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SPAD Formatter

The Buffer Interface Between the Satellite Prediction Computer and the Display

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ABSTRACT

The Naval Research Laboratory has developed a computer-driven display (SPAD) for presenting the predicted positions of artificial earth satellites. The buffer interface between the digital computer and the display console is known as the SPAD formatter. The computer generates information for as many as 11 satellites each 1.1 seconds. The formatter accepts these computer output words as they are generated and, through appropriate gating and timing sequences, presents the data to the display at a rate of 30 frames per second. The formatter also contains a magnetic core memory device which permanently retains map grid symbol information and provides temporary storage for points representing a suborbital path.

As an experimental device, the formatter was built in a three-bay rack cabinet with room provided for possible expansion or modification of the design. To facilitate calibration and maintenance, a rack-mounted four-channel cathode-ray oscilloscope can be connected to a circuit drawer and desired test points selected by means of rotary switches. Other circuit features permit maintenance personnel to rapidly check the performance of computer and formatter and isolate any malfunction. The formatter performed as desired.

This report discusses in general the design problems common to computer driven displays and considers specifically problems encountered in designing the SPAD formatter as well as the theory of operation of the overall equipment. Alternative approaches to the digital logic design problems are presented whenever possible, and the philosophy and reasons for the particular approaches chosen for SPAD are given.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

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SPAD FORMATTER: THE BUFFER INTERFACE BETWEEN THE SATELLITE PREDICTION COMPUTER AND THE DISPLAY

INTRODUCTION

A computer-driven Satellite position Prediction and Display equipment (SPAD)* (Fig. 1) has been developed at the Naval Research Laboratory (1) as a research tool in determining the Navy's operational requirement for a satellite display. Basically, SPAD consists of a digital computer which uses orbital elements of selected satellites to generate position and height at an arbitrarily designated time, a display formatter which stores and assembles this information, and a display console which presents against a map grid background the positions of up to 11 satellites as well as own ship and, for one satellite, the orbit, velocity vector, and area of view. Additional information on a single satellite can be viewed on a separate tabular display.

In the course of equipment design, major consideration was given to fabrication techniques facilitating changes and additions to the circuitry. These changes were expected to occur as design and construction proceeded and experience was gained in using the equipment. Thus, aside from the use of standard digital logic minimization techniques in the digital design, no great effort was made to either simplify or miniaturize the equipment. Furthermore, certain items were salvaged from earlier experiments. All the digital logic circuitry is composed of discrete solid state components mounted on plug-in printed circuit boards. Integrated microcircuits were used only in the operational amplifiers of some of the analog circuits.

This report discusses in some detail the digital logic design of the circuits contained in the buffer interface between the display console and the digital computer, and the theory of operation of the overall equipment. This buffer has been designated as the SPAD formatter. The function of the formatter is to accept all computer output words and, through appropriate gating and timing sequences, make the data available in a form which is compatible with the display console. The formatter also serves as a permanent storage device for certain information as well as temporary storage of data waiting to be displayed.

DESIGN CONSIDERATIONS

A previous NRL report (2) outlined in some detail the tentative requirements for a satellite position display. Several possible display configurations were proposed, and detailed discussions of their inherent advantages and disadvantages were presented. This report concluded with the recommendation of a preferred display configuration. It was this configuration, modified somewhat as design progressed, which was finally implemented and is reported here as well as in Ref. 1.

The present report documents the philosophy and design decisions which culminated in the initial version of SPAD. The report also explains in some detail several pertinent aspects of circuit operation. It is recognized that although the equipment operates as

*This and other symbols are defined in the glossary, Appendix A, as well as where they first appear in the text.

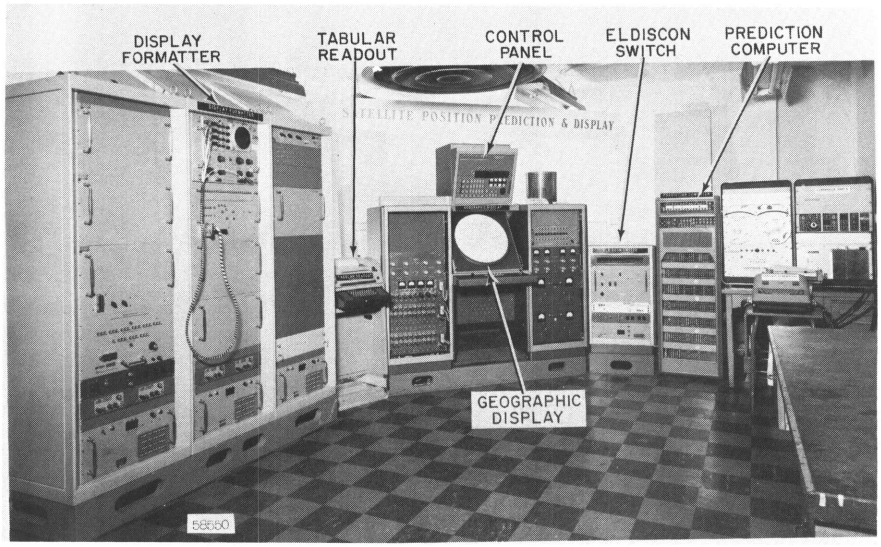

Fig. 1 - Laboratory installation of SPAD

desired, there are areas where a different philosophy or a modified design decision would have led to a better display. As study of a second-generation SPAD proceeds, other areas for improvement are being found. Thus, the present report does not pretend to have the ultimate answer to either the hardware or the philosophical questions. However, it does describe an experimental model of a satellite display which served as a research tool in studying display requirements.

The basic goals of SPAD can be considered rather briefly in the following manner: The display should provide a world map representation capable of displaying the subsatellite positions of up to 11 satellites plus the position of a ship. It should also permit rectangular and polar expanded representations capable of displaying either the ship or one satellite in the central portion of the expanded display. Adjacent to the position dot of each satellite there should appear a group of six symbols denoting category, track number, and satellite height. The symbol group adjacent to the ship's position dot should denote the ship's speed and heading and should designate that a ship is represented. The manner in which these satellites are chosen and the versatility extended to the operator for tailoring the display content to fit his needs have been discussed in detail in Ref. 1.

A major consideration in any electronic display is the rate at which the data is presented. Due to the characteristics of the human eye, information should be presented at least 30 times a second in order to prevent intolerable flickering of the displayed information. Although several factors such as ambient light and display luminance influence the critical fusion frequency at which flicker is perceptible, Ref. 2 points out that this rate is required when the display surface itself does not provide appreciable storage. Thus, with a storage cathode-ray tube (crt) the repetition rate of information can be reduced considerably. However, a storage tube was rejected for SPAD use because it appeared that such a tube would lack the required resolution. The crt used was a Charactron.* This crt generates arbitrary symbols by extruding the electron beam through a symbol matrix. While there are many satisfactory ways of generating symbols on a more conventional crt, the Charactron was used because it was readily available and suitable for demonstrating the feasibility of the SPAD concept.

*"Charactron" is a registered trademark of the General Dynamics Electronics Corp.

An AN/UYK-1 digital computer was selected as the position prediction computation device, since it was already available, on a part-time basis, aboard the ship selected for the SPAD evaluation. Subsequent investigation of the computer specifications led to the conclusion that it would satisfy most all the SPAD requirements with ease. However, it became evident that the machine was not fast enough to compute the required information 30 times a second.* The results of an earlier study (3) indicated that a mean solution time for the orbital equations being implemented was about 0.1 sec when run on the NAREC computer at the NRL Computer Center. With solution times of this magnitude, 11 satellites could be updated only once each 1.1 sec.

The foregoing considerations were thus strong arguments for providing external temporary storage of the position information, so that the display cycle could be independent of the computer update cycle. These stores within the formatter are interrogated once each display cycle, and the computer attempts to update these same stores at its own convenience. This approach led to a provision for a so-called busy signal to assure that each computer word, temporarily held in a buffer store, is transferred to the addressed store at a time compatible with the display cycle.

With the preceding decisions now rather firmly based, it was necessary to investigate whether the computer update cycle would satisfy the position resolution specification; i.e., errors in position were not to exceed 60 naut mi. Calculations performed in Ref. 4 show that for a position error of not more than 60 naut mi, a satellite with a 90-min circular orbit must have its position updated at least once every 14 sec. Furthermore, as a limiting case, a satellite with a highly elliptical orbit and traveling at maximum ground speed at low perigee must have its position updated at least every 9.93 sec (4). It was thus clear that the 1.1 sec necessary to update 11 satellites was more than adequate to satisfy the SPAD requirement.

Generally required in any map display are latitude and longitude grid lines with appropriate identifying symbols. One common method consists of placing a map overlay over the crt face. This overlay is made of a transparent material with appropriate etched lines and, in some cases, edge lighting. However, although economical, this method yields inaccuracies of position information due to parallax error. The situation is further complicated when rectangular expanded and polar expanded modes are required. There are techniques which can resolve these difficulties; however, they generally entail a large amount of peripheral equipment.

