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Microprocessor-Based Scan Control Unit for Electron and Photon Beams Used in Surface Analysis

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MICROPROCESSOR-BASED SCAN CONTROL UNIT FOR ELECTRON AND PHOTON BEAMS USED IN SURFACE ANALYSIS

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ABSTRACT

A microprocessor-based X-Y scan control unit was developed to interface with existing PHI Scanning Auger Microprobe and exoelectron emission electronics. The unit provides precise and versatile control of the rastered beams used for surface analysis. In addition to manual control there are options for automatic line and area scans with up to 1000 discrete beam analysis points per line (up to 10⁹ for an entire frame area) and scanning rates continuously adjustable from 1 to 2000 points per second. The design of the unit is such that it can be used in a variety of applications requiring accurate X-Y position control. This report gives a complete description of the scanning control unit's operating controls, internal programming, and circuitry.

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I. Introduction

A Scan Control Unit has been designed to provide versatile and precise control of the beam probe used in two different surface analysis techniques: scanning Auger spectroscopy and uv photon-stimulated exoelectron emission. For the former, the Scan Control Unit interfaces with existing commercial electronics for digital scan control of a PHI model 545 Scanning Auger Microprobe (SAM), and for the latter it controls the position of an ultraviolet light beam used to excite exoelectrons.

The Scanning Auger Microprobe (see Figure 1) is used for the determination of surface composition on specimens mounted in an ultrahigh-vacuum system. As the electrostatically deflected electron beam is focussed on a point or is swept along a line or across an area on a specimen, it generates (through the system electronics) an Auger-electron, secondary-electron, or absorbed-current image which is capable of being displayed on a TV monitor, storage oscilloscope monitor, or film exposed to a high-resolution display monitor. Beam scanning and display are synchronous.

The uv photon-stimulated exoelectron emission technique (see Figure 2) is particularly useful for detecting surface cracks in specimens before they can be seen by other techniques. Point, line, and area scans yield images observed on either the storage or display monitor (the very high scan rate required for TV is not possible).

The Scan Control Unit allows either manual or automatic control of the incident beam position. Manual control is through a single control stick. A digital X-Y position display allows one to return to the same precise point or line on a specimen at any time. In the automatic mode there is a choice of single or repetitive line scanning, single or repetitive entire-frame area scanning, or single partial-area scanning. Scanning is along a line in the X direction at some (constant) Y, followed (in area scans) by the next line at $Y + \Delta Y$. X and Y scanning increments are operator selectable. Scan rate is continuously adjustable from 1 to 2000 points per second. The scan rate can also be set through a Princeton Applied Research model 1112 electron counter in a pulse-counting configuration when data signals are low.

As an example of the operation of the Scan Control Unit, Figure 3a shows a SAM secondary electron image of a polished nickel sample with a 0.003-in.-diameter Chromel-Alumel thermocouple which is spot welded to the surface. Figure 3b shows a chromium Auger map (using the 529-eV Auger transition) of the same sample region. Figure 3c, a line deflection scan, shows the chromium Auger signal intensity across the sample.

The remainder of this report is organized as follows: Section II explains the front panel control functions. Section III describes the preprogrammed routines and their flowcharts. Section IV contains the circuit description and Appendix A is a program listing.

Figure 1. Block Diagram of Scanning Auger Microprobe Configuration
(Shows interconnection and signal paths between scan control unit and commercial electronics.)

Figure 2. Block Diagram of Exoelectron Emission Configuration
(Shows interconnection and signal path between scan control unit and commercial electronics.)

Figure 3a. SAM Secondary Electron Image of a Polished Nickel Sample With 0.003-in.-Diameter Chromel-Alumel Thermocouple Wire Spot-Welded to the Surface.

Figure 3b. Chromium Auger Map (using the 529-eV Auger transition) of the Same Sample Region as in Figure 3a. (Only one wire contains chromium)

Figure 3c. A Line Deflection Scan Shows the Chromium Auger Signal Intensity Across the Figure 3a Sample

II. Front-Panel Operating Controls

Figure 4 shows a photograph of the front panel of the Scan Control Unit. A description of each control function follows:

-Position Displays: The displays indicate the position of the X and Y output voltages applied to the beam control of the SAM or Exo Scanning system (which in turn maps into a position on the surface of the specimen). Each axis ranges from 000 to 999 with 500 representing the center of the scan. The position X=000, Y=000 corresponds to the upper left hand corner position (refer to Figure 5).

Increment Thumbwheel Switches: These controls are used to select the increments by which the X,Y positions are changed by the microprocessor during a scan. These are selectable from 1 to 99 for each coordinate. For example, in a frame scan mode a thumbwheel switch setting of X=03, Y=05 will cause the microprocessor first to increment the X position by threes, i.e., 000, 003, 006, etc. to 999, subsequently increment the Y position by 5, and then increment the X position as before. In the surface analysis applications described in this paper, the thumbwheel switch settings are determined by factors such as controlled beam diameter, desired picture resolution, and scan speed.

Reset: When pressed, the reset clears all random access memory, the program counter, index registers, the arithmetic logic unit (ALU), and output ports of the microprocessor. The reset operation is equivalent to turning on power to the Scan Control Unit.

