A PROGRAMABLE DISPLAY SYNTHESIZING SYSTEM

FOR MAN-MACHINE COMMUNICATIONS RESEARCH

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ABSTRACT

Much of the experimental development required in the area of flight control-display interface design can be accomplished in the time-proven research simulator. However, the methods ustilized to implement simulator display panels have been encumbered by the long time lags and high costs of instrument development and by the inflexibility and clutter of single-purpose instrument arrays. This paper describes a new concept for research simulator display, the purpose of which is to provide for a more effective, less costly, and less time-consuming means of creating dynamic instrument replicas for simulator evaluation. This concept employs the synthesis of desired instrumentation at the control-display interface of the man-machine loop utilizing a programable electronic display system.

The synthetic display concept described is based on an electronic animation technique which allows the cockpit display designer to proceed directly from static instrument mockups to dynamic displays which are simulated at the display interface by high-resolution closed-circuit monochrome TV. The electronic animation technique utilizes the principle that most desired flight displays are composed of static patterns and dynamic patterns which can be separated for photographic storage and, under the control of programed instructions, machine dynamics, and manned inputs, can be electronically recombined for composite, dynamic display.

This paper includes a description of the display system configuration with regard to major components required to achieve electronic animation. Major subsystems described include a stored program control unit and a digitally controlled vidicon film scanner, flying spot film scanner, and scan converter. Programing techniques and system operational modes are discussed from the viewpoint of relating how dynamic and static display patterns are called up from random access film storage, how individual dynamic patterns are electronically modified, written into transient storage, and updated to convey motion, and how dynamic and static portions of the display are combined to form animated composites.

Examples of synthesized flight displays are exhibited. System performance is discussed and compared with that of conventional computer-CRT stylized displays. The advantages of electronic animation with regard to format change, program complexity, regeneration rates, and image characteristics for certain classes of displays are presented.

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1. INTRODUCTION

The problem of man-machine integration in aerospace vehicles is a continuing one which has become increasingly important with the advent of the newer, high-performance vehicles and more complex, multiphased missions. In advanced missions man is faced with greater quantities of control information, events which occur more rapidly, and the requirement for more exacting control. He is called upon to act in the accepted roles of sensor, computer, and controller as well as the newer roles of decision maker and systems manager.

In manned flight, displays are the key to vehicle control, and are tantamount to high total efficiency of the man-machine system. Thus, a great deal of effort is devoted to the experimental development and design of displays. Much of this experimental development can be accomplished in the time-proven research simulator. However, the methods utilized to implement simulator display panels have been encumbered by the long time lags and high costs of instrument development and by the inflexibility and clutter of single-purpose instrument arrays. This paper describes a new concept for research simulator display, the purpose of which is to provide for a more effective, less costly, and less time-consuming means of creating dynamic instrument replicas for simulator evaluation.

2. MOTIVATION FOR SYSTEM DEVELOPMENT

2.1 The Display Problem

Even though the time-proven research simulator is in widespread use both for human factors research and for control-display interface design, it has inherent deficiencies which can be improved upon. The deficiencies with regard to information display generally fall into the following categories:

(1) Instrument developmental time lags and costs

(2) Inflexibility of single-purpose instruments and arrays

These deficiencies are discussed below.

2.1.1 Developmental Time Lags and Costs

The simulation of aerospace vehicles calls for the creation of replicas of desired displays for experimental evaluation. These instrument replicas display various simulated vehicle parameters to a test subject and simultaneously, if required, to an experimenter's console. Whenever possible simulation instruments are chosen from a manufacturer's stock, designed into the simulation system, and procured with normal lead time. Yet, in many instances, these instruments must be specifically designed, resulting in delay in procurement and in the accomplishment of the simulation. The creation of dynamic instrument replicas can call for many of the following time-consuming techniques:[1,2]

- The selection and/or design of many types of electromechanical instruments

- Modification of meter faces or tapes

- Construction and/or modification of servo-driven gear trains

- Construction of special oscilloscope drive circuitry

- Modification of image projectors

In the case of more sophisticated electronic displays, new instrument designs require even longer lead time, and can prove to be quite costly. An additional disadvantage to the above-mentioned techniques for implementing research simulator display panels is that instruments chosen or developed frequently must be discarded subsequently because of pilot opinion, poor pilot performance, and/or system design changes.

2.1.2 Inflexibility of Instruments and Arrays

The constraints put on spacecraft displays with regard to weight, reliability, and reluctance to use untried techniques make the aerospacecraft display system a field full of new ideas, but the hardware being developed is mostly conventional.[3] The main trend is to push conventional displays into as highly an integrated form as possible, without taking the major step of going to a single time-shared, general-purpose display and the consequent removal of the traditional maze of instruments. Yet studies have revealed a great deal of pilot scanning activity with conventional instrument arrays.[3] These findings along with the recognized trend toward increasingly more complex pilot's tasks have led to many proposals for an integrated display using a computer-driven, general-purpose device such as a cathode ray tube.[4,5,6]

The general-purpose display concept has much to recommend it since less equipment and panel space might be required, which would afford lower total weight and volume. The capabilities attendant to most computer-generated displays for programing, panel space time-sharing, and display integration could be made available in the cockpit. Yet there is general disagreement among flight control-display system designers as to whether the general-purpose display concept or the conventional instrument array concept offers the greatest potential.[7] Thus, it becomes imperative that the capability be established to evaluate general-purpose display concepts utilizing the research simulator as a means of providing experimental data for a basis of comparison.

Single-purpose instruments and arrays of these instruments are, by their nature, limited in flexibility and provide no means of evaluating general-purpose display concepts. Capabilities generally lacking are the following:

- programability

- time-sharing

- control parameter integration

2.2 A Potential Solution

A solution to the above-mentioned display problems appears to lie in a new concept proposed in July 1962, by the author, who later found that a similar concept was being investigated at Wright-Patterson Air Force Base under contract to North American Aviation, Inc.[1,2] This concept is based on the premise that a programable electronic display system can be developed which synthesizes desired instrumentation at the control-display interface. A pictorial diagram representing this concept in terms of simulator signal flow is shown in Figure 1. It can be seen that such a system would operate in conjunction with a flight simulation computer and the simulated cockpit control-display interface. The synthesized displays would be driven dynamically in accordance with the flight equations as perturbed by pilot control inputs.