The method chosen for SPAD consists of generating the rectangular map grid lines electronically by using a TV-type raster having 361 active noninterlaced lines. Predetermined horizontal sweep lines are brightened for latitude lines, and at appropriately spaced intervals along each sweep line, the electron beam is brightened by short video pulses for longitude lines. This method permits a variety of map grid lines to be generated merely by altering the interval between brightened sweep lines and the video pulse intervals along each line. Thus, the same TV raster but with one of two map grid schemes is used to present either the world map display or the rectangular expanded display. The polar region is more conveniently represented by a radial raster resembling that generated by a radar PPI sweep; but the principle of painting the radial and concentric-circle grid lines using the radial raster is basically the same as painting the rectangular lines using the TV raster. Digital counters for both the horizontal and the vertical sweep coordinates in the case of the TV raster and for both the azimuthal and radial sweep coordinates in the case of the radial raster are used to keep track of the video pulse intervals and the number of sweep lines, respectively.

*Since a thorough investigation of other machines was foregone, it is not certain that any machine of equivalent size and price could indeed have been fast enough.

Before proceeding into the determination of the number of sweep lines, and line and pulse intervals chosen, it will be convenient to discuss the method for presenting the position points of satellites and own ship. With the prediction computer providing a position in digital form, a voltage generated by a digital-to-analog converter can be used to position the electron beam at any arbitrary location on the crt face. With such random ("jump scan") beam positioning, there can sometimes occur a memory or hysteresis effect characterized by previous beam positions perturbing the point where a given satellite appears on the crt face.

Such minor deflection discrepancies were eliminated in SPAD by painting position points with reference to grid lines which are also painted during the raster; since any deflection distortions apply equally to both positions and map grids, any deflection distortion has only a minor effect on display interpretation. The world map area (Fig. 2) is quantized into discrete horizontal points along discrete horizontal lines, with position points falling only on these designated points. In order to satisfy the 60-naut-mi maximum error criteria, the discrete points chosen must be no further apart than the equivalent of 60 naut mi. At the equator, one degree in longitude corresponds to 60 naut mi; thus for the world map display, 361 discrete horizontal points are required. Since the pulse intervals are already being counted for proper placement of map grid brightening, it was obvious that by providing digital counting of appropriate granularity, it would be possible to locate on the map a discrete horizontal point merely by designating its digital

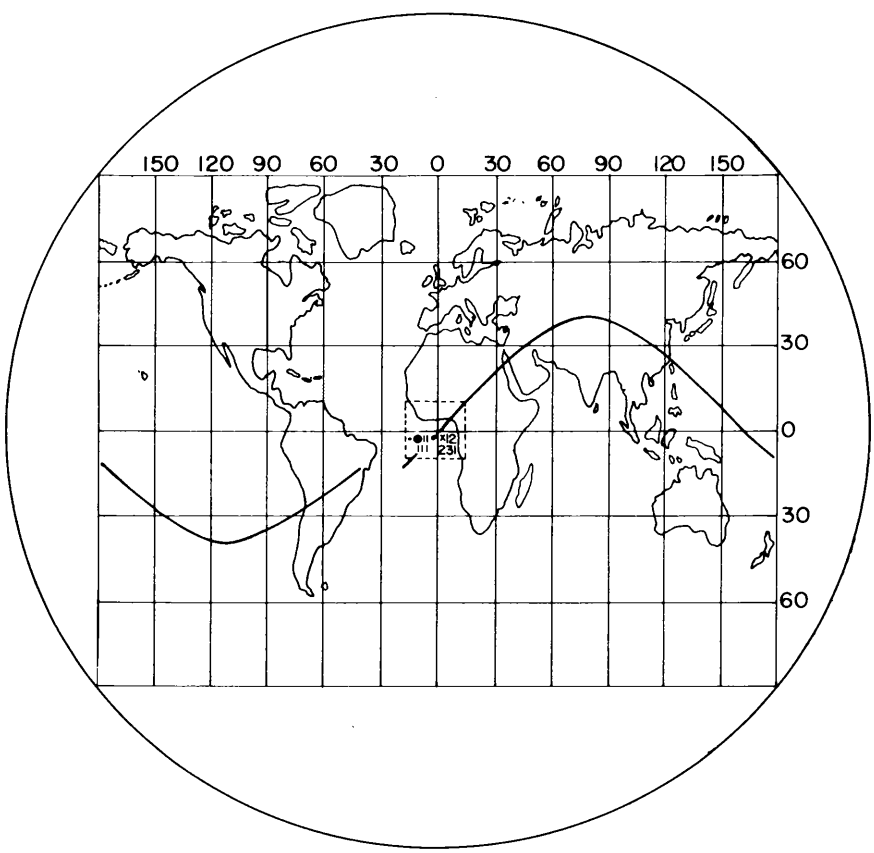

Fig. 2 - Idealized representation of the world map display. The actual display does not show the continental outlines.

count. A digital counter controls the vertical sweep and counts 361 horizontal sweep lines (0.5 degree of latitude per line) to provide a noninterlaced raster having a pleasing appearance and adequate granularity. The state of this vertical counter designates any line from 0 to 360. Hence, it follows that the prediction computer must provide a position in digital form compatible with the latitude and longitudinal counters. Each new state of the counters is compared with the position store, and at coincidence a video pulse is generated to provide a brightened position point at the designated location.

There are 13 such position stores, each used with a digital comparator to generate position video. In addition to the ten category stores denoted C1 through C10 for up to ten satellites selected according to category, there is the OS store for own ship, the TN store for the satellite selected by track number (an orbit, view area, and tabular readout are provided for this satellite), and the TN_v store for this satellite's vector tail dot denoting subsatellite position 5 minutes ago. Individual buttons at the display console act to inhibit the position and symbol video associated with each of these stores. These buttons serve to resolve ambiguities in the presentation and are useful in troubleshooting.

While the satellite position at a designated time is displayed with quantization intervals of 1 degree in longitude and 1/2 degree in latitude, the additional points representing the rest of the suborbital path for one orbit are displayed with a quantization interval of 4 degrees in both longitude and latitude. That is, if the path crosses any given 4-degree-by-4-degree elemental area of the earth's surface, the display is brightened at a point representing the approximate center of this elemental area. The resulting orbit appears as shown in Fig. 3. Here own ship is shown in its current position together with the position of a selected satellite at the designated time. The orbit is computed for one period beginning approximately half a period prior to this time. By a fortuitous event, the orbit in this figure appears to begin and end at the equator; in general, this will not be true.

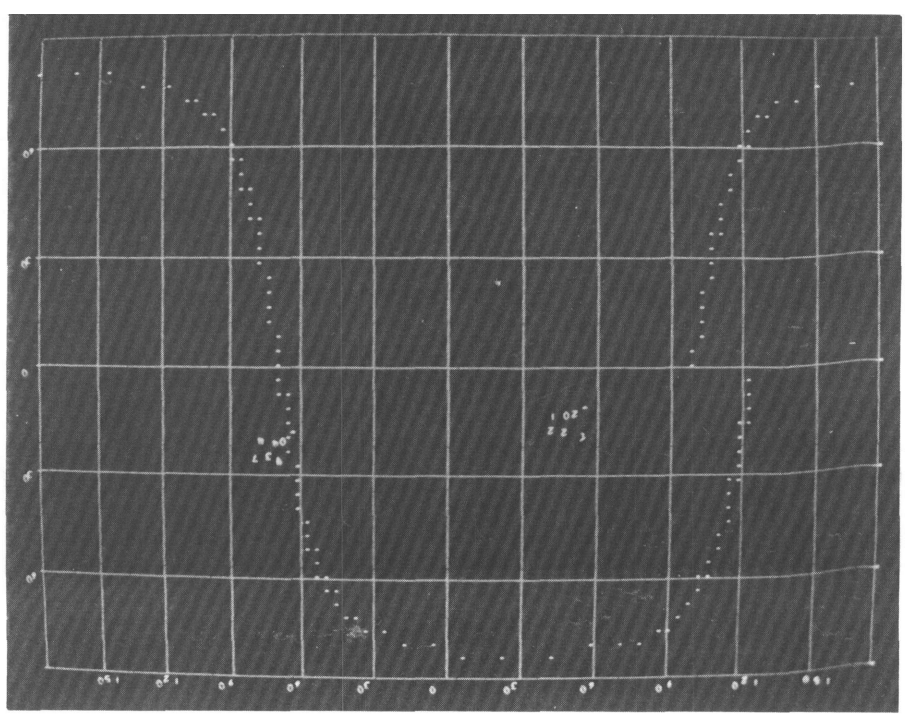

Fig. 3 - Orbit, satellite, and own ship on the world map display. The latitudes and longitudes are as shown in Fig. 2.

During the rectangular expanded mode, the same raster, composed of 361 raster lines and 361 equally spaced line segments, was chosen to represent an area 20 degrees in latitude by 30 degrees in longitude (Fig. 4). This eliminated the need for separate counters and sweep circuits and also provided a target positioning of greater resolution. The map grid markings were changed to conform to the expanded display appearance by simply altering electronically the line and pulse intervals which control the map-grid brightening signals. The digital computer was thus required to perform appropriate expansion computations in order to read out the X and Y position counts relative to the expanded scale. Thus, the formatter circuit for comparing the states of the digital counters with the position counts operates in the same manner as for the world map (WM) mode.