Scan Rate: When the Count switch is up, this 10-turn knob allows for scan rates continuously adjustable from 1 to 2000 position changes per second. The scan rate potentiometer controls a voltage-to-frequency converter whose output pulses determine the time between successive additions of the X and Y output position. The scan rate and X-Y thumbwheel switch increment settings determine the sweep time of the X-Y frame or line scan.

Position Control (Joystick): The position control is used for manual control of the X-Y beam position. It is operable when the button JOY STK is depressed. Movement of the control stick to any position away from its normal position (in the center) causes the beam to move in the same direction with a speed proportional to the magnitude of the deflection. As soon as the control stick is released, it returns automatically to its normal position and beam movement ceases. As long as the control stick is held away from its normal position the beam will continue to move. For example, if the control stick is moved horizontally to the right and held, the beam will move horizontally to the right until it reaches X = 999. It will then reappear at X = 000 (Y still constant) and continue as before. If REP LINE, SNG LINE, or PART FRM is selected, the control stick is used to select the Y coordinate (prior to scanning).

Scan Mode Select: The scan mode push buttons and toggle switch are used by the operator to select the pre-programmed X-Y output control routine needed for a specific task. A description of each mode follows.

Figure 4. Front Panel of the Scan Control Unit

Figure 5. Course Frame Scan (X and Y Increments are Set at 37) With no Z-Axis Modulation. (Front panel display positions are labeled.)

Count: When this toggle switch is up, the scan rate is set by the SCAN RATE potentiometer. When it is down an external electron counter (PAR model 1112) controls the scan rate.

Repetitive Frame (REP FRM): After START is pushed, scanning is from (000,000) to (999,999) in increments determined by the thumbwheel switches and at a rate set by the scan rate potentiometer or the external electron counter. Entire frame scanning is repeated indefinitely until START is pushed again.

Single Frame (SNG FRM): Same as for REP FRM, except that scanning automatically terminates after one frame. A "beep" announces that the frame has completed. The single frame mode was designed particularly to facilitate taking pictures on the Tektronix Model 606A High Resolution Display Monitor using the Tektronix Model C52 camera.

Repetitive Line Scan (REP LINE): After START is pushed, scanning takes place along a line of constant Y in increments determined by the X thumbwheel switch and at a rate set by the scan rate potentiometer or the electron counter. The line scan is used to produce an Auger-electron, secondary-electron, absorbed-current, or exoelectron line deflection or line intensity profile across one Y value of a specimen on the display device. The particular Y value of interest is selected with the manual control stick. The line scan is repeated indefinitely until START is pushed again.

Single Line Scan (SNG LINE): Same as for REP LINE, except that scanning automatically terminates after one line. A "beep" announces that the line has completed. This mode was designed to facilitate taking pictures of line intensities or line deflection data across a line on a specimen.

Partial Frame (PART FRM): After START is pushed, scanning begins at a Y position selected with the manual control stick, in increments determined by the thumbwheel switches and at a scan rate set by the scan rate potentiometer or the electron counter. Scanning terminates at (999,999), at which time a "beep" sounds. This mode was designed to expedite slow scans when only a portion of the frame area is required.

III. Scan Mode Routines

Flowcharts for each routine are shown in Figures 6-12. A complete program listing is given in Appendix A. An individual description of each routine follows.

Repetitive Frame (Figure 6): The first action of this mode is to blank the Z axis of the display monitor so that a stationary beam does not produce a bright spot on the CRT phosphor. Next, the output is zeroed (beam positioned to the upper left-hand corner) and the processor waits for the START command. When the START button is depressed, the processor reads and stores the thumbwheel switch X and Y increment values. The Z axis is turned on, and the X and Y register positions are rezeroed and read out. The processor then waits for a pulse from the SCAN RATE control or, if the COUNT switch is down (refer to alternate flowchart path indicated by dashed

DASHED LINE INSERT INDICATES
ALTERNATE PATH USED FOR PRINCETON APPLIED
RESEARCH ELECTRON COUNTER WHEN COUNT SWITCH
IS DOWN

Figure 6. Repetitive Frame Flowchart. (Inset shows interrupt/mode select flowchart.)

Figure 7. Single Frame Flowchart

DASHED LINE INSERT INDICATES
ALTERNATE PATH USED FOR PRINCETON APPLIED
RESEARCH: ELECTRON COUNTER WHEN COUNT SWITCH
IS DOWN

Figure 8. Repetitive Line Flowchart

Figure 12. Y-Axis Only Joystick Flowchart

line in Figure 6), a "start counting" command is sent to the electron counter and the processor waits for the end-of-counting cycle before continuing. The X increment is then added to the previous X position and output to the digital-to-analog (D/A) converter. The processor waits for the next SCAN RATE or electron counter cycle and increments the X position again until finally X exceeds full scale position (999) at which time X is set to 000 and Y is set to the previous Y position plus the Y increment. This process continues until both X and Y exceed the full scale position (X=999, Y=999) completing the frame. X and Y are rezeroed and the procedure continues, repeating sequential frame scans.

If at some time during the frame scan the operator presses the START push button, the routine is interrupted, the rastering is halted and the X and Y positions are set to zero with the Z axis off, while the processor waits for further commands.

