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A Large Scale Computer-Based Educational System For The Seventies

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ABSTRACT

A computer-based education system in use at the University of Illinois is described. Based on many years of teaching experience with this system and on several technological breakthroughs, a design for a large scale computer-based education system capable of serving up to 4,000 student terminals is presented. Working prototypes of a student console and a data distribution system are described. Finally, a cost estimate of the system is presented.

INTRODUCTION

The University of Illinois has initiated the design and development of a 4000 student terminal computer-based education (CBE) system, designated as PLATO IV(1,2).This system is based on the experiences and data obtained over the last nine years from PLATO III, a CBE system which has gradually developed from a single terminal to a computer-based system controlling several geographically scattered classrooms. Over 100,000 student contact hours have been accumulated on PLATO III in a large variety of courses which were developed to test the capability of this teaching system.

In spite of the enthusiastic reception PLATO III has received, it was soon realized that, for economic reasons, this sytem has its shortcomings. The system design of PLATO III, using state-of-the-art technology available some nine years ago, was concerned more with developing a highly versatile educational system than being restrained by economic viability. As its technical feasibility and educational versatility was demonstrated by sucessfully teaching a large number of credit courses, the system design emphasis changed to economic viability. A large effort was expended on the development of a graphic terminal which would make a CBE system technologically and economically feasible. A technological breakthrough came in 1964 with the invention of the plasma display panel (3,4,5) at the University of Illinois. This display device immediately showed great promise as a potentially inexpensive graphic terminal. Furthermore, it opened the way for drastically slashing data distribution costs for cases where thousands of geographically scattered student stations are to be connected to a central computer. On the basis of the invention of the plasma display panel and the large accumulation of teaching experience on PLATO III, the design of a new system, PLATO IV, was initiated by the Computer-based Education Research Laboratory (CERL) at the University of Illinois.

This paper describes the proposed PLATO IV system by first tracing its technological and educational development via the PLATO III system. Finally, it presents a cost analysis to demonstrate its economic viability. Some of the material here has been presented in other papers listed in the references.

THE PRESENT PLATO III SYSTEM

The present CERL teaching system, PLATO III, evolved from two previous systems (6,7,8) which used one of the first electronic computers, Illiac I, as the central control unit. These earlier systems proved useful for studying some of the problems encountered with multiple student use and for testing the educational capability of the teaching system. One of the most important features incorporated in these systems was the superposition on the student's graphic display of two types of information - computer-generated alphanumerics and optical images generated from photographic negatives. This is a unique feature of all PLATO CBE systems, past, present and proposed.

Figure 1 represents a block diagram of the present PLATO III system illustrating one student terminal. Each student station consists of a keyset for communicating with the computer and a video amplifier and CRT or television monitor which displays the superimposed video data.

Information to the CRT comes from two sources which are superimposed on the CRT. One of these sources is a random-access slide selector which stores information of the type ordinarily found in a textbook, and is designated as static information. The slide selector stores 122 photographic slides (35 mm) and has a slide access time of less than one microsecond. Information, in the form of a 4.5 mc bandwidth video signal, is simultaneously available from all of the slides and each student video display is electronically connected to any of the 122 video signals by the central computer.

The second source is an electrostatic storage tube assigned to each student terminal. Alphanumeric or pictorial material generated by the computer in a point-by-point fashion is stored in the storage tube and continuously fed from there to the student display in the form of a 4.5 mc video signal.

The student uses the keyset for constructing answers, questions, for setting up real or simulated experiments and for controlling his progress through the lesson material. The computer responds to the student's requests within one-tenth of a second. The computer also controls other devices, such as movie projectors, lights, audio devices, etc. The students at the terminals can interact with each other through the computer, thus permitting games to be played which require communication between the players.

In addition to keeping detailed records of student's performance, the computer can provide individualized instruction, immediate feedback, and remedial training by the use of complex internal branching and the alteration of presentation or type of material based on the student's past performance. These unique features seem to make the computer an ideal instructional device for developing cognitive skills.