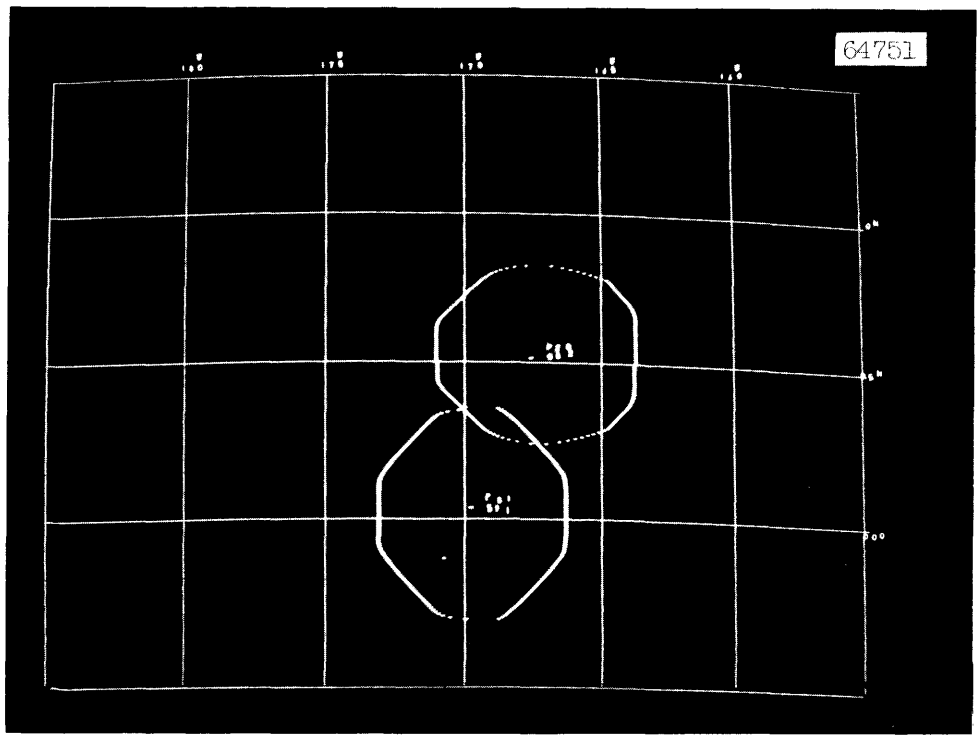

Fig. 4 - Rectangular expanded display with own ship, selected satellite, and areas of view near the equator. The selected satellite (lower position) also shows the vector dot.

A minor change in gating was required for the polar mode, but both the horizontal and the vertical counters continued to perform as for both the previous mentioned modes. Radial sweep lines were generated for each cycle of the horizontal counter. Naturally, the line interval and pulse interval for painting map grids in the polar mode were also suitably altered electronically to produce the map grid lines shown in Fig. 5.

With the map presentation and point positioning philosophy decided upon, a procedure for symbol and alpha-numeric generation and positioning was required. It was evident that the only time available for symbol generation was during the vertical sweep "dead time" or "recovery time." In this interval the symbol groups appropriately identifying the grid lines and the points are positioned by random deflection of the electron beam. This interval has thus been designated the jump scan interval as distinguished from the TV interval.

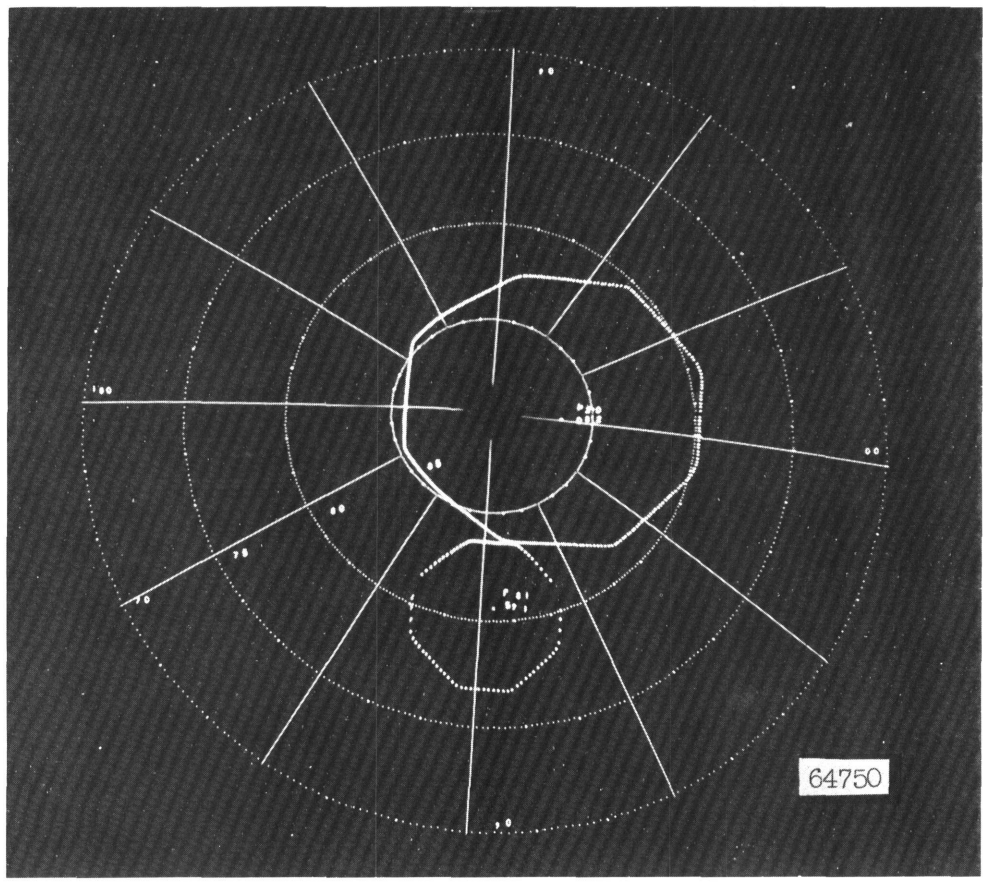

Fig. 5 - Polar expanded display with own ship, selected satellite, and areas of view

Associated with each of the position storage registers is a symbol word store. This store is actually a magnetostrictive delay line which is constantly recirculating 24 bits denoting the six symbols in a symbol group. The symbol store is updated by the computer each time the corresponding position register is updated. Thus the appropriate symbols for any given position are always available.

The method by which the symbols are generated is immaterial for this feasibility study, but it will be mentioned here for completeness. The Charactron crt paints symbols by extruding the electron beam through a stencillike matrix in the tube neck. This 8 by 8 matrix contains 63 unique apertures and one blank area; six bits are required to select a symbol. During the TV interval, the smallest circular aperture in the matrix is selected for line and spot writing. A symbol is selected through electrostatic deflection; the voltages required for this deflection are obtained from the display console's symbol selection digital to analog (D/A) converters. Since the binary representation of a symbol in the matrix is merely a function of its physical location in the matrix, the binary number presented to the D/A converter has no relation to the symbol itself. Thus, since the symbol word received from the computer is in binary-coded decimal (BCD) form (i.e., four bits/symbol) and does have a direct relation to the numeric, this word is converted to the binary format of the binary coded matrix (BCM) prior to being sent to the D/A converter. This conversion is accomplished within the formatter BCD/BCM converter to be described later.

To position the symbols being selected on the crt, the binary content of the corresponding position storage register is fed to the console's deflection D/A converter. The resulting voltage is sent to the deflection amplifier which drives the deflection yoke. It should be noted that with this crt, the beam is positioned through electromagnetic deflection, while the symbol is selected through electrostatic deflection. After an appropriate time interval to allow for deflection yoke settling, the first symbol is selected and a video pulse applied. The remaining symbols of a symbol group are selected in turn, with appropriate minor deflection voltages being applied in order to provide for spacing of the symbols within a group.

The foregoing procedure continues until all 11 satellite symbol groups and the ship symbol group are painted. Following this, the symbols identifying the map grid are painted. These groups are selected and positioned in a manner similar to that for the points. However, since the map grids for any particular display mode are fixed, their position and symbol words need not be generated each time by the computer. Thus they are stored permanently in an auxiliary digital memory unit (DMU) and read out in sequence under control of the formatter circuitry. Upon completion of the symbol painting, the jump scan interval is terminated and the TV interval commences.

CIRCUIT OPERATION

The manner in which the formatter accepts computer-generated data for storage and assembly in the display format is suggested by the simplified data flow diagram of Fig. 6. Formatter operation is perhaps best understood in terms of three levels of storage: Computer output data is first held in a buffer until the right moment in the display cycle for placing that data in the individual data word stores, which form the second level. The symbol selection and symbol position words are repetitively shifted to third-level stores for interfacing with the display console.

Computer Output Buffer

Computed data is entered into the formatter via the computer output buffer in the following manner. As soon as the computer puts a word on its output lines, it sends a "ready" pulse out on what is called the external function line. This pulse is used by the formatter to initiate a cycle in the buffer which first resets the buffer shift register and then transfers the data word into the register for temporary storage. The buffer accepts the 30-bit computer output word in parallel form and then shifts the data portion in serial fashion to the proper store.

The first five bits of the output word contain the address corresponding to one of the 32 stores (Fig. 6) in the formatter. If the sixth bit, which is a spare bit in the present configuration, were used as another address bit, 64 stores could be addressed. The address bits are decoded to provide an address gate which enables the data word to be shifted into the appropriate store. The data portion of the computer output word contains from 12 to 24 bits. The number of data bits and consequently the number of shift pulses to be generated by the buffer shift pulse generator is determined by the address gates. The address gates can be used for this function, since the number of data bits in the computer output words for any given address is always the same and is predetermined by the computer program.