Assuming that such a display synthesis system could be developed, it would reduce a basically hardware problem to that of a software problem. If the design allowed for rapid and efficient programing and was sufficiently universal in nature, it would have the potential for producing research simulator displays at lower cost, at higher speed, and at more advanced levels than conventional techniques will allow. For maximum efficacy such a display synthesizer should have many of the following characteristics:

(1) Rapid and efficient programing with a minimal turn around time

(2) Synthesis of desired instruments with the completed system requiring little or no new hardware design

(3) Universal in nature; thus, capable of the synthesis of a wide spectrum of displays including electro-mechanical as well as electronic and electro-optical displays

(4) Employing a combination of devices not exceeding the state-of-the-art and producing a feasible, reliable system

(5) Capable of use at a central location with remotely driven displays, which are compatible with fixed-base and dynamic flight simulator cockpits

(6) Compatible with flight simulation computers and associated trunking networks

(7) Utilizing, if possible, new techniques being proposed for, and directly applicable to, next generation flight vehicles, thereby making it useful as a test bed as well as a simulation research tool

The remainder of this paper will be devoted to (1) a discussion of the technique chosen as a basis for synthetic flight display generation, (2) the description of a programable display synthesis system utilizing this technique, and (3) the discussion of initial system performance.

3. DISPLAY SYNTHESIS APPROACH

3.1 Potential Techniques

Of the display techniques studied, which are applicable to the synthetic generation of flight displays, those classes of displays known as programed electronic displays afford the most promise for providing a repertoire ranging from simple electro-mechanical displays to sophisticated general-purpose displays.[8] Most programed electronic displays come under the category of computer-generated CRT displays which have the desired advantages of unrestricted display format, of good image quality, and of programability.

A major problem is encountered, however, in the area of programing, in attempts to apply existing computer-CRT displays to the task of flight display synthesis. The programing requirements for effective display can be very extensive, often running to many thousands of digital words.[9] Specific disadvantages are encountered with the character and vector generation schemes generally in use with CRT displays.[10] These disadvantages may be categorized as follows:

(1) Stylized display - Since all dynamic displays must be composed of alphanumerics and vectors, the visual image takes the form of rudimentary line drawings or stylized displays rather than continuous tone, photographic-type displays.

(2) Lengthy programs - Since all characters and lines in the dynamic portions and many times in the static portions of visual displays must be selected, positioned, and unblanked on an element-by-element basis, the computer word program can become quite lengthy.

(3) Regeneration rates - Since each element of the visual display must be manipulated individually and regenerated individually at a rate no less than 25 cps to avoid flicker, the digital word rate required for generation of complex displays can become high enough to prohibit interlacing the display program with other computer control and arithmetic sequences. In these cases a separate recirculating memory is required in the display console for regeneration of the display. The basic regeneration rate may be expressed as:

$$[D] \cdot [F] = [R] \qquad (1)$$

where

D = number of digital words in computer program required for display generation,

F = frame rate of display in cycles per second, and

R = digital word regeneration rate in words per second.

(4) Character change - Display symbols can be changed only through the substitution of new circuit modules, scanning tubes, or display tubes.

The disadvantages of these character generation schemes limit the direct use of existing computer-CRT combinations as a programable display synthesizer. Thus, it is apparent that a new means of dynamic pattern image generation must be provided in order to implement a truly utilitarian display

synthesizer. Such a means of dynamic pattern image generation is described in the following two sections.

3.2 Principle of Operation

The techniques selected for dynamic and static image generation and for overall display synthesis are based upon the principle illustrated by Figure 2. This principle asserts that most desired flight displays are composed of static patterns and dynamic patterns which can be separated for photographic storage and, under the control of programed instructions, machine dynamics inputs, and manned inputs, can be electronically recombined for composite, dynamic display. A programed display synthesis technique based on this principle can best be described by the term, "electronic animation."

3.3 Rudimentary System Requirements

The basic requirements for electronic animation consist of (1) the means for calling up static and dynamic display patterns from random access film storage, (2) the means for electronically modifying scanned dynamic patterns (in accordance with flight dynamics equations) to convey motion, and (3) the means for combining static and dynamic portions of the display to form animated composites. The rudimentary system components required to achieve electronic animation are shown in Figure 3.

The choice of the dynamic image generation method is by far the most important factor in the shaping of an electronically animated display system. This is because it is this method that sets the requirements for control sequences, storage capacity, regeneration rates, programing, and techniques for combining static display information for composite display. The dynamic image generation method shown in rudimentary pictorial form in Figure 3 is that of a random access flying spot film scanner. Major advantages of the flying spot film scanner for this application are the following:

(1) Unrestricted scanning format, with regard to size and aspect ratio of rasters

(2) Highest resolution television scanning device available, exceeding 3,000 TV lines for some tubes

(3) Changeable symbols, characters, and pictures through the substitution of photographic transparencies

(4) Both optical and electronic magnification and demagnification can be utilized

(5) Can provide high-speed, random access to individual patterns through beam positioning

(6) Can generate video for continuous tone, photographic-like displays at TV rates

The use of a raster-scan pickup for dynamic image generation implies the use of a raster-scan display, where the pickup and display raster are scanning in synchronism. For illustrative purposes a rear-ported CRT is shown in Figure 3 as the raster-scan display means. Here static pattern information is combined optically with dynamic pattern information.

Since most flight display panels contain multiple dynamic display patterns, each of which must relate motion individually, the use of multiple pattern photographic storage and of individual pattern scanning with diminutive rasters is indicated.[11] Each pickup raster must be positioned to the appropriate dynamic element on the film store and its corresponding display raster must be positioned to the appropriate display location at the appropriate time in the display composing sequence. Additionally, some means must be provided to supply the appropriate motion to each dynamic element of the display. These motions should convey at least the basic dynamics of flight display instrumentation, which consists of (1) horizontal and vertical translation, (2) horizontal and vertical expansion and contraction, and (3) rotation. Display dynamics is supplied in the case demonstrated by Figure 3 by electronic modification of each display raster in accordance with the appropriate sampled flight dynamics channel from the flight simulation computer.

The final requirement for implementation of a rudimentary electronic animation system is for some form of program storage and control sequence generation. This function can be performed by a small digital computer or by a special purpose programable control unit as is shown in Figure 3.