To encourage development of critical thinking skills, the author sets up the teaching strategy and presents the student with questions or problems so the student must think about what information he needs, about possible solutions to the problems or sources of information, interpret the data gathered, and test his solution. The computer immediately provides appropriate feedback to open-ended questions, thus reinforcing a correct approach, or in the case of an incorrect response, encouraging the student to a new approach.

The computational use of the computer appears in several ways. First, experiments can be simulated by the computer, immediately providing the student with results he uniquely requested. These same results might require hours or even days to calculate by hand. Second, a large amount of computation is involved in processing student responses. The more flexibility provided for the student to answer a question, the more feedback is needed to inform him of the correctness of his response. When only multiple-choice responses are required, the processing is relatively simple, but when the student is permitted to construct long alphanumeric and graphic responses the computer must analyze his answer to see if it is equivalent to a correct response, check for spelling and completeness of the answer, as well as inform him which part of an incorrect answer is unacceptable.

Whenever possible, algorithms are used to determine the correctness of the student's response. For example, when the student is asked to give a positive, even integer, the student's answer is checked to see if it is positive and then it is divided by two and checked for a remainder. If there is no remainder, the answer is correct. The use of algorithms instead of comparing the answer against a long list of pre-stored answers not only makes the system more flexible but also saves memory space. In some cases this approach is almost a necessity. For instance, in teaching algebraic proofs, students can prove theorems in any manner as long as their statements follow logically from the available axioms and their previous statements. We have one example in which the author of the material was unable to prove a theorem in the twelve lines provided and, thus, was unable to supply even one prestored solution. Nonetheless, one student was able to complete the proof in the required twelve lines and was told by the computer he was correct.

A major improvement in the PLATO III system software occurred with the introduction in 1967 of an author language called TUTOR (9). TUTOR, consisting of about seventy commands, was designed specifically for use by lesson authors lacking prior experience with computers. The language is extremely easy to learn and to use, so that authors are normally able to write useful lessons after a one-hour introduction to TUTOR. The language is sufficiently rich and flexible so that the ultimate complexity of TUTOR lessons is limited mainly by the ingenuity and experience of lesson authors. The advent of TUTOR has decreased the cost of preparing lesson material by more than one order of magnitude.

To illustrate the interaction between a student and the PLATO III CBE system, a lesson taken from a course in geometry written in TUTOR will be described. These lessons were developed to give 7th and 8th grade students an understanding of geometric concepts (10). A grid is provided on which the student draws and manipulates geometric figures. The computer is used to determine the correctness of the figure, independent of its size, location, and orientation on the grid. The student must select points of the grid to be used as the vertices of his figure. To do this, eight keys on his keyset have been defined which move a bright spot around on the grid. Figure 2 shows a diagram of these keys. The arrows on the keycaps indicate the direction in which the key jumps the bright spot on the grid. Once a student has decided on a point, he communicates his selection to the computer by pressing the "MARK" key. He presses the "CLOSE" key to close the figure (connect the first point to the last point). To judge the figure the student presses "NEXT" and the computer either okays the figure or indicates the student's error.

In the following sequence, the student is asked to draw quadrilaterals with a single line of symmetry. In Figure 3a the student is instructed to draw a quadrilateral with one line of symmetry: the two possibilities are an isosceles trapezoid and a kite. He selects the points he wishes to use for his figure and marks them. Figure 3b shows the partial construction of the trapezoid. When four points have been marked the student closes his figure and asks the computer to judge it. In Figure 3c the completed figure is judged and the computer points out to the student that the symmetry line for an isosceles trapezoid does not go through the vertices.

The student then moves to the next page of the lesson and is asked to draw a quadrilateral with a single line of symmetry that does go through the vertices (Figure 3d). The student, however, reconstructs the trapezoid. The computer, when judging the figure, recognizes the duplication and tells the student that he has drawn the same figure as he drew before (Figure 3e). The student then draws a kite which has a single line of symmetry through vertices and the figure is judged "OK" (Figure 3f).

