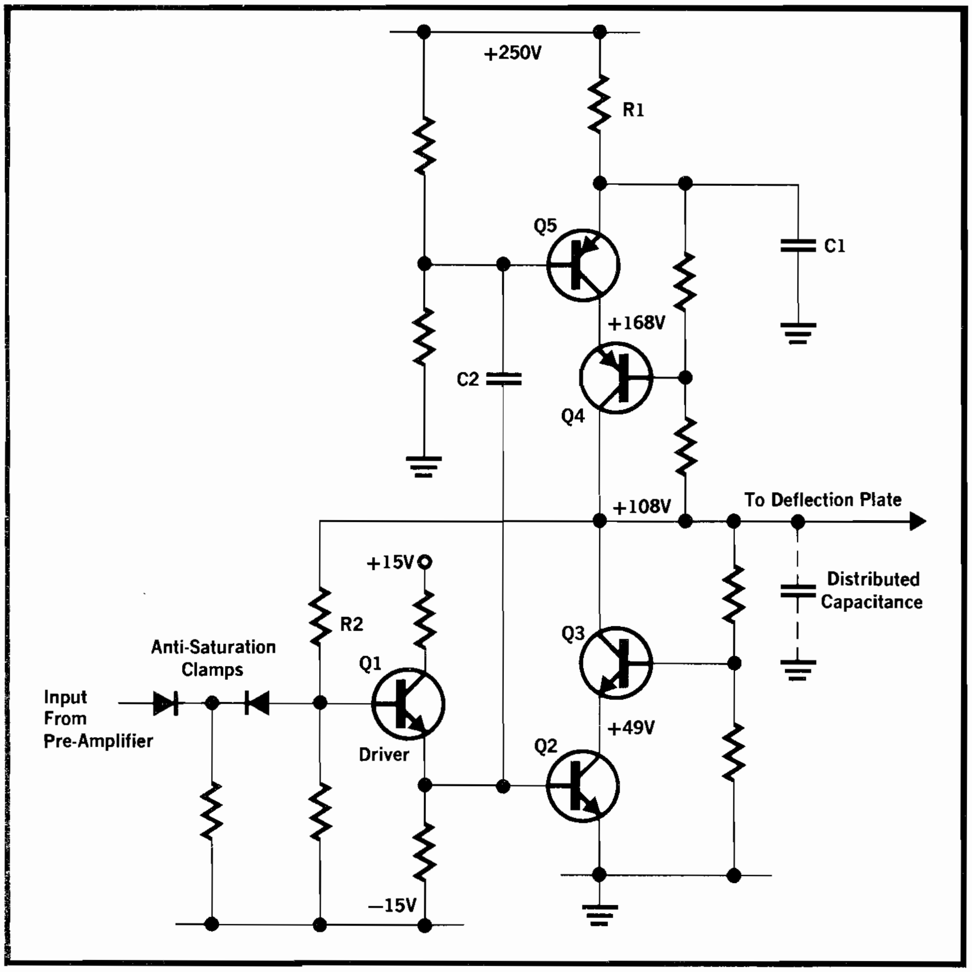


Fig. 5. *Output stage achieves fast response without requiring large, steady-state currents. Transistors Q2 and Q3 form cascode amplifier, with negative feedback supplied to driver stage Q1 through resistor R2. Transistors Q4 and Q5, also connected in cascode, comprise driven current source. Steady-state current level is established by resistor R1 while extra current needed by fast transients is supplied by capacitor C1. High-frequency components of deflection signal are coupled to current source through coupling capacitor C2. Frequency response is 5 MHz.*

