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# A High-Quality, Low-Cost Graphics Tablet

*It enables the user to interact easily with a computer graphics system to generate illustrations using predefined and user-defined shapes, point-to-point plotting, and continuous line drawing or tracing.*

**by Donald J. Stavely**

THE HP 9111A GRAPHICS TABLET offers a new combination of features for the easy generation of computer graphics information. These features are contained in a low-cost human-engineered package (Fig. 1) and include high-level HP-IB* programming, comprehensive self-tests, and built-in softkey menu.

A graphics tablet is a peripheral device that provides a host computer with data corresponding to the position of a pen-like stylus relative to a surface, or platen. A pressure-activated switch in the stylus is the method used by the operator to inform the computer of a "picked" position.

Normally, the position data is used to manipulate a cursor on a graphics display device. This mode of operation, with the user's hand on the platen and eyes on the display, might sound awkward at first, but actually is quite natural. It often is the primary mode of graphical input in interactive graphics applications such as a printed-circuit, LSI, or mechanical design system.

A graphics tablet can be used in its own right for menuing applications, where the user picks items from a menu document placed on the platen. This menu can be thought of as a custom keyboard that can be easily understood by users with little or no technical training. The 9111A incorporates a built-in set of sixteen softkeys that are recognized by the tablet firmware. Program applications can use these softkeys for menuing or program control without X,Y coordinate analysis in the program. The ability to place a document on the platen surface also allows the tablet to act as a digitizer in applications where the high accuracy of the HP 9874A Digitizer[1] is not required.

*Hewlett-Packard's implementation of IEEE Standard 488 (1978).

### Graphics Tablet versus Digitizer

The 9111A was designed using the basic technology developed for the 9874A Digitizer. In fact, the 9111A HP-GL command set is fully compatible with a large subset of the 9874A commands. While this product design used many of the technical aspects of the 9874A, new contributions in the areas of human engineering and low-cost design were required to satisfy the special requirements of an interactive graphics device.

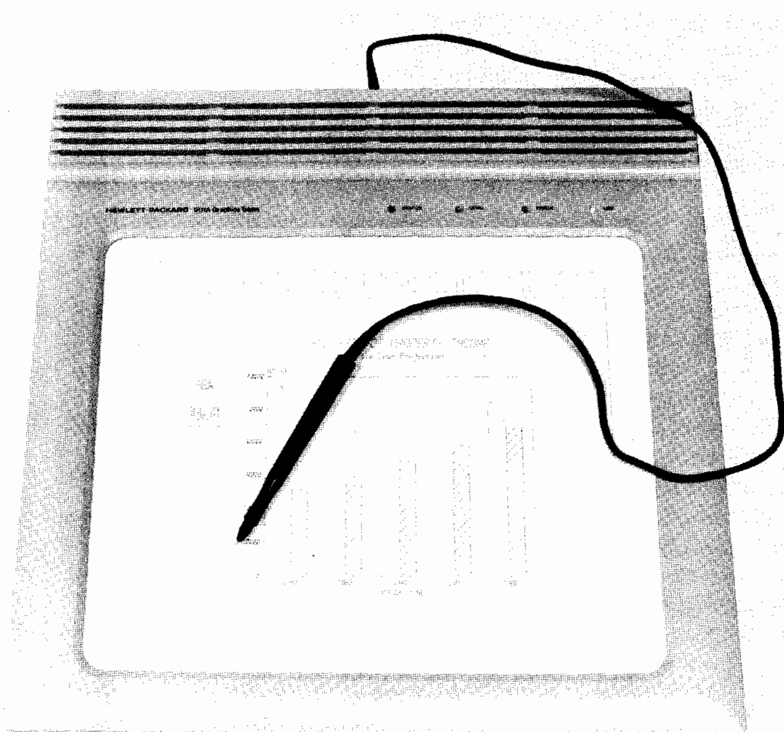


**Fig. 1.** *The 9111A Graphics Tablet provides easy user interaction with computer graphics systems. The stylus can also select shapes or functions from a menu overlay in addition to creating or modifying graphics images. Sixteen regions on the platen are designated for use as user-defined softkeys.*

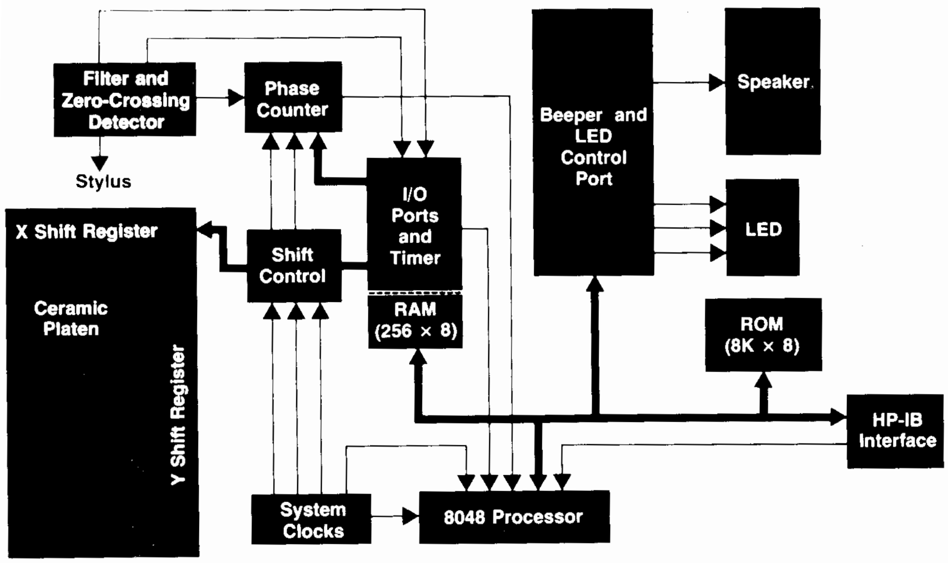



**Fig. 2.** *9111A system block diagram. The microprocessor in the system controls the interface functions, selects measurement modes, tests the system, and communicates with the host computer in addition to computing the position of the stylus.*

Somewhat different specifications are critical for the two operations. For digitizing, high accuracy with commensurate resolution is of paramount importance. Data rates do not have to be particularly high since the human can accurately trace figures only at limited speeds. Rates less than 20 points/second are normally sufficient. For interactive graphics, smoothness of cursor motion is a useful attribute. This means a high data rate is desirable. The 60 points/second maximum rate of the 9111A equals the refresh rate of most raster displays. Even if the logical position of the cursor is updated more rapidly, the user can only see changes at the display refresh rate.