A substantial amount of evidence has been amassed from students taught by PLATO in accredited courses at the college, junior college, professional and elementary levels. Three basic findings have consistently appeared throughout this time:(11)

1. Results of teaching by PLATO have been as good or better than those obtained by other methods;

2. Students generally learn more material per class hour when taught by PLATO than when taught by standard lecture methods;

3. Students accept PLATO as a good teaching medium and this acceptance increases with continued experience.

At the present time the maximum number of simultaneously operating student terminals controlled by the PLATO III central computer (CDC 1604) is twenty; however, a total of 71 terminals, most of them located in the Champaign-Urbana community are connected to the system via a coaxial CATV system. Twelve terminals are located at Parkland Junior College, 14 at Mercy Hospital School of Nursing, 12 at Washington Elementary School, 12 at the University of Illinois School of Life Science and one at Springfield High School, located 90 miles away. Any 20 of the terminals in the network can be operated at one time, this number being limited by the 20 electrostatic storage tubes. PLATO statistics and queuing theory indicate that up to 50 terminals could be handled by the CDC 1604.

THE ADVENT OF PLATO IV

It became evident early in PLATO's history that in order to expand the CBE system and keep it economically viable, an inexpensive student display which contained memory was required. This would eliminate expensive data distribution systems which require 4.5 mc bandwidth video signals for each student station. Even though the demand for PLATO III was large, effort was instead concentrated on a potentially inexpensive display with memory, which resulted in the plasma display panel.

The plasma display panel combines the properties of memory display and high brightness in a simple structure of potentially inexpensive fabrication. In contrast to the cathode-ray-tube display, whose images must be continually regenerated with a video signal, the plasma display retains its own images and responds directly to the digital signals from the computer. Digital data can be sent over telephone lines, thereby considerably reducing the cost of data distribution lines. The plasma panel is discussed in detail in the listed references (3,4,5).

Briefly, it consists of two glass panels separated by a glass spacer. The space thus formed between the two glass panels is evacuated and filled with a gas. On the outside surface of each glass panel is deposited a set of parallel conductive lines barely visible to the eye. The lines of one glass panel are orthogonal to those of the other. A spot can be selectively ignited (gas discharge turned off by proper application of voltages to the orthogonal grid structures) without influencing the state of the remaining spots.

The plasma panel is transparent, allowing the superposition of optically projected images. This is an extra bonus, which allows the use of an optical projector for projecting prestored (static) information, on the rear of the glass panel display. This permits the stored information in the form of colored slides to be superimposed on the panel which contains the computer-generated (dynamic) information. Consequently, the need for transmitting any video information is eliminated, and only digital information for addressing the plasma panel and operating a random-access slide selector need be transmitted to a student station. A suitable slide selector, described later, was subsequently developed to operate with the plasma panel.

The development of the plasma panel display gave impetus to the design of a large scale, economically viable computer-based education system capable of controlling up to 4,000 student terminals simultaneously. On the basis of CERL's experience with PLATO I-III, certain design philosophies were formulated. First, each student terminal requires a keyset and a display, both connected to an inexpensive data transmission system which can also drive optional equipment such as random-access audio devices, reward mechanisms, move films, lights, and so forth. Second, each student terminal must be capable of superimposing randomly-accessed color slide images on the computer-generated graphics. Third, the system should be controlled by a large-scale centrally-located computer rather than many small computers located at the classroom sites. This decision is based upon social and administrative factors as well as on system economics. Semiconductor large-scale integration techniques may some day make the use of small computers as effective as large ones, but the added human expense of operating a computer center does not promise to scale as effectively. It is our opinion that the initial low cost of a single terminal will permit tightly-budgeted public schools systems to economically incorporate computer-based teaching into their programs. The number of terminals could be increased or decreased as the needs of the school system dictate. Fourth, the cost per student contact hour for the proposed system must be comparable with equivalent costs of traditional teaching methods. Fifth, the language for preparing course material must be simple, yet must allow great flexibility and complexity limited only by the ingenuity and experience of authors. Sixth, the cost of lesson material should constitute only a small fraction of the educational costs just as the textbooks and lesson materials represent only a small part of educational costs today.

