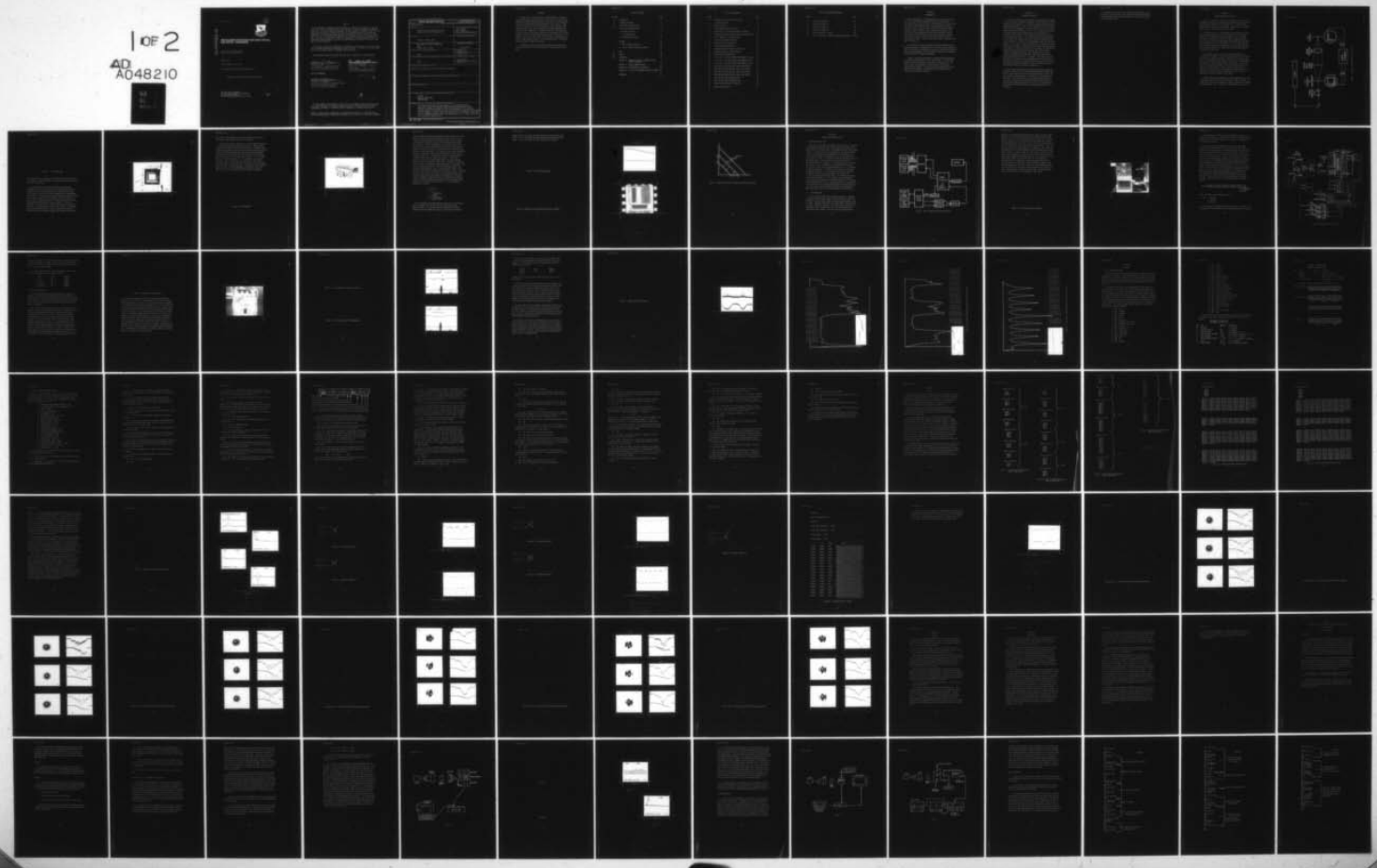
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SPECKLEGRAM DATA REDUCTION USING OPTICAL AND DIGITAL TECHNIQUES

Electro-Optics Technology Branch
Electronic Technology Division

November 1977

TECHNICAL REPORT AFAL-TR-77-203

Final Report for Period May 1974 to September 1976

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Charles R. Lane

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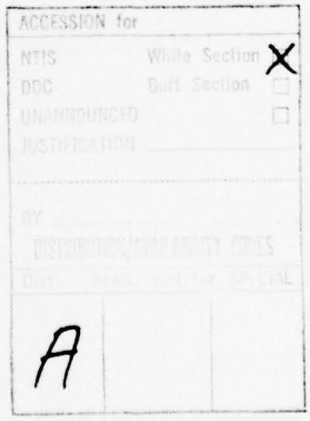
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report describes the development of a specklegram data reduction system for automatically analyzing specklegram output. The basic design incorporates a PDP-11 minicomputer as an overall control center with various optical and electronic components interfaced to the computer. Typical data runs yielded 1-2 second turn around time for each specklegram data point and approximately 1-2 fringe resolution over a specific output halo.

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FOREWORD

The major goal of this program is the development of a breadboard in-house laboratory measurement system. In pursuing this objective many experimental results were obtained which shed light on some improvements that could be made toward further development of such a system. These results are presented in this report along with some tried designs and proposed designs. The system was designed to readout specklegram data and display the information in a readable format with an automated optical-digital set-up, thus reducing the analysis time greatly over existing methods. The overall system design and end results are discussed in this report, which will be a final report to the Air Force Flight Dynamics Laboratory under project 1367-02-12. Mr. Gene Maddux and Dr. Frank Adams were the scientific contacts from AFFDL.

I would like to thank Dave Flannery of AFAL/DHO-2 and Chuck Skinn of System Research Lab. for their assistance in pursuing these Program goals.

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SECTION I

INTRODUCTION

Near the beginning of FY74 Gene Maddux and Dr. Frank Adams of the Air Force Flight Dynamics Laboratory visited Tom Williamson and Dick Lane of the Air Force Avionics Laboratory seeking a feasible method for analyzing specklegram data with a semi-automated optical data processing system. A set-up, made up of existing in-house equipment including a desk calculator, digital voltmeter A/D converter, and a motor driven scanning detector, was constructed immediately in the Laboratory of Bldg 22B and after several test conclusions indicated that an optical processing system could be fabricated to meet the requirements of AFFDL. (A copy of the initial study is attached at the end of the report.)

In January 1974 Dr. Adams requested and obtained $24,000 of AFFDL Laboratory Director's Funding (LDF-74-1) to finance a joint program with AFAL for developing an automated data readout and reduction technique for laser speckle photography. AFFDL funding was used to procure equipment and AFAL provided the engineering manpower.

A plane of attack was then begun for which the following equipment was ordered at the beginning of FY75: Minicomputer, X-Y Translation Stage, 2 dimensional detector, A/D convertor, clocking circuit. The final delivery of equipment was received in May of 1975 and the fabrication was underway. This report gives the demonstration of the brassboard optical-digital system fabrication for performing data reduction of specklegram recordings.

SECTION II

STATEMENT OF PROBLEM

In the early 1970s several researchers in the United Kingdom showed that small in-plane displacement measurements could be made by using the inherent speckle properties of laser light and employing double exposure photography (References 1 to 6). Further development of this technique, called "Speckle Photography," has been pursued at the Air Force Flight Dynamics Laboratory (References 7 to 11). It was found that the speckle distribution change during stressed and unstressed conditions on specified surfaces gives a direct indication of the amount of surface motion present under stress. This recording process is performed with a single beam laser imaging system, and as many as 40,000 data points can be recorded on a 4 inch by 5 inch photographic plate with one double exposure. At this point it was realized that to use the high resolution recording to its utmost, a readout system had to be established to speed up the method for extracting the data in its entirety. The laboratory readout method used originally consisted of projecting the output fringes on a ground glass screen, then orienting a slow scanning detector orthogonal to the fringe lines, and scanning the detector while plotting directly onto an x-y recorder. This process has to be performed for each data point on a specklegram plate with the addition of one accurate method for scanning from data point to data point. The average point to point recording time could be as large as 5 minutes, thus requiring 140 hours to analyze a single plate.

Careful study has shown that to establish the speckle photography method as a feasible tool for performing non-destructive testing, the point to point data collection time, including the point to point scan time, must be 1 second or faster. At these rates, the maximum time required to read a specklegram plate at maximum resolution would be 1.5 hours. A faster time can be achieved with some modifications to the existing brassboard described in this report. The modifications are discussed in the section entitled "Conclusions with Alternate Solutions."

The problem of data reduction of specklegram output appears to be solvable by a digital-optical system, and with further experimentation, a time improvement and resolution improvement are realizable over the initial brassboard setup.

SECTION III

DESCRIPTION OF OPTICAL SETUP

Figure 1 is a graphical illustration of the optical section of the brassboard system used for reading out specklegram data provided by the Flight Dynamics Laboratory for experimental use. A Spectra Physics Model 124-A He-Ne Laser with 15 milliwatts of power and a 1 millimeter diameter beam is the light source for the system.

Two lenses with a 4 to 1 focal length ratio are required to reduce the laser beam diameter to its optimal operating size. Microscope objectives of 20 power and 5 power were chosen for this experiment. The lenses are oriented such that the distances between them equals $f_{20} + f_5$, thus the 1 mm collimated beam emerging from the laser enters the specklegram plate at .25 millimeters. A .25 millimeter beam was chosen because experimentation showed that a smaller beam would create large secondary speckle and a larger beam would reduce the inherent resolution of a data plate.

The specklegram plate is held in a plate holder attached to a 5 inch by 5 inch Yosemite x-y translation stage (Figure 2). The stage, with .0001 inch stepping resolution, mechanically positions the data plate to each new data point position, with two Slo-Syn stepping motors tied directly to the worm gear mechanism on the stage. Each step of rotation by the motors represents a .001 inch lateral motion of the stage and is controlled by the PDP-11 central processor tied to a specially built electronic circuit constructed in-house by AFAL. The details of the central processor software and control circuit are described in two later sections of this report.

A ground glass plate, ground with 10 micron Carborundum, serves as a projection screen from which the specklegram fringes are imaged. The ground glass screen can be vibrated as a means of reducing the unwanted secondary speckle noise. An opaque 1/2 inch diameter spot is placed

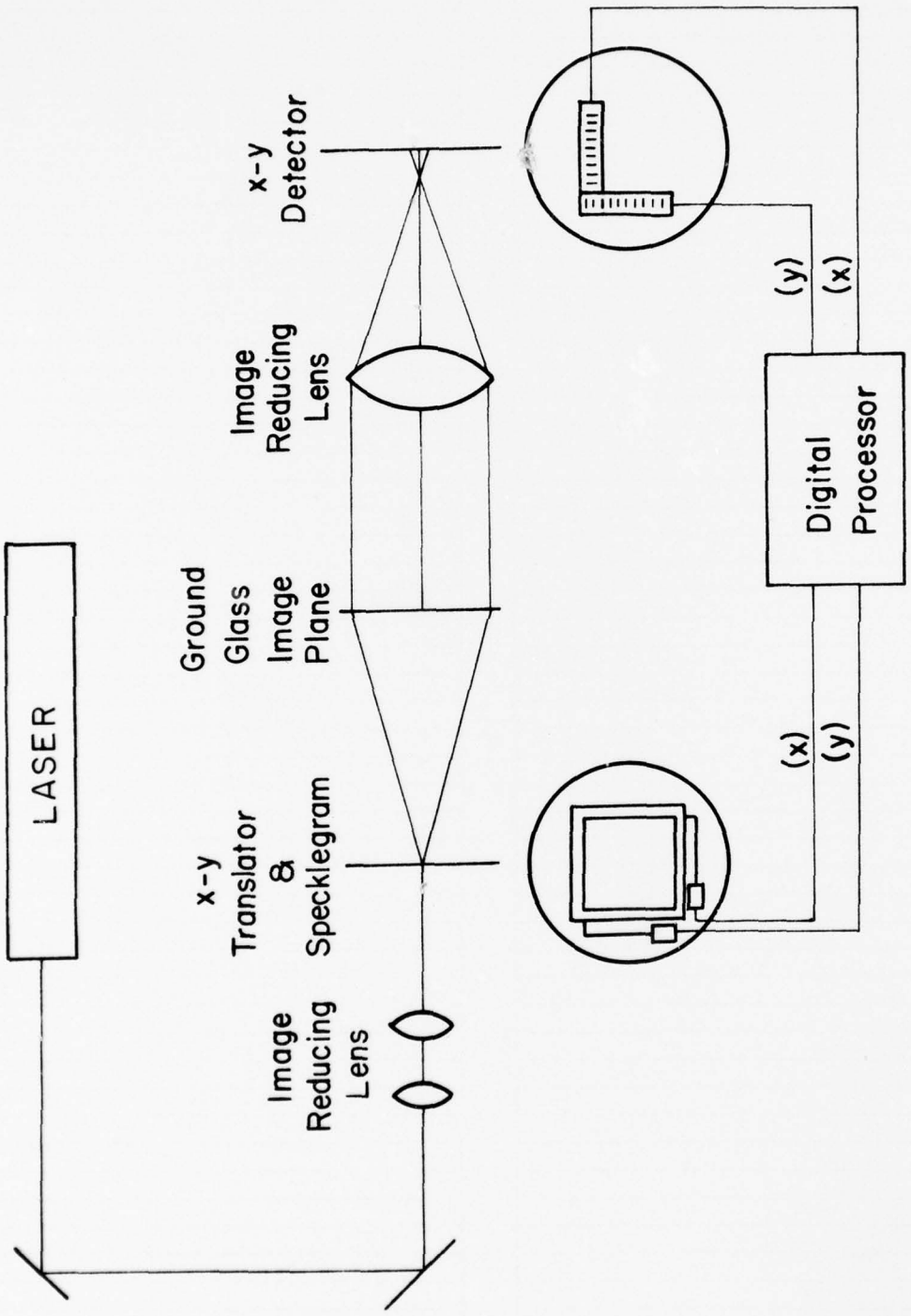


Figure 1. Graphical Description of Optical Setup

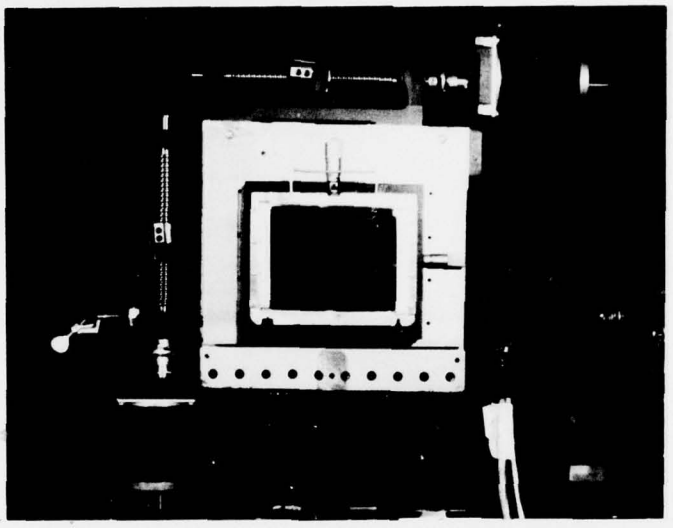


Figure 2. X-Y Stepping Stage

on the ground glass at the center of the speckle pattern canceling the D.C. component of the readout beam, in order to avoid detector saturation at the D.C. imaging point.

The primary speckle size used in constructing a specklegram determines the projection cone angle of the fringe pattern; thus as a ground glass screen is moved further from a specklegram the fringe size increases as the area of a plane, subtending a cone perpendicular to the cone axis. When sizing the secondary speckle to match the ground glass screen consistency, a hole of about six inches in diameter is optimal; thus an image reducing lens is required to project the proper fringe size onto the orthogonal detector assembly. A vivitar 28 Millimeter focal length lens is used for the brassboard system being described. Since specklegrams, as stress analysis tools, are produced with different imaging systems, varying reconstruction cone angles dictate that the optical geometry between the specklegram and detector

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FIG-2

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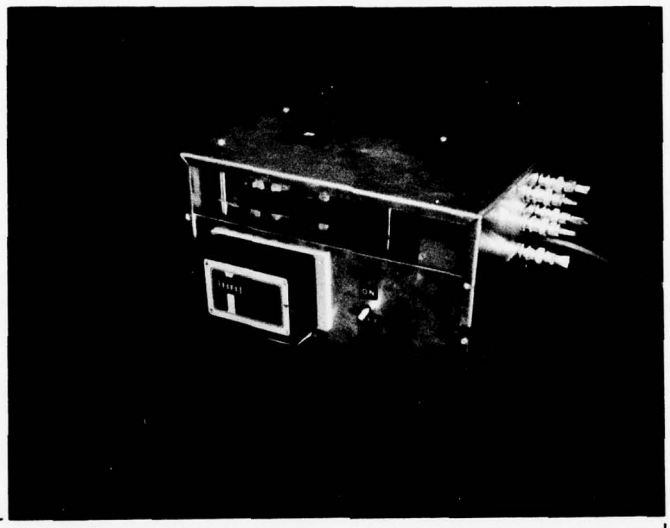
be variable. The ground glass screen and the detector assembly are positioned by two micrometer controlled slide stages.