An important characteristic is the stability of the position indicated by the tablet when the stylus is held motionless. If the X,Y coordinate has instability in the lowest-order digit, an annoying flicker of the cursor will result. The 9111A outputs data that typically doesn't vary when the stylus position is stable. The stability performance is achieved by data averaging techniques in the hardware and by data processing algorithms in the firmware.

Another parameter contributing to the perceived quality of cursor motion is synchronization between the refresh rate of the CRT and the data rate of the tablet. If the tablet is putting out 59 points/second, the CRT is refreshing at 60 sweeps/second, and the stylus is in constant motion, then the cursor on the CRT will move 59 times in a row. Every sixtieth sweep, the tablet will not have new data available —causing the cursor to freeze for one frame. The human eye is surprisingly sensitive to this interference effect between the devices. To overcome this problem, the tablet update rate can be accurately set to any integer value between 1 and 60, inclusive. Timing for this process is derived from the master crystal oscillator, with minor deviations introduced by firmware routines. The design goal was ±0.2 Hz from the programmed rate. Better than ±0.1 Hz is achieved at most frequencies. This means that a beat frequency will be present, but the period is so long that cursor jumping will be infrequent enough to be unobjectionable. This approach gives good performance with 60-Hz-refresh crystal-controlled CRTs as well as line-synchronized 50-Hz and 60-Hz displays.

Another advantage of data rate programmability in an interrupt-driven graphics system is that the computation load placed on the CPU can be accurately set by a single command to the tablet from a device driver or application program.

The time lag between the measurement of stylus position and the corresponding movement of the CRT cursor affects how fast a desired point can be picked by a human. A feedback loop is formed by the human to eliminate the error between the desired and actual location of the cursor. Delay in the feedback loop can cause overshoot and oscillation of the person's arm when rapidly moving to a point. The firmware in the 9111A is designed to minimize lag, regardless of the programmed data rate. Positional data is gathered from the hardware as late as possible during a measurement period. At the beginning of the next period the data is organized into the final format with 100-micrometre resolution. As soon as this is done, any pending commands can be executed. If the command is one that requests data, then the data delivered is as fresh as possible. Input of commands may occur virtually any time during the cycle. By limiting the time window in which commands are executed, the mainframe can synchronize easily with the data rate of the tablet. For example, the tablet has the computational power to execute approximately ninety OC (Output Cursor position) commands/second, but a fast controller will actually sync at the 60-points/second update rate of the tablet. The time window does not preclude more frequent execution of other more simple commands because up to 200 such commands can be executed per second.

Although optimized for interactive graphics, the tablet is also adequate for some digitizing applications. It is rated at ±600-micrometre accuracy (±0.024 in). This is suitable for the entering of small sketches and some strip chart applications.

## How It's Done

The 9111A Graphics Tablet uses the capacitive-coupling, electrostatic-drive technique of the 9874A Digitizer to determine the X,Y coordinates of the stylus. A block diagram of the system is shown in Fig. 2. The platen is an epoxy-glass printed circuit board with a grid of metal traces spaced 6.4 mm apart. The traces run vertically on the circuit

# Capacitive Stylus Design

**by Susan M. Cardwell**

The stylus for the 9111A satisfies a set of stringent design requirements. It is mechanically rugged. It can withstand being dropped on the floor or having its cable pinched in a drawer. Since the stylus will be held by the user for extended periods of time, it is slim, light, and provides clear tactile feedback of a "picked" position on the platen surface. These and other electrical performance and reliability criteria are met by an integrated system of transducers, body parts and cabling.

### Signal Transducers

Two independent types of information are transmitted from the stylus to the tablet:

1. The signal that is interpreted as X-Y location, and
2. A switch signal used to identify a given point as chosen for purposes of digitizing, picking or program control.

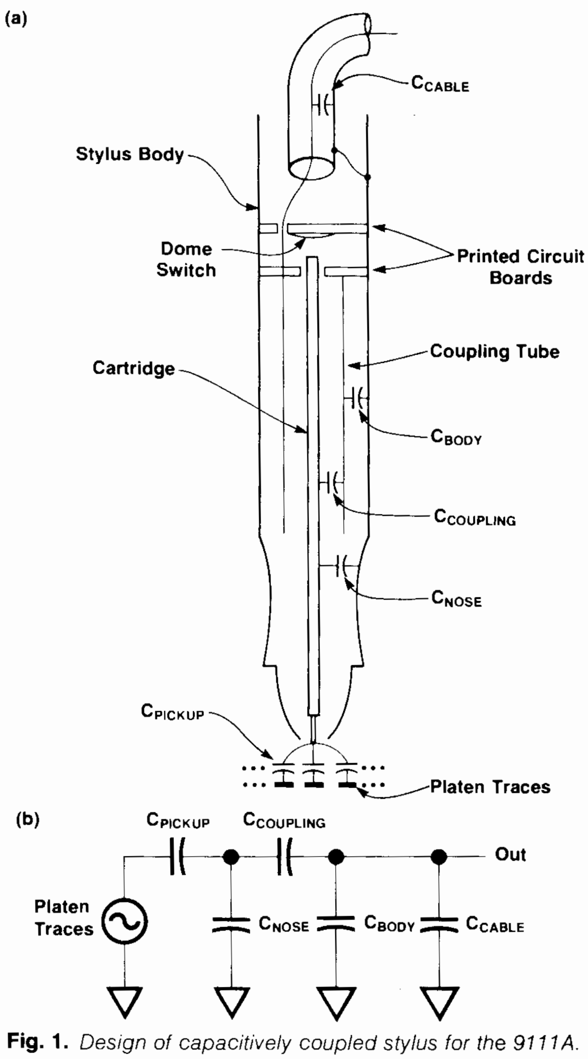



**Fig. 1.** *Design of capacitively coupled stylus for the 9111A. (a) Cross-sectional view showing the conductors and capacitive components. The stylus cartridge can be replaced by an ink-filled cartridge for users drawing images instead of tracing them. (b) Equivalent circuit for the stylus signal path from the platen traces to the instrument.*

The location of the stylus is determined by the capacitive coupling established between the platen grid and the tip of a metal pen cartridge. This cartridge is capacitively coupled to a coaxial tube within the stylus body (Fig. 1). To select a point, the pen tip is pressed, which activates a dome switch at the base of the cartridge. The snap action of the dome switch provides tactile feedback to the user.

The second stage of capacitive coupling is used for its advantage over direct or sliding contacts. Direct contact with the cartridge requires a permanently attached contact which precludes easily exchangeable cartridges (ink and inkless) and necessitates adding a flexing signal wire to accommodate switch operation. A sliding contact is likewise undesirable in that it impairs the distinct tactile feel of the dome switch and it creates electrical noise.