THE PROPOSED PLATO IV SYSTEM

The selection of a central computer for the proposed PLATO IV, large scale CBE system depends greatly on statistics gathered from student performance over many years. Statistical records of over 100 million requests on PLATO indicate that the average request rate per student depends upon the teaching strategy used, but the product of the average request rate and the average processing time is relatively constant. For example, when using a drill-type teaching strategy the average request rate per student is one request every 2 seconds and the average processing is 10 milliseconds. When using a tutorial or inquiry strategy, the average request rate per student is one request every 4 seconds but the processing time is 20 milliseconds. We will base our calculations on the 20 millisecond processing time which is equivalent to executing approximately 1000 instructions in the CDC 1604.

The request rate probability density function versus computer execution time is approximately an exponential curve; therefore, student requests requiring the least amount of computer time occur most frequently. For example, the simple and rapidly-processed task of storing a student's keypush in the computer and writing the character on his screen represents 70 percent of the requests. On the other hand, the lengthy process of judging a student's completed answer for correctness, completeness, spelling, etc., occurs only 7 percent of the time.

Several existing large-scale computer systems can perform about 4×10^6 instructions per second. Even if we double the number of instructions needed, providing 2000 per student request, it is seen that these large-scale computers require an average processing time of only 500 microseconds per request. Allowing a safety factor of two to insure excellent system response time, the system can accept an average of 1000 requests per second. This safety factor implies that the computer will be idle approximately 50 percent of the time. However, the computer time not utilized in processing the student requests can be effectively used for other purposes such as background batch processing. Since the average student request rate is 1/4 of a request per second, the system can handle up to 4000 students simultaneously, allowing one millisecond to process a request.

Assume that the student input arrival time is Poisson distributed (a reasonable assumption for 4000 independent student stations), and that the request rate probability density function versus computer execution time is approximately exponential (PLATO statistical records substantiate this).

From queuing theory (7,12) the expected waiting time E(w) that elapses before the computer (single channel) will accept a given student's request is given by

$$E(w) = \frac{\rho^2 + m\,\sigma_t^2}{2m\,(1-\rho)} \qquad (1)$$

where

m = request rate = 1,000 request/sec.,

σ_t = execution time standard deviation = 500×10^{-6} sec.,

$E(t)$ = execution time expected value = 500×10^{-6} sec.,

$\rho = m\,E(T) = 0.5$

These values yield an expected waiting time E(w) of 500 microseconds. The probability P(w) that a student's request will wait a time w or longer before being served by the computer is given by

$$P(w) = \rho \exp\,[-w\,(1-\rho)/E(T)] \qquad (2)$$

The probability that a student must wait for 0.1 second or longer is negligible. Hence the probability of a student's request queue becoming long, or of the student experiencing a noticeable delay is very small.

Presently, each student needs to be assigned approximately 300 words of extended core memory to be treated individually. The maximum used in any teaching strategy has been 600 words per student. Let us allow on the average 500 words (fifty bit) for each student for a total of 2×10^6 words for 4000 students terminals. Our data shows that 20 percent of the computer instructions refer to these words of unique student storage. Therefore, the system must be capable of rapidly transferring data between the slower extended core storage and the high-speed core memory. Some existing computers are capable of transferring data at 10 words per second, requiring only 50 microseconds to transfer the data each way between the memory units. This transfer time is acceptable.