Single Frame (Figure 7): The Single Frame mode functions the same as the repetitive frame mode except after completion of one frame a momentary alarm is sounded to inform the operator the frame is complete. The X and Y output are zeroed, the Z axis is turned off, and the processor waits for another command.

Repetitive Line Scan (Figure 8): The display monitor Z axis is first turned off. The X position is zeroed and read into the D/A converter. The P bit is complemented: If it is set, the processor jumps to the Y-axis-only routine (Figure 12), in which the operator can manually control the Y axis with the joystick. If the P bit is not set, the processor zeros the X position register, reads and stores the X thumbwheel switch increments, and turns on the display monitor Z axis. Next the processor enters a loop, reading the X position registers and sending its value to the X D/A converter, waiting for the SCAN RATE or electron converter cycle, adding the X increment, and checking for carryover. If there is no carryover, the processor returns to the start of the loop; if there is a carryover, X is zeroed and the processor then returns to the start of the loop. The routine remains in this loop, with the beam scanning at the selected Y value, until the operator presses START, at which time the processor again complements the P bit, jumps to the Y-axis-only joystick routine, and waits for joystick action or another START command to resume scanning.

Single Line Scan (Figure 9): This mode scans across the selected Y position determined by the joystick at a rate determined by the SCAN RATE or electron counter cycle. It functions the same as Repetitive Line Scan except that when carryover occurs, the Z axis is turned off, the X position is zeroed, "beep" is sounded to inform the operator the scan is finished, and the processor goes to the Y-axis-only joystick mode and awaits joystick action or another command. This mode is used for photographing the data on the 606A High Resolution Display Monitor.

Partial Frame (Figure 10): Partial Frame functions the same as Single Frame except that an initial Y position other than 000 can be selected manually. When START is pressed, the selected initial Y position is stored. The routine then continues as in Single Frame. When the frame is complete, the previously selected Y position is restored and the processor waits for another Y start position to be selected or a START command.

Count Subroutine (dashed lines, Figures 6-10): When the Count toggle switch is down, the SCAN RATE cycle is by-passed and an alternate subroutine is used. Since the electron counter is used primarily in photon stimulated exoelectron studies, there is an initial 3-msec delay to account for the slow response of the mirrors which deflect the light beam. The processor then sends a pulse to the counter to start timing and accepting data signals. The processor loops until counter timing is completed, at which time the X position is incremented, etc.

Joystick: When the JOY-STK mode is selected, the output position is initialized to the center of the frame (500, 500). The processor next enters the fetch X rate subroutine and then the fetch Y subroutine. These subroutines (see flowchart, Figure 11) control the A/D joystick axis position conversions. They return with a flag set if the joystick X or Y axis magnitude is zero (indicating no joystick action by the operator for that axis) or with a flag cleared and a value in a register pair which represents the magnitude of the joystick position for that axis.

The processor continues the fetch X and Y rate loops until the operator moves the joystick. The processor interrogates each Z axis flag to see if one or both are clear, and for each axis delays for a time determined by the register pair value loaded in the fetch rate routine. When the time period elapses, the processor increments or decrements (depending on the polarity of the joystick position--see the Increment/Decrement subroutine) the axis position registers and outputs the position, fetches a new rate value, and continues sampling and using the joystick position to determine the direction and speed at which the X and Y positions are moved.

IV. Circuit Description

The scan control unit contains 9 printed wire cards, each is described briefly below.

Prolog 4417 (4040): Processor Card: This card includes the 4040 micro-processor, clock, external and power on reset circuitry, and RAM capacity to 1280 characters. It also has interrupt, data, address, and control lines.

ProLog 4418 PROM Card: Contains plug-in PROM capacity to 4096 words for program and look-up table storage.

Prolog 4413 TTL Input/Output Cards: One output and one input card is used. Each card provides field-selectable 8 output or 8 input ports.

D/A Converter X-Y Output Cards: Two separate cards (one for each axis) are used. The X-Y scan controlling voltages are provided by Burr-Brown DAC-80 12-bit BCD Digital-to-Analog Converters. The digital output position is loaded under program control to the X and Y output position ports. These ports drive the front panel X and Y position displays and the D/A

converters through D latches. The output of the unipolar D/A converters undergo offset and gain adjustment to provide a bipolar output compatible with the X and Y inputs of the SAM and exoelectron scanning system. The schematic drawing is shown in Figure 13.

Mode and Test Bit Selector Card: Through the use of an interrupt, the mode and test bit selector card provides fast response mode selection without continuous polling in the program routines for mode changes made by the operator.

The eight push buttons and one toggle switch located on the front panel provide 16 different possible mode selections to be made. The first 7 push button (from left to right) switches are mechanically tied together so only one can be selected at a time (see Figure 14). The eighth (START) is an independent momentary contact switch and may be pressed without affecting the first seven.

The eight push-button switches go to an 8-to-3-line priority encoder (74148). Even though one of the mode select switches is down, the "START" switch having the highest priority overrides the other selections and produces an interrupt when pressed. When "START" is released it produces another interrupt and allows the processor to read the selected mode.

The toggle switch enables the eight push button switches to double their function as mode selectors.