The AN/UYK-1 computer can be programmed to present output words either upon request or else at the computer's own rate. The first or request procedure is generally used when the computer would read out data too fast, or when the receiving device requires a long time for processing the data. Since this did not seem to be the case for SPAD, the procedure chosen permits the computer to read out data at its own rate rather

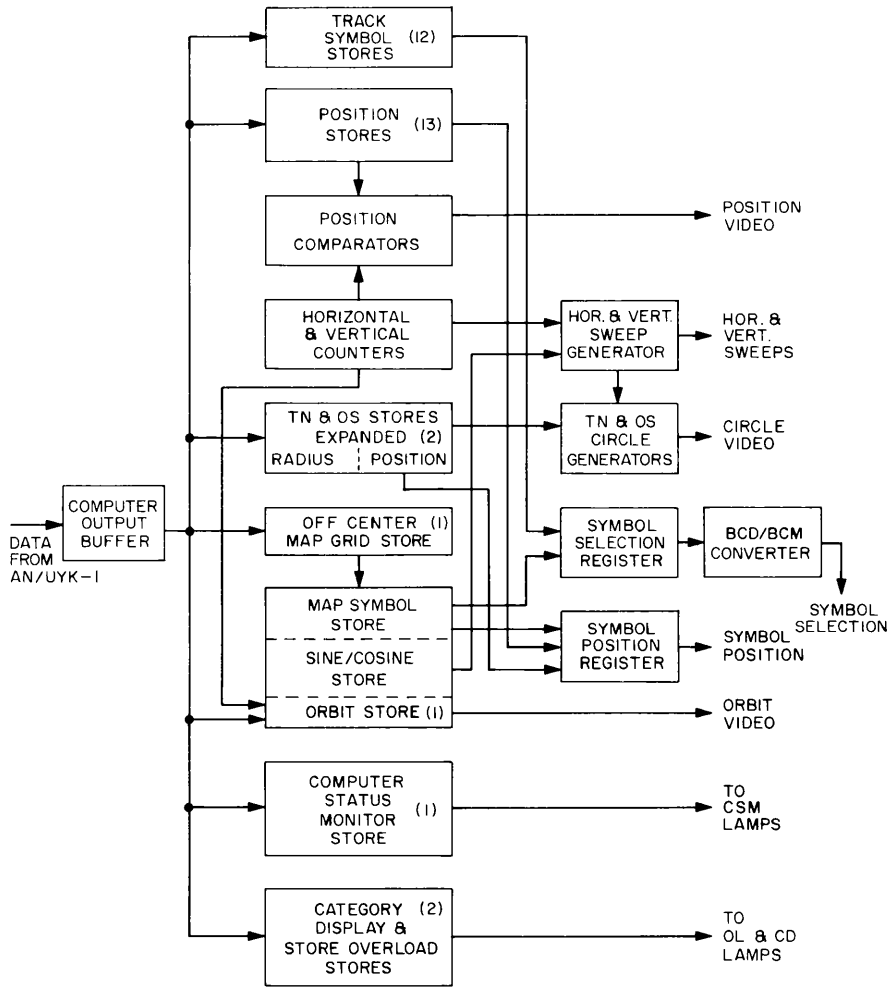

Fig. 6 - Simplified data flow diagram. The numbers in parentheses indicate the 32 discrete stores addressible by the computer.

than be required to await data request commands. Thus the computer operates quite independently from the formatter, merely updating the formatter stores at appropriately programmed intervals. Use of this procedure eliminated a certain amount of circuitry and also some additional programming sequences. A maximum of about 64 μsec, which includes a certain timing signal, is required to transfer the data word from the buffer shift register, serially into the appropriate store. The computer program was then written such that no output words would follow one another in less than 64 μsec, so that the buffer shift register would always be ready to accept the computer output.

The previously mentioned timing signal, serves two purposes. First, since the computer output words are sent to the formatter independently of the display cycle, it is necessary to provide a timing signal which prevents the shifting of new data into a store at the wrong moment in the display cycle timing. When used for this function, the timing signal constitutes the busy signal; it delays shifting out of the buffer shift register until such time as readout of the store has been complete. With this delay, plus the buffer set and reset pulses and several other synchronizing gates, a maximum of 40 μsec can transpire before shifting out of the buffer register can commence. If a maximum-length

data word of 24 bits is to be shifted at a 1-megacycle rate, the total time required by the buffer to be ready to accept a new data word is thus approximately 64 μsec. When there is no conflict between reading out and shifting into a store, the buffer can be ready for a new word in 36 μsec.

The other use of the timing signal is basically the same as for the previous case, in that the shifting of data out of the buffer shift register is delayed until arrival of the timing signal. However, in this case, the delay is required, because the magnetostrictive delay line memories which are used to store the symbol words cannot be entered at any arbitrary time. This is due to the nature of this type of storage; i.e., the data is continuously being recirculated in serial form. Hence, to preserve the timing sequence used in reading out of these stores, the entry into the line must be precisely synchronized.

These delay lines store the symbol words of all the satellites and of the own ship, for 12 separate delay lines. Each line stores six symbols of four bits each. By using this type of storage rather than the conventional shift register stores, a substantial decrease was afforded in both cost and rack space.

TV Interval

The display period is composed of a TV interval during which a raster is generated, and a jump scan interval during which the symbols are painted. These two intervals comprise one complete display frame, which is repeated approximately 30 times per second. During the TV interval, video is applied only when the electron beam is passing through a point where information is to be displayed. For the world map and the rectangular expanded displays, the TV interval consists of a 361-line noninterlaced raster with the first sweep starting at the bottom left corner of the display tube and the last sweep ending at the top right corner. For the polar display, a sweep is used which consists of 361 radial lines originating at the center of the display, with the first and last sweep lines coinciding. This type of sweep is similar to that of a radar PPI. It is produced by generating horizontal and vertical sweeps whose amplitudes are proportional to the values of sines and cosines stored in the digital memory unit (DMU). The DMU is an auxiliary memory device containing a random access magnetic core memory with portions reserved for several other functions which will be discussed later. For each sweep line, then, the corresponding values of sines and cosines are transferred in parallel to a D/A converter which generates the analog voltages used by the sweep generator.

Horizontal and Vertical Counters -- The TV interval is controlled by the horizontal and vertical counters. The length of each horizontal sweep line is controlled by a sweep gate which is turned on while the horizontal counter counts from 0 to 360. Thus each sweep line is divided into 361 discrete positions, with the state of the horizontal counter indicating the position of the beam along the sweep line.

The vertical counter is advanced at the end of each horizontal sweep, thus indicating which sweep line is being generated at any time during the TV interval. When the state of the vertical counter reaches 360, indicating that 361 horizontal sweep lines have been generated, the counter terminates the vertical sweep by turning off the vertical sweep gate. A counter known as the ELCOM (electronic commutator) counter is then advanced to terminate the TV interval and initiate the JS or jump scan interval during which all symbol groups are painted in a somewhat random fashion to be described later.

Map Grid Lines — The horizontal and vertical counter circuits also provide the video for painting the map grid lines on the display. During the world map and rectangular expanded modes (Figs. 3 and 4) the parallels are painted by brightening the appropriate sweep lines, while the meridians are painted by applying short brightening pulses along each sweep line. Thus, the meridians are actually made up of closely spaced dots.

During the polar mode (Fig. 5) the radial lines representing the meridians are produced by brightening the entire radial sweep line, while the parallels appear as dotted circles which are painted with brightening pulses along each radial sweep line. Also on the polar display, 10-degree hash marks indicating longitude increments are painted by means of video pulses that are slightly wider than those used for the other dots forming the parallels.

Position Video — In addition to the map grid lines, the position dots, and the vector tail dot, orbit and circle information are also painted on the raster during the TV interval. The position words for the 11 satellites, own ship, and vector are loaded into their respective stores as described earlier. These position words consist of 18 bits of information; nine bits for the horizontal coordinate and nine bits for the vertical. The position at the bottom left corner of the display corresponds to a position word of all zeros, while the top right corner corresponds to a binary number 360 in each coordinate.

The words in the position stores are compared with the states of the horizontal and vertical counters. When the binary state of the counters is equal to the binary number contained in a position store, the comparator generates a video brightening pulse which paints the position on the display. The video pulses from the comparator for the 11 satellites and own ship are combined before being sent as position video to the video amplifier in the display console. The vector tail dot, which is generated only during the expanded modes, is sent to the video amplifier as a separate input.

Orbit Video — The orbit video pulses are generated in the orbit store section of the DMU. Each orbit point is sent to the orbit store by the computer as a 13-bit word. Only 13 bits are necessary to specify the position of an orbit point because of the 4-degree quantization selected for the orbit points in each coordinate. This 4-degree quantization was chosen as a compromise between the high cost of higher resolution storage and the amount of quantization which would provide an orbit of satisfactory granularity from a human engineering standpoint. A typical result of painting orbits with the chosen granularity can be seen in Fig. 3. The states of the vertical counter, which designate each raster line, are used to address the memory for readout of appropriate video pulses corresponding to orbit points. The orbit is displayed only during the world map mode but is retained in the memory unit until erased. The time for which an orbit is requested is not recorded, and the operator must remember this time. Should this omission prove to be serious, an orbit time symbol group could be painted adjacent to the orbit.