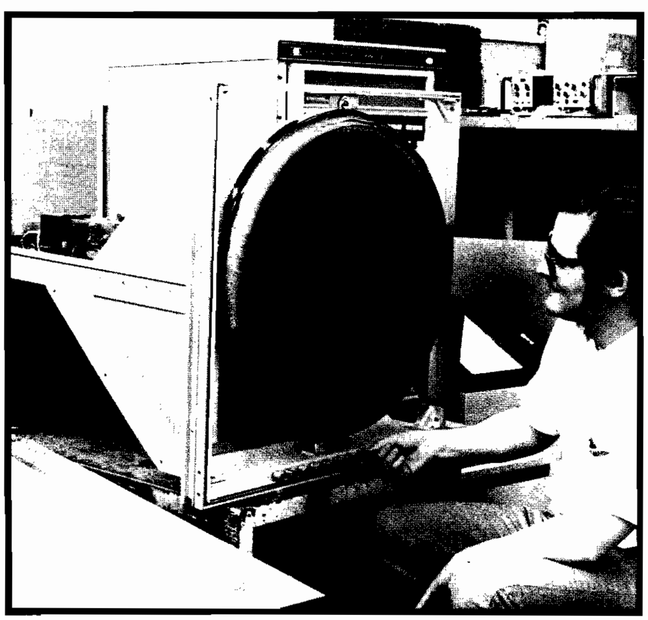


Fig. 4. *Electron gun and deflection system are adaptable to any glass envelope with deflection angles up to 90°, as in this experimental round tube display. Mechanical framework is also easily adapted to other CRT types.*

Conclusion

The high speed, low weight and low power consumption of these displays are real benefits for the ultimate user. Low weight and power consumption are immediate benefits but the speed of response will assume increasing importance as computer systems are designed to take advantage of it.

Acknowledgments

Much appreciation is due Milton Russell for the CRT design, without which this project would have been impossible. Appreciation is also due Bob Bell for guidance in product definition. Mechanical design was under the direction of Tom Schroth with industrial design contributions from Norm Tornheim. We also wish to acknowledge the contributions of Gene Severson, LaVern Gress, and Hal West for their help in keeping the project rolling.

John W. Riggen

Born and raised in Colorado, John Riggen earned his BSEE degree at Colorado State University in 1960. He then went to work for HP in Palo Alto on the 1750A and 1751A plug-ins for the 175A Oscilloscope and on the 1402A plug-in for the 140-series Oscilloscopes. Along the way he earned his MSEE degree at Stanford University in the HP Honors Co-op Program.

John and the HP Oscilloscope operations moved to Colorado Springs in 1964. There he worked on the Model 141A Variable-Persistence Oscilloscope mainframe before moving into CRT design and production. With that experience, he was ready to take charge of the 1310A/1311A Graphic Display project.

John enjoys golfing and skiing.

O. Douglas Fogg

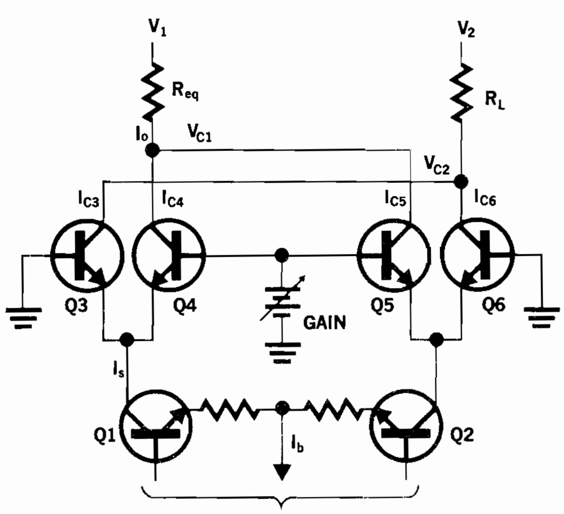
Another Colorado native, Doug Fogg earned his BSEE degree at the University of Colorado in 1964, where he was a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Tau. Following graduation, Doug moved to Albuquerque where he designed radar transmitters and power supplies while acquiring his MSEE degree at the University of New Mexico.

Doug moved back to Colorado in 1967, going to work for HP designing circuits for the 141B/141T Variable-Persistence Oscilloscope mainframes and then for the 1310A/1311A Graphic Displays.