Fulfilling the need for a medium to pick up the imaged fringe data is a custom built detector system consisting of two linear detector arrays and associated operating circuits (Figure 3). Appendix V gives a detailed description of the specification and operating procedures of a Reticon Corporation Detector System similar to the RL-64 WP Model incorporated in the optical setup. The circuitry for operating the detector consists of five main electronic sections: 1.) - 2.) Output drivers; 3.) Clocking circuit; 4.) - 5.) Sample and hold circuits. The output drivers, required for each linear array, simply amplify the output signal from each detector in the array to a 3 volt maximum during the light saturation operation. The amount of light required to reach saturation is obviously dependent on the length of time the detector is receiving light and, since the detectors integrated



Figure 3. Reticon Detector

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FIG-3

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all the incident light from one reading to the next, the scan time from detector to detector determines the optical saturation level. The clocking circuit which controls both detectors has a direct influence on the detector to detector read time. A more detailed description of the electronic circuit sequencing will be discussed in Section IV, 3. Circuits 4 and 5 are merely sample and hold electronics that read the output from the driver circuits and retain them for a time period long enough for an external readout. For instance, if the signal illustrated in Figure 4b were input to the sample and hold board it would emerge as shown in Figure 4a. In other words, a series of spiked pulses is transformed into a series of square wave pulses. At this point attention will be given to the configuration of the linear detector element relative to the optical fringe output. Figure 5 is a magnified view of the two linear detector arrays configured in a chip holder. The particular geometry chosen will allow the specklegram fringes to be projected onto the detector array at any angle but will make it still possible to determine the orthogonal spacing between fringes. By looking at Figure 6, we see that if the x and y axis represent the two linear detector arrays and the three skewed lines represent the fringe data, a simple trigonometric sequence allows us to determine the orthogonal spacing (d) and the fringe angle placement (θ) from the fringe spacing which appears on the detector arrays (x and y). The trigonometric sequence is as follows:

$$\theta = \tan^{-1} y/x$$

$$d = x \sin \theta$$

$$d = x \sin (\tan^{-1} y/x)$$

$$d = xy/\sqrt{y^2+x^2}$$

$$d = x /\sqrt{(1+(x^2/y^2))}$$

Thus, by employing two linear detector arrays set in a right angle field, a complete set of useful data can be extracted from any specklegram plate. The original detectors purchased from Reticon Corporation were 64 elements long, and since a maximum of 20 fringes

would ever enter the system, the Sampling Theory says 64 elements would suffice. But, it has been determined through experimentation that this number is too low to perform the job as accurately as required.

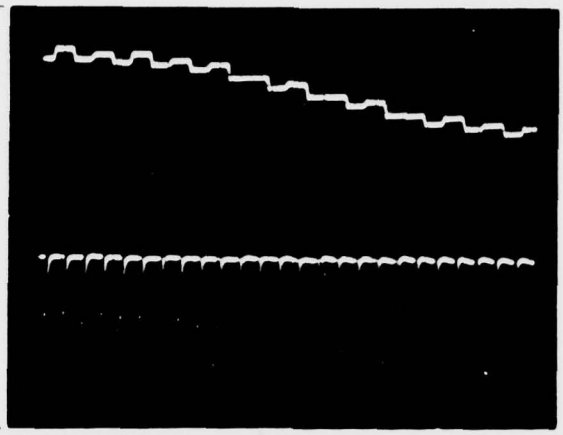


Figure 4. Reticon Output Samples



Figure 5. Magnified View of the Reticon Detectors Elements

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b

FIG-4

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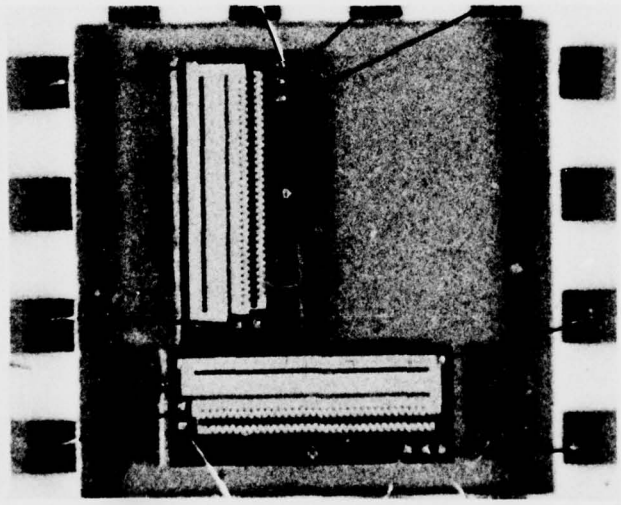


FIG-5

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FIG-4 + 5

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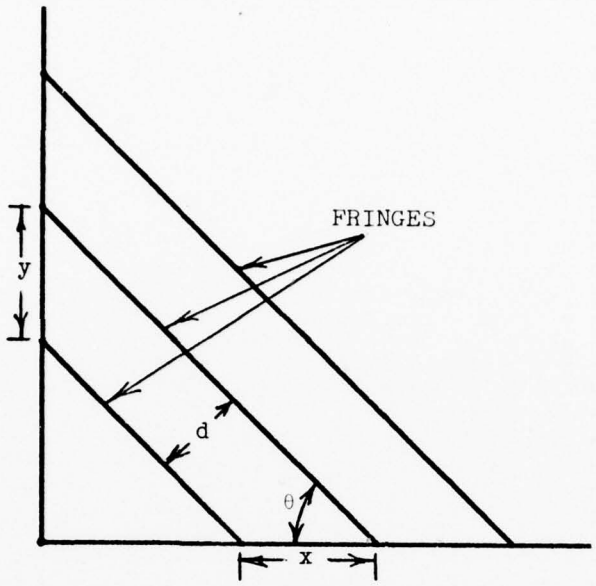


Figure 6. Graphical Description of Angle and Spacing Calculation

SECTION IV

DIGITAL AND ELECTRONIC SETUP

1. COMPUTER MODEL PDP-11-05

The nucleus of the entire specklegram analysis system is a Digital Equipment Corporation Model PDP-11-05 minicomputer with 4000 decimal word storage at 16 bits per word. The computer performs, under program control, all calculations on the incoming data, the stepping sequence of the x-y translation stage, the addressing of the detector, the scanning of the detector, and the retrieval of the data through an A/D converter. Figure 7 is a graphical layout of the processor and its peripheral hookup. A brief sequence of extracting data from a specklegram might be as follows: 1.) Load the plate into its holder and position it to a starting point at the edge of the data array. 2.) Set up the optics for the recorded magnification. 3.) Initialize all peripheral devices. 4.) Enter the x-y stage point differential (stepping resolution). 5.) Step the plate to its first data point. 6.) Address the detector array and perform the detector scan. 7.) A/D the serial data into core memory. 8.) Process the data into fringe spacing and angle. 9.) List the data to the teletype and, 10.) Step to the next data point and repeat the process. At the end of the complete process, the x-y scan parameters can be re-entered and a finer or coarser scan can be performed, based on the previous data run. At this point a more detailed discussion of the procedure for performing Steps 5 and 6 in the above sequence will be discussed.

2. X-Y STEPPING STAGE

The x-y stepping stage (Step 5) assembly consists of a Yosemite 5 inch by 5 inch translation stage, two Slo-Syn stepping motors, two Aerotech Drive Units, and a custom built plate holder mounted to the x-y stage. Stepping of the motors is accomplished by shifting pulses in a serial string to the motors. Each pulse rotates the motors 1.8° (200 pulses - 360°), and the polarity of the pulse determines the direction of motor rotation. The motor driving pulses and their

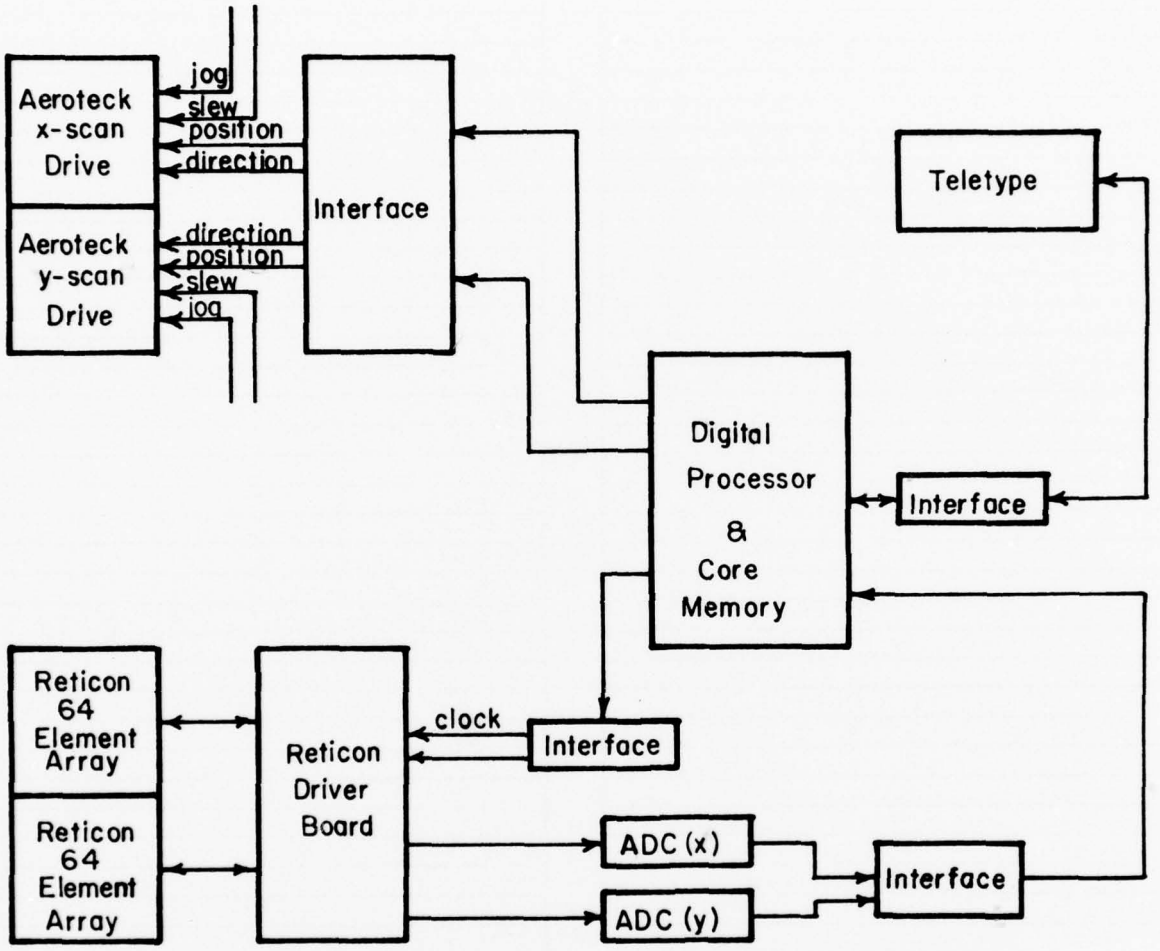


Figure 7. PDP-11 Computer and Peripheral Hookup

polarization are generated by the Aerotech Drive Units and only signals inherent to or input to these drive units will be discussed from this point on. For the case of externally driving the stage, it is required to apply separate 5 volt, 50 μsec pulses to the Aerotech Drive inputs for rotating the motors, and either a 0 or 5 volt signal to the direction inputs to dictate positive or negative direction of rotation. Each unit has the capability of running internally or externally, and in each case the number of pulses can be monitored by a digital readout on the front panel of the unit. Figure 8 shows the 2 Drive Units in their rack mount. During internal operation, for use in initializing plate position, the motors can be stepped in single pulse mode or in the slow mode; this will repetitively transmit pulses to the motors at a rate preset by a potentiometer on the front panel. Another necessary feature of the internal operation is the ability to reset the digital counter at any time during operation, which will create a zero start reference point. Thus, the drive units can be set to internal operation for initializing the x-y plate position, zeroing the digital meter, and then switching to the external mode for the minicomputer to take control.

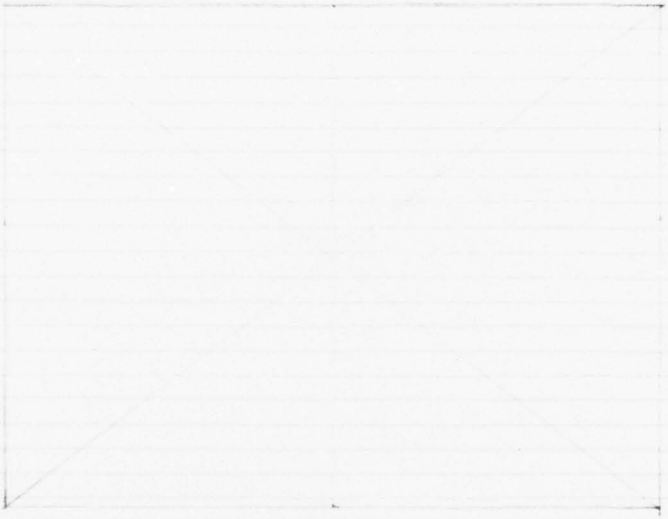
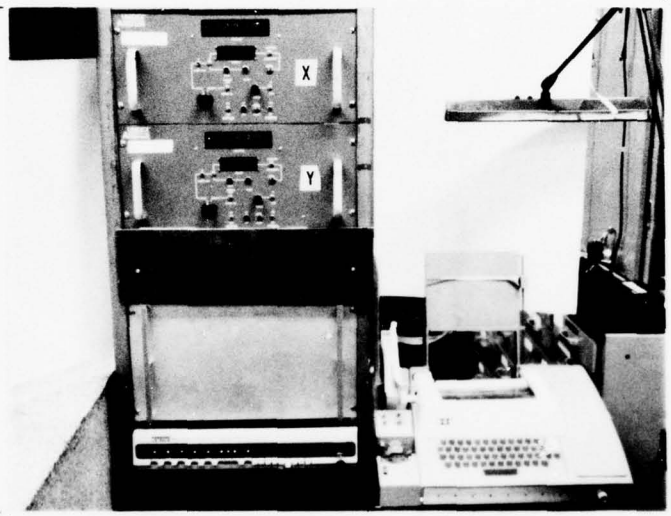


Figure 8. Digital and Electronic Hardware



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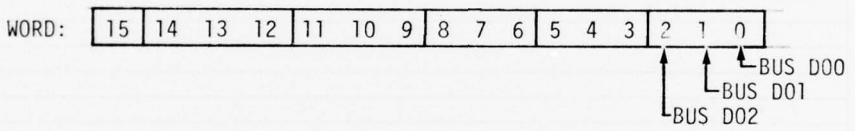
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FIG-8

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Since no commercial interface cards were available to drive the Aerotech Units externally, a computer interface was constructed in-house to generate the required driving signals. Figure 9 is a schematic of the interfacing circuitry.

Four signals had to be generated to drive the x-y stage under computer control, two directional signals and two scanning signals. For simplicity, discussion will be limited to only the x portion of the staging, assuming the y portion to be self-explanatory. The x-clock output supplies 50 μsec, 5 volt pulses to the x-drive unit as required, to drive the x-scanning motor. In order to get a pulse out to the x-clock line through the Figure 9 electrics, a signal has to be applied to lines D1 and E1, simultaneously activating the D303 one shot gate, which, depending on the capacitor value tied to the one-shot, will produce a low voltage 50 μsec pulse (capacitor = .022 μf). This output pulse is then amplified to a 5 volt pulse with an operational amplifier tied to a 5 volt, 1 kilohm resistive network. The problem now is to determine how the computer uniquely addresses the lines D1 and E1. D1 is hooked to V2 and an output from this AND gate is achieved by applying a signal on BUS D00, since the other gate input is always set high. The three BUS lines are simply binary outputs defined as follows:



where: the numbers 1-15 represent power of 2,

thus: 1 = BUS D00
2 = BUS D01
4 = BUS D02

E1 is hooked to the AND Gate with inputs S2 and N1. The details of these outputs can be referenced in the Peripheral Handbook under the M105

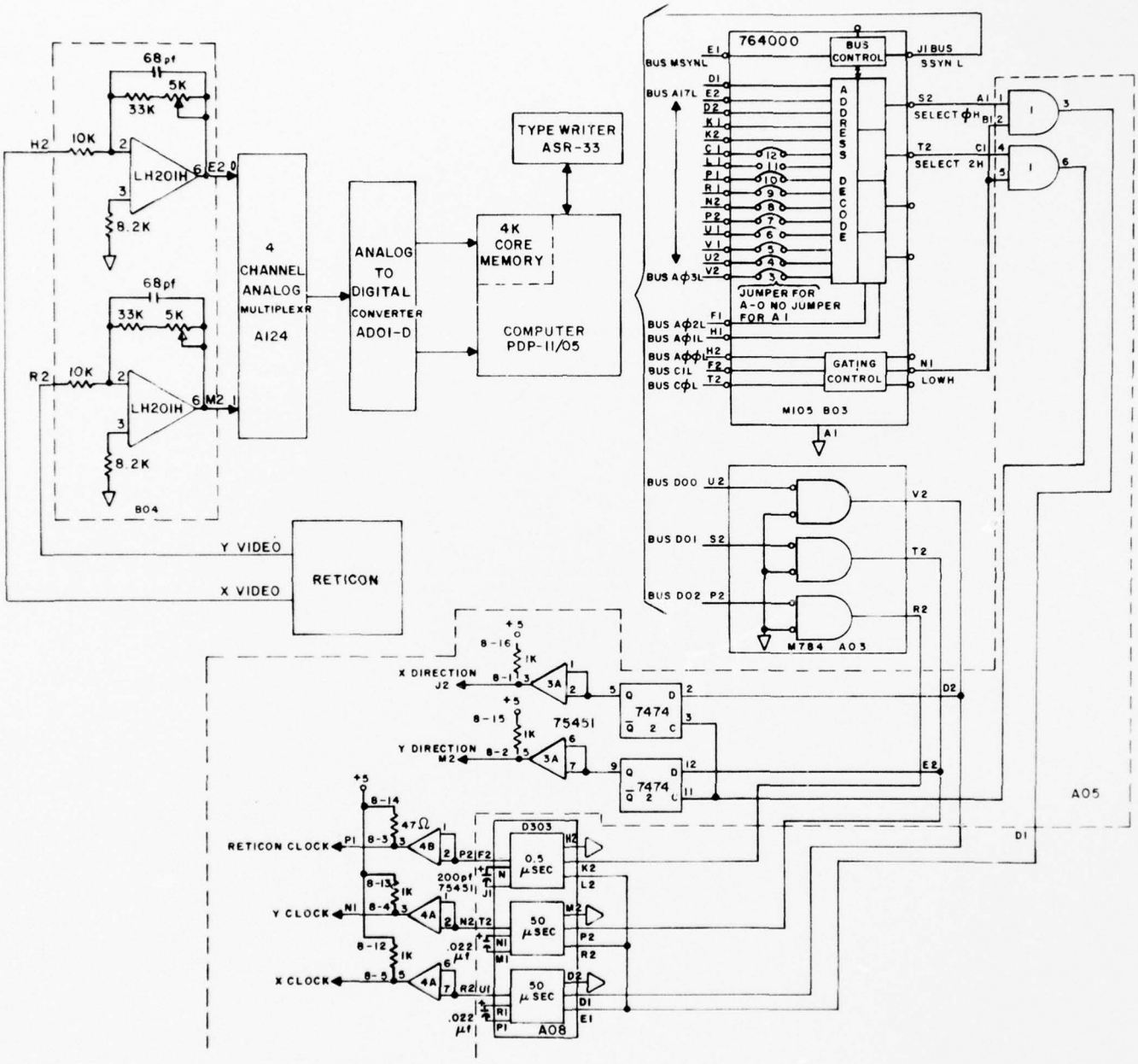


Figure 9. Peripheral Driving Electronics

circuit card chapter. For all practical purposes, in understanding this circuitry, the address to output a signal at point S2 is 164000 and at point T2 is 164002. In total, to get an x-clock output, the number 1 has to be moved to address 164000.