Under normal operating conditions only one orbit can be stored in the memory unit at a time. Thus, each time a new orbit is requested, the previously stored orbit is destroyed. However, a temporary wiring change permitted the DMU to store two orbits as shown in Fig. 7. The orbit of a synthetic SYNCOM satellite having a rather high inclination angle appears as a large "figure eight." With the temporary wiring change, only one of the two orbits is identified by a symbol group, with any ambiguity being resolved by means of the TN video inhibit button. Since a new orbit can be quickly generated, there seems to be no need for more than one orbit at once.

Circle Video — Circle video enclosing a satellite's area of view is painted on the expanded display (Figs. 4 and 5) with a radius varying up to 504 naut mi in increments of 8 naut mi. This circle, centered about the subsatellite point, may represent the radio horizon, the area covered by a cloud camera, or any other convenient variable. A similar circle is painted about own ship to represent, say, the distance which that ship could travel in one day. Two identical circle circuits are used to generate circle video for own ship and the TN satellite, and the following discussion applies to either circuit.

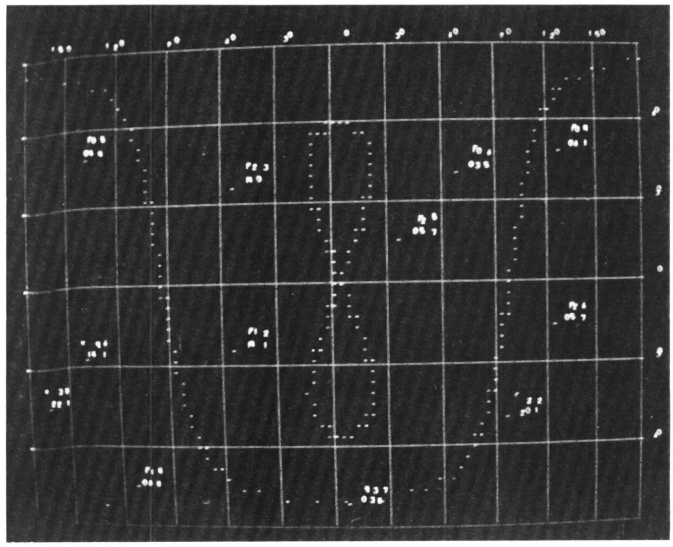

Fig. 7 - Two orbits, eleven satellites, and own ship on the world map display

The circle generator involves a simple analog computer using operational amplifiers and a resistor-diode function generator. Circuit design details are presented in Ref. 5. The inputs required include the horizontal and vertical sweep voltages, the X and Y coordinates of the center of the circle, i.e., the satellite or own ship position and the radius of the circle. The center coordinates are taken from the satellite and own ship expanded mode stores. The only time the contents of these stores differ from that of their respective position stores is during the polar expanded mode, when the position stores contain a position in polar coordinates, while the expanded mode stores contain the positions in rectangular coordinates. The expanded mode stores also contain six bits of additional information which denote the radius of the circle to be generated. From these stores, the coordinates of the center and the radius are converted into analog voltages for inputs to the circle generator. The generator then provides video pulses which paint an octagon on the display. In this version of SPAD an octagon is used to approximate a circle; however, a polygon with more sides such as 12, 16, 20, or 24 could have been used with very modest increase in the number of resistors and diodes.

Because of the convergence of the meridians, a circle on the rectangular expanded display must become more and more distorted as the displayed area approaches either pole. The required "stretching" of the curve in the horizontal direction is approximated by varying the voltage amplification of certain operational amplifiers in discrete jumps to produce the curve shown in Fig. 8. The resulting discontinuities in the curve could be rendered less noticeable by augmenting the logical circuits to provide smaller increments in latitude for the jumps.

There is an important advantage to painting map grid lines, satellite positions, vector tail dot, and the orbit as the raster lines are generated. Any deflection distortion or drift in the sweep generation and deflection circuits will affect all such information alike. Thus, with moderate deflection distortion there will be negligible error in viewing position information with reference to the map grid lines. The timing of all the above video information is precisely determined by digital counters and digital comparators, so that any error introduced by the display must arise through interpolating a position lying between two map grid lines.

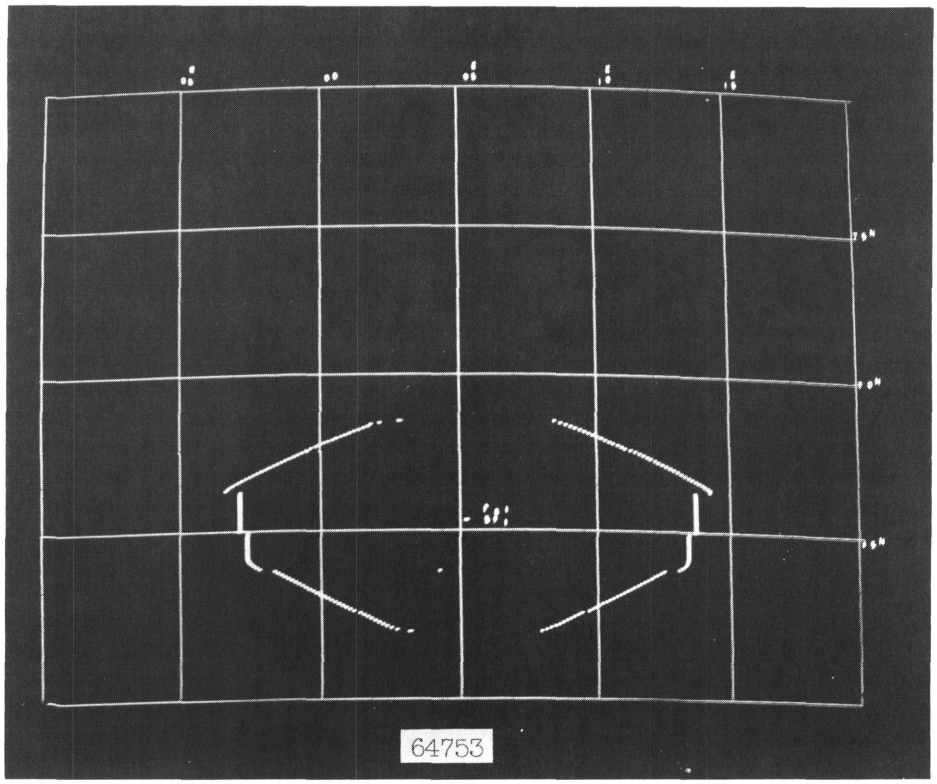

Fig. 8 - Approximation to a circle compensated for convergence of the meridians

Jump Scan Interval

During the jump scan (JS) interval, which begins at the end of each TV interval, the symbols are painted. Both the electronic commutator (ELCOM) and the display shift pulse generator (DSPG) control the operations and timing of the JS interval.

The ELCOM consists of a counter whose states are decoded to provide gates which permit one symbol group at a time to be painted. A tabulation of ELCOM output gates and their corresponding function is shown in Table 1 for each of the three modes of operation. The display appearance of the symbol groups listed in the table is shown in Figs. 2, 7, 9, and 10. During the TV interval, the ELCOM is in the reset state; i.e., the R_0 gate is at the ONE level, thus enabling the generation of the raster. At the end of the TV interval, the vertical counter advances the ELCOM by one count, thus producing a gate which enables the painting of the first symbol group. Since all symbol groups are painted in an identical manner, the discussion which follows will treat only the own ship symbol group enabled by R_1.

The actual painting of the first symbol group is delayed until the DSPG symbol gates are in synchronism with the symbol display cycle. These symbol gates indicate which symbol of a symbol group is available for readout at the delay line memory outputs at any particular time. Upon termination of this synchronization delay, the DSPG generates shift pulses which move the own ship position word from its store into the symbol position register. This register acts as a buffer between the formatter and the display console. These words are sent to the display console in parallel form, where they are converted into analog voltages for use as the deflection inputs which position the electron beam in

Table 1
Electronic Commutator Output Gates and Their Corresponding Function in Each of Three Modes of Operation

ELCOM Output Gate	Corresponding Function		
	World Map*	Rectangular Expanded Model†	Polar Expanded Model‡
R_0	TV interval	TV interval	TV interval
R_1	OS symbol	OS symbol	OS symbol
R_2	TN symbol	TN symbol	TN symbol
R_3	C1 symbol	10W map symbol	70 map symbol
R_4	C2 symbol	5W map symbol	75 map symbol
R_5	C3 symbol	0 map symbol	80 map symbol
R_6	C4 symbol	5E map symbol	85 map symbol
R_7	C5 symbol	10E map symbol	0 map symbol
R_8	C6 symbol	5S map symbol	90 map symbol
R_9	C7 symbol	0 map symbol	180 map symbol
R_{10}	C8 symbol	5N map symbol	90 map symbol
R_{11}	C9 symbol		
R_{12}	C10 symbol		
R_{13}	150 map symbol		
R_{14}	120 map symbol		
R_{15}	90 map symbol		
R_{16}	60 map symbol		
R_{17}	30 map symbol		
R_{18}	0 map symbol		
R_{19}	30 map symbol		
R_{20}	60 map symbol		
R_{21}	90 map symbol		
R_{22}	120 map symbol		
R_{23}	150 map symbol		
R_{24}	60 map symbol		
R_{25}	30 map symbol		
R_{26}	0 map symbol		
R_{27}	30 map symbol		
R_{28}	60 map symbol		

*Symbol groups for ELCOM output gates R_1 through R_{12} are shown in Fig. 7. Symbol groups for gates R_{13} through R_{28} are shown in Fig. 2.