Doug enjoys the Colorado hills, skiing on them in the winter and riding his motorcycle cross-country over them in the summer.

Appendix
Equalizing Power Dissipation in an Electronic Attenuator

An equivalent circuit for the electronic attenuator used in the new Graphic Displays is shown below. For this discussion, the collectors of Q4 and Q5 can be considered as tied together to an equivalent



Thevenin voltage V_1 through an equivalent resistance R_{eq}, as shown in the diagram below. This is because these transistors normally drive a push-pull amplifier but since the emitters of this amplifier are tied together, their bases are essentially at the same voltage level. This voltage remains constant with differential changes in the Q4 and Q5 collector currents but will vary with common-mode changes, such as those caused by changes in bias.

Referring to the diagram, the power P_4 dissipated by transistor Q4 is:

$$P_4 = V_{c1} r I_s \qquad (1)$$

where r is the fraction of current I_s that passes through Q4. The power P_3 in transistor Q3 is then

$$P_3 = V_{c2}\ (1-r)\ I_s \qquad (2)$$

It is desired to make the power dissipation in these transistors equal for all values of r and I_s, where r is proportional to signal attenuation and I_s proportional to the input signal.

$$V_{c1}\ rI_s = V_{c2}\ (1-r)\ I_s$$

or

$$V_{c1}\ r = V_{c2}\ (1-r) \qquad (3)$$

Because the transistor pair Q5-Q6 functions identically to the pair Q3-Q4, r is also the ratio of output current I_o to total current I_b.

Thus,
$$V_{c1} = V_1 - rI_b\ R_{eq}$$
$$V_{c2} = V_2 - (1-r)\ I_b R_L$$

Substituting these values into equation (3):

$$(V_1 - rI_b\ R_{eq})\ r = [V_2 - (1-r)\ I_b R_L]\ (1-r)$$

from which

$$r^2 I_b(R_L - R_{eq}) + r(V_1 + V_2 - 2I_b R_L) + (I_b R_L - V_2) = 0$$

For this to hold true for all values of r, the coefficients of r^2, r^1, and r^0 must all equal 0. Thus,

$$R_L = R_{eq}$$
$$V_1 + V_2 = 2I_b R_L$$
$$V_2 = I_b R_L$$

Hence
$$V_1 = V_2$$

The same result would be obtained, of course, for transistors Q5 and Q6. Hence if $R_L = R_{eq}$ and $V_1 = V_2$, the transistors in each pair will maintain equal power dissipation for all Input signals ($0 < I_s < I_b$) and for all values of attenuation ($0 < r < 1$).

SPECIFICATIONS

HP Models 1310A and 1311A Graphic Displays

VERTICAL AND HORIZONTAL AMPLIFIERS

RISETIME: 70 ns, 10% to 90% points for full-screen deflection or less.

BANDWIDTH: DC to 5 MHz (3 dB down at 5 MHz) with 3.5-inch deflection in 1311A and 5-inch deflection in 1310A.

PHASE SHIFT: <0.1° to 50 kHz and <1° to 250 kHz for full-screen signals.

LINEAR WRITING SPEED: >10 in/μs

DIAGONAL SETTLING TIME: Signal settles to within 1 spot diameter of final value in <1 μs for any on-screen movement.

SEQUENTIAL POINT-PLOTTING TIME: Signal settles to within 0.01 inch of final value in <200 ns for any 0.1-inch step.

REPEATABILITY: <0.15% of full-screen error for re-addressing a point from any direction on screen.

CROSSTALK: <0.015 inch with one input shorted and the other input excited by 500 kHz.

DEFLECTION FACTOR:

	Vertical	Horizontal
1310A	1 volt for 11-inch deflection	1 volt for 15-inch deflection
1311A	1 volt for 8½-inch deflection	1 volt for 11-inch deflection

Horizontal and vertical deflection factors adjustable from front-panel control with attenuation of 1.75:1.

SPOT JITTER and MOTION: <0.025 inch.

POSITION: Zero input can be set to any on-screen position.