4. SYSTEM DESCRIPTION

4.1 General Configuration

A simplified block diagram of the Programable Display Synthesizing System actually implemented at Langley Research Center is shown in Figure 4. The design of this system is based on the techniques for electronic animation discussed in the previous section and on the basic design presented in Figure 3, with the exception of modifications necessitated by a change to high-resolution closed-circuit monochrome TV as the display means. High-resolution closed-circuit TV (1203 lines/60 fields/2-to-1 interlace) was chosen as the display means so that overall system design could comply with guideline (5) of Section 2.2. This guideline calls for use of the display synthesizer at a central location with remotely driven displays, which are compatible with fixed-base and dynamic flight simulator cockpits. In addition, this choice provides for flexibility and economy of display since closed-circuit TV displays are available in many configurations and are relatively inexpensive.

The scan conversion unit of Figure 4 replaces the direct diminutive raster display of Figure 3. Its primary purposes are for transient storage of

scanned dynamic patterns and for scan converting from the diminutive raster-scan format to the same closed-circuit TV format utilized for scanning static patterns with a vidicon film scanner. In this manner dynamic display patterns and static display patterns can be combined through video mixing.

For simplicity in the diagram of Figure 4, the previously shown analog signal multiplexer, which samples signals from the flight dynamics analog computer, and the digital-to-analog converters, which position the beam in the random access film scanner and in the scan converter, are considered a part of the programable control unit.

The major subsystems of Figure 4 are identified in the system photograph of Figure 5. Each of these major subsystems are described in the following sections. The final section pertaining to system description will tie the major subsystems together in a discussion of system programing and operation.

4.2 Random Access Flying Spot Film Scanner

The random access flying spot film scanner for scanning dynamic patterns utilizing digitally controlled beam positioning and raster generation is shown in Figure 5. It is used as a device for storing patterns which are to be the dynamic elements in the final synthesized display. The emphasis in the design of the scanner is on (1) providing high-speed random access to any pattern in the addressable transparency store matrix, (2) the scanning of the pattern in such a manner as to hold horizontal and vertical resolution constant, and (3) maximizing the beam utilization efficiency regardless of the size and shape of the scanned pattern.

The beam utilization efficiency can be kept high only by providing a variety of sizes and shapes of scanning rasters which can be programed to be just slightly larger in X and Y than the pattern being scanned. The programable rasters available in the subject system are shown by the seven-by-seven matrix in Figure 6. The raster matrix of this figure is based on the final display window representing full scale, i.e., H1, V1 when scan converted would fill the closed-circuit TV monitor screen.

It is not sufficient to achieve the raster sizes and shapes shown in the matrix of Figure 6 merely by adjustment of sweep waveform amplitudes while maintaining constant waveform frequencies. This would result in a change in vertical and horizontal scanning resolution due to a changed line spacing and beam velocity. The solution is to constrain beam velocity and vertical line spacing to be constant, regardless of the size and aspect ratio of the raster selected. If these constraints are met, then the time required for scanning is linearly proportional to the area of the scanning raster. Thus, neglecting beam positioning time, the entire dynamic portion of the display can be composed with randomly sized and shaped rasters in the same length of time it takes to

scan the screen with a full-scale raster (1 TV frame), provided the total area scanned by the diminutive rasters is not greater than the full display screen area.

It can be shown[8] that the required horizontal and vertical sawtooth frequencies required for generation of the raster matrix of Figure 6 are given by

$$f_h = \frac{X}{x} f_{hp} \qquad (2)$$

where

f_h = horizontal sweep frequency of any raster,

f_{hp} = horizontal sweep frequency for generation of primary raster of full-scale horizontal scan (H1 column),

x = distance scanned by raster in the horizontal dimension, and

X = horizontal distance scanned by primary, full-scale raster (H1 column); and

$$f_v = \frac{XY}{xy} f_{vp} \qquad (3)$$

where

f_v = vertical sweep frequency of any raster,

f_{vp} = vertical sweep frequency for generation of primary raster of full-scale vertical scan (V1),

y = distance scanned by raster in the vertical dimension,

Y = vertical distance scanned by primary, full-scale raster (V1), and x,X are as above.

It can be observed that as one proceeds towards the right side and lower side of the raster matrix, the scanning frequencies become higher thereby setting the requirement for a wideband nonresonant deflection system.

Rasters are selected from the matrix by an appropriate digital code from the program control unit. Beam positioning is accomplished by 8 bit plus sign digital-to-analog converters under control of the program control unit, giving an average access time of 10μ seconds to patterns in film store and an array of 512 by 512 addressable beam positions.

Since the random access flying spot film scanner has the primary requirement for high-speed, random access to a multitude of dynamic patterns in photographic transparency store, the scanner CRT and optical system must be capable of much higher resolution than the video processing chain. This requirement is necessary so that a large body of dynamic elements can be utilized in film storage. Since the number of equal-sized dynamic elements

capable of being stored increases as the square of the scanner CRT resolution capability, it behooves one to attain as high a resolution as is possible. The resolution attained in the subject system is approximately 2,600 TV lines.

A front view of the random access flying spot film scanner optical subassembly is shown in Figure 7. The scanner is designed for the scanning of 4-inch by 5-inch cut film, lantern slides, $2\frac{1}{4}$-inch by $3\frac{1}{4}$-inch cut film, and double-frame, 35-mm slides in conjunction with a precision detent mechanism for accurate subject positioning. Optical magnification and demagnification of scanned subject material is available over a total range of 5-to-1.

The random access flying spot film scanner was developed by the Radio Corporation of America to the author's specifications.

4.3 Scan Conversion System

The video generated by the diminutive, high-frequency, random access raster-scan format of the flying spot scanner is not usable for direct display on a closed-circuit TV monitor. It must be scan converted to the specified closed-circuit TV standard of 1203 lines/60 fields/2-to-1 interlace for display of instrument dynamics. The scan conversion system utilized is shown in Figure 8. It was developed to the author's specifications by Image Instruments, Inc.

The scan conversion system is capable of simultaneous recording and readout of dynamic pattern information through the use of two single-gun recording storage tubes. These tubes are idenfified along with the associated storage tube circuitry in Figure 8. Read and write modes take place in different tubes alternately and independently, but in phase. Erase and prime mode speeds are adequate to allow for scan conversion of inputs equivalent to 15 new TV pictures per second.

The scan conversion system's modes and beam positioning are digitally controlled by the programable control unit. Display dynamics are attained in the scan converted output by the dynamic modification and positioning of the diminutive input rasters, which are updated at a 12 to 15 cps rate to prevent motion breakup.