The equation for the series capacitance between the coupling tube and the cartridge is:

$$C = \frac{2\pi\epsilon_o\epsilon_r L}{\ln(b/a)}$$

where b is the larger diameter, a is the smaller diameter, L is the length of the tubes, $\epsilon_o$ is the dielectric constant for a vacuum ($8.854\times10^{-12}$ F/m) and $\epsilon_r$ is the relative dielectric constant for air ($\approx$1.0006). Within the constraints of mechanical tolerances, the coupling capacitance is maximized to a value of $C\approx11.5$ pF. This provides approximately two-thirds of the signal output of a direct contact scheme. Signal strength is maintained by slightly increasing pen tip exposure.

### Body Parts

A combination of machined metal and molded plastic body parts supports and houses the transducer system. Both the dome switch and the capacitive coupling tube are mounted on two small, round, printed circuit boards at the back of the stylus. Shielding both the capacitive coupling tube and the signal-carrying metal pickup is essential to proper operation. Since the body parts must permit repeated exchange of cartridges and still insure a ground when connected, they are made of aluminum


**Susan M. Cardwell**

Susan Cardwell joined HP in early 1978 as a production engineer for the 9874A Digitizer. She worked on the development of the 9111A Tablet and is currently involved with LSI circuit design. Susan received the BS degree in engineering from Swarthmore College in 1977 and did graduate study at the Massachusetts Institute of Technology in the fall of 1977. She is a native of Detroit, Michigan and she and her husband make Loveland, Colorado their home. Susan is on the board of directors for the Canyon Concert Ballet Company and is an administrative member of the Loveland Bahá'í Spiritual Assembly. She enjoys the theatre, dance, and backpacking.

treated with a chromate conversion process to guarantee high conductivity.

Because the signal level is low, the system can be highly sensitive to triboelectric effects—friction forces at the interface between a conductor and an insulator that create charges and a resulting current. Molded polypropylene parts meet the multiple requirements of small geometries, dimensional stability, insulation and minimal tribolectric contribution at the cartridge bearing surfaces.

**Cable**

The cable carries two switch wires and a low-capacitance coaxial platen-signal wire from the stylus to the tablet. Because this component of the stylus experiences the greatest stresses, it greatly affects stylus reliability. Cable life is maximized by using multiple strands of a custom copper alloy wire with exceptional flex life. The switch wires are tightly coiled around the coax shield so that cable flexing places minimal tension and compression stresses on the conductors. Strain relief boots at both ends are carefully tapered to avoid sharp strain of the cable.

side and horizontally on the component side of the board. The signal picked up from each trace is a function of the distance between the tip of the stylus and the trace. The signal from any single trace is proportional to the drive voltage and coupling capacitance. Since the coupling capacitance is a function of distance, the stylus output voltage $V_0$ is the sum of the individual trace drive voltages reduced by the distance from each trace to the stylus (see Fig. 3).

In the 9111A the traces are driven by CMOS shift registers. The choice of 12-volt CMOS shift registers instead of the 5-volt registers used in the 9874A provides a proportionately greater signal to the stylus. Using the capacitive coupling technique, the stylus output voltage $V_0$ becomes cyclical at the same frequency as the 9.765-kHz signal driving the traces. This allows, after processing as described below, the 60-samples/second data rate desired for interactive graphics applications.

The stylus signal $V_0$ is buffered, filtered about 9.765 kHz and sent through a zero-crossing detector to recreate the original 9.765-kHz reference frequency. The recreated frequency is shifted in phase, depending on stylus position. To calculate the distance from the first trace to the stylus, we simply measure the phase shift of the stylus signal referred to the signal of the first trace.

The resolution of the 9111A is 0.1 mm. To achieve this, a series of phase measurements is made in calculating each X,Y coordinate pair. The sequence in which these measurements are made is:

X reference
X coarse
X fine
Y fine
Y coarse
Y reference

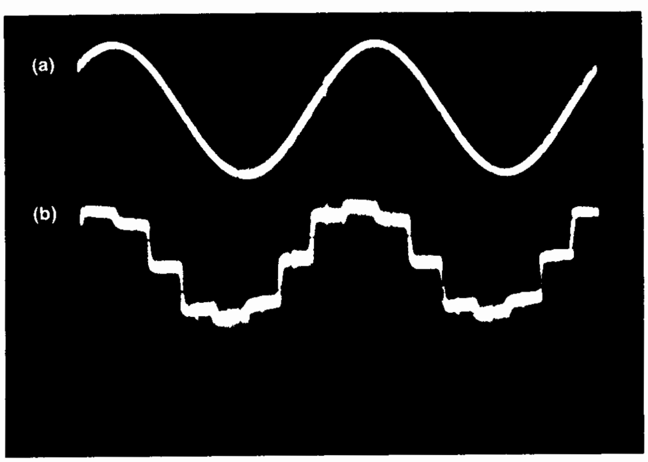



**Fig. 3.** *Stylus signals after (a) and before (b) bandpass filtering. The lower trace shows the stairstep waveform resulting from the summation of the signals from each of the platen traces.*

The reference measurements are used to compensate for the time delay added to the stylus signal by the filter electronics. This also eliminates error due to drift in component parameters because of aging, temperature and humidity. In reference mode, all the traces are simultaneously driven high and then all are driven simultaneously low at a 9.765-kHz rate. Since the signal on every trace is identical to the signal on the first trace, any phase shift in the stylus signal will be caused solely by the filter delay. The reference measurements are subtracted from the coarse and fine measurements.

In the measurement mode each trace is driven sequentially high and then each trace is driven sequentially low at a clock rate dependent on the resolution required. The coarse measurement rate addresses all of the traces during one cycle of the 9.765-kHz signal. The fine measurement clock rate is one-eighth that of the coarse rate so that eight cycles of the 9.765-kHz signal occur before all of the traces are addressed. The coarse mode creates a wavelength of 409.6 mm on the platen. Using the platen frequency, 9.765 kHz, we calculate the velocity of the signal and then find the wavelength.

$$\begin{aligned}\text{Velocity} &= (\text{trace spacing}) \times (\text{coarse mode clock rate}) \\ &= (6.4\ \text{mm}) \times (625{,}000\ \text{traces/second}) \\ &= 4000\ \text{m/s}\end{aligned}$$

$$\begin{aligned}\text{Wavelength} &= \text{velocity/frequency} \\ &= (4000\ \text{m/s}) / (9.765\ \text{kHz}) = 409.6\ \text{mm} \\ &= 16.12\ \text{in}\end{aligned}$$

This wavelength is longer than the platen's maximum dimension. The coarse measurement provides a rough but unambiguous guess of where the stylus is within this long wavelength.