A schematic of a proposed student terminal using the plasma display is shown in Figure 4. The display will be approximately 10 inches square and will contain 512 digitally addressable positions along each axis. A slide selector and projector allows prestored (static) information to be projected on the rear of the glass panel display. This permits the stored information to be superimposed on the panel which contains the computer-generated (dynamic) information. A prototype random-access slide selector for individual use is shown in Figure 5. This projector is digitally addressable, pneumatically driven, and contains a matrix of 256 color or black and white images on an easily removeable four-inch square plate of film. The film plate is mounted on a Cartesian-coordinate slide mechanism and can be simultaneously translated along either of the two coordinate axes to bring a desired image over a projector lens. The positions along each coordinate axis are selected by a set of four pneumatic cylinders mounted in series. The stroke length of each cylinder is weighted 8,4,2,1, the length of the smallest being 1/4 inch. Each slide selection requires less than three cubic inches of air at 8 psi. This prototype model, which has a wost-case random-access time of 0.25 second, has been cycled for at least 2×10^6 times before mechanical failure. This represents an expected lifetime of over 5 years.

A student terminal prototype using a 4 x 4 inch plasma display panel and a random-access slide selector has been built and is undergoing tests. Figures 6 and 7 are photographs of displays showing superposition of computer-generated information and projected images from the slide selector.

In order that data to student terminals can be ultimately distributed over uncompensated telephone lines, the peak data rate is held at 1200 bits per second. Assuming a word length of 20 bits, the terminal receives data at 60 words per second, an important design feature when considering standard TV tariff for communicating. With proper data formats, data rates will be adequate for the applications envisaged. For example, packing three character codes per word will permit a writing rate of 180 characters per second, which is a much faster rate than that of a good reader. Using 18 bits to specify a point on the 512x512 array, 60 connected lines of any length can be plotted per second.

Continuous curves requiring only 3 bits to specify the next point can be drawn at rates of 360 points per second. The keyset will provide the student with a means of communicating with the computer. The problem of converting the fast parallel output data from the computer into serial data for transmission to terminals at 1200 bits/sec. has been solved.

In the situation where a large number of students are located at considerable distances from the central computer, costs can be lowered drastically by use of a coaxial line instead of numerous phone lines. For example, the cost of a 4.5 MHz TV channel is approximately $28.00 per month per mile, whereas the rate for a 3kc telephone line is approximately $3.50 per month per mile. Each TV channel will handle 1008 terminals on a time-shared basis, each terminal receiving 1200 bits per second. Hence, for an increase in line cost of a factor of 10 over that of a single channel, an increase of a factor of 1000 in channel capacity can be obtained. In addition to a coaxial line transmitting 1008 channels at 1200 bits per second from the computer to the terminals, a data line for transmitting the student keyset information back to the main computer center is required. The data from the student's keyset is generated at a subtantially lower rate than that sent to his terminal; therefore, it can be easily handled over much lower cost, low bandwidth lines. Multiplexers for providing these cost-lowering features have been built and tested. Data to remote locations will be transmitted by a coaxial line to a central point; from this point local telephone lines rented on a subscriber's service basis would transmit the proper channel to each student terminal.

Over 200 cities, and on a more limited scale many schools, already use community antenna television systems or closed-circuit TV. Because FM radio had already established itself prior to the spread of television, a frequency gap existed between channels 6 and 7 which is approximately 14 channels wide. These existing channels can be used to communicate to over 8,000 home terminals.

The mainframe cost of a computer meeting the specified requirements is approximately 2.5 million dollars. The additional cost for two million words of memory and other input-output equipment is approximately 2 million dollars. An estimate for the system software, including some course development programming, is another 1.5 million dollars. The total of 6 million dollars amortized over the generally-accepted period of 5 years yields 1.2 million dollars per year.

Assuming that the 4000-terminal system will be in use 8 hours a day for 300 days a year, there are approximately 10 million student contact hours per year. The system costs, excluding the terminals, is thus 12¢ per student contact hour. In order for the equipment cost to be comparable to a conventional elementary school classroom cost of approximately 27¢ per student contact hour, the terminal costs must be limited to 15¢ per student contact hour, or to a total cost of about 7.5 million dollars over a 5 year period. The cost for each of the 4,000 terminals, which included a digitally-addressed graphical display device and its driver, a keyset, and a slide selector must therefore be a maximum of approximately $1900. Present indications are that this cost may initially be twice as high, but in production would ultimately reach the lower figure.