4.4 Static Pattern Film Scanner

The static pattern film scanner is shown in Figure 9. Shown is a 35-mm slide scanning setup with random access slide projectors projecting through an optical multiplexer into a vidicon camera. The vidicon pickup operates at the high-resolution scanning standard of 1203 lines/60 fields/2-to-1 interlace. The closed-circuit TV pickup raster in the vidicon is, of course, scanning in synchronism with the read mode rasters in the scan converter so that static and dynamic video picture information can be simply video mixed for composite display.

The random access slide projectors are under the control of the programable control unit and can be controlled manually by either the test subject or an experiment controller. The drum slide holder has an average access time of $2\frac{1}{2}$ seconds between slides. The projectors can be sequenced digitally, however, with optical multiplexer shutter control so as to eliminate time lapses between slide changes. The two projectors are capable of holding ninety-six static patterns in random access storage.

4.5 Stored Program Control System

The design of the stored program control system is based on the utilization of program storage in a random access magnetic core memory which is sequentially scanned in a recirculating manner to produce the control sequence of parallel digital words necessary for generating and refreshing the synthesized display. The manner in which the parallel memory word output is utilized for display system control is based on the one-address instruction type of coding format used in digital computers in which a portion of the digital word contains the operation code and another portion of the digital word contains the operand address. This coding format was selected on the grounds of machine simplicity and simplicity of coding.[12]

Thus, the parallel memory output word is broken up into two parts; the first part of which contains the information or data code for each digitally controlled subsystem throughout the system, and the second part of which contains the control code utilized for the selective enabling of each of these subsystems. This coding technique is further illustrated by the digital programing guide shown in Figure 10, which lists the control codes for selective enabling of the five major digitally controlled subsystems and the positional locations for the information or data codes for each of these subsystems. These digitally controlled subsystems and their functions are the following:

(1) Static pattern film scanner - decoded holding register output selects slides and controls shutters of projectors A and B

(2) Raster generator - decoded holding register output selects sweeps appropriate to generate programed sized and aspect ratio raster and determines mode (Erase, Prime, Write) of scanner converter operation

(3) Flying spot scanner beam positioner - digital-to-analog converter channels one (1) and three (3) provide dc voltages for selection of dynamic patterns

(4) Scan converter beam positioner - digital-to-analog converter channels two (2) and four (4) provide dc voltages for location of dynamic patterns in the final display

(5) Analog signal multiplexer - decoded holding register output selects channel from flight dynamics analog computer for dynamic analog control of raster modification

Information is loaded into the memory from 8-level punched tape with the memory information tape reader or, on a bit-by-bit basis, from the digital control panel, each of which is shown in Figure 11. Also shown is a memory address tape reader for providing automatically timed sequential addressing of the memory.

Control of the display synthesizer through the memory is accomplished in three basic modes, each of which is designed to provide for simulator investigation of the time-shared, general-purpose display concepts discussed in Section 2.1.2. These modes are provided by a memory addressing system which gives high-speed random access to paragraphs of digital words, each of which represents the control word sequence for generating a different dynamic display. The control modes are as follows:

(1) Pre-programed time-shared display - The display format may be changed automatically as the simulated mission progresses from phase to phase.

(2) Pilot adaptive time-shared display - Test subject has manual control over dynamic display format through a programable pushbutton array.

(3) Machine adaptive time-shared display - Control system can automatically display control parameters exceeding thresholds or having alarming trends.

4.6 Display Console

The display console is shown in Figure 12. Shown is the test subject's pushbutton array for display format selection. This array is portable for later use in simulator cockpits. Shown, also, are manual projector controls for test subject access to library-type information. The console houses, also, remote controls for the random access film scanner, the video mixer, and closed-circuit TV monitors for the monitoring of static, dynamic, and composite display formats. Space is provided for a future on-line compiler to facilitate programing, which is now done directly in machine language. Programing and overall system operation are discussed in the following section:

4.7 Programing and System Operation

The programing concept allows the flight control-display systems designer to proceed directly from cardboard mockups to simulated flight displays through the preparation of static pattern transparencies, a dynamic pattern transparancy, programed punched tapes, and patch board programs. The basic programing and system operation for electronic animation are best demonstrated by an

example. This example is illustrated in Figures 13(a), 13(b), and 13(c), which show typical dynamic pattern and static pattern cardboard mockups and the program word sequence for the synthetic generation of a 3-window vertical tape display from these mockups. In the vertical tape display the static pattern is seen to be a window with a lubber line. The dynamic pattern is a vertically oriented tape which appears to move up or down in the window according to the dynamics of a flight control parameter.

The program can be described as follows: The first digital word selects the 35-mm slide containing the static pattern for vidicon film scanning. Word #2 positions the beam in the scan converter for the soon-to-follow erase mode. Word #3 selects and generates a full-screen-sized raster to erase old information on recording storage tube A of the scan converter. This word also contains "memory stop" and "last raster" commands which (1) cause the memory to stop counting (so that blank words do not have to be programed and, thereby, wasted) during generation of the raster and (2) cause the memory to wait after generation of the raster until a vertical synchronization pulse is received from the television synchronization generator. This latter command is the means for synchronizing all control and scanning operations throughout the entire system and for assuring that sequencing between recording storage tube A and recording storage tube B in the scan converter always occurs during vertical retrace of the closed-circuit TV readout raster. Words #4, #5, and #6 each generate full-scale prime rasters for recording storage tube A. The prime mode is a portion of the erase operation. Word #7 selects the dynamic control input channel (analog computer voltage) for the motion control of the first vertical tape. Word #8 positions the flying spot scanner beam to the center (in X- and in Y-) of vertical tape #1 in transparency store. Word #9 positions the scan converter beam to that address (in X- and in Y-) which would superimpose the dynamic tape image to be stored in the scan converter with the window of the static pattern being scanned by the static pattern film scanner, when the output video signals these two units are mixed. Word #10 generates a tall, narrow write raster (the same size as the tape window), the offset of which, in the Y-dimension, is controlled in the flying spot scanner by the previously selected analog computer voltage. The shifting of this analog computer voltage will cause the pickup raster to slide up and down the photographically stored tape image in a linear manner thereby simulating the tape movement of an electronmechanical instrument on the face of the closed-circuit TV display monitor. Word sequence #7, #8, #9, and #10 are repeated for the simulation of the other two vertical tapes, with the exception that word #18 contains a "last raster" command so that the memory will wait until the next vertical synchronization pulse from the TV synchronization generator to recycle through the entire word sequence. Each time it is actuated bit 9 of word #3 triggers a T-type flip-flop which alternates the above-described erase, prime, and write sequences between scan converter tube A and tube B.