The coarse position is refined by making another measurement with increased resolution. The wavelength of the fine mode (51.2 mm) is one-eighth the coarse wavelength. By keeping the same phase resolution, the physical resolution of the system is increased over the resolution of the coarse mode by a factor of 8. The 8:1 ratio of wavelengths is large enough to attain the desired accuracy and stability of the machine, yet small enough to eliminate any possibility of having the coarse measurement "guess the wrong fine wave" to be refined. An error of this kind would result in an annoying jump in the position data supplied to the host.

The firmware also reduces this possibility by continuously monitoring the accuracy of the coarse estimate. The sequence of measurements calls for adjacent X-fine and Y-fine measurements to minimize the effect of any linear motion of the stylus during the sequence.

When measuring the phase of the filtered signal it is necessary to avoid incorrect measurements when the signals are near the 0/360° wrap-around point. This is done by checking the phase relationship of the stylus and reference signals while the filter is settling. This process is called reference adjustment. If the stylus signal rising edge is less than 90° or greater than 270° from the rising edge of the reference signal, then 180° is added to the reference signal. At the completion of the reference adjustment (once the filter is settled), the phase difference between the stylus and reference signals is between 90° and 270°, which gives the system increased immunity to noise in the stylus signal. If added, this extra 180° phase shift is subtracted later.

The phase shift of the 9.765-kHz stylus signal in each of the six measurement modes is summed for sixteen periods to further reduce noise effects on the measurement. Firmware reduces the summed measurement into a number representing the phase shift of each mode. This is simplified by the 6.4-mm spacing of the traces on the platen. The microprocessor uses the count from each of the six modes to compute the X,Y position of the stylus. The quality of the actual position measurement compared to the conservative specification is illustrated in Fig. 4.

The microprocessor also performs all algorithms necessary to sequence the platen, control the light-emitting diodes (LEDs) and variable tone beeper, and communicate with the host computer. The microprocessor controls the shift registers by writing data to the shift control which in turn creates the proper signals to drive the shift registers in the various platen modes.

The microprocessor-based system (Fig. 2) has the capability to perform extensive verification of its proper operation. The electronics self-test is initiated by the processor every time the instrument is powered on. It is also entered upon receipt of the IN (Initialize) command from the host computer. This test flashes the LEDs (for operator verification of their functionality) and then performs a series of tests on internal hardware. First, the microprocessor's internal registers are tested. Memory tests are a read-only-memory (ROM) checksum and extensive bit pattern testing of the read/write memory (RAM). The functionality of the three I/O ports for the shift control and phase counter is checked. The phase counter is cleared and the normal operating sequence of bit patterns required to perform reference adjustment and measurement summation is sent to the phase counter.

Communication with the HP-IB interface chip is verified and, finally, the programmable countdown timer is tested. This timer interrupts the processor for the normal sequencing of the six platen modes and is used to pace the processor to create the proper frequencies for the variable tone beeper. If the electronics passes the tests, a three-tone pass beep is generated by the beeper. If any of the tests fails, a loud, warbling error tone is output and the **ERROR** LED is lit.

The proper operation of the shift control, shift registers, filter and stylus can be verified by performing the user interactive self-test. This test is normally performed immediately after the instrument is powered on. It is initiated by toggling the **SELF TEST** switch on the rear of the graphics tablet while holding the stylus away from the platen. It can also be initiated by a TD (Test Digitizer) command. The user interactive self-test first performs the electronics self-test. After the pass-beep tone from the electronics self-test, the

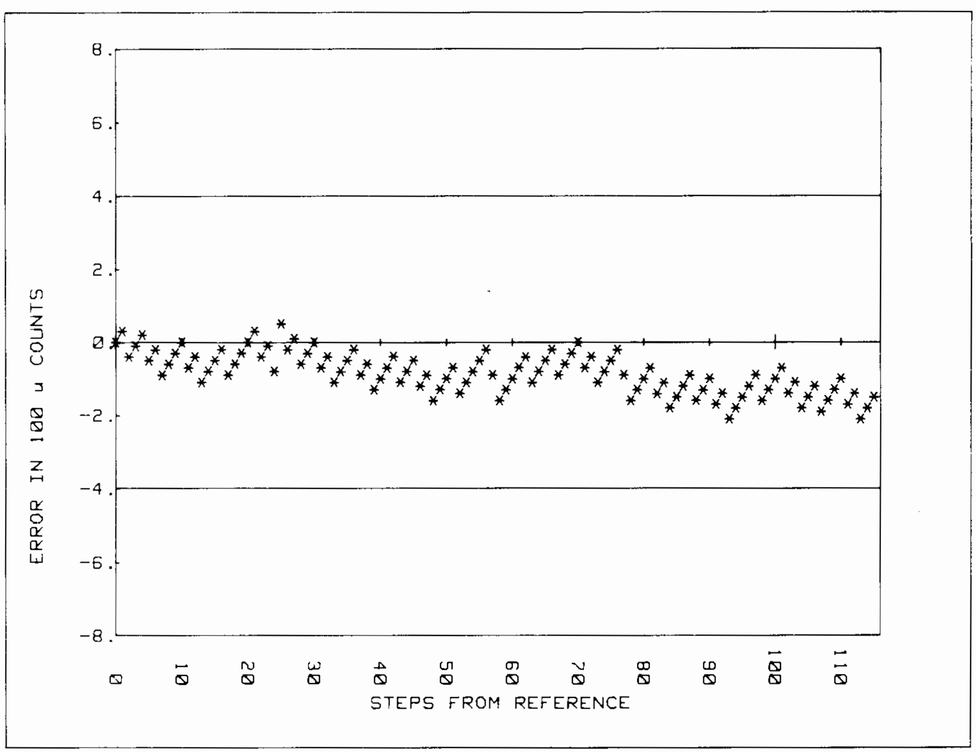



**Fig. 4.** *Typical position measurement accuracy plot. The system specification is ±600 micrometres with typical values within ±400 micrometres.*

# Programming the Graphics Tablet

by Debra S. Bartlett

The firmware of the 9111A provides easy high-level programming. For example, software for the HP 9845B Computer has been written that allows the user to create drawings interactively using circles, rectangles, arcs, lines, and labels. The user can also pick, place, and transform elements, and set up and interpret a user-defined menu. This software takes advantage of the following features of the 9111A Graphics Tablet: interrupts, softkeys, single and continuous mode digitizing, information received from the cursor statement, scaling, and variable beeper. Software has also been written for the HP-85, 1350A, and System 45C, and is underway for the HP-1000.