Data distribution costs for a CBE center approximately 100 miles from the main computer are approximated as follows. The coaxial line rental is approximately $2800 per month, or $2.80 per terminal per month, based on 1000 terminals. The channel returning student data will add approximately $1.00 per terminal per month. Allowing $2.50 per terminal per month for a private telephone line from the coaxial terminals to each student terminal gives a total data distribution cost of $6.30 per terminal per month, or 4¢ per student contact hour if each terminal is used 160 hours per month. The author costs were discussed previously. The earning power of the computer for the remaining 16 hours each day and for the idle time between student requests, which would further reduce costs, has not been considered.

CONCLUSION

Using newly-developed technological devices it is economically and technically feasible to develop large-scale computer-controlled teaching systems for handling 4000 teaching stations which are comparable with the cost of teaching in elementary schools. The teaching versatility of a large-scale computer is nearly limitless. Even while simultaneously teaching 4000 students, the computer can take advantage of the 50 percent idle time to perform data processing at half its normal speed. In addition, 16 hours per day of computer time is available for normal computer use. The approximate computer cost of 12¢ per student contact hour pays completely for the computer even though it utilizes only 1/6 of its computational capacity. The remaining 5/6 of its capacity is available at no cost.

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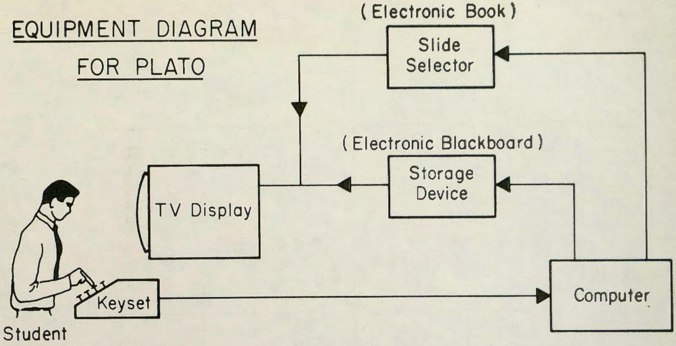

Figure 1. Block Diagram of PLATO III Student Terminal.

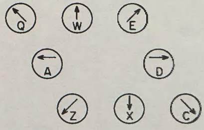

Figure 2. Special Keyset Keys for Geometry.

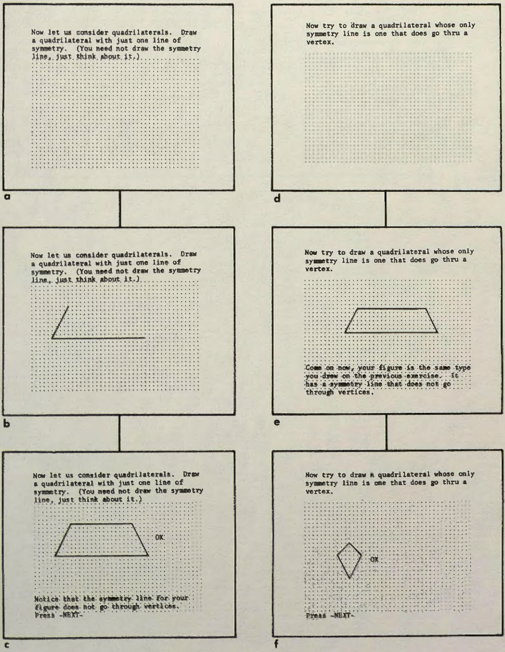

Figure 3. Student Display for a Geometry Lesson.