5. PERFORMANCE

A graphic demonstration of system performance is shown by photographs of typical synthesized displays. Figures 14(a), 14(b), and 14(c) show three types of vertical indicators synthetically generated by the programable display synthesizing system. These displays were photographed directly from a display system monitor and show the static and dynamic portions of the composite display and the composite display produced by the video mixing of the static and dynamic video signals. These displays were synthesized from the dynamic pattern transparency and the three static pattern transparencies shown in Figures 13(a) and 13(b), respectively. The displays shown are fully animated with no ambiguities or discontinuities. Short-term stability (over a 1-hour period) for the dynamic elements of typical displays, such as those shown in Figures 14(a), 14(b), and 14(c), is such that changes in position are less than 0.5 percent of full-scale value.

System performance can be compared briefly with that of computer - CRT stylized displays on the basis of the dynamic vertical tape display shown in Figure 14(c). The program required for synthesis of this display using electronic animation was shown in Figure 13(c) to contain 18 parallel digital words. The stylized display approach requires the generation of each character and line of the dynamic image on a separate basis, as opposed to a raster-scan of the entire displayed tape image as in the case of electronic animation. The tapes are seen to contain approximately 20 characters and 30 lines each. Based on allowing one digital word per character and two digital words per line, a conventional computer - CRT program could require as many as 240 digital words. The shorter program length of the electronic animation technique is an apparent advantage.

The shorter program length discussed above has the effect of reducing R, the digital word regeneration rate required for display generation, according to Equation (1). This regeneration rate can be lowered further by reducing F, the frame rate of the display. The scan converter of the programable display synthesizer does reduce the effective frame rate of the system by allowing regeneration of display dynamics at the lowest possible rate to prevent motion breakup. Flicker, due to low sampling rates, is prevented because the scan converter provides a continuous closed-circuit TV output.

The electronic animation technique, at this stage of its development, is not without its limitations. Resolution in the static portions of displays is quite good; however, resolution in the dynamic portions of displays requires some improvement. Some distortion is produced in dynamic portions of the display due to digital noise and a skewing of dynamic pickup rasters. Some flicker is evident in dynamic portions of the synthesized display due to the use of a two-tube scan conversion system.

These limitations are in the process of being corrected. In addition, the capabilities for the synthesis of digital displays and displays having rotational dynamics are being incorporated.

6. CONCLUSIONS

The research and development required to implement the system described has established the feasibility of rapidly programing a portion of the displays generally encountered in simulation and presenting them at the display interface via closed-circuit television.

In addition, this work has developed a man-machine communications research tool providing for a systems engineering approach to flight display panel design through the programed synthesis of electronically animated flight displays. This research tool provides for the study of time-shared, general-purpose display concepts through its basic time-shared control modes.

A new concept has been investigated and proven feasible - that of electronic animation. The advantages which this display generation concept can have over conventional computer-CRT generation concepts have been pointed out in terms of digital word program lengths, word regeneration rates, format change, and image quality. Two new types of electronic systems have been developed as a means of implementing the above concept - (1) a digitally controlled random access flying spot film scanner and (2) a digitally controlled scan conversion system, each of which has a repertoire of 512 by 512 beam positions and of 7 by 7 scanning formats.

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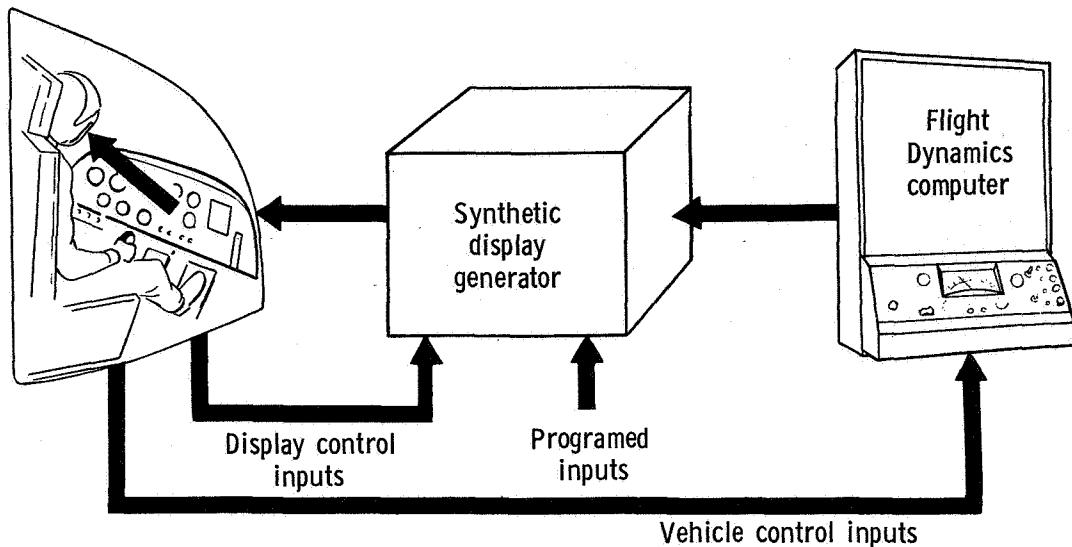
Figure 1.- Pictorial diagram showing simulator signal flow using programed synthetic display generation.
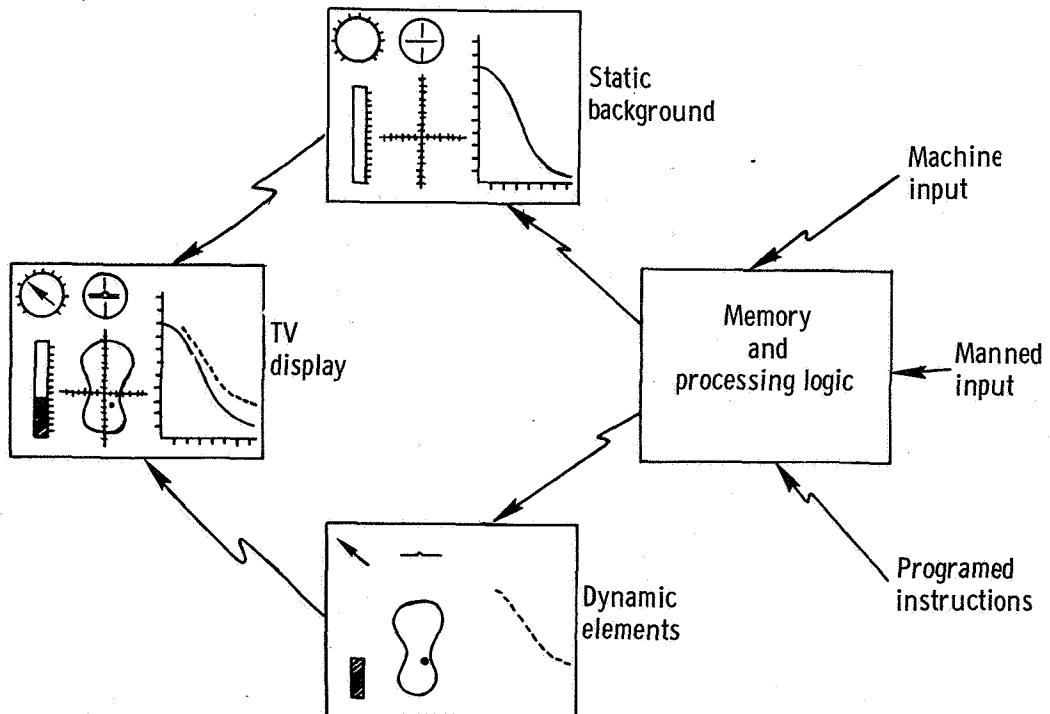
Figure 2.- Display synthesis principle — electronic animation.