When a mode selection is made, the output of the 8-to-3-line priority encoder, along with the toggle switch, produces a 4-bit mode select address. This 4-bit address appears at the mode-select input port. It also appears at the "A" input of a 4-bit magnitude comparator (7485). Since the new mode address differs from the previous selection the A=B output of the digital comparator goes low producing an interrupt at INT* of the processor. The processor acknowledges this interrupt via INTA* and clocks the new mode address through the D latches (74175) to the "B" input of the comparator. "A" and "B" inputs of the comparator are now equal making A=B out high thus removing the processor interrupt. Once the interrupt is read and acknowledged the processor can then read and run the newly selected mode.

Through the use of a 16 to 1 multiplexer the mode address also selects the proper Test bit input needed for the various routines.

Joystick A/D Converter Card: The joystick A/D converter card is used to convert analog joystick voltages to digitized values representing a speed and direction vector. The joystick analog signals arrive at the converter card and undergo offset and gain adjustment to make them compatible with the full scale input of the Micro Networks Corporation Model MN5120 8-bit A/D converters (see Figure 15). Under processor program control the proper signals necessary

Figure 13. Schematic of D/A Converter Card

to convert the present position of the joystick are then sent to the A/D converter.

Only the five most significant bits of the A/D converter are used. The most significant bit represents the polarity, and the remaining four the magnitude. The four magnitude bits pass through exclusive OR gates and are complemented only if the sign of the polarity bit is negative. This complementing technique makes the magnitude of the joystick position always increase from 0000 independent of the polarity (see Figure 16). The polarity is used to increase or decrease the position value, and the magnitude is used to determine how fast the position is changed.

VCO/General Purpose Card: This card contains the Burr-Brown Model VFC32 voltage-to-frequency converter. Its output pulses, whose rate is controlled by the front panel SCAN RATE potentiometer, go to the Test bit of the microprocessor. This Test bit is read under program control and is used in several routines to determine the scan rate. This card also includes the interface between the processor output ports and both the Z-axis ON-OFF control (see Figure 17) and alarm used to signal the end of single scans.

		MSB			LSB	↑ Increasing Magnitude ↓
Center of Joystick Motion →	-9.961 →	0	0000	000 →	0	1111
	-5.000 →	0	1111	000 →	0	0000
	-4.961 →	1	0000	000 →	1	0000
	0 →	1	1111	111 →	1	1111
		Polar-ity	Magni-tude	Dropped	Polar-ity	Magni-tude
Output of A/D				Output of Exclusive OR		

Figure 16. 0 to -10 V Analog Input vs Logic Code Output for the Joystick MN5120 A/D Converter

Figure 15. Schematic of A/D Converter Card

to convert the present position of the joystick are then sent to the A/D converter.

Only the five most significant bits of the A/D converter are used. The most significant bit represents the polarity, and the remaining four the magnitude. The four magnitude bits pass through exclusive OR gates and are complemented only if the sign of the polarity bit is negative. This complementing technique makes the magnitude of the joystick position always increase from 0000 independent of the polarity (see Figure 16). The polarity is used to increase or decrease the position value, and the magnitude is used to determine how fast the position is changed.

VCO/General Purpose Card: This card contains the Burr-Brown Model VFC32 voltage-to-frequency converter. Its output pulses, whose rate is controlled by the front panel SCAN RATE potentiometer, go to the Test bit of the microprocessor. This Test bit is read under program control and is used in several routines to determine the scan rate. This card also includes the interface between the processor output ports and both the Z-axis ON-OFF control (see Figure 17) and alarm used to signal the end of single scans.

	MSB		LSB			
Center of Joystick Motion →	-9.961 →	0 0000	000 →	0 1111	↑ Increasing Magnitude ↓	
	-5.000 →	0 1111	000 →	0 0000		
	-4.961 →	1 0000	000 →	1 0000		
	0 →	1 1111	111 →	1 1111		
	Polar-ity	Magni-tude	Dropped	Polar-ity	Magni-tude	
	Output of A/D			Output of Exclusive OR		

Figure 16. 0 to -10 V Analog Input vs Logic Code Output for the Joystick MN5120 A/D Converter

APPENDIX A

PROGRAM LISTING FOR THE SCAN RATE CONTROL UNIT

•TITLE SCAN CONTROL UNIT

```

      NOP
      JMS      INTZ      INITIALIZE
INTEN: JMS      RESTR
      SKP
RESTH: DBS
DEGI:  SBU
      FIM      1,7,0    ISELECT MODE SW POINT
      SRC      1
      ROR
      XCH      B        IREAD MODE SW
      JMS      DELAY    ISTORE READING
      FIM      0,SUBHT  IADD MODE+MODE
      LD       0
      CLC
      ADD      1
      XCH      1
      TCC
      ADD      0
      XCH      0
      LD       0
      CLC
      ADD      1
      XCH      1
      TCC
      ADD      0
      XCH      0
      JIN      0        IJUMP TO SELECTED ROUTINE
SUBRT: JUN      REPRF    I0 REPETITIVE FRAME
      JUN      SNGFR    I1 SINGLE FRAME
      JUN      REPLN    I2 REPETITIVE LINE
      JUN      SNGLN    I3 SINGLE LINE
      JUN      PARTFR   I4 PART SINGLE FRAME
      JUN      JOYSK    I5 JOYSTICK
      JUN      DEG      I6 FUTURE USE
      JUN      DEG      I7 START
      JUN      DREPRF   I8 DUAL/CHOP REP FRAME
      JUN      DSNGFR   I9 DUAL/CHOP SINGLE FRAME
      JUN      DREPLN   I10 DUAL/CHOP REP LINE
      JUN      DSNGLN   I11 DUAL/CHOP SINGLE LINE
      JUN      DPRIFR   I12 DUAL/CHOP PART SINGLE FRAME
      JUN      JOYSK    I13 JOYSTICK
      JUN      DEG      I14 FUTURE USE
      JUN      DEG      I15 START
      .PAGE
REPRF: JMS      ZOFF     ITURN OFF SCOPE Z-AXIS
      JMS      ZENUX    IINITIALIZE POSITION REGS
      JMS      ZENY
      JMS      OUTY     IOUTPUT Y
      JMS      OUTX     IOUTPUT X
      JMS      START
      JMS      TWS      IREAD TWS
      JMS      ZON      ITURN ON SCOPE Z-AXIS