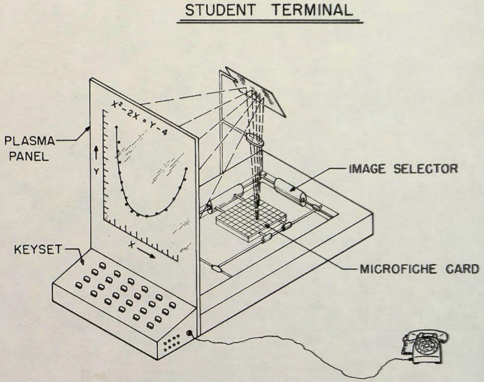

Figure 4. Schematic of PLATO IV Student Terminal.

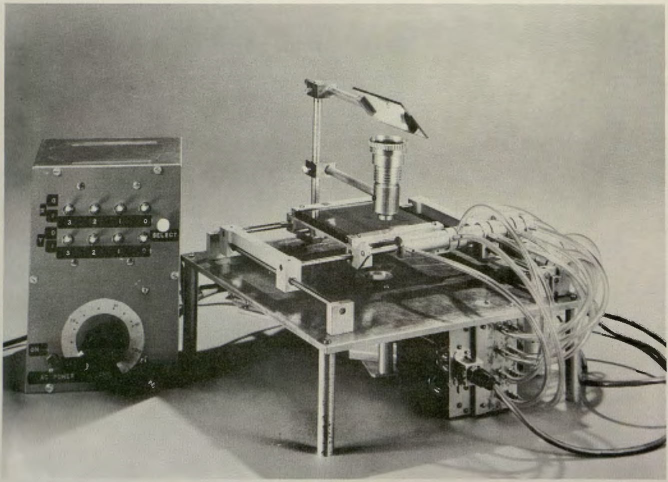

Figure 5. Random-Access Slide Selector.

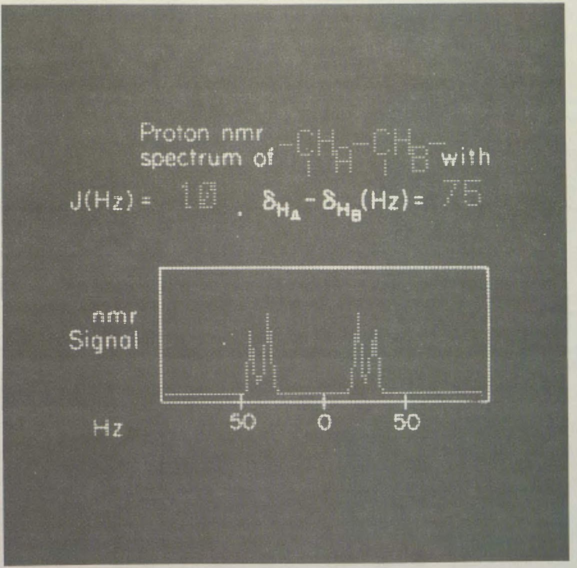

Figure 6. Plasma Panel Display Illustrating Superposition.

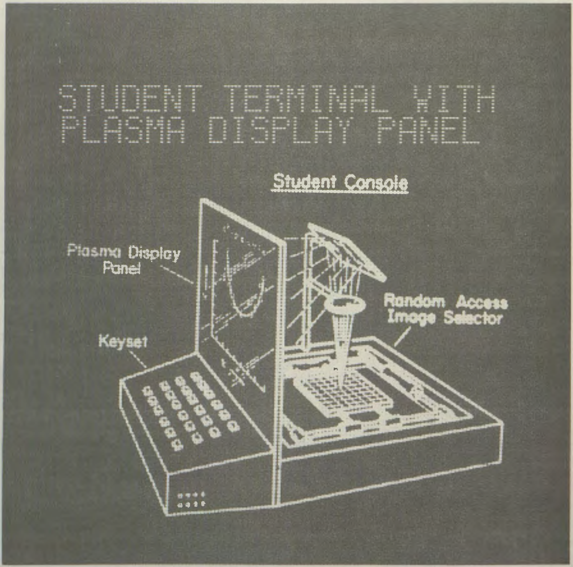

Figure 7. Plasma Panel Display Illustrating Superposition.