The main driver for all the programs is set up on the basis of being able to interrupt the main program selectively. First, interrupts on the HP-IB SRQ line are enabled. Then by simply sending the IM (Input Mask) instruction to the 9111A Graphics Tablet, the programmer can specify the actions that will cause a service request. The programmer can set the input mask to interrupt on errors, a digitized softkey, a digitized point, or on proximity. The input mask can also be set to enable the recognized errors and to select status conditions that will cause a response from the 9111A to a parallel poll. The 9845B/9111A software is set up to generate a service request whenever the user digitizes on the active area of the tablet or digitizes one of the sixteen softkeys. This interrupt capability allows the program to track the cursor without having to check continually to see if the user digitized a point or selected a softkey. The code is simpler and the cursor moves faster.

Once the service request has been received, the program must determine what caused it. To do this, the program looks at the status word from the 9111A. This word is retrieved by simply sending an OS (Output Status) command to the tablet and then by reading it into the 9845B. Information contained in this word is pen press, new cursor position, proximity, digitized softkey, SRQ, error, and digitized point available.

If the seventh bit of the status word has been set, the program knows that the user has digitized one of the sixteen softkeys. Because of the firmware in the graphics tablet, the program can then execute a RS (Read Softkey) command to determine exactly which softkey (1-16) was selected. As a result, the program does not have to look at the exact X,Y coordinate digitized and see if it falls within certain boundaries to determine which softkey was digitized. This provides the programmer with an easily used predefined menu area. The 9845B/9111A software uses these softkeys to perform such operations as get a picture, save a picture, label, delete object, delete line, snap to a grid, plot, clear the CRT, and help.

If the second bit of the status word has been set, the program knows that the user has digitized a point on the active area of the platen. The drawing program and the editor program use this area for menuing, cursor moving and placing. Part of the platen is used for cursor movement and placement and the other part of the platen is used as additional menu space for such items as pen, line type, character, and element selection, or for rotating, scaling, and moving objects in the editor program. To determine which area has been selected, the program sends the tablet an OD (Output Digitized point) command and then reads in the digitized X,Y coordinate from registers in the graphics tablet. Because the 9111A has registers for storing the X and Y values of the digitized point, the user does not have to worry about moving the stylus too quickly and losing the X and Y values before the program can get to it. Thus, the program always knows the exact point that the user has digitized.

The firmware in the tablet allows for two modes of digitizing. The first is the single-point mode. In this mode, each time the stylus is pressed, a coordinate point is stored in the registers on the tablet. The software for the 9845B/9111A uses this mode for menu picking, placing elements, and drawing straight lines.

The second mode of digitizing is the continuous sample mode. This mode can be set to take points when the stylus has been pushed down and released, stop when the stylus is pressed down again (switch normal) or take points only when the stylus is pressed down (switch follow). The data rate for this continuous mode can be specified (one to sixty updates per second) by the programmer simply sending the graphics tablet a CR (Cursor Rate) command. The drawing program uses the continuous switch follow mode. This mode lets the user draw curved lines and trace pictures placed on the platen.

The graphics tablet's firmware is set up so that the program can tell what the user is doing without using interrupts. The CURSOR statement is one way to do this. The CURSOR statement returns the X,Y coordinate of the stylus location, the pen parameter, the number of the softkey if one has been selected, the status word and the error number. The 9845B/9111A software uses this method within the subprograms. For example, when in the subprogram for drawing single-point lines, the program uses this information to determine if the user has digitized a point on the active area of the platen. If the user has, the program checks to see if the digitized point lies within the placement area of the menu. If it does, the program reads in the point and draws to it. If it does not fall within the placement area, the program returns to the main program where the unread digitized point can cause an interrupt and branch to the subprogram that the user has selected. This versatility gives programmers a way to vary the method of retrieving information from the tablet.

The graphic tablet's implementation of HP-GL allows the programmer to use scaling commands as implemented in the 9845 graphics ROMs. The software takes advantage of this to do a one-to-one mapping of the placement area on the tablet to the CRT screen of the 9845B. First the program uses the LIMIT command to specify in metric units those areas of the CRT and the tablet that will be used for cursor tracking. Then the program executes a SHOW statement to scale the tablet and CRT to the same number of units in the X and Y direction. This makes the program simpler to code because it does not have to be concerned with transforming every point received from the graphics tablet.

The 9111A Graphics Tablet has a programmable beeper. The programmer can specify the frequency, duration, and amplitude of the beep. It has a range of four octaves, can last from one millisecond to 33 seconds, and can have six different degrees of loudness. The software for the 9111A/9845B takes advantage of this function to give feedback to the user by specifying five different sequences of beeps to indicate different conditions. There is a pick tone for indicating that a menu item was picked, an error tone indicating that the user has digitized an undefined area or didn't answer a question correctly, a data tone indicating that a point was placed, a question tone indicating that the user needs to answer a question, and a finished tone indicating that a particular operation has been completed.

The firmware has some other features that make higher-level programming easier. The first is the OI (Output Identity) command. This command is used to determine which peripheral device is on the bus. This lets a programmer use the same piece of software for the 9111A and the HP 9874A Digitizer. When the program starts executing, it checks to see which input device is connected and then the program can set the correct scaling parameters for that particular size platen. Another useful command is the OE (Output Error) command. The tablet is set up so that if a program statement sends the tablet an unrecognized command or illegal parameter, it will not cause the program to quit. Instead the **ERROR** LED on the tablet is lit to indicate an error and the error number is stored in a register in the tablet. After the tablet has received the error, the programmer can read in the error number using the OE command.

**Debra S. Bartlett**

Debbie Bartlett has a BS degree in mathematics awarded by Purdue University in 1977 and is currently studying for a master's degree in computer science at Colorado State University. She has been with HP since 1979 writing software for new products. Her previous work experience involved statistical analysis. Debbie is married (her husband works at HP's Loveland Instrument Division) and lives in Loveland, Colorado. She is a native Hoosier from Indianapolis, Indiana and likes water skiing and hiking.