```

```

INIT:  JMS  ZERUX  ISET X AND Y= 0
        JMS  ZERUY
OXY:   JMS  OUTY  IOUTPUT Y
OTX:   JMS  OUTX  IOUTPUT X
        JMS  TEST  IWAIT FOR RATE PULSE
        JMS  ADDX  IADD X INC TO X, RETURNS W/ OVERFLOW STATUS
        JCN  CO,UTX IADD X AGAIN IF NO CARRY
        JMS  ZERUX ISET X=0
        JMS  ADDY  IADD Y INC TO Y, RETURNS WITH OVERFLOW STATUS
        JCN  C1,INIT
        JUN  OTY

```

```

SNGFN: JMS  ZOFF  ITURN OFF SCOPE Z-AXIS
        JMS  ZERUX IINITILIZE POSITION MEGS
        JMS  ZERUY
        JMS  OUTY  IOUTPUT Y
        JMS  OUTX  IOUTPUT X

```

```

        JMS  START
        JMS  RTWS  IREAD TWS
        JMS  ZON  ITURN ON SCOPE Z-AXIS
OXY1:  JMS  OUTY  IOUTPUT Y
OUX1:  JMS  OUTX  IOUTPUT X
        JMS  TEST  IWAIT FOR RATE PULSE
        JMS  ADDX  IADD X INC TO X, RETURN WITH CARRY
        JCN  CO,OXY1 IADD X AGAIN IF NO CARRY
        JMS  ZERUX ISET X POSITION TO 0
        JMS  ADDY  IADD Y INC TO Y, RETURN WITH CARRY
        JCN  CO,OXY1 IADD Y AGAIN IF NO CARRY
        JMS  ZOFF  ITURN OFF SCOPE Z-AXIS
        JMS  ZERUX ISET X AND Y=0
        JMS  ZERUY
        JMS  OUTY  IOUTPUT Y
        JMS  OUTX  IOUTPUT X
        JMS  BEEP
        JUN  SNGFN IRETURNS TO TOP, TOGGLES "START"&"STOPS"

```

```

REPLN: JMS  ZOFF  ITURN OFF SCOPE Z-AXIS
        JMS  PAGE
        JMS  ZERUX IZERO X POSITION MEG
        JMS  OUTX
        JMS  COMP  ICOMPLEMENT P FLAG-RETURN OR JUMP TO YJOY
        JMS  ZERUX IINITILIZE X POSITION
        JMS  RTWS  IREAD TWS
        JMS  ZON  ITURN ON SCOPE Z-AXIS
NCX:   JMS  OUTX  IOUTPUT X
        JMS  TEST  IWAIT FOR RATE PULSE
        JMS  ADDX  IADD X INC TO X, RETURN WITH CARRY
        JCN  CO,NCX
        JMS  ZERUX IZERO X TO START AGAIN
        JUN  NCX

```

```

SNGLN: JMS  ZOFF  ITURN OFF SCOPE Z-AXIS
        JMS  ZERUX
        JMS  OUTX

```

```

      JMS      COMP      ;COMPLEMENTS P FLAG-RETURN OR JUMP TO YJOY
      JMS      ZEROX     ;INITIALIZE X POSITION
      JMS      RTNS
      JMS      ZON       ;TURN ON SCOPE Z-AXIS
NUCX:  JMS      OUTX
      JMS      TEST      ;WAIT FOR RATE PULSE
      JMS      ADDA
      JCN      CO,NUCA
      JMS      ZOFF      ;TURN OFF SCOPE Z-AXIS
      JMS      ZEROX
      JMS      OUTX
      JMS      BEEP
      JCN      SNGLN     ;RETURNS TO TOP,TOGGLES "COMP" GOES TO "YJOY"
;
PARTPR: JMS      ZOFF
      JMS      ZEROX
      JMS      OUTX
      JMS      COMP      ;COMPLEMENTS P FLAG-RETURN OR JUMP TO YJOY
      JMS      STORY
      JMS      RTNS
      JMS      ZON
YIUT:  JMS      OUTY
XIUT:  JMS      OUTX
      JMS      TEST
      JMS      ADDA
      JCN      CO,XIUT
      JMS      ZEROX
      JMS      ADDY
      JCN      CO,YIUT
      .PAGE
      JMS      ZOFF
      JMS      ZEROX
      JMS      KESTRY
      JMS      OUTA
      JMS      OUTY
      JMS      BEEP
      JCN      PARTER
;
OREPPR: JMS      ZOFF
      JMS      ZEROX     ;REPETITIVE FRAME,DUAL/CHOP,INTERFACES
      JMS      ZERY      ;WITH PAK PHOTON COUNTER
      JMS      OUTY      ;OUTPUT Y
      JMS      OUTX      ;OUTPUT X
      JMS      START
      JMS      RTNS      ;READ X AND Y INCREMENTS FROM TWS
      JMS      ZON       ;TURN ON SCOPE Z-AXIS
ORGIN:  JMS      ZEROX     ;SET X AND Y =0
      JMS      ZERY
      JMS      OUTY      ;OUTPUT Y
      JMS      OUTX      ;OUTPUT X
      JMS      DELAY     ;DELAY 3 MSEC FOR MIRROR RESPONSE
      JMS      CONV      ;SEND COUNT CYCLE START AND WAIT FOR END
      JMS      ADDA
      JCN      CO,OUX     ;COME BACK WITH CARRY
                        ;CX=1?