In a similar manner, a table can be constructed to summarize the four x-y stage outputs needed for computer control:

	OUTPUT	INPUT	ADDRESS
1.	x-clock	001 = 1	164000
2.	y-clock	010 = 2	164000
3.	x-direction	001 = 1	164002
4.	y-direction	010 = 2	164002

3. RETICON DETECTOR ARRAY

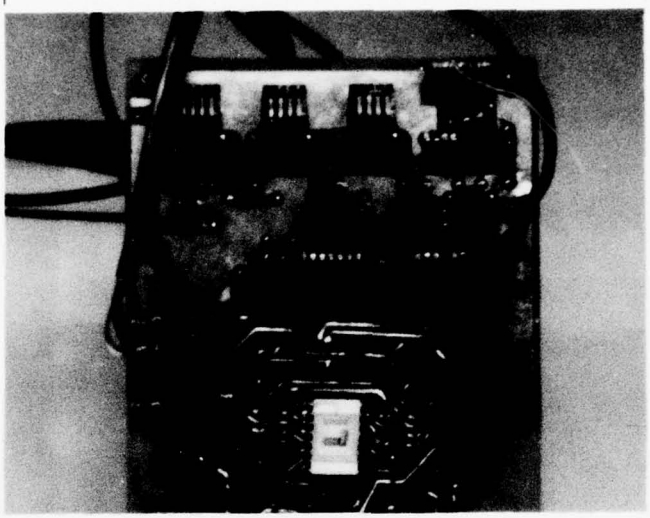
Since the specklegram has now been positioned for a data point readout, the detector has to be addressed to read the fringe data. A brief description of the Reticon Array operation would be of assistance at this point. For simplicity, the discussion will be limited to only one of the linear arrays, because the electronic inputs affect both arrays simultaneously.

Each linear array consists of 64 individually addressed detector elements, which are interrogated one at a time by a scanning clock and the charge accumulated by each element is read and cleared upon interrogation. These clock pulses can be generated internally by a separate clocking circuit at a preset rate or can be input to the clocking circuit from an external source at any rate up to 10 MHz, provided the pulses are at least .5 μsec in duration and 5 volts in amplitude. Whether from an internal or external clock source, the pulses must pass through additional circuitry to be counted for the purpose of generating start and end of scan pulses. The clocking circuit board has 12 binary switches (Figure 10) for setting the time delay (number of pulses delay) desired between readings, thus the maximum delay is 2^{13}-1 (8191 pulses). At the end of each scan an end

Figure 10. Toggle Switch Configuration

of scan pulse is generated for external triggering and immediately before each scan a trig pulse is generated also for internal triggering. Referring to Figure 11, a typical scan for taking a single data reading is illustrated, with three lines of information. The top line represents the fact that the data is being read to the computer by a negative going pulse, the middle line shows the data itself, and the bottom line shows the end of scan pulses. As can be seen, there are actually two complete scans of the detector elements, before the third scan is read into the computer. The reason for the three scans is that, since the detectors integrate the light incident upon them up until they are interrogated, the first scan most likely will be saturated with ambient light as seen by the center scan at the far left of the figure. The second scan sometimes does not contain all 64 elements of detector information; thus the third scan is the first complete scan containing the data information only. An expanded view of the third scan computer reading, data display, and end of scan pulse is given in Figure 12.

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FIG-10
PAGE-17

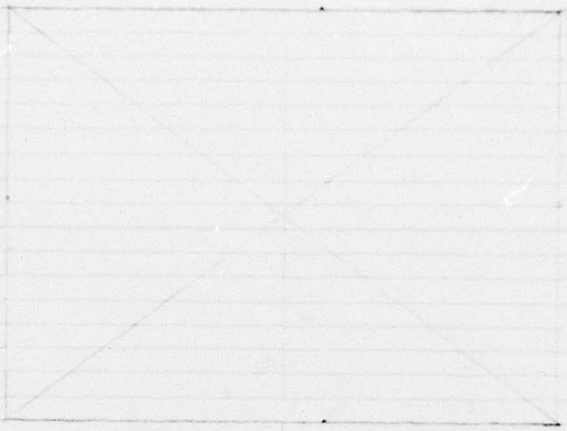


Figure 11. Clock Sequence for Read Initialization

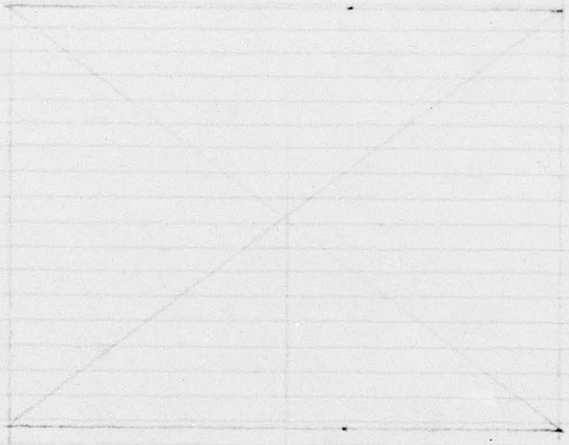


Figure 12. Clocking Sequence for Read Operation

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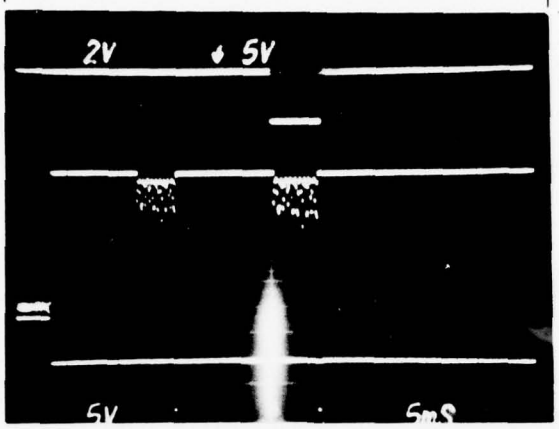


FIG-11

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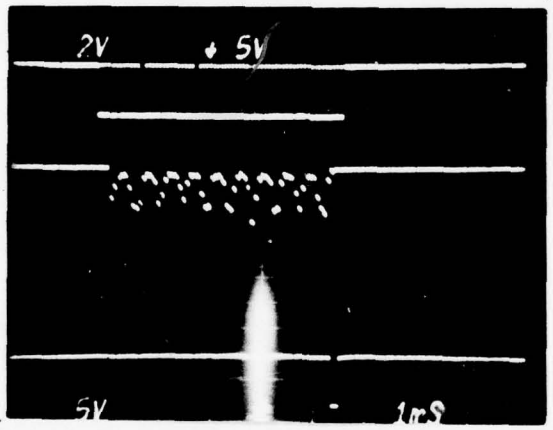


FIG-12

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HFHL-TR-77-203

FIG-11 & 12

PAGE-18

Referring to the schematic of Figure 9, let's now look at the circuitry built to generate the clock pulse and A/D the data to the computer. The same address decoder and input BUS word are used to generate the clock pulses.

OUTPUT	INPUT	ADDRESS
RETICON	100 = 4	164000
CLOCK		

A 200pf capacitor is tied to the the D303 one shot, giving a 5 μsec pulse output.

Special circuitry had to be constructed to match the Reticon data output to the input of the 4 channel Analog multiplexer (Model A-124). The multiplexer, A/D converter combination requires a Ø to 10 volt input swing to give the full 2^9 levels of digital resolution; thus a variable operational amplifier circuit is used to gain the maximum resolution of the A/D converter by taking the reticon 3 volt signals to the 10 volt maximum. The end-of-scan pulse is input to the 3rd channel of the multiplexer directly and is used to synchronize the software program to the detector and electronic hardware.

Two cash boards had to be attached to the outputs of the data from the reticon to act as a sample and hold circuit to maintain the data from each detector pulse long enough for the A/D converter to read its value. Figure 13 shows two data outputs before and after the cash board circuitry. Notice the short length of time the detector output remains peaked without the Cash Board.

Figure's 14, 15, and 16 are a few examples of 1,2, and 9 fringe outputs respectively. In the lower left hand corner of the figure is an oscilloscope trace of the reticon array output, with its analog to digital conversion data retrieved from computer core, to the immediate right and a graphical plot of the digital data is displayed above the computer printout. Notice how closely the detector output matches the graphical plot of the computer data.

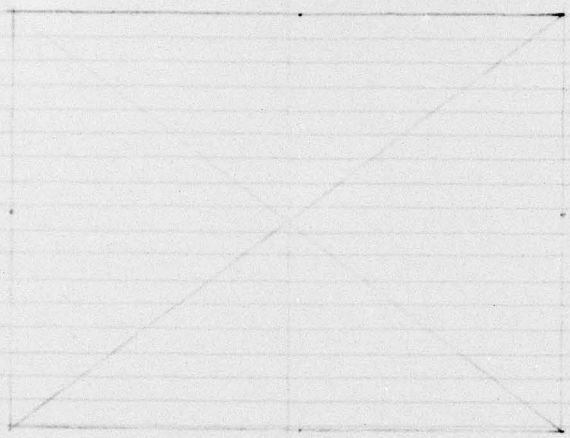
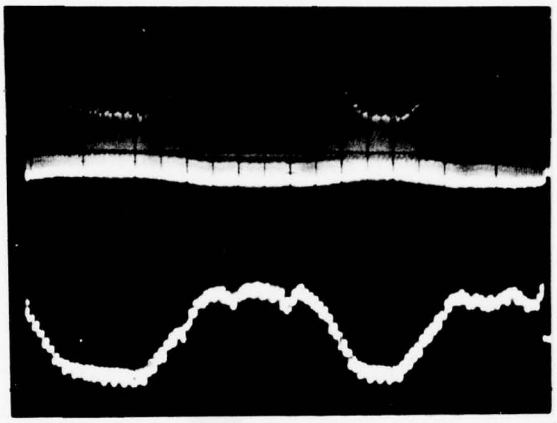


Figure 13. Sample and Hold Illustration



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AFAL-TR-77-203

Fig-13

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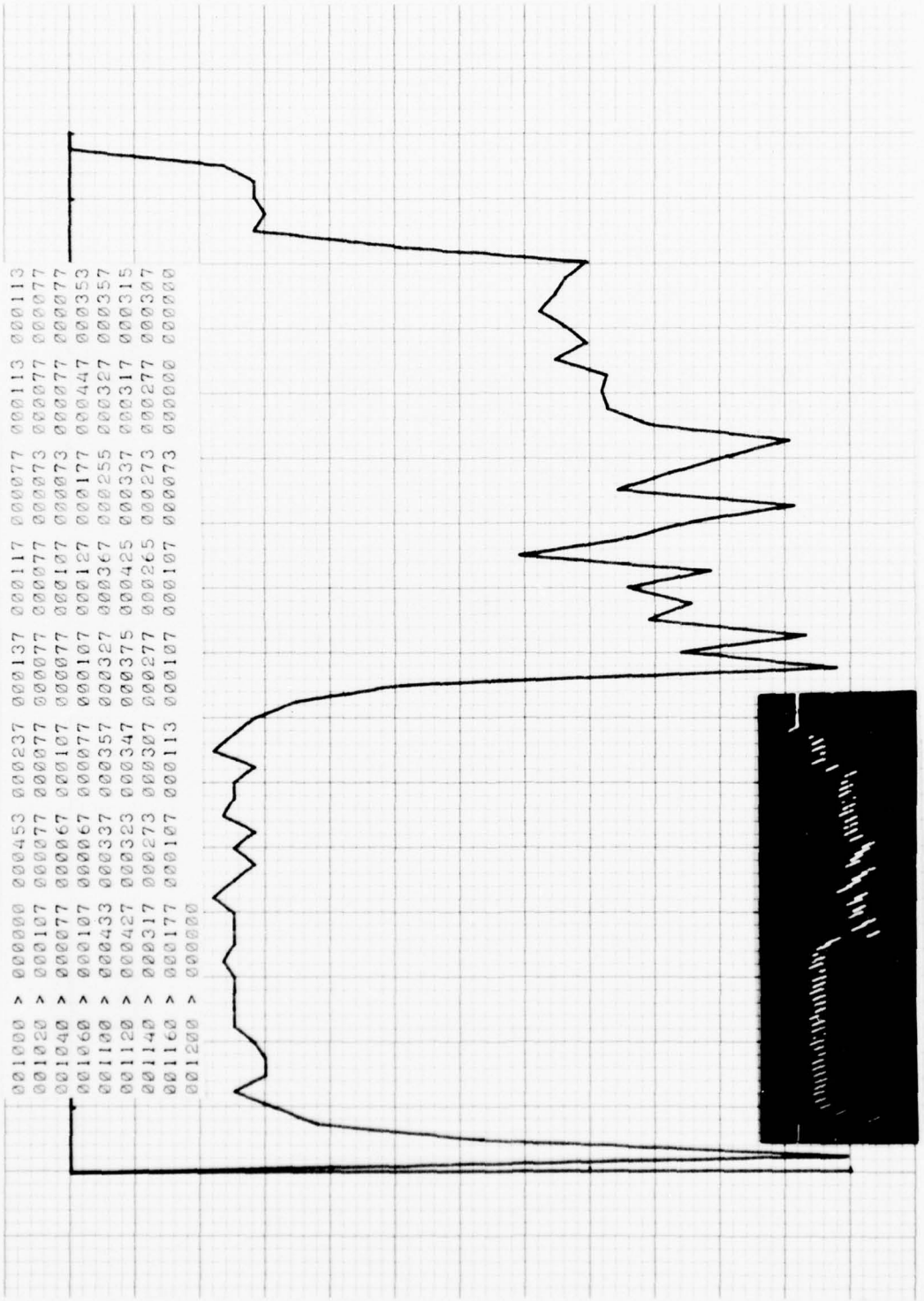
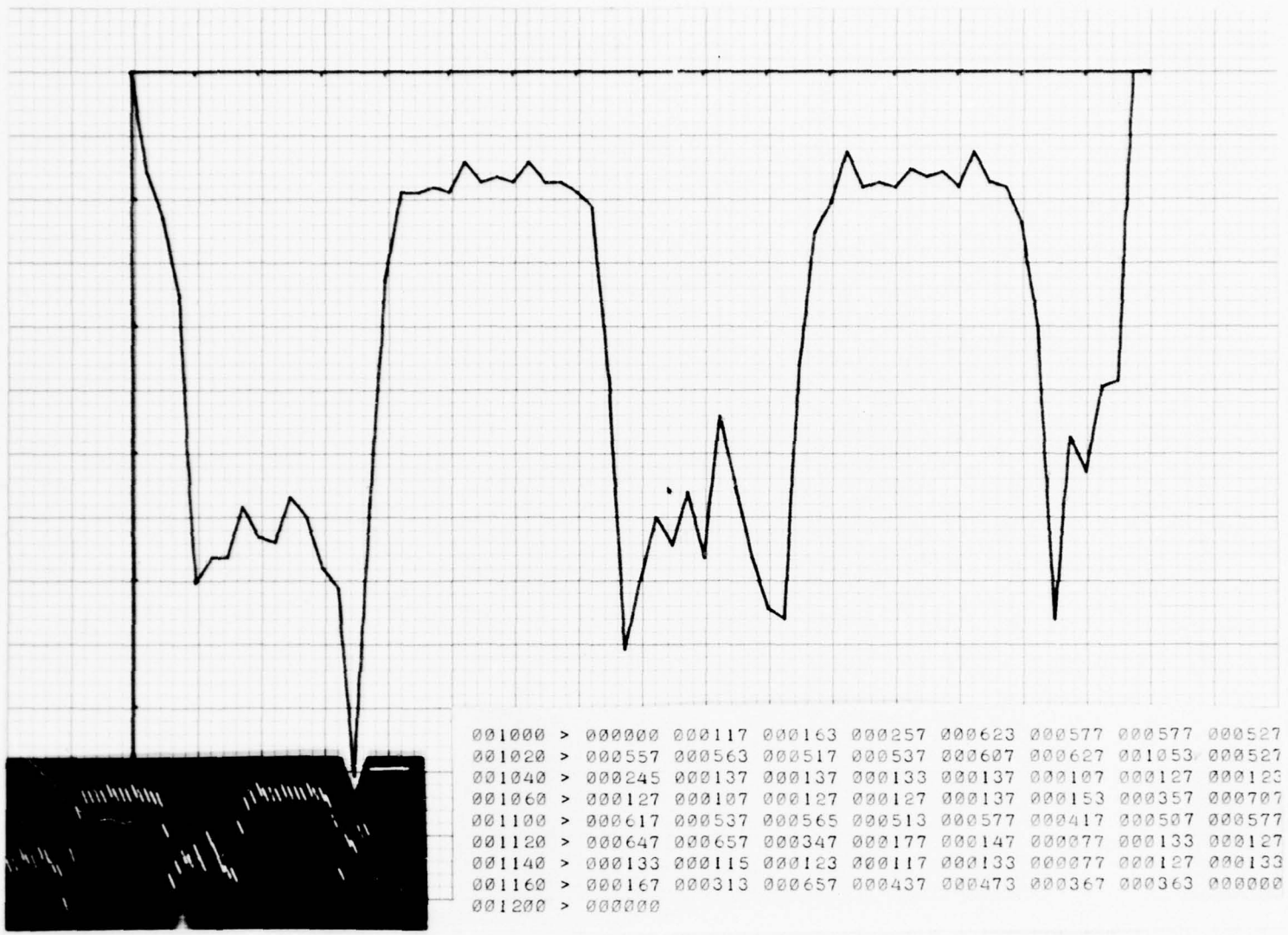
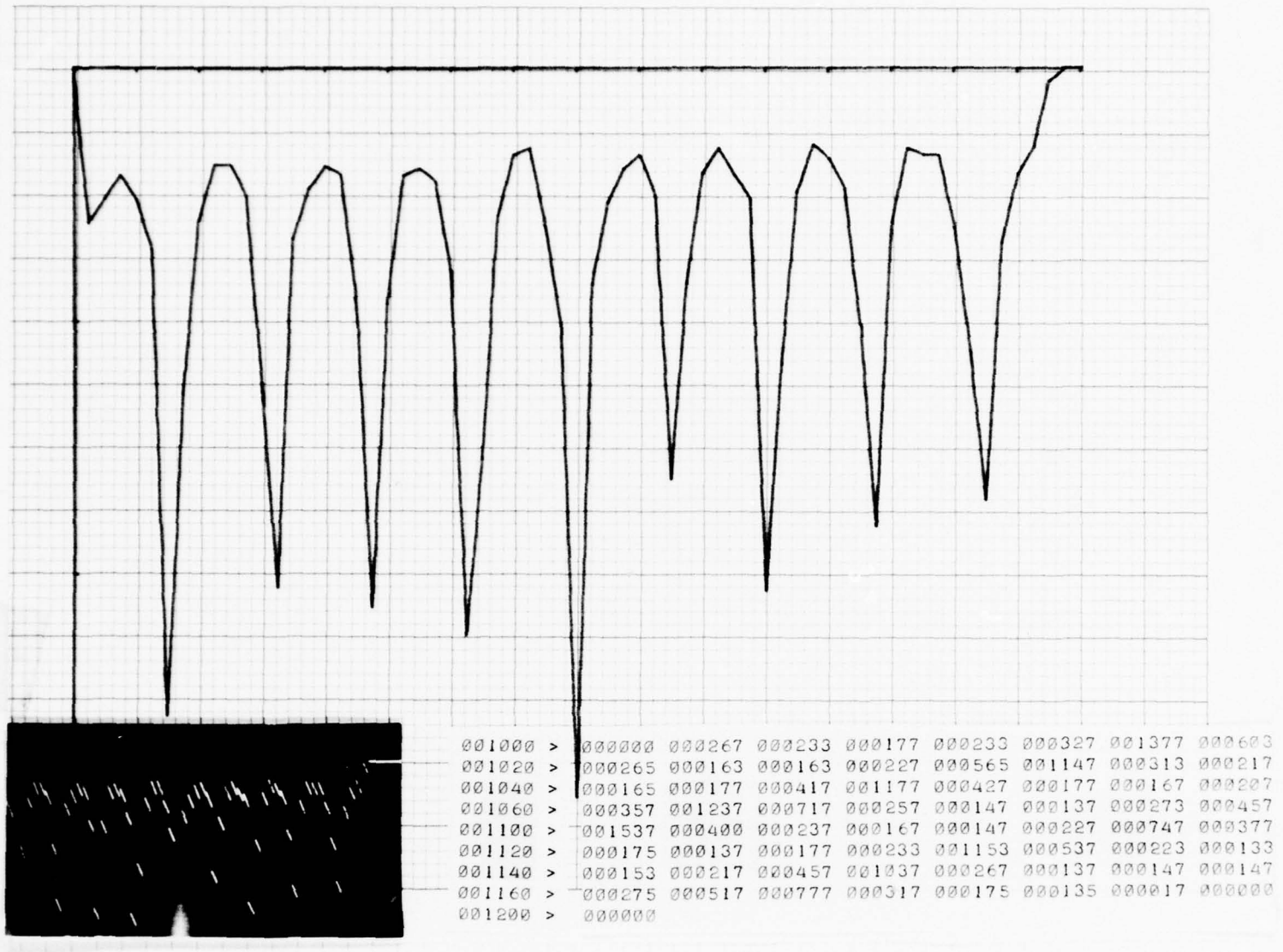