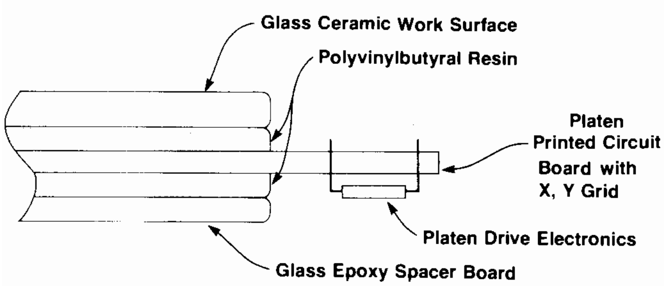



**Fig. 5.** *Cross-section of platen printed circuit board assembly. The ceramic work surface provides a durable layer that resists scratching and is dimensionally stable.*

user must digitize the dot at the lower right corner of the platen artwork. If the shift control, shift registers, stylus and filter circuitry are all operating properly, another pass-beep tone will be generated. Failure of the test is indicated by the error tone and the lit **ERROR** LED.

Any error from the electronics or user interactive self-tests, improper or unrecognized commands, or system failure can be analyzed by sending an OE (Output Error) command to the 9111A. A read or enter statement will retrieve the value representing the error.

The microprocessor-based system is designed to help a trained service technician troubleshoot the digital electronics using the 5004A Signature Analyzer. Signature analysis routines for the system clocks, microprocessor addressing, ROM and phase counter can be activated by proper placement of removable jumpers on the printed circuit board. Additionally, test points are available for signature analysis, microprocessor, clock frequencies, filter and phase counter signals, as well as for voltage and ground.

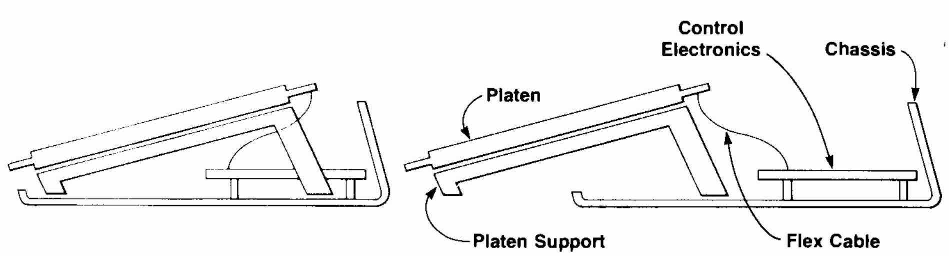
## Mechanical Design

The 9111A platen assembly consists of an X-Y coordinate grid sandwiched between a work surface above and an insulating layer below (Fig. 5). These are laminated using a sheet form of polyvinylbutyral resin. The grid is built on a standard two-layer glass-epoxy printed circuit board with 56 X-traces on the top side of the board and 46 Y-traces on the bottom. By extending the edges of the printed circuit board, platen drive electronic components are loaded next to their respective traces, eliminating the need for extensive cabling.

Of the many materials considered for the work surface, the glass ceramic chosen stands out with its exceptional durability, high dielectric constant and homogeneity. The axis lines and sixteen menu boxes are permanently fired into the platen surface. Thermal stability over a wide temperature range enables straightforward lamination and wave soldering. Lamination ensures a homogeneous dielectric constant by excluding air pockets. Furthermore, it provides a safety-glass construction between the ceramic and the printed circuit board.

Simplicity of construction dominates the internal product design. A sheet-metal chassis holds the control printed circuit board and power supply. A second piece of sheet metal mounted on the chassis both supports the platen and shields its grid from the electronics below. The flex cable connecting the two printed circuit boards is positioned such that the instrument can be fully operational during service (Fig.6).

A survey conducted at the beginning of the design indicated that users prefer the comfort of a sloping surface to that of a flat pad. This simultaneously allows a low front edge and enough space to fit all the electronics in the rear. The resulting wedge shape is more convenient, comfortable




(a) (b)

**Fig. 6.** *The 9111A hardware design allows service personnel to easily open the unit for servicing and still maintain normal operating functions. (a) Normal operating configuration. (b) Open for servicing.*

# Tablet/Display Combination Supports Interactive Graphics

by David A. Kinsell

Interactive graphics systems have special I/O requirements that place a heavy burden on the computer. To move a cursor on the CRT requires a number of very short messages between the tablet and the display device. Even if the computer can devote full time to this cursor tracking, an unacceptably low update rate can result due to the system overhead required to set up each data transfer. To solve these problems, the 9111T was created.

The 9111T has all the capabilities of a standard 9111A, plus firmware enhancements that allow direct HP-IB communication to a 1350A Graphics Translator. The result is high-performance cursor movement and rubber-banding (stretching of lines) done by the peripherals that is totally independent of computer speed. In essence, the peripherals act in harmony as if they were a single graphics terminal. They also can be used independently with no physical reconfiguration of the bus.

This type of direct communication on the HP-IB, from one non-controller device to another, has always been provided for in the bus definition. It is rarely used because few combinations of peripherals have anything useful to say to each other. Data formats may differ and some form of mnemonic commands is usually required to control each device. For instance, let's look at the feasibility of having a digitizer device (9874A) plot digitized points directly to a plotter device (9872A).

After the user has digitized a point the digitizer must receive the OD (Output Digitized point) command to enable output of the digitized data. The command PA (Plot Absolute) must preface X,Y coordinates for the plotter to function properly. If a digitizer and plotter were hooked together on a bus and addressed as talker and listener, nothing would happen because the proper commands would not be received by the peripherals. Also, no scaling could be done to compensate for the different sizes of the devices. These details are normally taken care of by the computer, which is an acceptable approach for the low data rates of manual digitizing.

In contrast, the 9111T has the capability of issuing commands to the 1350S Display System in the language used by the 1350A Graphics Translator (Fig. 1). After being set up by the computer with a single command, the 9111T repeatedly streams out commands and data directly to the 1350A that perform cursor movement and rubber-banding functions. The scaling is changed to map most of the 9111T active area onto the display (Fig. 2). The stroke refresh used by the 1350A is ideal for rubber-banding and moving objects. Only a few vector locations need to be changed by the tablet, in contrast to the large number of pixels that must be altered in a raster refresh system.