```

```

JMS ZER0X ;SET X=0
JMS ADDY ;COME BACK WITH CARRY
JCN C1,ORGIN
JUN OUTY

;
DSNGPR: JMS ZOFF
JMS ZER0X ;INIT POSITION REG
JMS ZER0Y
JMS OUTY ;OUTPUT Y
JMS OUTX ;OUTPUT X
JMS START
JMS RTNS ;READ TWS
JMS ZON ;TURN ON SCOPE Z-AXIS
YOUT: JMS OUTY ;OUTPUT Y
XOUT: JMS OUTX ;OUTPUT X
JMS DELAY ;DELAY 5 MSEC FOR MINROM RESPONSE
JMS CONV ;START COUNTEN AND RETURN WHEN DONE
JMS ADDX ;ADD X INC TO X, RETURN WITH CARRY IF OVER FLO
JCN C0,XOUT ;ADD X AGAIN IF NO CARRY
JMS ZER0X ;SET X=0
JMS ADDY ;ADD Y INC TO Y, RETURN WITH CARRY IF OVER FL
;PAGE
JCN C0,YOUT ;ADD Y WHEN CARRY = 0
JMS ZOFF ;TURN OFF SCOPE Z-AXIS
JMS ZER0X
JMS ZER0Y
JMS OUTY ;OUTPUT Y
JMS OUTX ;OUTPUT X
JMS BEEP
JUN DSNGPR ;RETURNS TO TOP, TUGGLES "START" & STOPS

;
DKEPLN: JMS ZOFF
JMS ZER0X
JMS OUTX
JMS COMP
JMS ZER0X
JMS RTNS
JMS ZON
CNA: JMS OUTX
JMS DELAY
JMS CONV
JMS ADDX
JCN C0,CNX
JMS ZER0X
JUN CNX

;
DSNGLN: JMS ZOFF
JMS ZER0X
JMS OUTX
JMS COMP
JMS ZER0X
JMS RTNS
JMS ZON

```

CXN: JMS OUTX
 JMS DELAY
 JMS CONV
 JMS ADDX
 JCN CB,CXN
 JMS ZOFF
 JMS ZEROX
 JMS OUTX
 JMS BEEP
 JCN SNGLN

OPRTER: JMS ZOFF
 JMS ZEROX
 JMS OUTX
 .PAGE

JMS COMP
 JMS STORY
 JMS RIMS
 JMS ZUN
 Y2UT: JMS OUTY
 X2UT: JMS OUTX
 JMS DELAY
 JMS CONV
 JMS ADDX
 JCN CB,X2UT
 JMS ZEROX
 JMS ADDY
 JCN CB,Y2UT
 JMS ZOFF
 JMS ZEROX
 JMS RENTRY
 JMS OUTX
 JMS OUTY
 JMS BEEP
 JCN OPRTER

ADDX: CLB JRO,R1 AND R2 + R6 AND R7

LD 6
 ADD 0
 UAA 0
 XCH 0
 LD 7
 ADD 1
 UAA 1
 XCH 1
 TCC 1
 ADD 2
 UAA 2
 XCH 2
 DBL 0

JRETURNS WITH C=1 IF OVERFLOW

ADDY: CLB JRS,R4 AND R5 + R8 AND R9
 LD 8
 ADD 5

	DAA		
	XCH	3	
	LD	9.	
	ADU	4	
	UAA		
	XCH	4	
	.PAGE		
	TCC		
	ADD	5	
	DAA		
	XCH	5	
	BBL	0	

IRETURNS WITH C=1 IF OVERFLOW

1	SUBX:	STC	
		ICS	
		SUB	6
		CMC	
		ADU	0
		UAA	
		XCH	0
		ICS	
		SUB	7
		CMC	
		ADU	1
		UAA	
		XCH	1
		ICS	
		ADU	2
		UAA	
		XCH	2
		BBL	0

IRETURNS WITH C=0 IF NEG NUM.

1	SUBY:	STC	
		ICS	
		SUB	8.
		CMC	
		ADU	3
		UAA	
		XCH	3
		ICS	
		SUB	4.
		CMC	
		ADU	4
		UAA	
		XCH	4
		ICS	
		ADU	5
		UAA	
		XCH	5
		BBL	0

IRETURNS WITH C=0 IF NEG NUM.