Random access
film
scanner

Video
pickup

Small raster
video

Static
pattern
projecter

Dynamic
pattern
store

Slide
select

Display
CRT

```
        9  0  1
      8         2
      7         3
        6     4
           5
```

Raster
generator
and
modification
unit

x,y sweeps

Horizontal
and
vertical
beam
positioning

Pattern
select

Raster
select

Modified
x,y sweeps

Horizontal
and
vertical
beam
positioning

Flight
Dynamics
Inputs

Analog
signal
multiplexer

Dynamic
raster
control

Dynamic
channel
select

Program
storage and
control
unit

Display
location
selection

Programed
inputs

Figure 3.- Pictorial diagram showing rudimentary system components required
for electronic animation.

ANALOG
CONTROL
OF DISPLAY
DYNAMICS

DIGITAL
CONTROL
WORD

SCAN MODIFICATION
SELECT

RASTER

GENERATING

UNIT

SCAN
MODIFCATION
AND
POSITIONING
UNIT

BACKGROUND
PATTERN   SELECT

WRITE   RASTER
SELECT

ERASE   RASTER
SELECT

PROGRAMMABLE

CONTROL

UNIT

ERASE SWEEPS
AND BLANKING

X,Y WRITE
SWEEPS
AND
BLANKING

FROM
ANALOG
COMPUTER

RANDOM ACCESS

FILM SCANNER

SCAN

CONVERSION

UNIT

MODIFIED X,Y
SWEEPS AND
BLANKING
FOR
DISPLAY
DYNAMICS

PUNCHED
PAPER
TAPE
INPUTS

LIBRARY
INFO.
SELECT

CLOSED CIRCUIT
TV   VIDEO

BACKGROUND
PATTERN
FILM   SCANNER

T V VIDEO

MIXER

TO
ANALOG
COMPUTER

PILOT
CONTROL
OF DISPLAY

SMALL
RASTER
VIDEO

COMPOSITE
TV VIDEO

PILOT

CONTROLS

DISPLAY

CONSOLE

Figure 4.- Programable Display Synthesizing System block diagram.

Analog
Computer

Scan
Conversion
System

Stored Program
Control System
(Hybrid Portion)

Stored Program
Control System
(Digital Portion)

Random Access
Flying Spot
Scanner

Experiment
Control
Console

Figure 5.- Programable Display Synthesizing System showing all major components except static pattern film scanner and display console.

Scan Converter Picture Monitor

Recording Storage Tubes

Storage Tube Circuit Modules

Matrix Switch
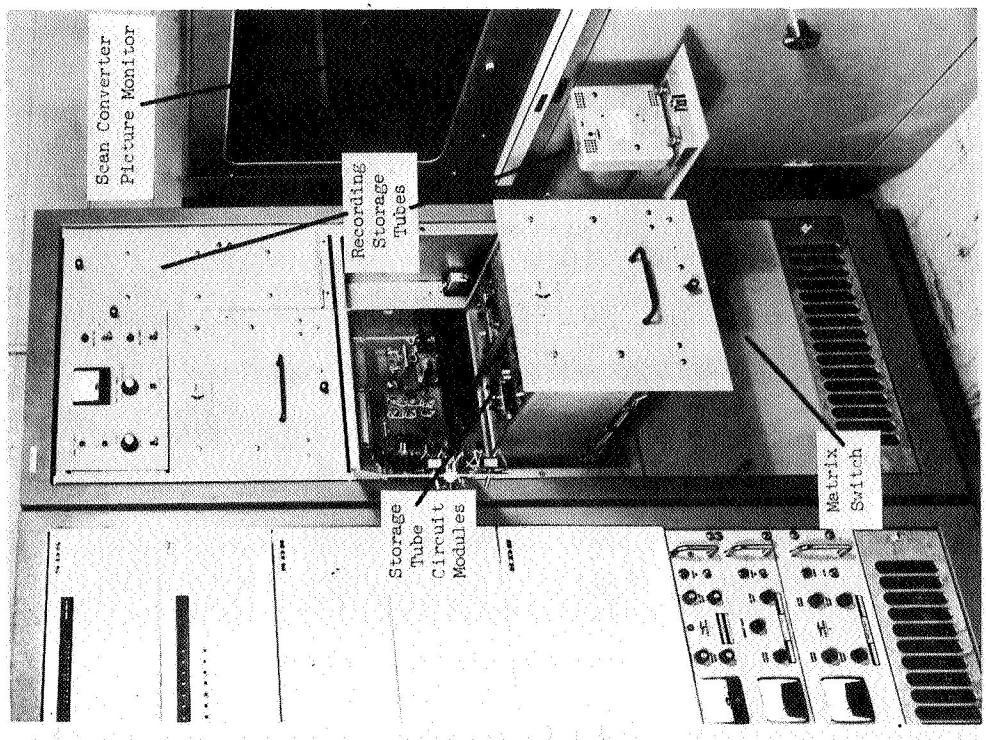
Figure 8.- Scan conversion system.