The 9111T provides these additional functions, listed with the corresponding number of updates/second:

- Moving alpha or cursor symbols (60)
- Single-line rubber-banding — normal, forced horizontal, and forced vertical (60)
- Double-line rubber-banding (60)
- Rectangle rubber-banding (60)
- Variable-size cursor (single-dot to full-screen) (40)

The added capabilities are aimed primarily at IC and printed

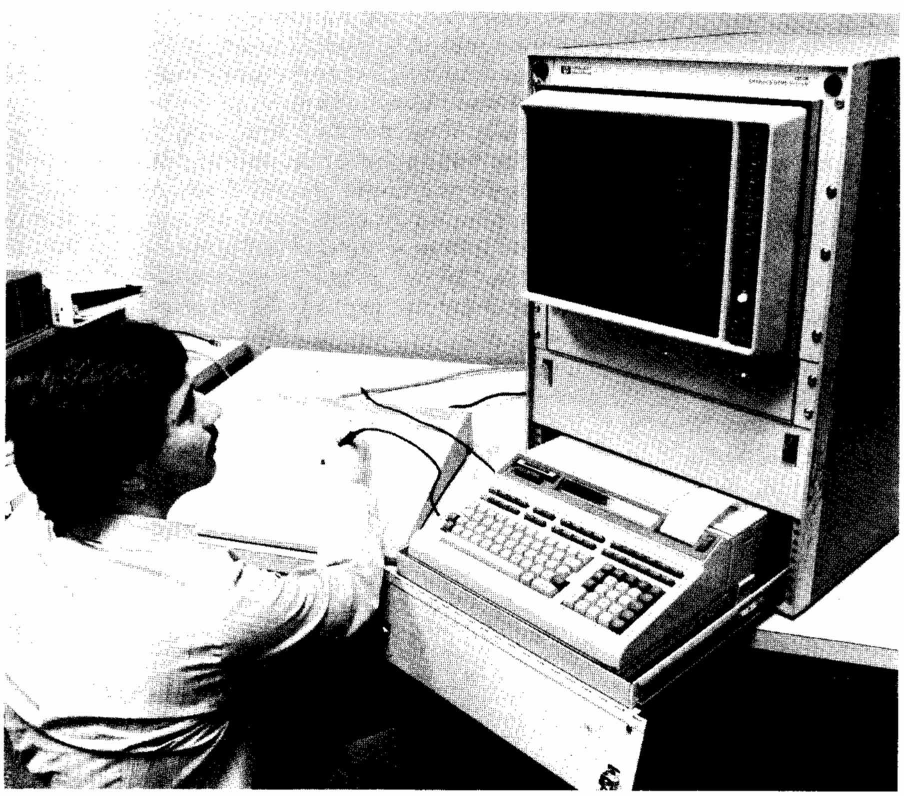


**Fig. 1.** *The combination of a 9111T Graphics Tablet, a 1350S Display System and a controller such as the 9825 provides powerful interactive graphics in an inexpensive workstation.*

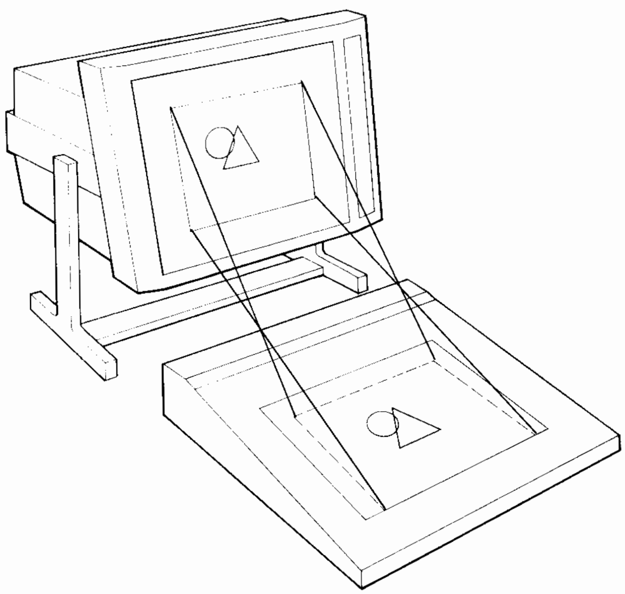


**Fig. 2.** *The platen area on the 9111T Graphics Tablet is directly mapped onto the CRT of the 1350S Display System as shown.*

circuit layout applications, but other applications involving menu picking, symbol picking, picture creation, or the use of valuators will also benefit.

To access one of these features, the following things need to be done:

1. The computer plots data in a few of the vector locations of the 1350A.
2. The computer sends the EE (Enable Echo) command with proper options and parameters to the 9111T to put it in the 1350A mode.
3. The computer configures the bus with the 9111T as talker, and the 1350A as listener.
4. The computer arms itself to respond to SRQ (the interrupt line on the bus).

After this setup is accomplished, the computer is uninvolved with the data transfer on the bus. It is free to handle other tasks (including servicing other 9111T/1350As on other bus systems).

The user moves the cursor or rubber-bands a line until it is in the proper position, then presses the pen to pick a particular point. When this happens, several things occur. The tablet stores the coordinates of that point, finishes any communication that might be in progress with the display, and then asserts the SRQ line on the HP-IB to request computer service.

The computer responds to the interrupt and interrogates the tablet for the digitized point. The value returned is scaled in terms of the display screen coordinates instead of the normal coordinate system of the 9111T. Thus, to convert from a user coordinate system to the peripheral coordinate system, a programmer need not worry about maintaining different scale factors for the tablet and the display. Typically, the user redraws a rubber-banded object in the 1350A's memory using the coordinates of the digitized point. Snapping points to a nearby grid intersection is easily done during this operation.

Instead of picking a point, the user could pick a menu box to control the program. The menu item selected is read by the computer in the normal manner.

The high resolution of the 1350A (1023×1023), along with the fast update rate and stable output from the tablet, combine to provide tracking with excellent aesthetics. The independence from computer I/O performance makes interactive graphics feasible for smaller computers (such as the HP-85) and opens the way to multi-workstation operation on large computer systems.

**David A. Kinsell**

Dave Kinsell started work at HP in 1975 after receiving the MSEE degree from Purdue University. He also earned the BSEE degree from Purdue in 1974. Dave has done NMOS IC R&D, graphics display studies, production support for the 9874A Digitizer, and, most recently, the implementation of firmware and system specification for the 9111A Tablet. Dave is a native of Remington, Indiana and now lives in Loveland, Colorado. He is a member of the IEEE, rides his bicycle to work, likes mountain hiking and skiing, and is a glider pilot.

and compact than a tablet that requires separate boxes for electronics and/or power supply.

Internal layout promoting natural convection paths, combined with low power dissipation, permits an instrument with no fan, hence a quiet machine. Air enters along the bottom of both sides and exits at slots in the rear.

While the tablet functions primarily to move a CRT-display cursor for some users, others have applications for which they need to place a menu directly on the work surface. To please both groups, it is necessary to provide an unobtrusive means to hold down paper. In the edge of the case where it meets the platen are four thin slots that accommodate tabs on a clear mylar overlay. With this design the user can protect a menu while holding it in place. When menus are not in use, the tablet is free from protruding or unsightly mechanisms.