1	OUTX:	FIN	7,0,0	1
		.PAGE		
		SKU	7	

10UTPUTS REG 0,1,2 TO PORTS 0,1,2

LD	0	
WRR		
INC	E	
SRC	7	
LD	1	
WRR		
INC	E	
SRC	7	
LD	2	
WRR		
FIM	7,7,0	IX STROBE
SRC	7	
LDM	1	10001
WRR		
LDM	0	10000
WRR		
DBL	0	

OUTY: FIM 7,3,0 10UTPUTS REG 3,4,5 TO PORTS 3,4,5

SRC	7	
LD	3	
WRR		
INC	E	
SRC	7	
LD	4	
WRR		
INC	E	
SRC	7	
LD	5	
WRR		
FIM	7,7,0	IY STROBE
SRC	7	
LDM	2	10010
WRR		
LDM	0	10000
WRR		
DBL	0	

RTWS: FIM 7,0,0 1LOAD X AND Y FROM TWS
 ITO REG 6,7 AND 8,9

SRC	7	
RDR		
XCH	6	
INC	E	
SRL	7	
PAGE		
RDR		
XCH	7	
INC	E	
SRC	7	
RDR		
XCH	8	
INC	E	
SRC	7	
RDR		
XCH	9	


```

1      BBL          0
2
3      START:  FIM      1,0,0
4              SKC      7
5              RDB
6              CMA
7              WNR
8
9      SELF:    JCN      A1,SELF
10             BBL      0
11
12     ZEROX:   FIM      0,0,0      ISET X POSITION REG TO 0'S
13             CLB
14             XCH      2
15             BBL      0
16
17     ZEROY:   FIM      2,0,0      ISET Y POSITION REG TO 0'S
18             CLB
19             XCH      3
20             BBL      0
21
22     CONV:    DIN
23             FIM      7,0,0      ISEND START TO PHOTON COUNTER
24             SKC      7
25             LUM      F          I1111
26             WNR
27             LUM      0          I1101
28             WNR
29             LUM      F          I1111
30             WNR
31
32     PRGMD:    EIN      IENABLE INTERRUPT DURING COUNT CYCLE
33             JCN      TO,PRGMD    ILOOP UNTIL END OF COUNT CYCLE
34             DIN
35             LUM      0          I1011 SET PRG*
36             WNR
37
38     DONE:    JCN      I1,DONE IPRGMD RETURNED TO 0??
39             .PAGE
40             LUM      F          I1111 CLEAR PRG*
41             WNR
42             EIN
43             BBL      0
44
45     COMP:    FIM      7,0,0      ICOMPLEMENT P (PROGRAM SELECT FLAG)
46             SKC      7
47             RUS
48             CMA
49             WKS
50             JCN      A0,RETURN    IRETURN TO PROGRAM OR JUMP TO YJOY
51             JUN
52             BBL      0
53
54     INTZ:    SBW      ISELECT REG BANK 0
55             FIM      7,0,0      IINITIALIZE PHOTON COUNTER,JOYSTICK A/D
56             SKC      7          ICONVERTER & CHOP OUT- OUTPUT 6
57             LUM      F          I1111