Figure 14. 1Hz Input Fringes With Reticon Plot and A/D Listing



```
001000 > 000000 000117 000163 000257 000623 000577 000577 000527
001020 > 000557 000563 000517 000537 000607 000627 001053 000527
001040 > 000245 000137 000137 000133 000137 000107 000127 000123
001060 > 000127 000107 000127 000127 000137 000153 000357 000707
001100 > 000617 000537 000565 000513 000577 000417 000507 000577
001120 > 000647 000657 000347 000177 000147 000077 000133 000127
001140 > 000133 000115 000123 000117 000133 000077 000127 000133
001160 > 000167 000313 000657 000437 000473 000367 000363 000000
001200 > 000000
```

Figure 15. 2Hz Input Fringes With Reticon Plot and A/D Listing



001000 >	000000	000267	000233	000177	000233	000327	001377	000603
001020 >	000265	000163	000163	000227	000565	001147	000313	000217
001040 >	000165	000177	000417	001177	000427	000177	000167	000207
001060 >	000357	001237	000717	000257	000147	000137	000273	000457
001100 >	001537	000400	000237	000167	000147	000227	000747	000377
001120 >	000175	000137	000177	000233	001153	000537	000223	000133
001140 >	000153	000217	000457	001037	000267	000137	000147	000147
001160 >	000275	000517	000777	000317	000175	000135	000017	000000
001200 >	000000							

Figure 16. 9Hz Input Fringes With Reticon Plot and A/D Listing

SECTION V

SOFTWARE

1. PDP-11 SOFTWARE FUNCTIONS

The PDP-11-05 family of minicomputers operates on simple 16 bit machine language with 7 registers for program manipulation, 2 of which are a stack pointer (R6) and a program counter (R7). The stack pointer acts as storage pointer for keeping track of subroutine jumps and the program counter keeps track of all addressing within a program, including automatic word or byte sequencing.

The method chosen for writing a program depends on the software compilation routine desired by the user to generate the machine language for computer operation. The highest level language that can be used is Fortran but many hardware options have to be tied to the computer hardware directly, and along with the high cost of the Fortran compiler software, a substantial cost increase is realized. Due to the limited budget available, the simplest of all languages was chosen, and other than creating a substantially more complex programming routine, this simple language proves to be adequate for doing the job. This simple language (assembly language) is comprised of the following programming commands:

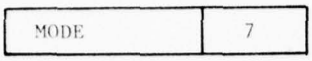
1. CLR - clear
2. DEC - decrement
3. INC - increment
4. NEG - negate
5. TST - test
6. COM - complement
7. ASR - arithmetic shift right
8. ASL - arithmetic shift left
9. ADC - add carry
10. SBC - subtract carry
11. ROL - rotate left
12. ROR - rotate right
13. SWAB - swap bytes
14. MOV - move
15. ADD - add
16. SUB - subtract

17. CMP - compare
18. BIS - bit set
19. BIT - bit test
20. BIC - bit clear
21. BR - branch
22. BEQ - branch on equal
23. BNE - branch on not equal
24. BMI - branch on minus
25. BPL - branch on plus
26. BCS - branch on carry set
27. BCC - branch on overflow set
28. BVS - branch on overflow clear
29. BVC - branch on less than
30. BLT - branch on greater than
31. BGE - branch on greater than or equal
32. BLE - branch on less than or equal
33. BGT - branch on greater than
34. BHI - branch on high
35. RTS - return from subroutine
36. JSR - jump to subroutine
37. HALT - halt
38. WAIT - wait for interrupt
39. JMP - jump

The modes available for applying the above commands are listed briefly on the following tables and are described in detail in the PDP-11 Processor Handbook.

MODE	R

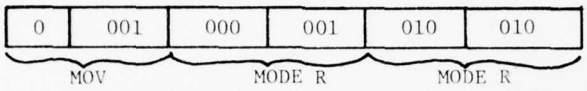
MODE	NAME	SYMBOLIC	DESCRIPTION
Ø	REGISTER	R	R is operand
1.	REGISTER DEFERRED	(R)	R is address
2.	AUTO INCREMENT	(R) +	R is address; R + 2 → R
3.	AUTO INCREMENT DEFERRED	@ (R) +	R is address of address; R + 2 → R
4.	AUTO DECREMENT	- (R)	R - 2 → R; R is address
5.	AUTO DECREMENT DEFERRED	@ - (R)	R - 2 → R; R is address of address
6.	INDEX	X (R)	R + X is address
7.	INDEX DEFERRED	@ X (R)	R + X is address of address



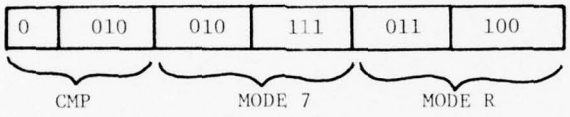
MODE	NAME	SYMBOLIC	DESCRIPTION
2	IMMEDIATE	# n	operand n follows instr
3	ABSOLUTE	@ # A	address A follows instr
6	RELATIVE	A	instr address + 4 + X is address
7	RELATIVE DEFERRED	@ A	instr address + 4 + X is address of address

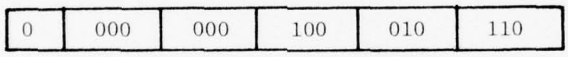
Three examples using the commands and modes listed above are given as follows.

MOV R1, (R2) +



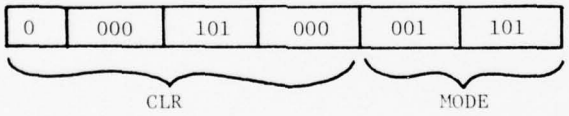
CMP # 426, @ (R4) +





0 0 0 4 2 6

CLR (R5)



2. CONTROL PROGRAM SOFTWARE DESCRIPTION

Due to the limited commands and the lack of arithmetic functions, the software required to control the complete analysis system is quite complex and lengthy contrary to what might be expected when using a higher level language. The program can be outlined into 21 different sections or subroutines as follows.

1. PROGRAM START AND PARAMETER LOADING - START
2. ASC II AND DECIMAL TO OCTAL CONVERSION - ASC II
3. CONTROL - MANIP
4. FAST FOURIER TRANSFORM - FIT
5. DETECTOR READ - READ
6. DISPLACEMENT & ANGLE LIST - PRINT
7. ANGLE CALCULATION - ANGLE
8. AMPLITUDE CALCULATION - AMP
9. TELETYPE OUTPUT - TTYOUT
10. OPERATION SELECTOR - OPER
11. TELETYPE INPUT - INPUT
12. DISPLACEMENT CALCULATION - DISP
13. FRINGE FREQ DETERMINER - FREQ
14. OCTAL TO DECIMAL CONVERSION - OTD
15. X-Y STAGE CONTROL - STAGE
16. PRINT POSITION - POSITN
17. DATA BUFFERS - RRØ - STEPLY
18. PRINT BUFFERS - ASKAV - QUES
19. TRIG TABLE FOR ANGLE - TANBUF - SINBUF
20. TRIG TABLE FOR FFT - COS - SIN
21. SYMBOL TABLE - A - ZEROX

Each subprogram can be described briefly in the order that it appears in the overall program as follows:

1. TITLE merely sets a title heading for the program that appears at the top of each page.

5. ENABLE AMA sets the assembler to define the machine language in the Absolute Memory Addressing mode.

8 - 15 These lines define the labels assigned to the bottom 7 words of core in computer memory with register numbers, stack pointer, and program counter.

16 - 19 Lines define the labels assigned to the listed core locations 177560-177566 which address the input and output from the teletype terminal. KBS and TPS are merely status words and KBB and TPB are input and output buffers.

27. 500 is the starting address of the program.

28. START: This is the first line of the main program which assigns a stack pointer address.

30 - 31 Prints "No. of Data Averages" by addressing the TTYOUT Subroutine.

32 - 37 Loads ASC II value of No. of Averages to the "MEAN" buffer via the INPUT subroutine and then coverts the ASC II values to an octal value and stores it in the TIMES buffer.

39 - 42 Clears all buffers from X LIMIT to STEP-X in the data buffer subroutine called RRØ.

43 - 75 Prints enter, and convert to octal: "X-Tot Scan Distance," "Y-Tot Scan Distance," "X-Increment," and "Y-Increment," similar to the method described in lines 32 - 37.

68. Sets the direction of the X and Y scan to be positive. Referring to Figure 9, move a 4 to 164002 which moves zeros to 164002 through Bus D00 and D01, making the output to the direction lines 0 volts or "low" produce a positive direction.

76 - 77 Prints the header title as shown in the data section of this report.

78 - 79 Jumps to the subroutine "STAGE," which initiates the X-Y stepping stage.

80 - 81 Prints "X-Y SCAN COMPLETED."

83. Halts.

86 - 90 ASC II: Subtracts 60_8 from each ASC II entry; thus the member 61_8(ASC II for 1)-60_8 = 1_8 and 71_8(ASC II for 9)-60_8 = 11_8, which continues until a carriage return is received (#15).

92 - 94 Loads Least Significant Digit, which is already in octal format.

98 - 104 Converts 2nd digit to octal format as follows: Add 12_8 (10_{10}) to a dummy register for each unit value in the 2nd digit and then loads the final value to R3, which is the finish of the ASC II routine, and is the final octal value of the complete list of digits.

105 - 132 Converts the 3rd, 4th, and 5th digit in the same manner as in steps 95 - 104.

133 - 135 Stores final answer in OBUF.

138 - 142 Clears working registers and buffers from RRO to KEEP (lines 892 - 911).

143 - 140 Clears FBUFAV and FFTBUF.

147 - 153 Self explanatory.

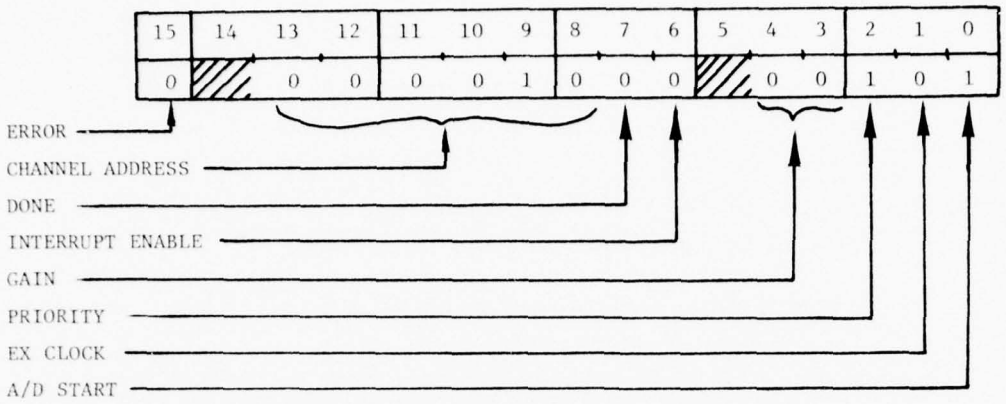
154 - 158 If the frequency is below 4 fringes then prints "LOW;" if not, then prints Go To a Frequency.

159 - 162 Changes Octal Frequency Count to Decimal Value and converts to ASC II Code; then prints value in Base 10 to Teletype Output Printer.

163 - 175 The first time through MANIP performed complete analysis on X direction of Detector data, and now the Y-direction data is analyzed through MANIP and printed out to TTYOUT.

178 - 462 FFT: Due to the complexity of the Fast Fourier Transform Routine details of its operation can be obtained from Mr. Lane of AFAL/DHO, and will not be covered in this report.

471. READ: Moves a clock pulse from the Electronics Unit schematically illustrated in Figure 9 to the clock input of the Reticon Array.



472. Moves the number 1005_8 to the control and status register (links the A/D converter to the software) which addresses channel 2 of the A/D converter, sets the priority level to 1 and starts the A/D operation.

473. Loads the CSR (Control and Status Register) to RØ.

474 - 475 Checks for the Done Bit of CSR (Bit 7), and if not sets return to DONE 1, otherwise must go to next line and load data.

476 - 478 Moves the data from channel 2, through data Register 176772, to register R1. Channel two is hooked to the detector end of scan (EOS) line which emits a pulse when a complete scan of the 64 detector elements is finished. After the data load, the program checks to see if the end of scan pulse has appeared. If not, branches to CLOCK 1.

479 - 482 Allows for 2 EOS pulses before continuing to the next program section.

483 - 487 Continues clocking the detector through the dead time between scans that are preprogrammed through the toggle switches on the clocking circuit board. The switches are set to

$$0000 \quad 1111 \quad 0011 = 227_{10}$$

Thus, it works out that 202, as programmed in the software, provides the proper delay to allow a data read at the correct time.

488 - 491 Is a software delay that allows a large enough time between clock pulses, for the pulse generator of Figure 9, to operate properly. If, for instance, the MOV # 4, @ # 164000 operation were performed in a small program loop, the pulses generated from the address decoder, arrive at too high a rate for the one-shot delay, thus exiting at the clock pulse output as a voltage level, not a pulse.

492 - 494 Decides whether to read the X detectors or the Y detectors.