Ease of assembly affects the people who build an instrument, those who service it, and the cost to the user who buys it. The case top was designed to be independent from instrument operation; no components are mounted in it. When assembled, two long conical bosses in the case top reach through holes in the platen assembly to align the platen in the case top window. The LEDs are mounted directly on the platen assembly as well. Therefore, both platen and LEDs are positioned with no hardware, no loose parts and no wiring.

### Interface Language

For compatibility with other HP graphics devices, the tablet communicates primarily in Hewlett-Packard Graphics Language (HP-GL). This language was developed by several HP divisions for use with mechanical plotters and manual digitizers. It uses ASCII-encoded two-letter mnemonics and free-field integer representation of data. This is a very common type of data formatting used on the HP-IB. It can be handled by just about any general-purpose

I/O driver used with the bus. Its main disadvantage is the time required to do the numerical conversion from this format to the internal format of the mainframe. Conversions from the tablet's internal format to the integer representation are handled by the fast lookup algorithms in the tablet.

To help relieve the host computer of the conversion burden, binary formatted data of the X,Y position is also available from the tablet in a straightforward format supported by several HP computers. These include the 9835, the 9845, the HP-85, and the HP 1000. The I/O drivers can input two bytes of data and place them directly into a 16-bit integer variable. This format is also convenient to use when assembly language drivers are written to support the tablet.

The tablet can also be put into a Talk Only mode. The same binary formatted data is available in this case. Although commands cannot be sent to the tablet, it is easy to design a custom interface to read the data.

The HP-GL language gives coordinate values in an absolute peripheral coordinate system. To simplify programming, high-level support is available on a number of computers to provide scaling into user-defined units and to support the digitize function. The 9825 with a 9872A plotter ROM provides single-point digitizing support that can be used for continuous-mode digitizing with some additional HP-GL programming. The 9835 and 9845 computers have graphics ROMs that provide BASIC-language support of the tablet. The HP-85 printer/plotter ROM is essentially equivalent. A high-level graphics support package will also be available on the HP 1000.

The System 45C (Model 9845C) provides a powerful set of high-level programming features through its graphics ROM. The GRAPHICS INPUT IS ... statement allows a full complement of graphics input devices, including the 9111A Graphics Tablet, 9874A Digitizer, light pen, and arrow keys to be handled uniformly in an application program.

Once the tablet has been declared as the input device, the programmer can set up a software interrupt with a single command, ON GKEY .... With this command in effect, the program will branch to a desired location any time a point or softkey is digitized on the platen. Another command TRACK...IS ON allows automatic tracking of the cursor on the CRT. When this command is in effect, the cursor position is updated after every executed BASIC line. Finally, the CURSOR... command, while also implemented on the 9845A/B computers, returns additional tablet information concerning clipping and softkey values only on the 9845C. The additional capabilities of the 9845C graphics firmware together with the 9111A graphics tablet make applications programs shorter and easier to write and debug.

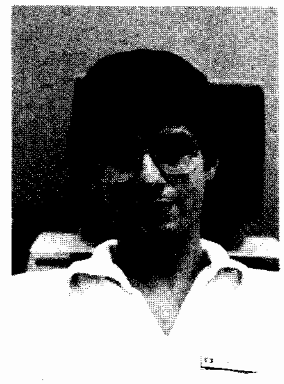
### Acknowledgments

Several people played key roles in the success of the 9111A. Susan Cardwell was responsible for the total mechanical design of the instrument. Dave Kinsell wrote the 9111A firmware, and personally initiated and implemented the 9111T follow-on. Mark Gembarowski designed the digital hardware, and Tim Hitz designed the analog circuitry and power supply. Dave Jarrett implemented the 9111A stylus, and Debbie Bartlett implemented the application utility routines. Mo Khovaylo was responsible for the industrial design. Special thanks to Dave, Susan, and Mark for their contribution to this article. I am indebted to Larry Hall who, as initial project manager through breadboard, passed on an efficient, well-run project.

### Reference

1. F.P. Carau, "Easy-to-Use, High-Resolution Digitizer Increases Operator Efficiency," Hewlett-Packard Journal, December 1978.

**Donald J. Stavely**



Don Stavely was born in Detroit, Michigan and attended the University of Michigan where he received the BS degree in electrical engineering in 1975 and the MS degree in computer engineering/computer science in 1976. He came to HP that same year and has worked on firmware for the HP 250 Computer and directed the completion of the 9111A Tablet development. Don is currently managing an LSI design project. His outside interests include canoeing, backpacking, and woodworking. Don and his wife live in Fort Collins, Colorado.

## SPECIFICATIONS
### HP Model 9111A Graphics Tablet

**FEATURES:**
- MENU: Sixteen softkeys.
- COMMAND SET: Twenty-five HPGL commands through HP-IB interface (Hewlett-Packard's implementation of IEEE Standard 488 (1978)).
- BEEPER: Programmable in pitch, volume, and duration.
- ACTIVE DIGITIZING AREA: 218.5 × 300.8 mm, not including menu area.
- DATA RATE: Programmable from 1 to 60 coordinate pairs/second. Average rate ±0.2 Hz from nominal.
- SELF-TEST CAPABILITY
- PLATEN: Ceramic surface, artwork (origin, self-test dot, any border) accuracy measured versus documented is ±2.8 mm.

**GRAPHICS DATA:**
- FORMAT: ASCII or binary X, Y coordinate data.
- RESOLUTION: 0.100 mm.
- ACCURACY: ±0.600 mm at 20°C, each measured point. Derate 0.004 mm/°C deviation from 20°C.
- STYLUS MOTION RATE:
  - On paper: 500 mm/s.
  - On platen: 730 mm/s.
- REPEATABILITY: ±one resolution unit from mode of data.
- DOCUMENT MATERIAL: Single sheet, electrically nonconductive, homogeneous, less than 0.5 mm thick.

**POWER REQUIREMENTS:**
- SOURCE (±10%): 100, 120, 220, or 240 Vac.
- FREQUENCY: 48 to 66 Hz.
- CONSUMPTION: 25 W, maximum.

**SIZE/WEIGHT:**
- HWD: 85 × 440 × 440 mm.
- WEIGHT: 5.8 kg, net; 10.8 kg, shipping.

**OPERATING ENVIRONMENT:**
- TEMPERATURE: 0 to 55°C.
- RELATIVE HUMIDITY: 5 to 90% at 40°C, noncondensing.

**PRICE IN U.S.A.:**
- 9111A: $1950.
  - 88100A (Utility Software Package for 9845B Computer): $500.
- 9111T (Option for use with 1350S Display System): $2450.

**MANUFACTURING DIVISION:** GREELEY DIVISION
3404 E. Harmony Road
Fort Collins, Colorado 80525 U.S.A.