†Map symbol groups for the rectangular expanded display are shown in Fig. 9. The five latitude values and three longitude values will change according to the position of the point on the world map.

‡Map symbol groups for the polar expanded display are shown in Fig. 10.

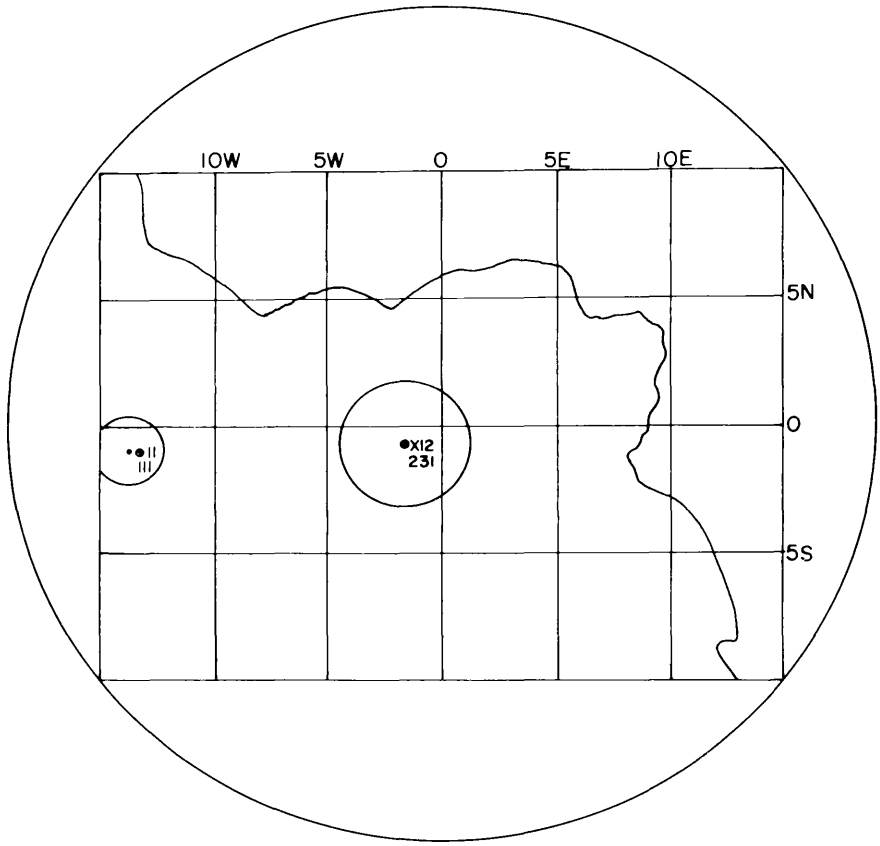

Fig. 9 - Rectangular expanded display with symbol groups gated as tabulated in Table 1. This is an expansion of the dashed area indicated in Fig. 2.

locations adjacent to the appropriate position dots. After a suitable delay to allow for settling of the deflection circuit, the DSPG generates four shift pulses which move the first symbol of the own ship symbol word out of the delay line memory into the symbol selection register. This four-bit symbol code is held in the symbol selection register until the symbol has been displayed and the next four-bit symbol code is transferred. Since the symbol code is in a four-bit BCD format and the console requires a six-bit word to select a symbol from its 8 by 8 alpha-numeric matrix, a conversion is required. This conversion to the six-bit binary coded matrix (BCM) is accomplished in the BCD/BCM converter circuitry. The information required by the BCD/BCM converter in addition to the BCD symbol code is a gate from the DSPG indicating whether a category symbol or a numeral is being painted, and other gates which designate what type of symbol groups are being painted, e.g., map grid symbols as opposed to satellite symbols.

After the first symbol code has been sent to the display console and a delay has elapsed for the analog circuits to settle, the DSPG generates a symbol video pulse which paints the symbol on the display. At the trailing edge of this video pulse, the next symbol code is shifted into the symbol selection register. This process is repeated until all six symbols of a symbol group are painted. The DSPG then advances the ELCOM counter, which produces a gate that selects the next symbol group to be painted. Intragroup deflection signals are generated by the DSPG to provide the proper spacing between the symbols of each symbol group.

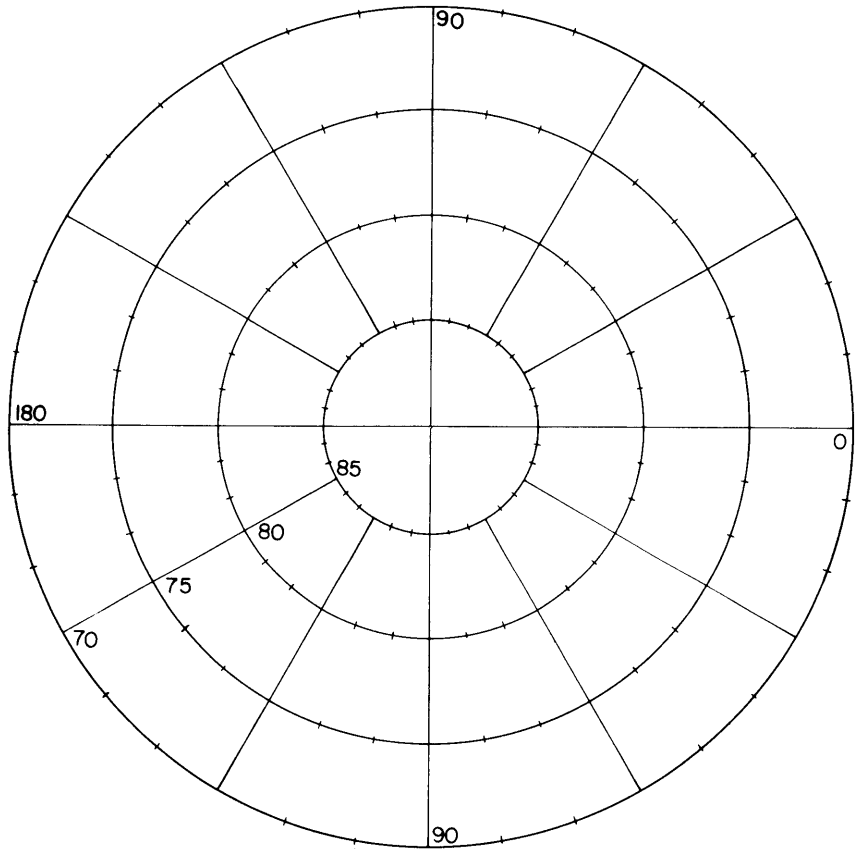

Fig. 10 - Map grid for expanded polar display with symbol groups gated as tabulated in Table 1

As a design economy, six symbols are generated for every symbol group, even though the map grid symbol groups are made up of no more than four symbols. In this case, several blanks are selected in place of actual symbols so that only the necessary digits are displayed. Thus, the map grid symbol groups are in the identical format as those of the satellite groups. However, since the map grid symbols are fixed and therefore need not be updated, their position and selection words are permanently stored in the DMU. These stores are read out after all target symbol groups are displayed, as indicated in Table 1. After all symbol groups have been displayed, the ELCOM counter is reset, which initiates the TV interval, thus starting a new display frame. As can be seen in the table, this resetting of the ELCOM occurs at different times according to whether a world map display or an expanded display is presented.

When there are less than 11 satellites selected for display at any one time, the computer sends all binary ONEs to the unused position stores. Since the horizontal and vertical counters never reach a state of all ONEs (i.e., the binary equivalent of 511), no comparison can occur and hence no position video is generated. When the position word is shifted into the symbol position register in the normal sequence, the binary ONEs in the two most significant bits of the horizontal coordinate of the position word are sensed by a logical AND circuit. When both bits are a binary ONE, this circuit will produce a video inhibit gate; valid satellite symbols will not be inhibited, since a valid position cannot have two binary ONEs in the most significant bits.

Map Grid Symbols

For the world map display, the map grid symbol groups of Fig. 2 are painted in the arbitrary order shown in the second column of Table 1. When the display is expanded about the TN satellite of Fig. 2, the area within the dotted rectangle appears on the rectangular expanded display of Fig. 9. This display is seen to be 20 degrees in latitude by 30 degrees in longitude, with the satellite (or own ship) always appearing within the central 10 by 20 degree area. For the given central area, the map grid symbol groups will be painted as shown in the third column of the table. However, when the satellite moves outside this particular central area, the display is automatically displaced either 10 degrees in latitude or 20 degrees in longitude and an appropriate new set of symbol groups is called out of the DMU.

The foregoing displacement is accomplished as follows: For each jump in either latitude or longitude, the computer sends a 12-bit off-center word which contains seven bits to identify the first longitude symbols to be painted and five bits which identify the first latitude symbols. This 12-bit word is stored in the off-center map grid store. At the beginning of each JS interval, the two portions of this word are set into separate binary counters. The coding is such that with the initial word in each counter the succeeding map grid symbols can be selected from the DMU by advancing the appropriate counter by one count for each new symbol group and then sending the state of the counter to the DMU as an address for symbol group readout.