495 - 500 The entire clocking routine previous to these steps were initialization procedures aimed at setting up the A/D converter to read data from the detector array at a time when meaningful data was present. These few lines read this unambiguous data and load it into core memory. (R4) is the storage medium where R4 points to either FFTBUF or FBUFAV.

505 - 512 If averaging of the data is desired, which is a buffer that designates a data load to either FFTBUF, or FBUFAV.

513 - 525 Repeats the data read operation for the Y-axis with the same logic as in steps 492-509.

526 - 540 Averages the data and loads the averaged data to the FFTBUF buffer. Since the averaging method probably does not appear obvious, a brief description follows: 523 - 525 TIMES contains the number of desired averages with TRACK incrementing with each average performed (TRACK = TIMES means done). 526 - 527 The data is loaded to FFTBUF from the first data read; 528 - 534 after first two data reads, each data buffer (FFTBUF: FBUFAV) is divided by 2 (ASR) added together and loaded to FFTBUF. 535 - 537 Prepares to load new data to FBUFAV for another average.

543 - 549 Allows for reduction of redundancy between first and second half of the detector active elements by loading the data stored for the first half of the detector into the storage location delegated for the second half.

555. PRINTS.

556 - 562 Clears the XDISTO and YDISTO buffers; then calculates the X-spacing from the X-frequency as follows: (f/No. of detectors = spacing) where f = ROBUF, No. of detectors = 64_{10} = 100_8.

563 - 567 Same as above for Y-spacing.

568 - 576 Goes to Angle calculation subroutine; then returns and prints answer. Goes to Displacement subroutine; then returns and prints answer.

581. ANGLE.

582 - 593 Loads X and Y spacings; multiplies the Y spacing by 100_8 to obtain a whole-number output from the division of Y by X. The angle is calculated by:

$$\theta = \tan Y/X$$

594 - 599 Takes the value Y/X (stored in R0) and scans it through the tangent table (TANBUF), listed in one-degree increments, until the two values compare; then stores the comparison address to RATIO.

600 - 607 Clears DBUF then Jumps to Subroutine OTD and loads to DBUF.

612. AMP.

613 - 620 Loads start address for Real Part of FFT (FFTBUF) and imaginary Part of FFT (FFTBUF + 200). Checks to see if data point of real and imaginary are negative, if so make positive.

621 - 628 Squares the real data point amplitude.

629 - 641 Squares the imaginary data point amp.

637 - 641 Adds real and imaginary data points and moves to original real data point storage location and checks to see if all data points have been squared; if not, increment the FFTBUF addressed for real and imaginary and repeats the complete process starting at line 615.

651. TTYOUT.

651 - 656 Tests the Teleprinter Status; if read, moves data to Teleprinter Buffer and prints. Checks if finished printing by a 0 data point appearing.

661. OPER.

661 - 678 Checks if a given letter (S, X, Y, or D) was input from the Teletype and, if so, load R5 accordingly.

683. INPUT.

683 - 687 Checks the Keyboard Status and, if ready, moves the ASC II code of the desired key to R4; then clears the part bit (Bit 7) and moves the answer to address of (R0).

696 - 702 Prints correct character; checks if input is completed (#15 - Carriage Return) and moves a line feed to the printer (#12).

704. DISP.

704 - 707 Moves Sin Buffer address to R1 and adds RATIO to it. Ratio contains the address representation of the angle calculated in the ANGLE subroutine. Since the Displacement is calculated by

$$d = X \sin \theta$$

and the sin of θ can be calculated from a table similar to TANBUF, called SINBUF, which is also set up in one-degree increments; d is easily obtained by multiplying X by the value obtained from the SINBUF table.

708 - 723 Multiplies X DISTO by sin θ and divides the answer by 100_8 since SINBUF value is premultiplied by 100_8; then the answer is changed to decimal and control is returned to PRINT.

727. FREQ.

729 - 731 Checks for a high amplitude D.C. component in the FFT Data; if lower than 156, sets HIDC.

732. FFTBUF + 140 represents a fifteen Hertz frequency bin and, for determining the frequency, it is assumed that no frequency will be higher than 15 Hz or 15 fringes.

733 - 738 Checks for highest amplitude frequency bin by comparing the amplitude of the presently addressed bin to the maximum amplitude of all the previously searched bins; if larger goes to HOLD. If it is smaller, increments the next bin and either returns to search at SRCH or moves to QUIT if all bins have been searched.

739 - 747 For HIDC, checks data with #10 amplitude; if below GTO QUIT - 6.

748 - 750 If frequency was valid, loads address to R2 and the amplitude to R3, the increment between data point scans.

753 - 757 If no frequency was stored (R3 - 0), then moves 1 to NONE.

758 - 765 Looks at amplitudes on both sides of the highest amplitude frequency bin (R3) and determines if the actual frequency is slightly higher or lower than R3 by loading 1 to R5, if above; and loading 0 to R5, if below.

766 - 769 Since FFTBUF + 200 is 0 frequency and each bin in the FFTBUF is one cycle, then subtracting R2 from FFTBUF + 200 and dividing the answer by two, results in the final frequency in Hertz.

770 - 777 Loads the frequency to OBUF and a + or - to OBUF + 2. Returns control MANIP.

786. OTD.

786 - 822 Changes data in OBUF to a base 10 equivalent; then converts to ASC II code for printout.

827. STAGE.

832 - 840 MOV #1, @ # 164000 sends a X-clock pulse to the X-Y stage driver. Unit keeps track of the number of pulses transmitted for each scan between data points, whereas LINE keeps track of the total number of pulses transmitted to the total X-scan for one line. DELAY simply stores a programmed delay to allow the pulses to zero before another signal appears. Unit is compared to STEP X which contains the data determining the increment between data point scans.

845 - 848 Checks to see if the end of line distance is reached; if so, Branch to ZEROX.

865 - 873 Changes the sign of X and sends pulses to drive the X unit until the X position is 0 or its original position. A long delay is required (40000) before further execution of scanning to allow for experimental stabilizing. At this point the X sign is changed again and a Y scan is performed.

883. POSITN.

883 - 886 Clears the Decimal Buffer (DBUF).

887 - 890 Loads the X-position in octal and converts to decimal for terminal printout.

891 - 896 Same as above for Y-position.

897 - 900 Reloads the data point scan separation and returns to STAGE subroutine.

The last two pages of the program are a table showing the numerical address assigned to all Labels in the program.

The description of the software for operating the overall System, has been explained only in brief for the purpose of this report and a more detailed discussion can be planned upon request by the Flight Dynamics Laboratory.

SECTION VI

DATA

In this section of the report we will discuss the individual data shown in Figure 17 through 30 and the significance of the overall data collection as presented in the Results Section. A complete data collection operation had not been performed at the writing of this report, but shortly thereafter, it was anticipated that a complete set of data would become available for listing to the Flight Dynamics Laboratory.

The first method pursued for analyzing specklegram data was to look for amplitude peaks or nulls in the detector scanned data signals and average the distance between each peak or null by counting the number of detectors lying between them.

For initial experimental trials a set of fringe negatives were constructed photographically to input to the optical systems as a sample of high contrast fringes for setting up the computer software. Some data from these initial runs is shown in Figures 17, 18, 19, and 20. Frequencies of 5 Hz, 6 Hz, 7 Hz, 8 Hz, 9 Hz, 10 Hz, 20 Hz, 30 Hz, and 40 Hz were the photographic inputs. As can be seen, the system operated nearly flawlessly for these types of fringe inputs. At this point some real fringe data was input to the optical system and a couple of the best data runs are shown in Figures 21 and 22. Notice the variance in what appears to be peaks or nulls in the digital data printout. The data for most cases was less impressive than that shown, thus a new method for counting the fringe data had to be established.

Coincidental with our search for a new method of analysis, an electronics equipment oriented company made available an FFT (Fast Fourier Transform) operator for demonstration. This turned out to be the opportunity we needed to see if an FFT program would solve some of the problems we had encountered during peak detection. A typical specklegram data was projected onto a Reticon Array that we supplied and input to the FFT hardware they supplied.

BEST AVAILABLE COPY

PEAK REGISTERS

00001
00024
00063

PEAK REGISTERS

00015
00054
00065

PEAK REGISTERS

00001
00035
00065

PEAK REGISTERS

00008
00047
00065

5 Hz

PEAK REGISTERS

00001
00018
00051
00065

PEAK REGISTERS

00016
00049
00065

PEAK REGISTERS

00005
00038
00065

PEAK REGISTERS

00012
00045

6 Hz

Figure 17. Data Runs With High Contrast, Ideal Fringe Pattern

PEAK REGISTERS

00013
00041
00065

PEAK REGISTERS

00001
00028
00056
00065

PEAK REGISTERS

00011
00039
00064

PEAK REGISTERS

00001
00023
00052
00065

7 Hz

PEAK REGISTERS

00005
00029
00054
00065

PEAK REGISTERS

00001
00019
00043
00065

8 Hz

PEAK REGISTERS

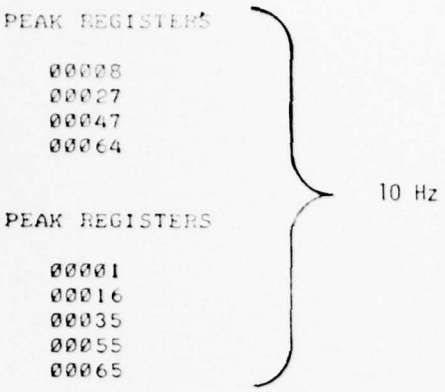
00001
00017
00038
00060
00065

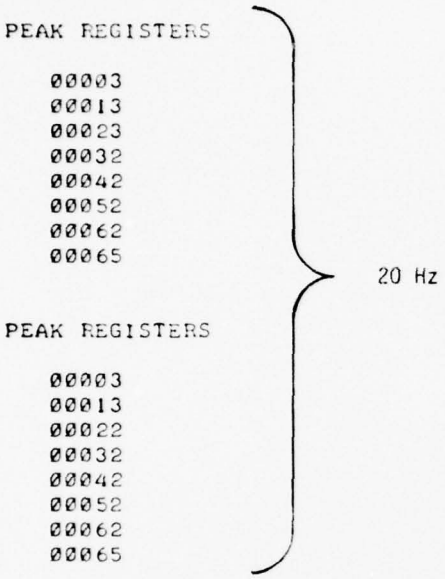
PEAK REGISTERS

00008
00029
00051
00065

9 Hz

Figure 18. Data Runs With High Contrast, Ideal Fringe Pattern





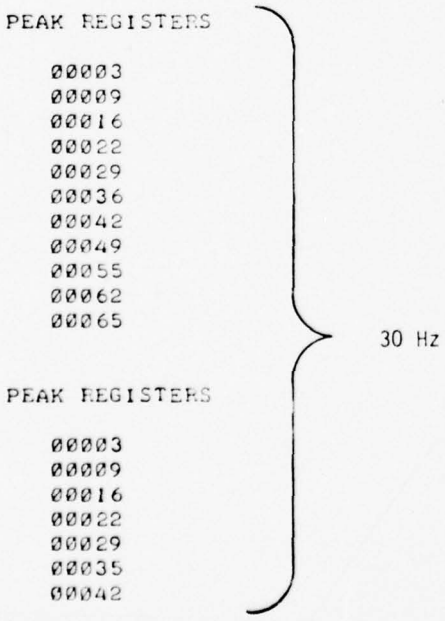


Figure 19. Data Runs With High Contrast, Ideal Fringe Pattern

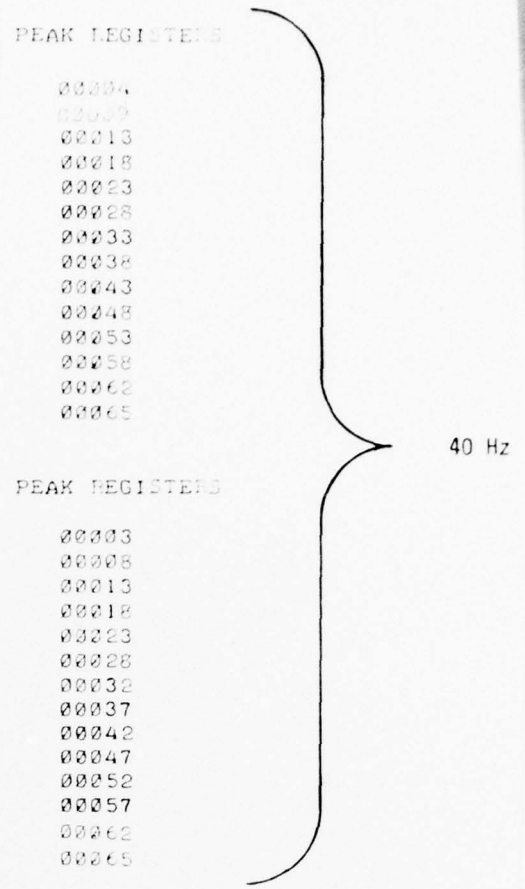


Figure 20. Data Runs With High Contrast, Ideal Fringe Pattern

BEST AVAILABLE COPY

```
PEAK REGISTERS

   00007
   00022
   00040
   00056
   00069

001554 > 000000 000000 000000 000000 000000 000107 000137 000147
001574 > 000237 000427 000757 000477 000577 000377 000457 000307
001614 > 000157 000107 000127 000117 000107 000077 000117 000123
001634 > 000157 000167 000427 000657 000763 000573 000553 000577
001654 > 000673 000323 000225 000153 000133 000107 000117 000113
001674 > 000115 000077 000157 000227 000553 000773 000527 000475
001714 > 000667 000417 000247 000147 000137 000077 000117 000117
001734 > 000117 000077 000133 000213 000477 000777 000657 000563
001754 > 000545 000337 000327 000000 000015 000012 000015

001772 > 000007 000026 000050 000070 000105 000012 000015 000000
002012 > 000000 000000 000000 000000 000000 000000 000000 000000
002032 > 000000 000000 000000 000000 000000 000000 000000 000000
002052 > 000000 000000 000000 000000 000000 000000 000000 000000
002072 > 001657

002074 > 000107 000137 000147 000157 000107 000127 000117 000107
002114 > 000077 000117 000123 000157 000157 000153 000133 000107
002134 > 000117 000113 000115 000077 000157 000147 000137 000077
002154 > 000117 000117 000117 000077 000133 000000 000015 000000
002174 > 000000 000000 000000 000000 000000 000000 000000 000000
002214 > 000000 000000 000000 000000 000000 000000 000000 000000
002234 > 000000 000000 000000 000000 000000 000000 000000 000000
002254 > 000000 000000 000000 000000 000000 000000 000000 000000
002274 > 001566

002276 > 001570 001572 001574 001616 001620 001622 001624 001626
002316 > 001630 001632 001634 001636 001640 001664 001666 001670
002336 > 001672 001674 001676 001700 001702 001724 001726 001730
002356 > 001732 001734 001736 001740 001742 001764 001766 000012
002376 > 000000 000000 000000 000000 000000 000000 000000 000000
002416 > 000000 000000 000000 000000 000000 000000 000000 000000
002436 > 000000 000000 000000 000000 000000 000000 000000 000000
002456 > 000000 000000 000000 000000 000000 000000 000000 000000
002476 > 042520
```

Figure 21. Data Runs With Real Specklegram Data

BEST AVAILABLE COPY

```
PEAK REGISTERS

   00009
   00021
   00034
   00047
   00061
   00069

001554 > 000000 000000 000000 000000 000000 000137 000137 000127
001574 > 000117 000077 000127 000213 000477 000467 000377 000357
001614 > 000417 000137 000127 000133 000117 000077 000127 000127
001634 > 000247 000577 000737 000615 001033 000477 000227 000147
001654 > 000153 000077 000127 000127 000217 000457 000757 000707
001674 > 000653 001113 000473 000177 000157 000077 000133 000117
001714 > 000137 000127 000377 000647 000537 000427 000633 000377
001734 > 000217 000123 000157 000127 000117 000107 000177 000377
001754 > 000647 000347 000253 000000 000015 000012 000015



001772 > 000011 000025 000042 000057 000075 000105 000012 000015
002012 > 000000 000000 000000 000000 000000 000000 000000 000000
002032 > 000000 000000 000000 000000 000000 000000 000000 000000
002052 > 000000 000000 000000 000000 000000 000000 000000 000000
002072 > 001657



002074 > 000137 000137 000127 000117 000077 000127 000137 000127
002114 > 000133 000117 000077 000127 000127 000147 000153 000077
002134 > 000127 000127 000177 000157 000077 000133 000117 000137
002154 > 000127 000123 000157 000127 000117 000107 000177 000000
002174 > 000015 000000 000000 000000 000000 000000 000000 000000
002214 > 000000 000000 000000 000000 000000 000000 000000 000000
002234 > 000000 000000 000000 000000 000000 000000 000000 000000
002254 > 000000 000000 000000 000000 000000 000000 000000 000000
002274 > 001566



002276 > 001570 001572 001574 001576 001600 001602 001620 001622
002316 > 001624 001626 001630 001632 001634 001654 001656 001660
002336 > 001662 001664 001704 001706 001710 001712 001714 001716
002356 > 001720 001740 001742 001744 001746 001750 001752 001764
002376 > 001766 000012 000000 000000 000000 000000 000000 000000
002416 > 000000 000000 000000 000000 000000 000000 000000 000000
002436 > 000000 000000 000000 000000 000000 000000 000000 000000
002456 > 000000 000000 000000 000000 000000 000000 000000 000000
002476 > 042520
```

Figure 22. Data Runs With Real Specklegram Data

BEST AVAILABLE COPY

Figure 23 is a four plot sequenced illustration of the result of this mock setup. The first plot shows the specklegram data after and before averaging 512 times (top and bottom respectively). The second plot shows the first FFT with a strong peak to the far left and a secondary peak to its immediate right. The first peak turned out to be the reticon clock frequency and the second peak the actual data frequency. The third plot shows the clock frequency filtered out, thus rendering the strongest frequency peak to be 4.2 KHz instead of the 200 Hz Reticon clock frequency. Plot four shows the inverse transform of the FFT data giving back a signal with the same frequency as plot number 1. Thus it was concluded that the FFT approach would become the solution to the problem.