Carriage

Mag. motor

Slide housing

Cassette

Cover

Lens drive rack

Brake adjust.

Objective lens

Focus lock

Scanning CRT

Focus motor
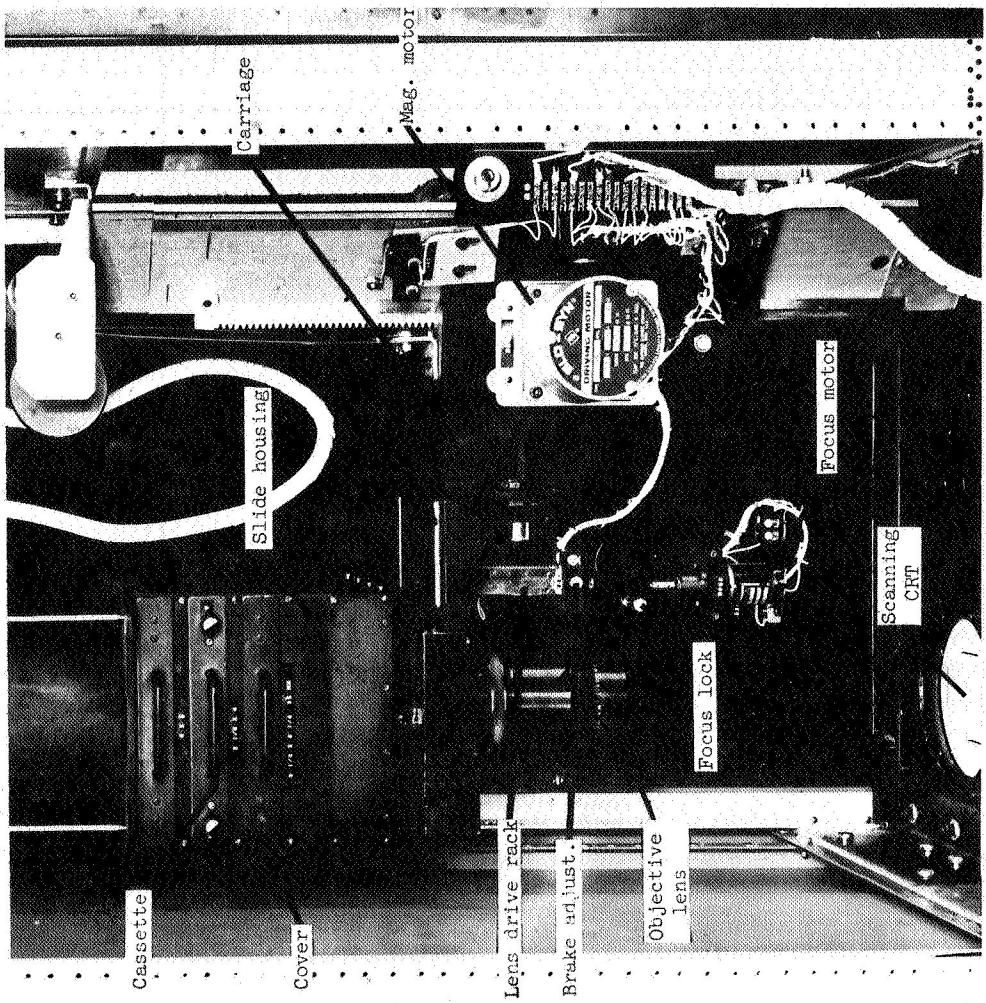
Figure 7.- Front view of random access flying spot film scanning optical assembly.
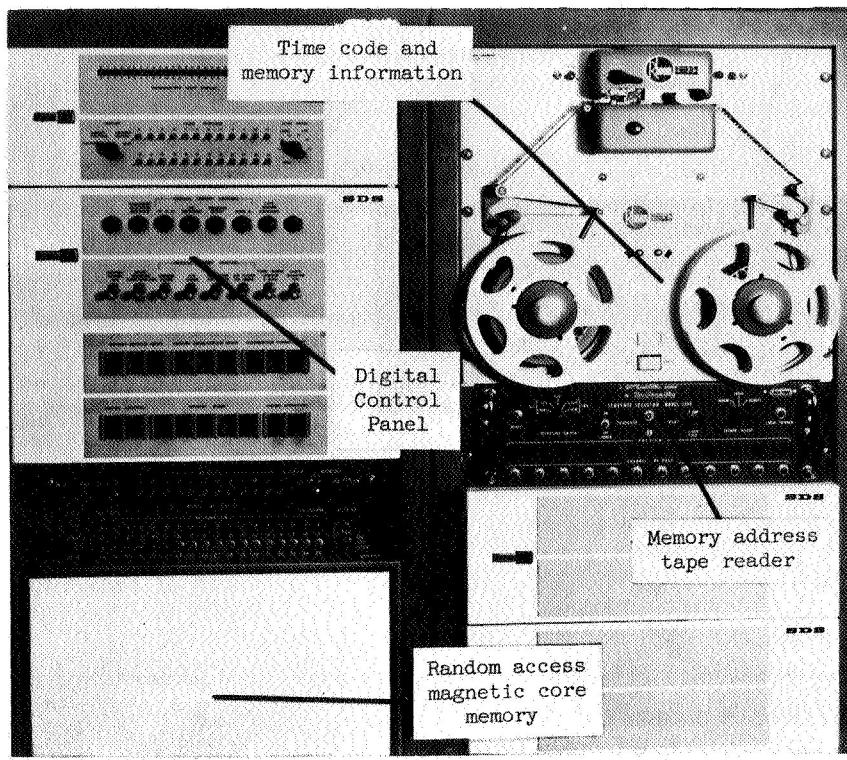
Figure 11.- Stored program control system (digital portion).
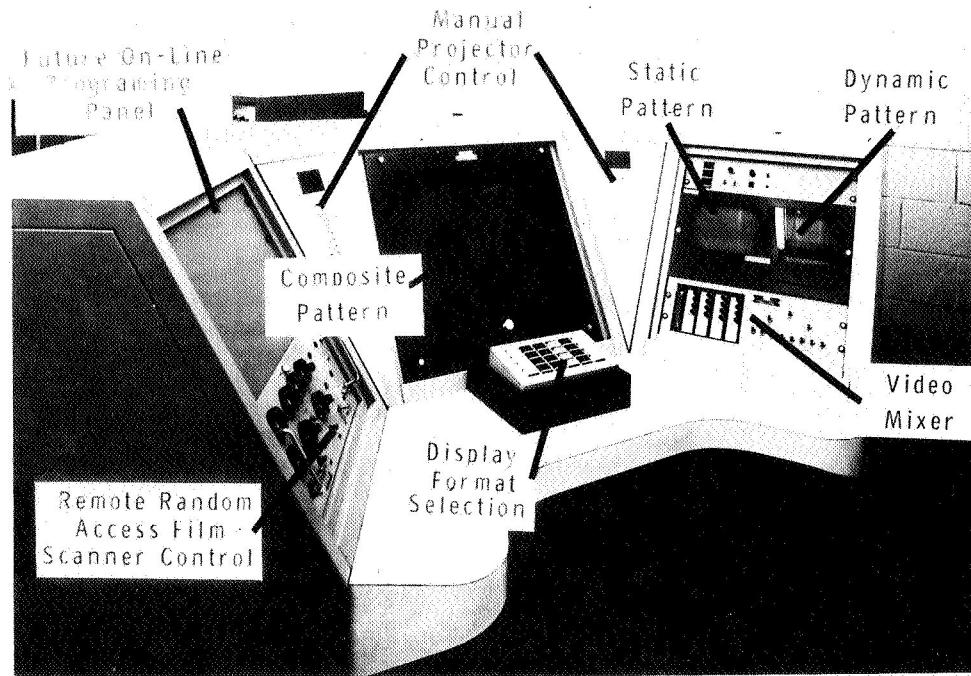
Figure 12.- Display console.
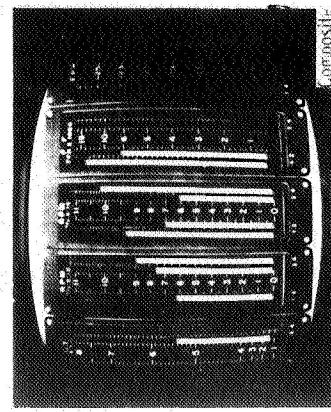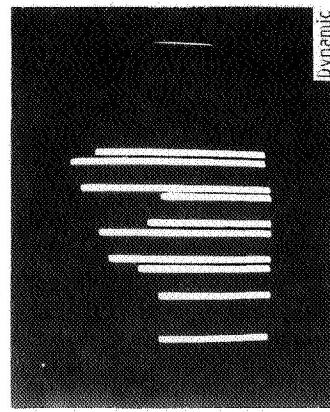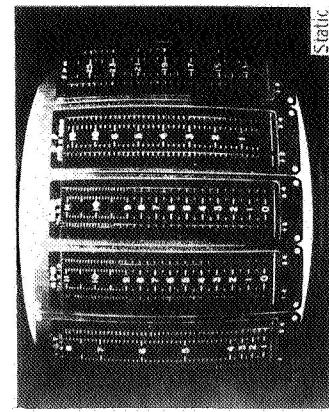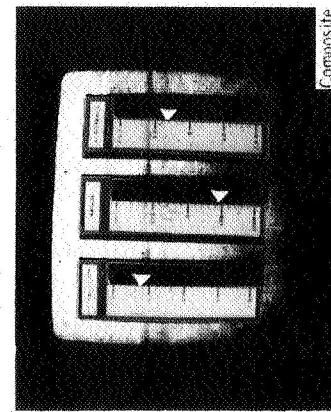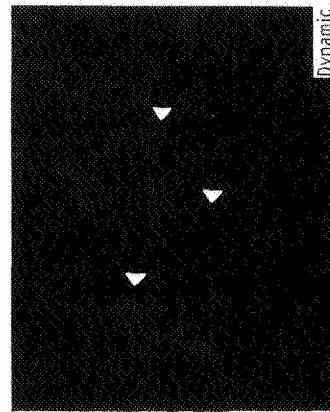