When, however, the TN satellite (about which the display is expanded) lies within 15 degrees of either pole, the display automatically appears with map grids and symbol groups as shown in the idealized drawing of Fig. 10. These symbol groups are painted in the order listed in the fourth column of the table and remain the same for either the north polar region or the south polar region.

The computer now generates a valid N or S bit to designate which polar region is depicted. Should experience disclose that the operator does need to be told, this bit could be used to paint either an N or an S at the display center to identify the pole. In view of the added circuit complexity, this feature will be implemented only if necessary.

Indicator Lamps

There are category displayed (CD) and store overload (OL) lamps on the computer control panel at the operator console which indicate the operating status of the display at all times. The stores and lamp drivers for these lamps are in the formatter. The stores consist of two 16-bit shift registers with one bit controlling each lamp. A logical ONE in any bit of the register is sensed by a lamp driver which turns on the corresponding lamp; a logical ZERO turns the lamp off. Each time the operator changes the display for any reason, the computer sends out an appropriate word which alters the status indication shown by the lamps.

Also located at the operator's console are six lamps designated as the computer status monitor (CSM) lamps. The storage registers and driver circuits for these lamps are also in the formatter. Five of the lamps can be considered as "tilt" lamps, since they indicate some error in operation. The errors which can be indicated are invalid interrupts, invalid track numbers, invalid days, invalid time (month or year), and invalid circle radius. The sixth lamp indicates that the position computation is being performed in a so-called nonprecision routine. For a detailed discussion of the function of the CSM, CD, and OL lamps, see Ref. 1.

The six CSM lamps are controlled by a 12-bit shift register which receives and stores the CSM word. Two bits, an On bit and an Off bit, are used to control each lamp. A logical ONE in the respective bit positions will turn the lamp either on or off under computer control. The apparent redundancy in this circuit approach was chosen in order to eliminate the need for each CSM word sent from the computer to contain data concerning all the lamps. If the CSM word contains data only for those lamps that are to be changed, the computer program is simplified at only a moderate increase in hardware cost.

Maintenance and Calibration Provisions

Packaging — The present configuration of the SPAD formatter is due to several considerations. The signal runs of the high-frequency circuits were carefully scrutinized in order to prevent as much as possible undesirable effects on these signals, such as stray coupling and attenuation. To facilitate maintenance and accessibility to the equipment all the circuit modules are contained in drawers which may be tilted as shown in Figs. 11 and 12 to provide access to both the wiring and modules. All the wiring on these drawers is point to point, using taper pin connections. Taper pins are used rather than solder connections to facilitate changes which inevitably result from experience with a research equipment.

Test Points — In those drawer units which contain the more complicated circuitry, special provision has been made for monitoring the test points. A rack-mounted oscilloscope in the formatter is connected to the individual circuit drawer by plug-in cable as shown in Fig. 11. The desired test points are selected for viewing on the oscilloscope by two rotary switches on the front panel of the drawers. The switch position for each test point is given in a table contained in the SPAD instruction manual. This table also includes the optimum setting for the oscilloscope controls and a photograph showing the correct waveforms for each of the selected test points. The oscilloscope has provision

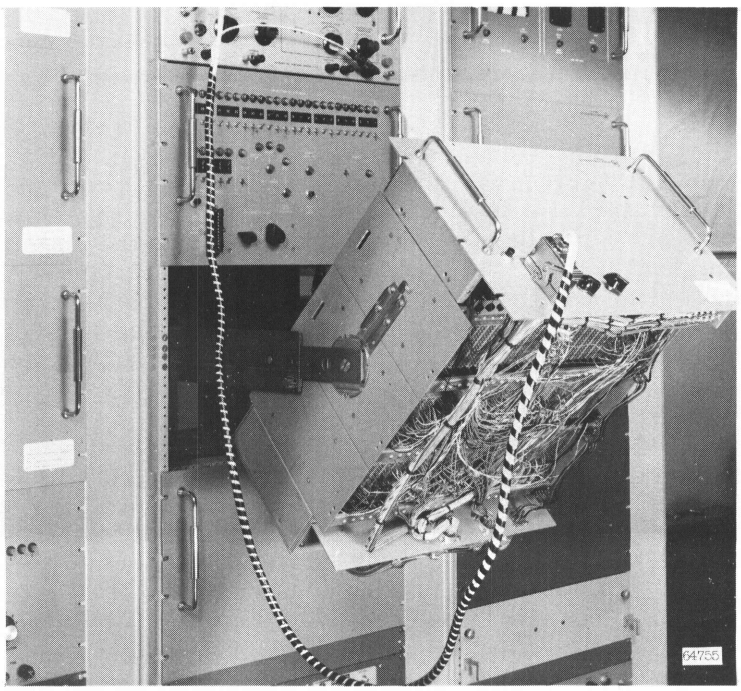

Fig. 11 - Circuit drawer showing access to wiring

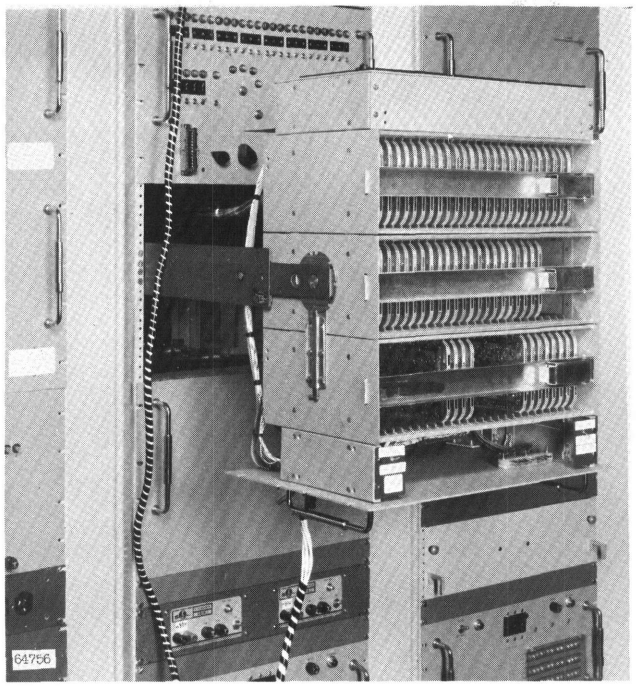

Fig. 12 - Circular drawer showing access to modules

for viewing four test points at a time. Thus, using 32 of the 33 possible positions of the rotary switches, 128 test points can be wired into each drawer unit. The 33rd position of the rotary switches is used to select other circuit points by means of plug-in probes.

Troubleshooting — As an aid in diagnosing equipment malfunctions, provision has been made at the computer output buffer circuit drawer unit (Fig. 13) to monitor each bit of the computer output words. An output word, monitored on 30 indicator lamps, is selected according to an operator option, either by a particular address or by simply being the next word sent by the computer. The word that is being monitored is retained in the buffer shift register by inhibiting the shifting of the word out of the register. While the word is being monitored, the buffer cannot accept any other data; thus all succeeding words from the computer are ignored. The monitoring is terminated by activating the manual transfer button, which shifts the word out of the buffer shift register into the proper store in the formatter. The buffer is then ready to receive a new word from the computer. This monitoring feature was desirable to determine whether an apparent malfunction was due to an equipment failure or whether it was due to invalid computer output words caused by program or computer problems. This feature was also helpful in debugging the computer program by making the output words readily available to the programmer.

Provision for manual entry of data words into the formatter has also been included on the computer output buffer unit. Once the data and an appropriate address is set up on the 30 toggle switches provided, data words can be entered into the formatter either by a single manual transfer or repetitiously at a rate of approximately 9 kilocycles. The repetitive entry feature permits monitoring on the oscilloscope of the entire sequence of events pertinent to data word transfers. The toggle switch entry of data also permits static conditions to be displayed without the use of the computer. Coordinates of specific locations on the crt can easily be entered via these switches and the resulting position

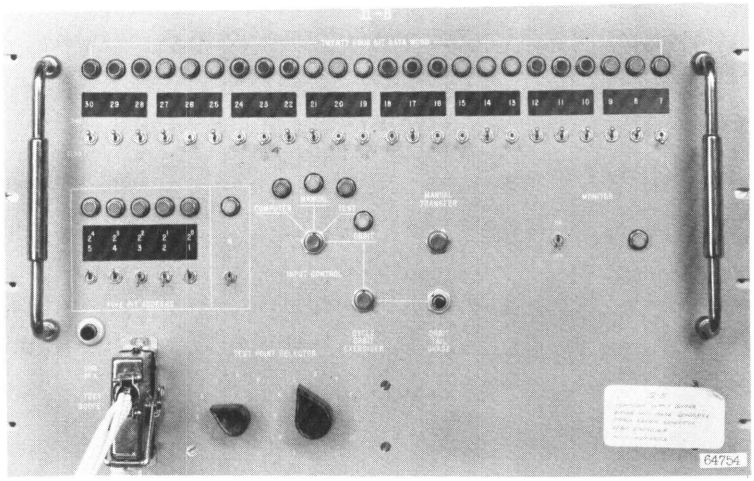

Fig. 13 - Computer output buffer drawer

spot used to determine whether deflection circuits are operating properly. The SPAD instruction manual contains the information an operator or technician requires in using the manual entry feature.