After an extensive amount of programming was performed to implement an FFT software routine, the photographic fringes were introduced into the system. Figures 24, 25, 26, 27, and 28 show a data run with different frequencies introduced into the x and y detectors of the Reticon Array. Notice please, that each frequency calculated is as nearly right as can be interpreted from the Reticon detector plot shown on the scope traces. The pluses and minuses listed before each frequency indicated whether the frequency displayed is slightly higher or lower than the frequency printed.

The computer listing of Figure 29 is a typical teletype printout obtained during a data run with the software advanced as far as it is today. The first question asks if the user wants a list of the FFT data. The second question asks how many times he wants the fringe data input and averaged before performing the FFT. "OUTPUT" asks if an x or a y detector scan is desired. The next few questions set up the scanning parameters for the x-y scanning stage, and are self-explanatory. At this point the computer takes over and prints out the x and y position of the data plate in the x-y translation stage, the calculated value for the frequency of the fringes, and a "LIST," which is merely a listing of the Fourier Transform of the averaged data, so as to determine if the calculated frequency agrees with the Transform data.

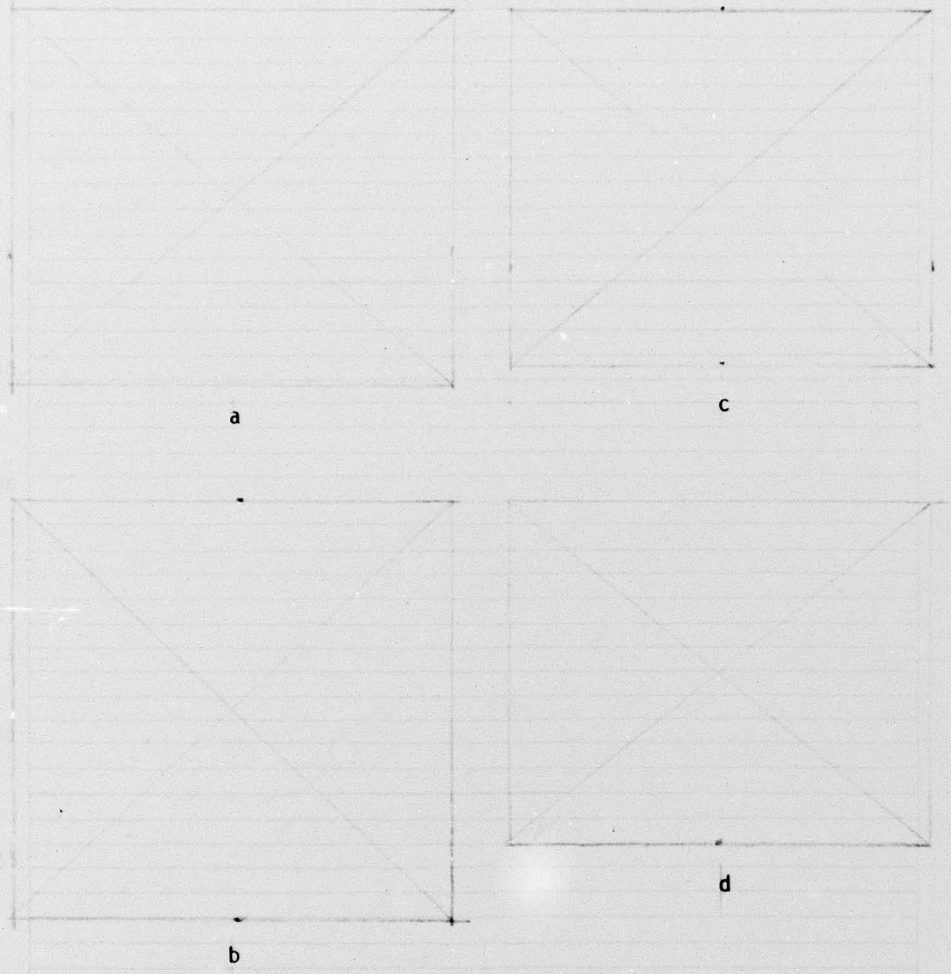
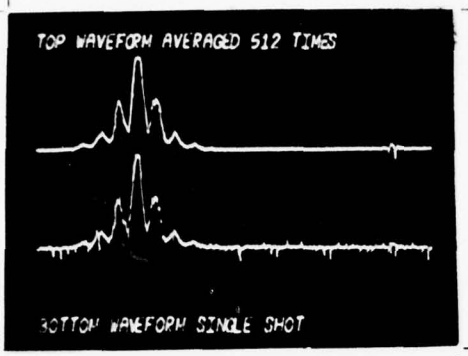
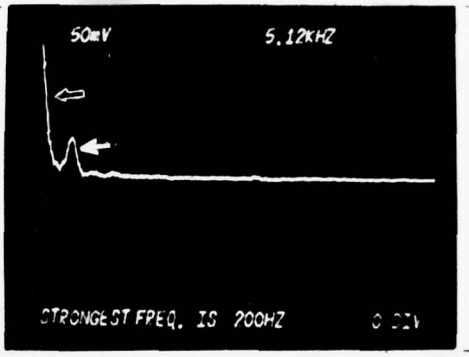


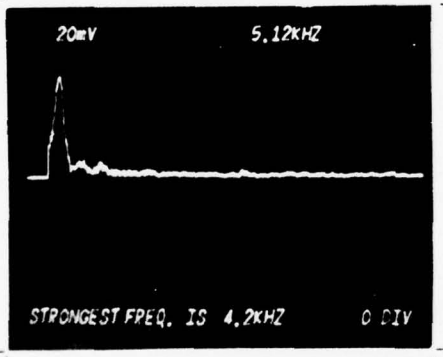
Figure 23. Sample Data Analyzed With Hardware FFT



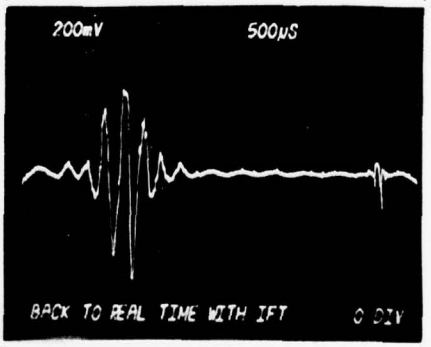
a



b



c



d

FIGURE 23. SAMPLE DATA ANALYZED WITH HARDWARE FFT

BEST AVAILABLE COPY

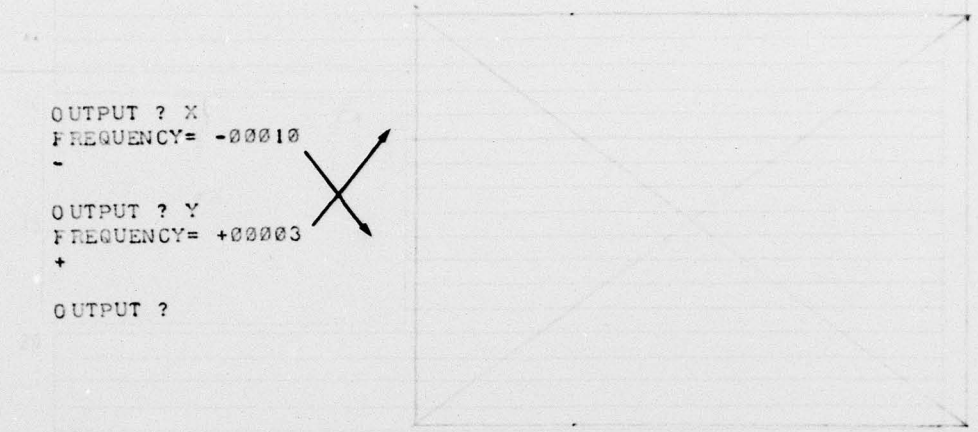


Figure 24. Data With Software FFT

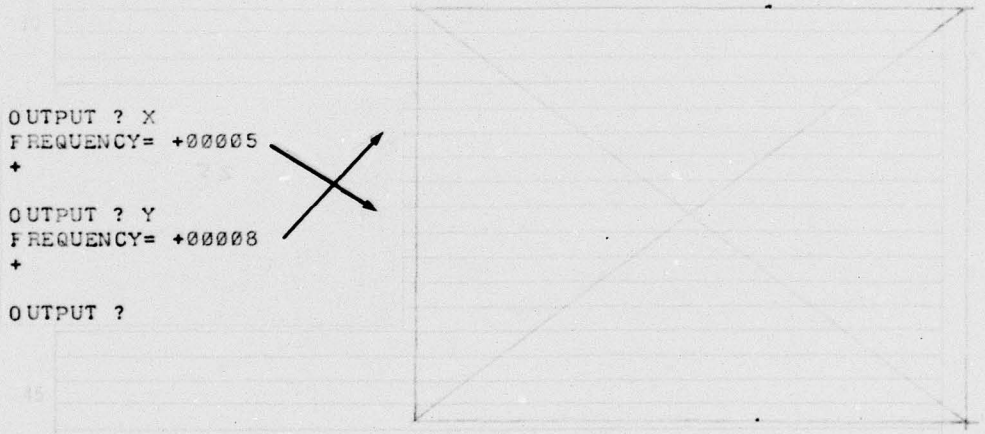


Figure 25. Data With Software FFT

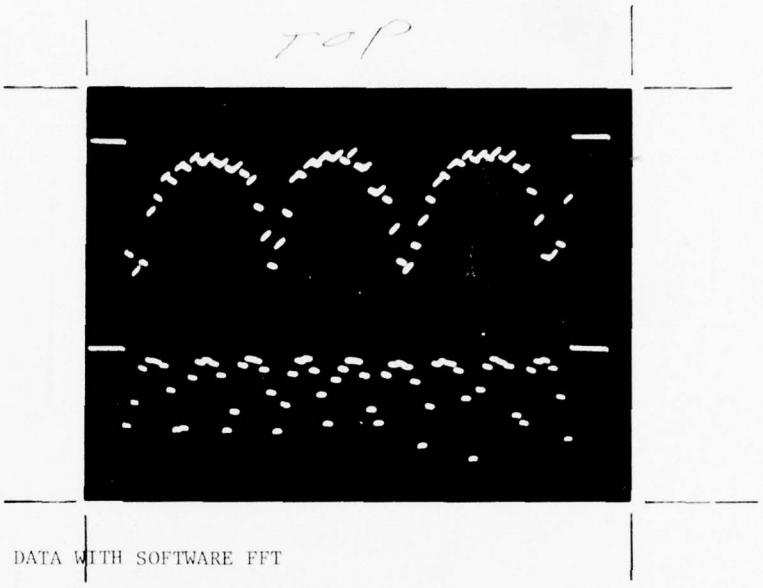


FIGURE 24. DATA WITH SOFTWARE FFT

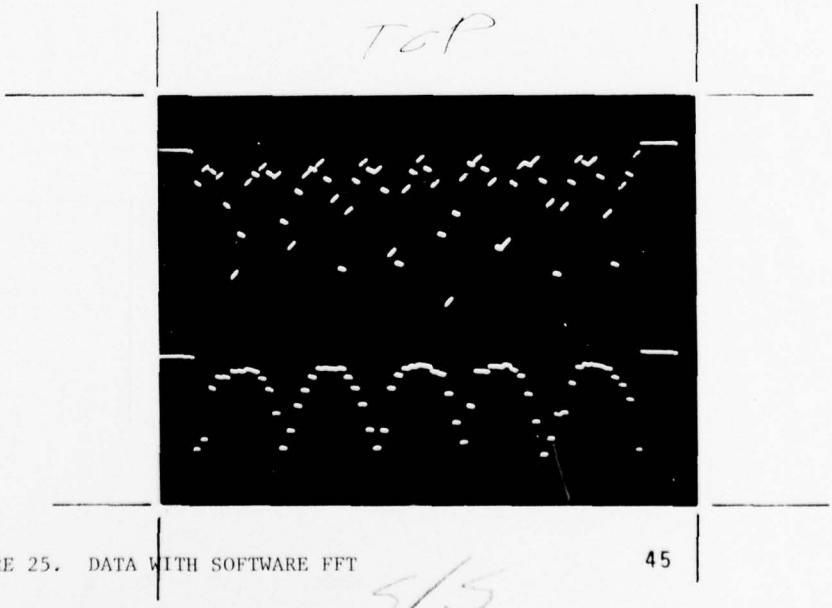


FIGURE 25. DATA WITH SOFTWARE FFT

BEST AVAILABLE COPY

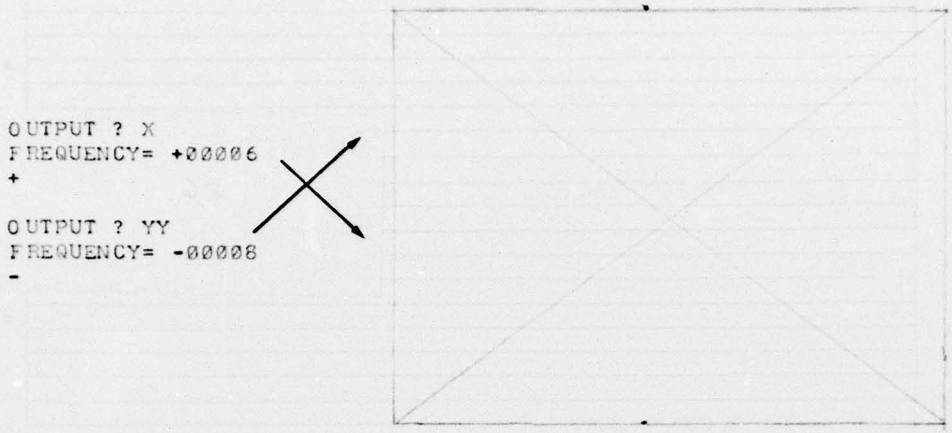


Figure 26. Data With Software FFT

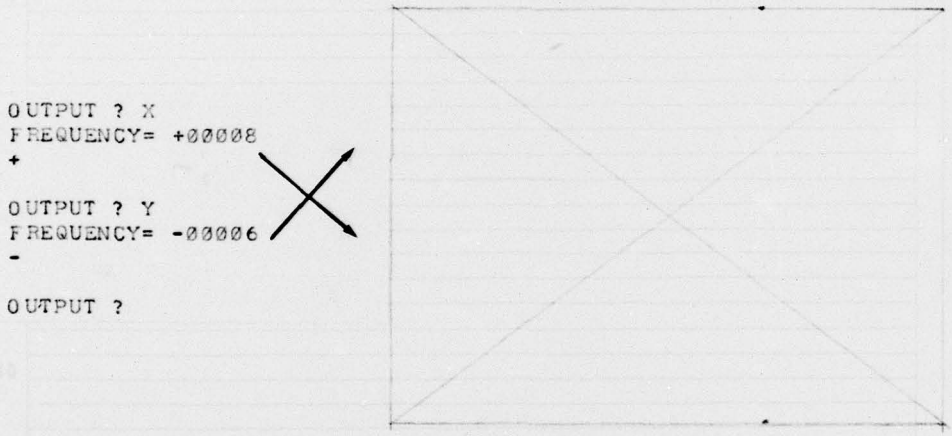


Figure 27. Data With Software FFT

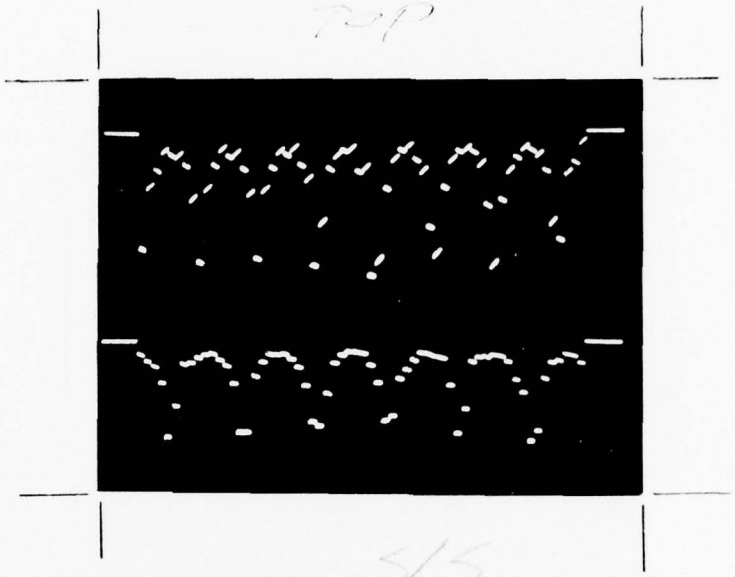


FIGURE 26. DATA WITH SOFTWARE FFT

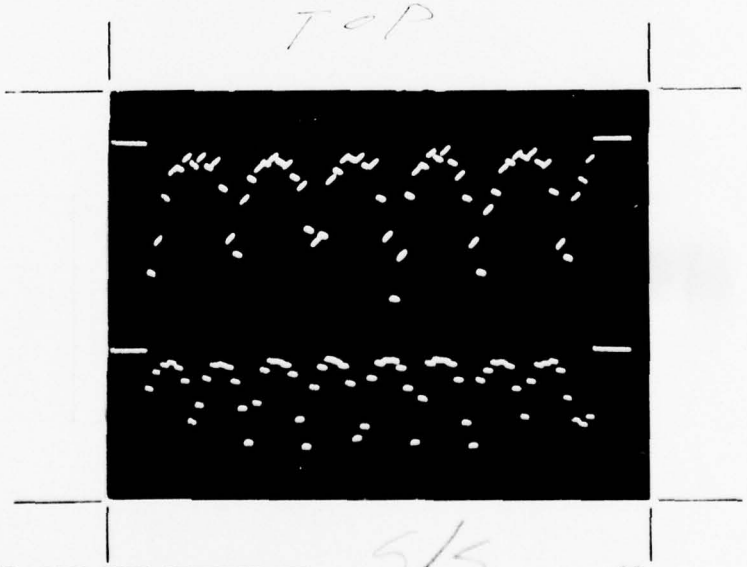


FIGURE 27 DATA WITH SOFTWARE FFT

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FIG-26+27
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BEST AVAILABLE COPY