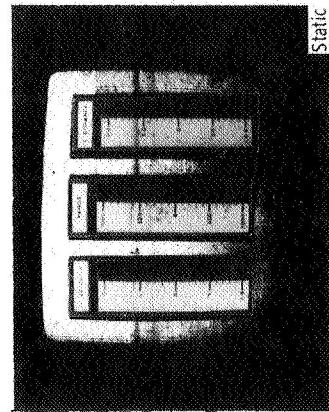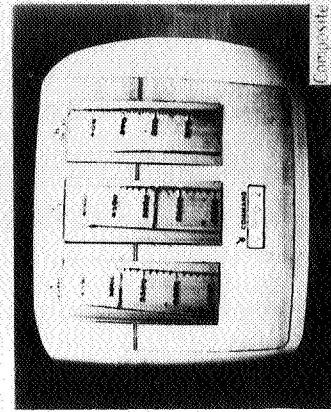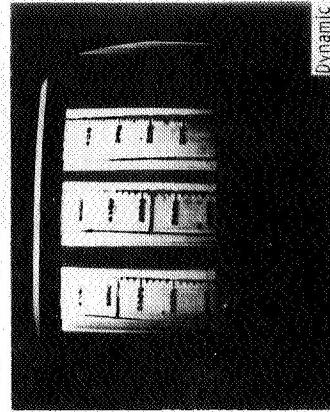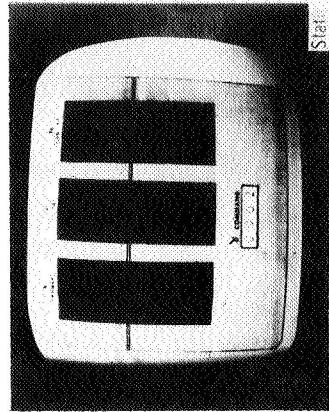
Figure 14(a).- Dynamic vertical bar indicator display photographed directly from 21-inch monitor showing static, dynamic, and composite pictures.

Figure 14(b).- Dynamic vertical scale indicator display photographed directly from 21-inch monitor showing static, dynamic, and composite pictures.

Figure 14(c).- Dynamic vertical tape indicator display photographed directly from 21-inch monitor showing static, dynamic, and composite pictures.