```

WRN
 FIM 2,0,5
 FIM 1,0,0
 FIM 0,0,0
 EIN
 DBL 0

11-AOSTC,2-PRTG,4-PHOTON COUNTER START,8- CHOP OUT
 INITIALIZE OUTPUT REGS FOR LINE SCAN PROGRAM

ENABLE INTERRUPT

STORY: FIM 7,1,0
 SRC 7

STORES Y POSITION REGS IN RAM

LD 3

WRN

1Y 1'S

LD 4

1Y 10'S

WRN

LD 5

1Y 100'S

WRN

DBL 0

RESTY: FIM 7,1,0

RESTORES Y POSITION REGS FROM RAM

SRC 7

KUD

1Y 1'S

XCM 3

KU1

1Y 10'S

XCM 4

KU2

1Y 100'S

XCM 5

DBL 0

TEST: .PAGE

HERE: JCN

T0,TEST

DBL

T1,HERE

0

BEEP: FIM 7,1,0

SRC 7

LUM 4

10100

WRN

JMS

DELAY

JMS

DELAY

FIM 7,7,0

LUM 0

WRN

DBL 0

ZOFF: FIM 7,7,0

SRC 7

LUM 8

10000

WRN

DBL 0

ZON: FIM 7,7,0

SRC 7

LUM 4

10000

WRN

DBL 0

```

/
OLAY1: FIM 7,7,7
COM: 1SZ E,COM
      1SZ F,COM
      BBL 0

/
DELAY: FIM 7,7,7
      FIM 6,7,8.
UAG: 1SZ C,UAG
     1SZ D,UAG
     1SZ E,UAG
     BBL 0

/
.NXTMG
JOYSK: FIM 2,0,5 ;JOYSK AND YJOY SHOULD RESIDE ON 1 FROM
      FIM 1,5,0 ;INITIALIZE X AND Y POSITION REGS
      FIM 0,0,0
      JMS OUTX ;OUTPUT X REGS
      JMS OUTY ;OUTPUT Y REGS
      .PAGE
NEPT: JMS FETX ;FETCH X RATE FROM JOYSTICK
      JMS FETY ;FETCH Y RATE FROM JOYSTICK
XYFS: SBO ;X AND Y FLAGS SET?
      FIM 7,0,0
      SRC 7
      RDI ;X FLAG
      JCN A0,XFS ;JUMP TO XFS IF FLAG NOT SET
      RDI ;Y FLAG
      JCN A1,NEPT ;JUMP TO NEPT BECAUSE X AND Y ARE SET
XFS: RDI ;X FLAG
      JCN A0,CONTX
      JMS FETX
      JUN STARY
CONTX: SBI
      1SZ 3,STARY ;PI*
      1SZ 2,STARY ;PI*
      SBO
      JMS IUX ;INC OR DEC X POSITION REGS
      JMS OUTX ;OUTPUT X POSITION
      JMS FETX ;FETCH X RATE FROM JOYSTICK
STARY: SBO
      FIM 7,0,0
      SRC 7
      RDI ;Y FLAG
      JCN A0,CONTY
      JMS FETY
      JUN XYFS
CONTY: SBI
      1SZ 5,XYFS
      1SZ 4,XYFS
      SBO
      JMS IDY
      JMS OUTY
      JMS FETY
      JUN XYFS

```

```

/
PETAN: JMS      ADSTC    /SEND STC,READ&STORE POLARITIES,WAIT FOR EOC
        FIM      7,4,0    /READ X INPUT 4
        SRC      7
        ROR
        JCN      A0,SXF    /SET X FLAG IF X=0
        SBI
        FIM      0,TABLE /P0'
        CLC
        ADD      1        /ADD X TO TABLE
        .PAGE
        XCH      1
        TCC
        ADD      0
        XCH      0
        FIM      7,0,0    /CLEAR X FLAG
        SRC      7
        LDM      0
        WRI
        FIM      1        /STORE TABLE VALUE IN P1'
        SBO
        DBL      0
        SYF:     FIM      7,0,0    /SET X FLAG
        SRC      7
        LDM      F
        WRI
        DBL      0

/
PETYN: JMS      ADSTC    /SEND STC,READ&STORE POLARITIES,WAIT FOR EOC
        FIM      7,5,0    /READ Y INPUT 5
        SRC      7
        ROR
        JCN      A0,SYF    /SET Y FLAG IF Y=0
        SBI
        FIM      0,TABLE /P0'
        CLC
        ADD      1
        XCH      1
        TCC
        ADD      0
        XCH      0
        FIM      7,0,0    /CLEAR Y FLAG
        SRC      7
        LDM      0
        WRI
        FIM      2        /STORE TABLE VALUE IN P2'
        SBO
        DBL      0
        SYF:     FIM      7,0,0    /SET Y FLAG
        SRC      7
        LDM      F
        WRI
        DBL      0
        ADSIC:   FIM      7,6,0    /SEND START CONVERSION TO A/D'S OUTPUT 6-1
        SRC      7

```

```

LDM F 71111
.PAGE
NRR
LDM E 71110
NRR
LDM F 71111
NRR
FIM 7,6,4 7REAL6STONE POLARITYSEDC
SNC 7
ADDEUC: NOR
ACH 0
LU 0
ACH 7 7EUC??
LDM C
AN/
CLC
ADD F
JCN A1,ADDEUC
BRL 0

;
IDY: LD 0 7X POSITIVE OR NEGATIVE?
ACH 7
LDM 1
AN/
JCN A1,PLUSA;X POSITIVE ADD,X NEGATIVE SUB
FIM 3,1,0 7LOAD 1 TO X INC REG TO SUB
JMS SUBA
DBL 0
PLUSA: FIM 3,1,0 7LOAD 1 TO X INC REG TO ADD
JMS ADDX
DBL 0

;
IDY: LD 0 7Y POSITIVE OR NEGATIVE?
ACH 7
LDM 2
AN/
JCN A1,PLUSY;Y POSITIVE ADD,Y NEGATIVE SUB
FIM 4,1,0 7LOAD 1 TO Y INC REG TO SUB
JMS SUBY
DBL 0
PLUSY: FIM 4,1,0 7LOAD 1 TO Y INC REG TO ADD
JMS ADDY
DBL 0

;
YJOY: JMS PETR 7JOYSTICK FOR Y AXIS ONLY
SBC
FIM 7,0,0 7Y FLAG SET
.PAGE
SNC 7
NDE
JCN A1,YJOY 7Y FLAG SET GO TO YJOY
YF: JMS
SBI 0LAY1

```

1SZ 5,YF
 1SZ 4,YF
 500
 JMS IOY
 JMS OUTY
 JUN YJOY

TABLE:

.BYTE	000	7NOT USED
.BYTE	000	7R=1
.BYTE	200	7R=2
.BYTE	220	7R=3
.BYTE	257	7R=4
.BYTE	312	7R=5
.BYTE	330	7R=6
.BYTE	337	7R=7
.BYTE	353	7R=8
.BYTE	361	7R=9
.BYTE	365	7R=10
.BYTE	370	7R=11
.BYTE	373	7R=12
.BYTE	375	7R=13
.BYTE	376	7R=14
.BYTE	377	7R=15

.END

.PAGE

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