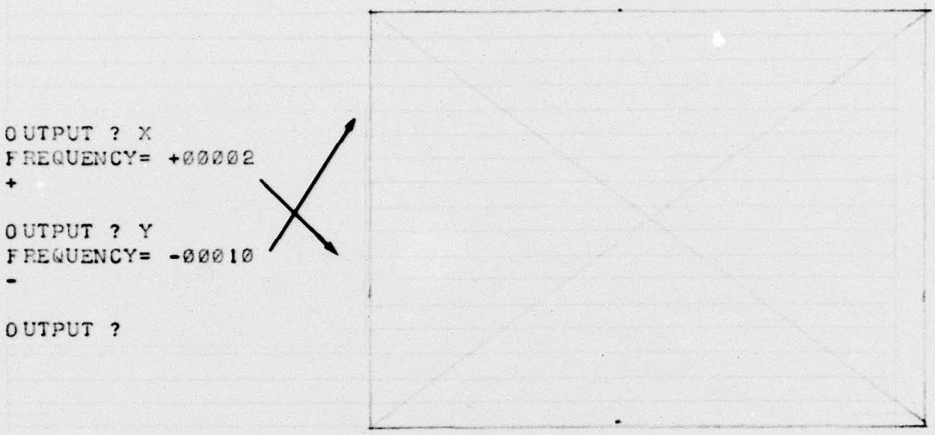


Figure 28. Data With Software FFT

LISTED ? Y

NO.# DATA AVERAGES , 1

OUTPUT ? Y

X-TOT SCAN DISTANCE ? , 1000

Y-TOT SCAN DISTANCE ? , 300

X-INCREMENT ? , 200

Y-INCREMENT ? , 100

X	Y	FREQ	LIST
00200	00000	LOW	226,001,001,001,005,001,002,001, 001,001,001,000,004,000,001,
00400	00000	0002	122,025,002,000,002,001,002,000, 001,000,001,000,004,000,001,
00600	00000	0007	065,009,010,000,001,001,026,009, 001,000,002,001,001,001,000,
00800	00000	0008	065,001,002,001,001,000,002,009, 001,001,002,000,001,000,000,
01000	00000	0007	050,001,001,004,001,001,005,004, 004,000,001,001,001,000,004,
00000	00100	LOW	200,004,001,004,001,001,002,000, 000,001,001,000,005,000,000,
00200	00100	LOW	197,000,001,001,002,000,001,001, 004,000,002,001,004,000,001,
00400	00100	0002	170,025,001,000,002,001,002,000, 001,001,005,000,001,000,001,
00600	00100	0007	050,001,001,004,001,009,037,000, 005,000,000,001,001,000,001,
00800	00100	0005	065,001,005,001,017,001,005,001, 005,000,002,001,001,001,001,
01000	00100	0006	050,004,002,001,002,009,005,004, 005,001,005,000,005,000,001,
00000	00200	LOW	122,002,002,001,002,001,002,001, 004,002,001,000,004,000,001,
00200	00200	LOW	170,005,001,001,002,001,000,001, 005,002,004,001,001,000,001,
00400	00200	LOW	170,004,001,000,002,001,002,001, 001,000,002,000,000,000,001,
00600	00200	0005	085,004,001,001,017,016,002,001, 002,000,005,000,001,001,000,
00800	00200	0006	082,001,005,000,005,025,001,000, 005,001,005,000,000,001,001,
01000	00200	0007	082,001,002,004,001,000,009,001, 004,001,000,004,004,000,001,
00000	00300	0011	082,004,005,000,001,001,001,001, 001,000,005,000,001,001,000,

Figure 29. Finalized Data Run. Sample

Figure 30: a-r gives a comparison between the data incident on the detector and the data plots from the exit lines of the scanning detector, monitored on an oscilloscope. The top line of each plot is a detector scan in the x-direction and the bottom plot is a detector scan in the y-direction. It is left to the reader to interpret the results.

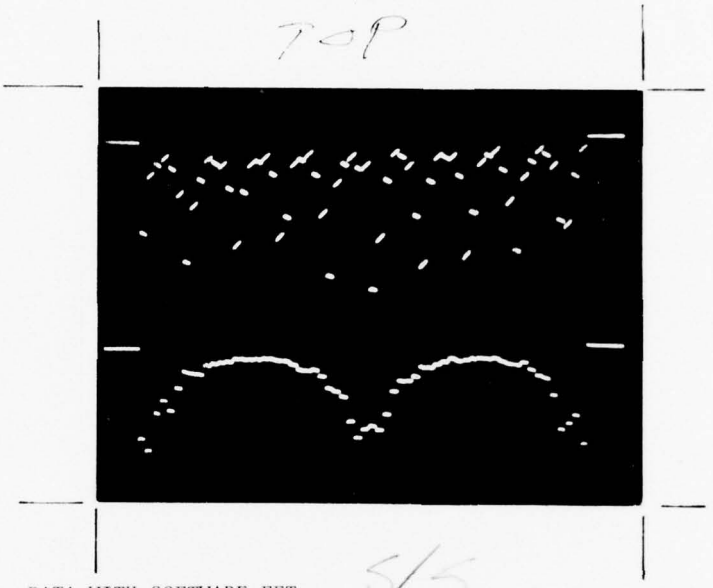


FIGURE 28. DATA WITH SOFTWARE FFT

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FIG-28
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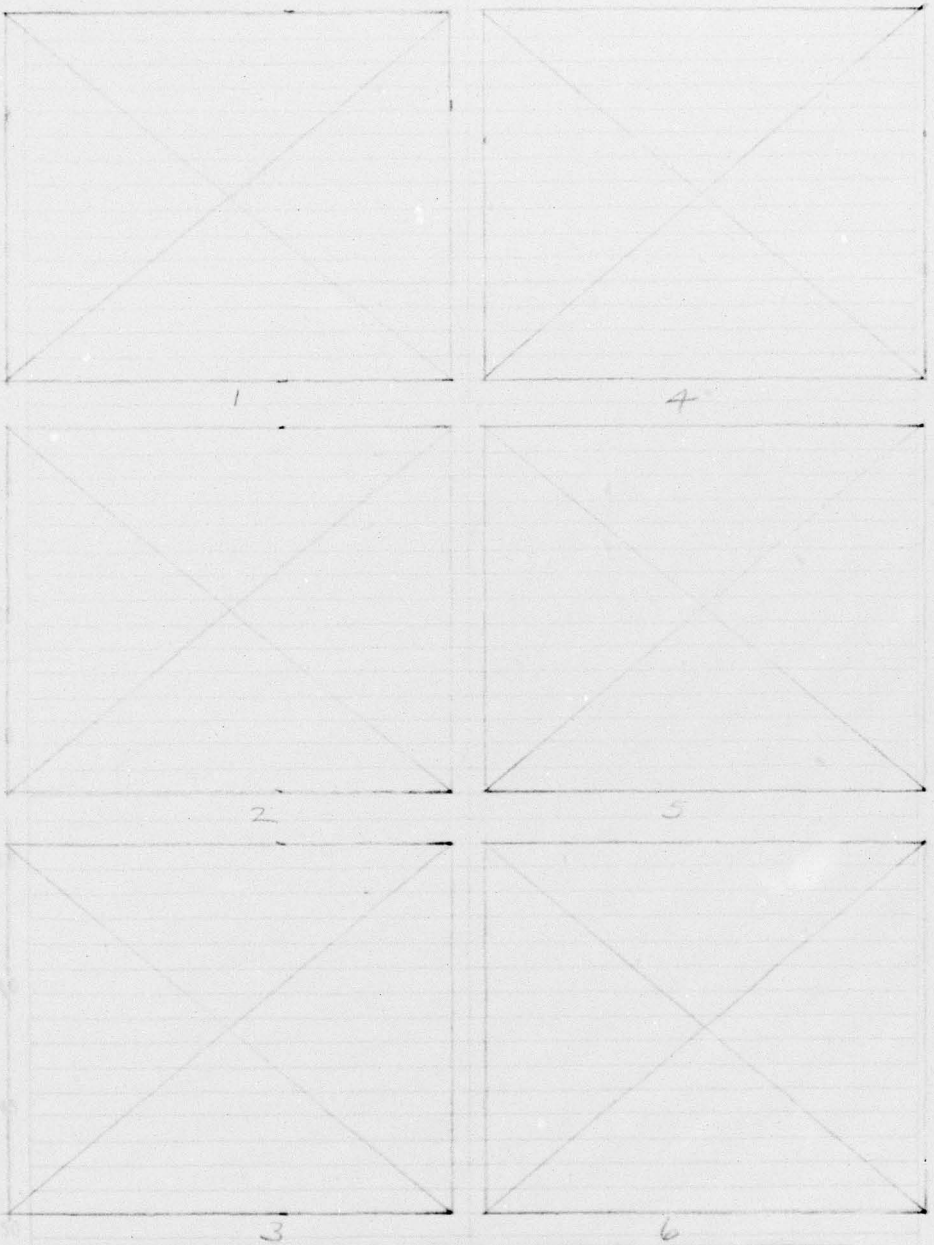