POLARITY: Positive vertical input moves beam up; positive horizontal input moves beam right. Polarity can be reversed by changing internal lead connections.

INPUT RC: Driven side 10k ohms shunted by <40 pF. Shield input is 47Ω to ground; this can be replaced with 10k ohms for differential input. Switchable 50-ohm termination between shield and center conductor is also provided.

MAXIMUM INPUT: ±50 V (dc + peak ac) with 10k-ohm internal termination; ±5 V (dc + peak ac) with 50-ohm internal termination.

LINEARITY: 1% of full-scale display along major axes.

DRIFT: 0.05 in/hr and 0.10 inch in 24 hrs with covers installed.

Z-AXIS AMPLIFIER

RISETIME: <14 ns.

SENSITIVITY: 1 V provides full blanking or intensity.

INPUT POLARITY: Internal switch selects polarity (switch is normally set so negative voltage unblanks signal).

GAIN ADJUST: Internally adjustable over 2.5:1 attenuation range.

BALANCE: Internal adjustment provides ±1 V offset.

INPUT RC: Approx 10k ohms shunted by approx 60 pF. 50-ohm termination may be selected with internal switch.

MAXIMUM INPUT: ±50 V (dc + peak ac) with 10k-ohm internal termination; ±5 V (dc + peak ac) with 50-ohm internal termination.

CATHODE-RAY TUBE

VIEWING AREA

Model 1310A (19 in): 11 in high, 15 in wide.

Model 1311A (14 in): 8½ in high, 11 in wide.

CRTs of other sizes and shapes available on special order.

TYPE: Post-accelerator, 28.5 kV accelerating potential, P31 aluminized phosphor is standard (P4, P7, P39 aluminized phosphors available). Electrostatic focus and deflection.

SPOT SIZE:

	Spot Size in Quality Area	Size of Quality Area
1310A	0.020 inch	11" x 11"
1311A	0.015 inch	8½" x 8½"

RESOLUTION: 67 lines/in using shrinking raster method.

BRIGHTNESS: At least 50 ft-lamberts measured at 0.1 in/μs, 60 Hz rate, with spot size of 0.020 inch on 1310A and 0.015 inch on 1311A.

CONTRAST RATIO: 4:1 or greater.

X-RAY EMISSION: CRT emission not measurable in background noise with Victoreen Model 440RF/C.

IMPLOSION PROTECTION: Rim and tension banding prevents implosive devacuation.

PHOSPHOR PROTECTION: Circuit detects absence of deflection and limits beam current.

GENERAL

X, Y, and Z INPUT CONNECTORS: BNC type mounted to rear panel.

WEIGHT

Model 1310A: Net 53 lb (24 kg), with covers 59 lb (26,8 kg); shipping, 71 lb (32,2 kg).

Model 1311A: Net 40 lb (18,1 kg), with covers 45 lb (20,4 kg); shipping, 62 lb (28,1 kg).

DIMENSIONS:

Model 1310A: 19$\frac{3}{16}$ x 16⅝ in at front, by 26 in deep. 13¾ in wide at rear. (497 x 422 x 660 cm; 350 cm).

Model 1311A: 16¾ x 12$\frac{15}{16}$ in at front by 22¾ in deep. 13¾ in wide at rear. (426 x 329 x 578 cm; 350 cm).

OPTIONS

003: Top and bottom covers with tilt stand (rack mount adapter not supplied with Option 003 instruments).

005: Neutral-density contrast screen; improves trace contrast for easier viewing.

PRICES IN U.S.A.:

Model 1310A 19-inch Display $3000

Model 1311A 14-inch Display $2875

For prices of Displays with other types of CRT's, please contact your local HP Field Engineer.

P4 or P39 phosphor in lieu of P31, no charge.

P7 phosphor, includes amber filter; add $50.

Top and bottom covers with tilt stand, add $100.

Neutral density contrast screen, add $40 for 1310A, $30 for 1311A.

MANUFACTURING DIVISION: COLORADO SPRINGS DIVISION
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