Testing the Orbit Store — For testing the orbit store portion of the DMU a circuit designated as the orbit exerciser has also been provided on the buffer unit. The testing consists of sending orbit words to the DMU which when displayed will form a distinctive pattern. Thus any orbit points which are not painted properly or are missing are easily detected. The four different patterns provided (Fig. 14) make it possible to check all possible orbit points of the DMU store. Approximately 128 of these points are used to display an orbit.

Display Alignment — An adjunct to the display console's alignment controls is the matrix raster generator. This test circuit provides signals necessary for selecting all the symbols in the 8 by 8 symbol matrix of the crt. It also generates the appropriate video pulses for painting these symbols on the display crt. During the alignment procedure, when such symbol selection is required, a test/operate switch at the console is placed in the test position, thus activating the matrix raster generator.

In order to properly position the symbols with respect to their position dots and map grid lines, during the operate mode, a switch provided at the formatter inhibits the intragroup deflection, thus causing all symbols of a symbol group to coincide.

CONCLUSIONS

The feasibility of a computer-driven satellite position prediction and display equipment has been demonstrated. State-of-the-art digital and analog devices have been employed in the design and construction of the SPAD formatter and other necessary hardware. Emphasis has been placed on demonstrating the feasibility of such a system and providing facility for field modifications rather than on operational packaging and design. During the past several months of complete operation and evaluation, no major equipment breakdown has occurred. With improved display devices the particular methods employed in the present version of SPAD might well be not the most efficient; nonetheless, the original goal for this equipment was to provide a satellite display for evaluating the Navy's requirements for such a device, and not necessarily to invent the best in hardware configurations. This goal has been adequately realized.

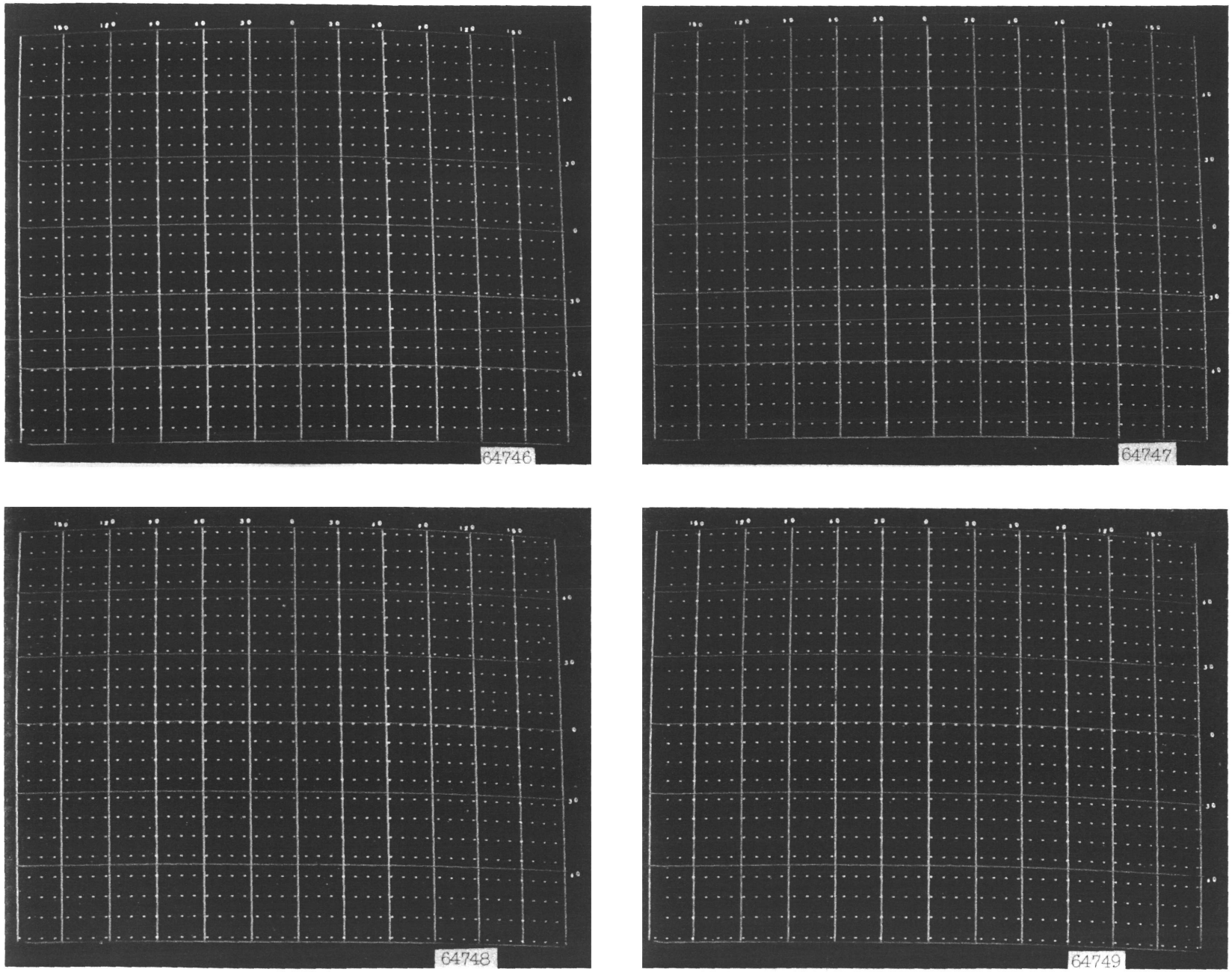

Fig. 14 - The four test patterns provided by the test circuit designated as the orbit exerciser

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Appendix A

GLOSSARY

Since many terms and symbols used in this report are peculiar to SPAD, they are assembled in this glossary as a convenience to the reader. Each entry is also explained where it first appears in the body of the report.

BCD	Binary Coded Decimal. The computer generates the decimal digits 0 through 9 in BCD form; other symbols, i.e., letters and category symbols, are said to be in BCD form, since they are arbitrarily assigned a 4-bit code.
BCM	Binary Coded Matrix. The six BCM bits select an aperture in the 8 by 8 symbol matrix in the crt.
CD	Category Displayed. A lit CD lamp indicates that one or more satellites of this category are shown on the world map display.
crt	Cathode-Ray Tube.
CSM	Computer Status Monitor. CSM lamps are controlled by the computer to indicate computer status. Five lamps indicate some error in operation; a sixth indicates that a less precise routine is used for faster position computation.
C1, . . . , C10	Stores labeled C1 through C10 are called category stores, since they contain information on satellites selected according to category. (However, individual satellites can be added or deleted by means of their track number.)
D/A	Digital to Analog.
DMU	Digital Memory Unit located in the formatter.
DSPG	Display Shift Pulse Generator: used to circulate words in the sonic memories and to shift symbol position and symbol selection words.
ELCOM	Electronic Commutator: a sequence control circuit in which the state of a counter is decoded to activate a different control line for each different state of the counter. The first counter state generates the TV gate. The following counter states (during the JS interval) generates gates used in painting the symbol groups.

Formatter	A device, combining the functions of data storage (display memory) and display raster and video generation, which is placed between the display and the source of displayed information for both storing this information and presenting it to the display in the proper sequence so that selected information appears in the proper format.
JS	Jump Scan. During the jump scan interval, symbol groups are painted in a somewhat random fashion.
OL	Overload. An OL lamp, when lit for a given category selection button, indicates that because all stores are full, no satellites in this category can be shown on the world map display.
OS	Own Ship.
PPI	Plan Position Indicator.
SPAD	Satellite position Prediction And Display equipment.
TN	Track Number: an arbitrary reference number assigned to each satellite in the computer memory.
TV	Television. A noninterlaced raster of 361 TV lines is used in SPAD.
WM	World Map mode: displays the earth's surface as a rectangle 360-degrees wide in longitude and 180-degrees high in latitude.

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13. ABSTRACT

The Naval Research Laboratory has developed a computer-driven display (SPAD) for presenting the predicted positions of artificial earth satellites. The buffer interface between the digital computer and the display console is known as the SPAD formatter. The computer generates information for as many as 11 satellites each 1.1 seconds. The formatter accepts these computer output words as they are generated and, through appropriate gating and timing sequences, presents the data to the display at a rate of 30 frames per second. The formatter also contains a magnetic core memory device which permanently retains map grid symbol information and provides temporary storage for points representing a suborbital path.

As an experimental device, the formatter was built in a three-bay rack cabinet with room provided for possible expansion or modification of the design. To facilitate calibration and maintenance, a rack-mounted four-channel cathode-ray oscilloscope can be connected to a circuit drawer and desired test points selected by means of rotary switches. Other circuit features permit maintenance personnel to rapidly check the performance of computer and formatter and isolate any malfunction. The formatter performed as desired.

This report discusses in general the design problems common to computer driven displays and considers specifically problems encountered in designing the SPAD formatter as well as the theory of operation of the overall equipment. Alternative approaches to the digital logic design problems are presented whenever possible, and the philosophy and reasons for the particular approaches chosen for SPAD are given.

DD FORM 1 JAN 64 1473

Security Classification

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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Display systems						
Computer storage devices						
Data storage systems						
Digital-to-analog converters						
Shipborne						
Computer-to-display interface						

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