Figure 30 (a-c). Real Data With Different Specklegram Outputs

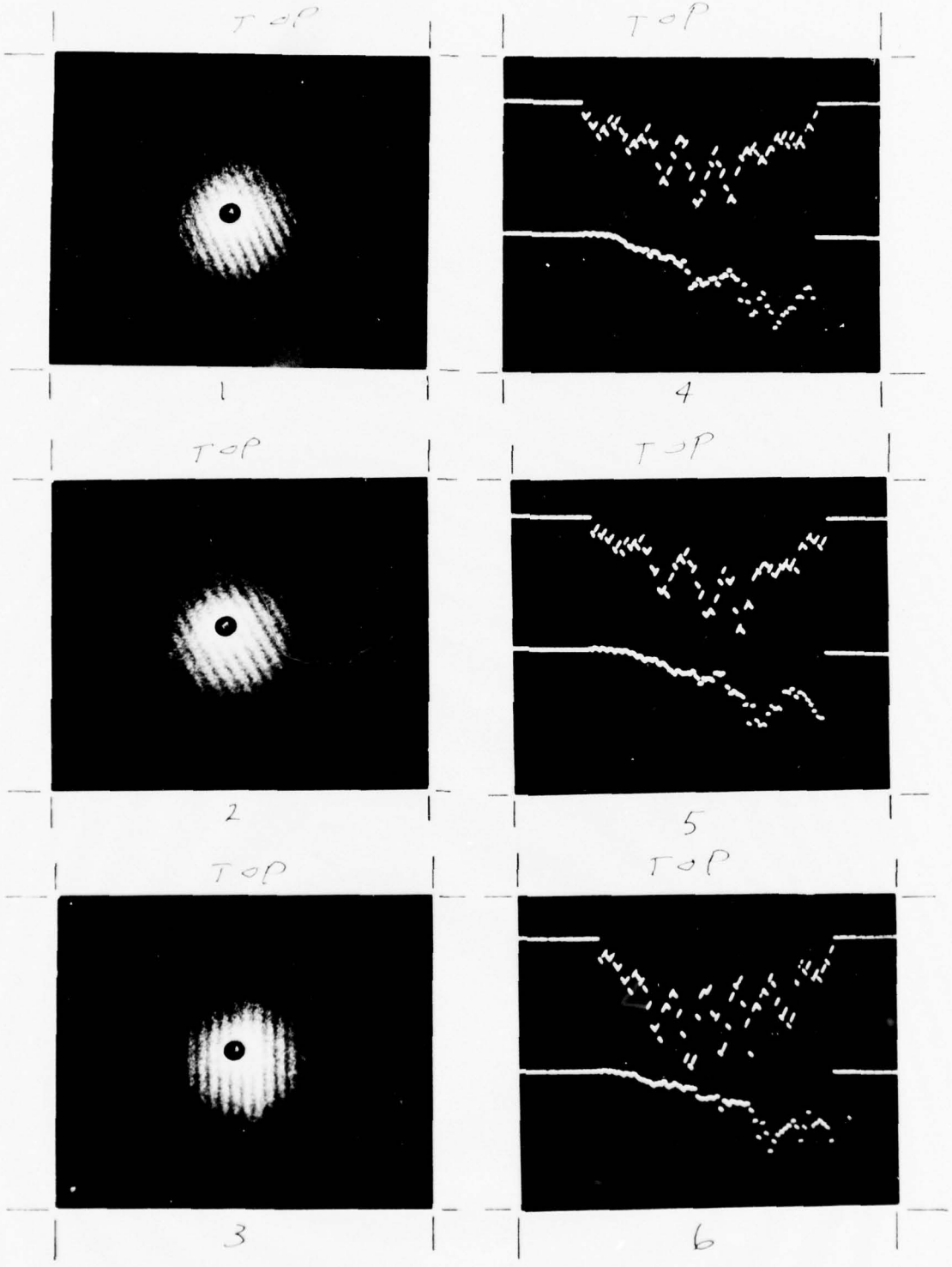


FIGURE 30. a - c

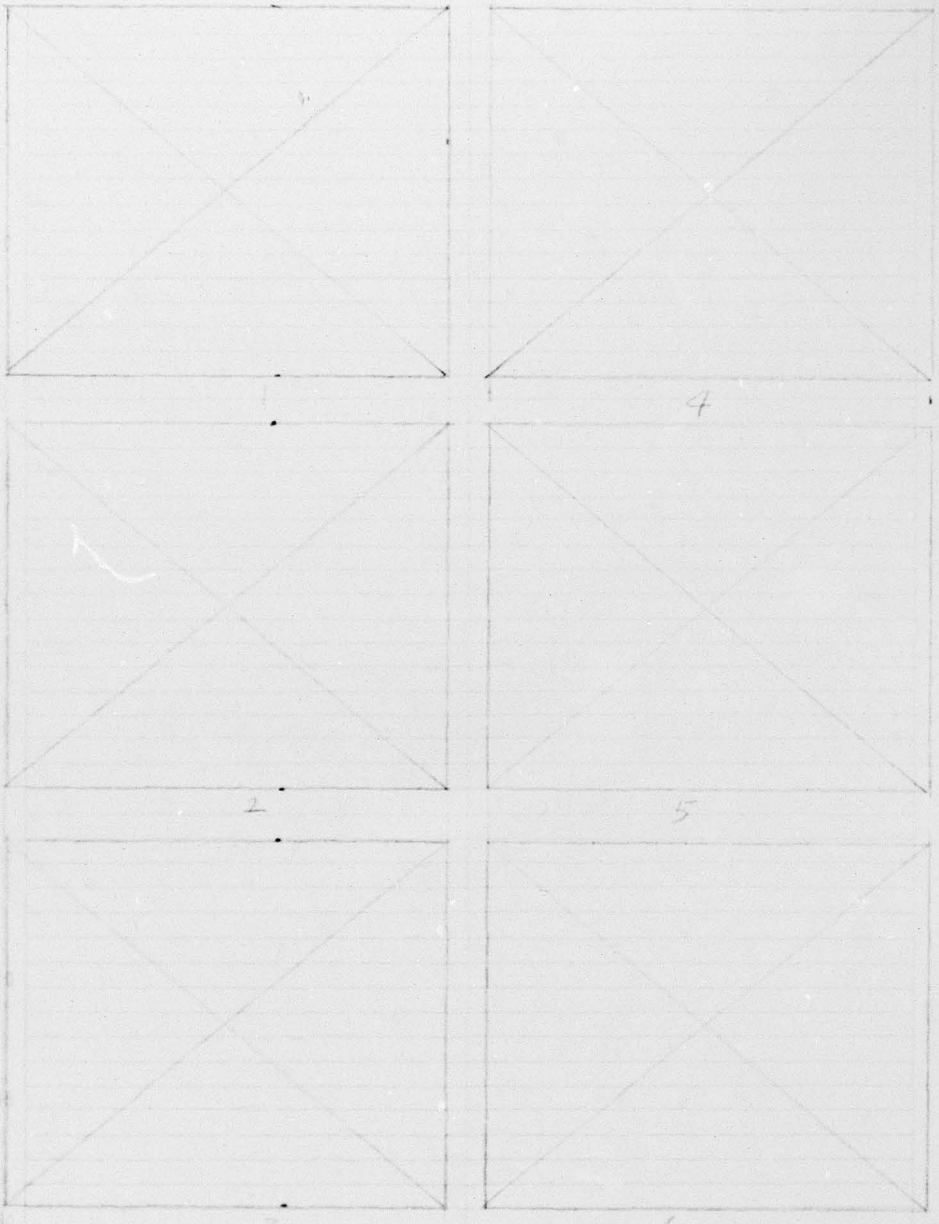


Figure 30 (d-f). Real Data With Different Specklegram Outputs

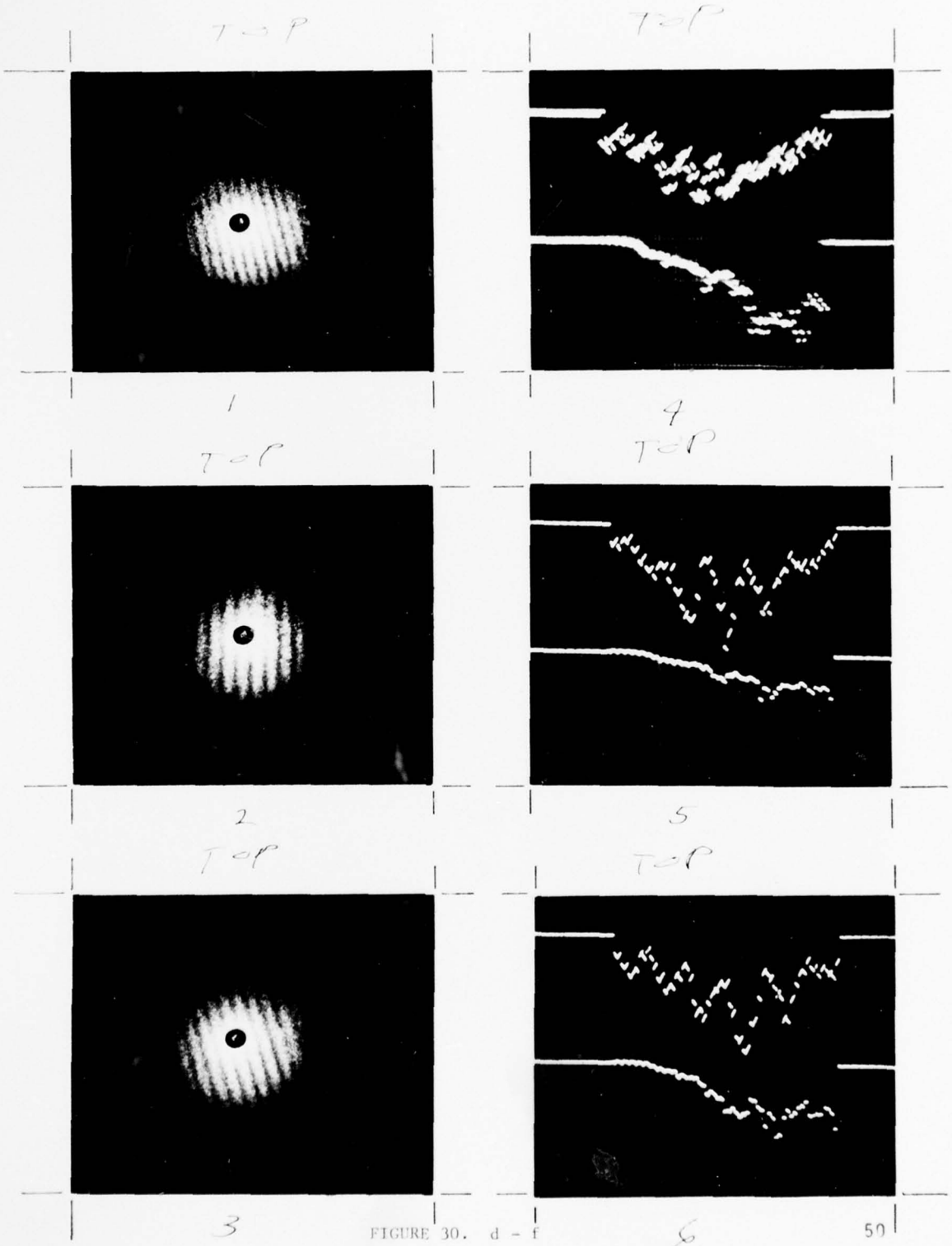


FIGURE 30. d - f

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HFHL-TR-77-203
Fig- 30. d-f
Pg-5-49

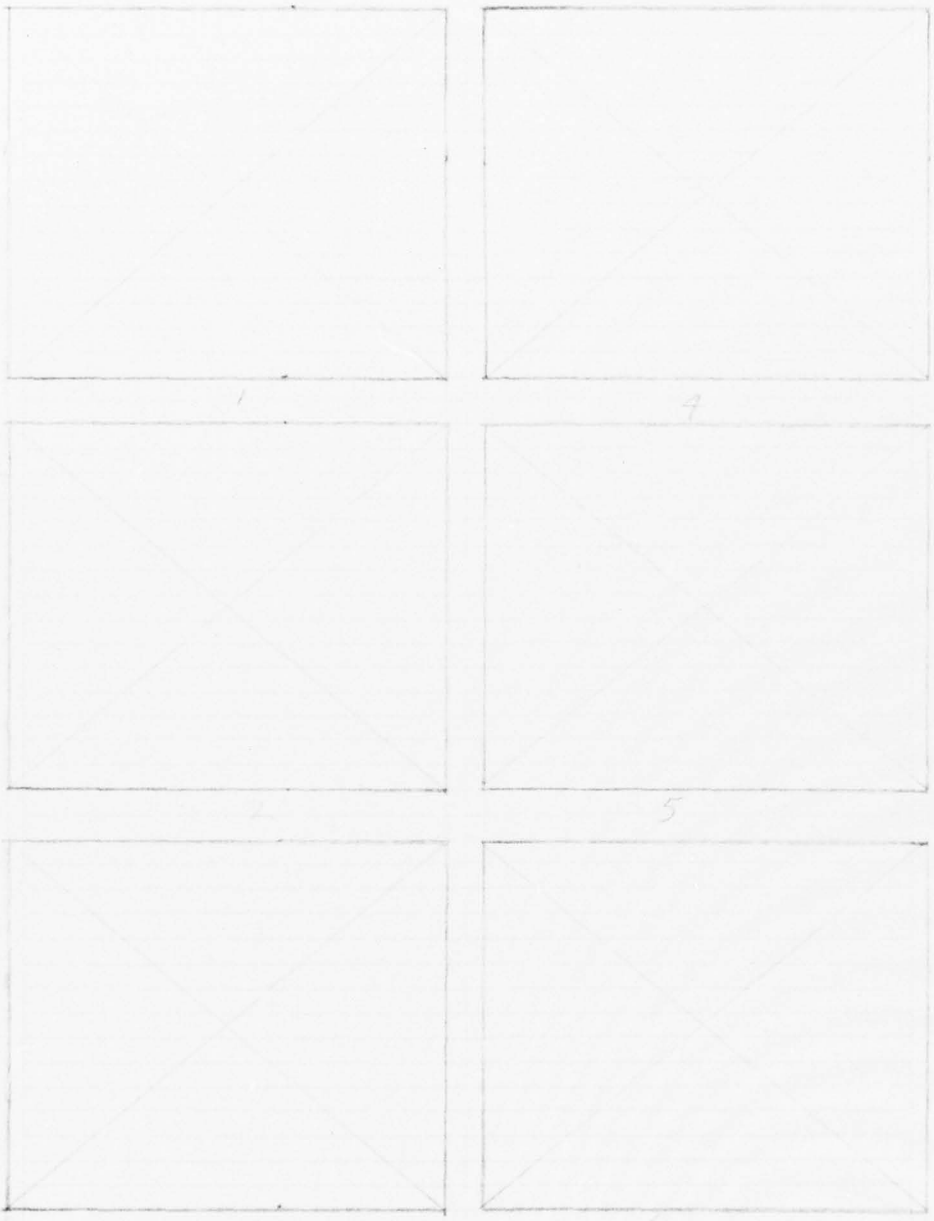


Figure 30 (g-i). Real Data With Different Specklegram Outputs

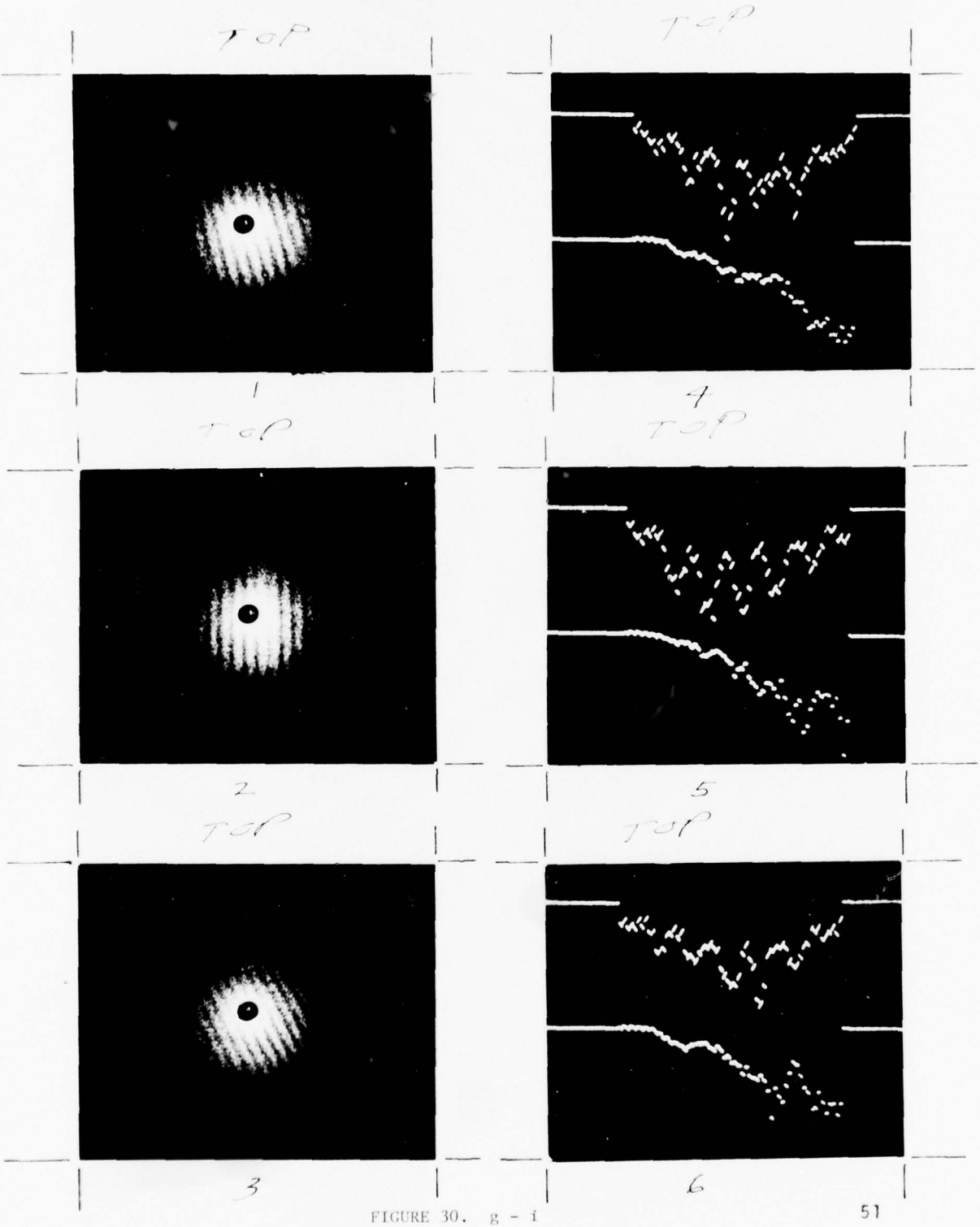


FIGURE 30. g - i

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FIG-30. g-i
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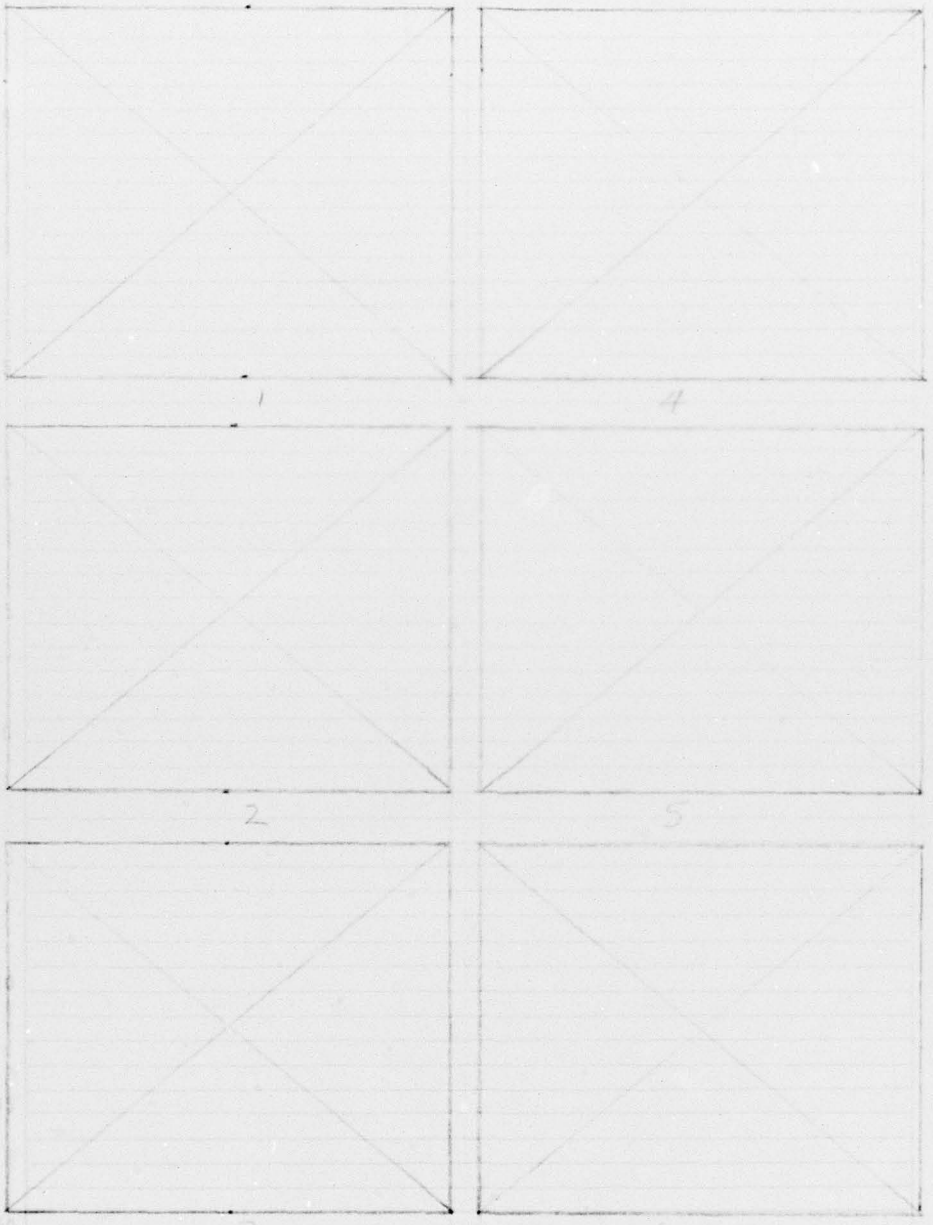


Figure 30 (j-1). Real Data With Different Specklegram Outputs

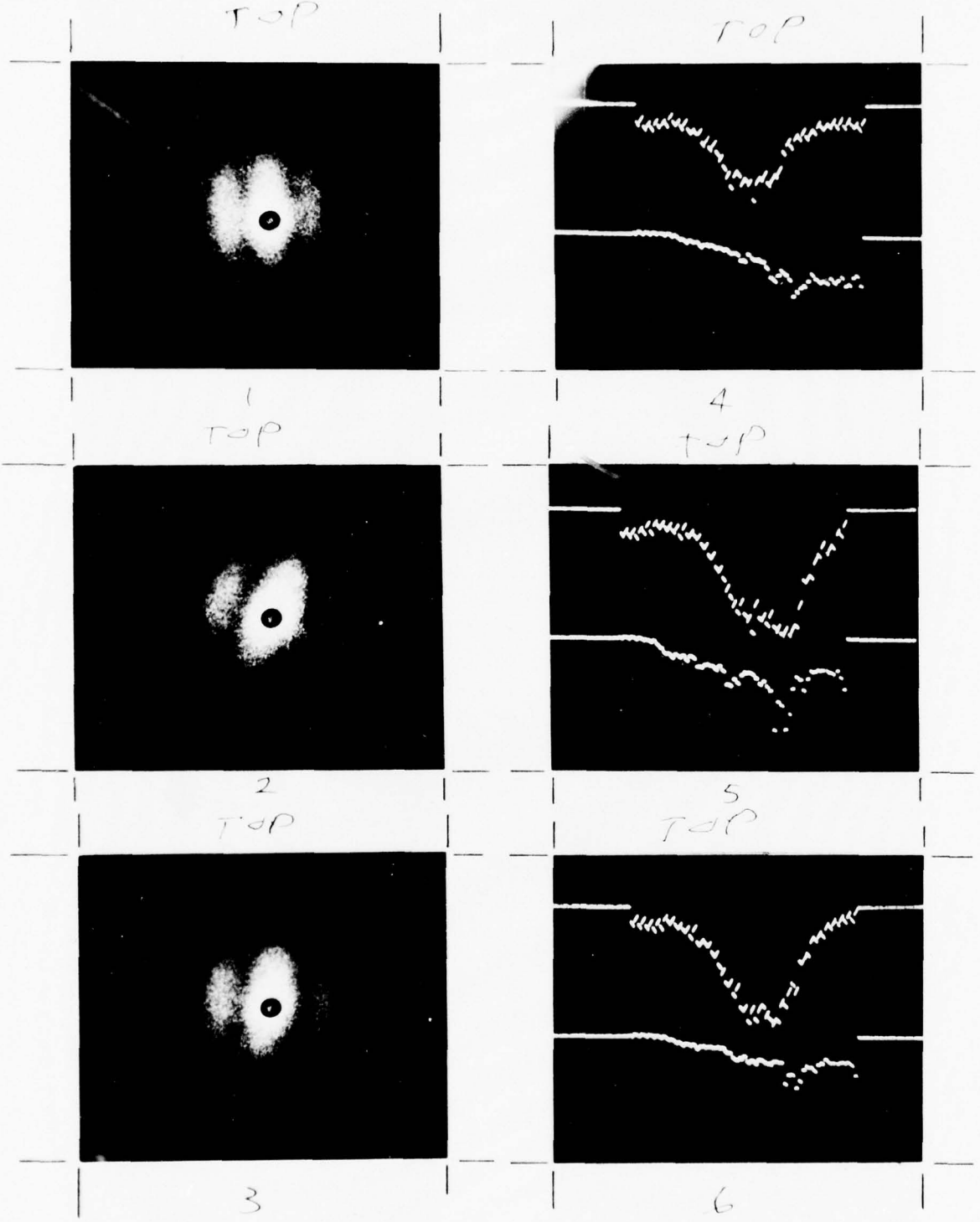


FIGURE 30. j - 1

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FIG- 30. J-1

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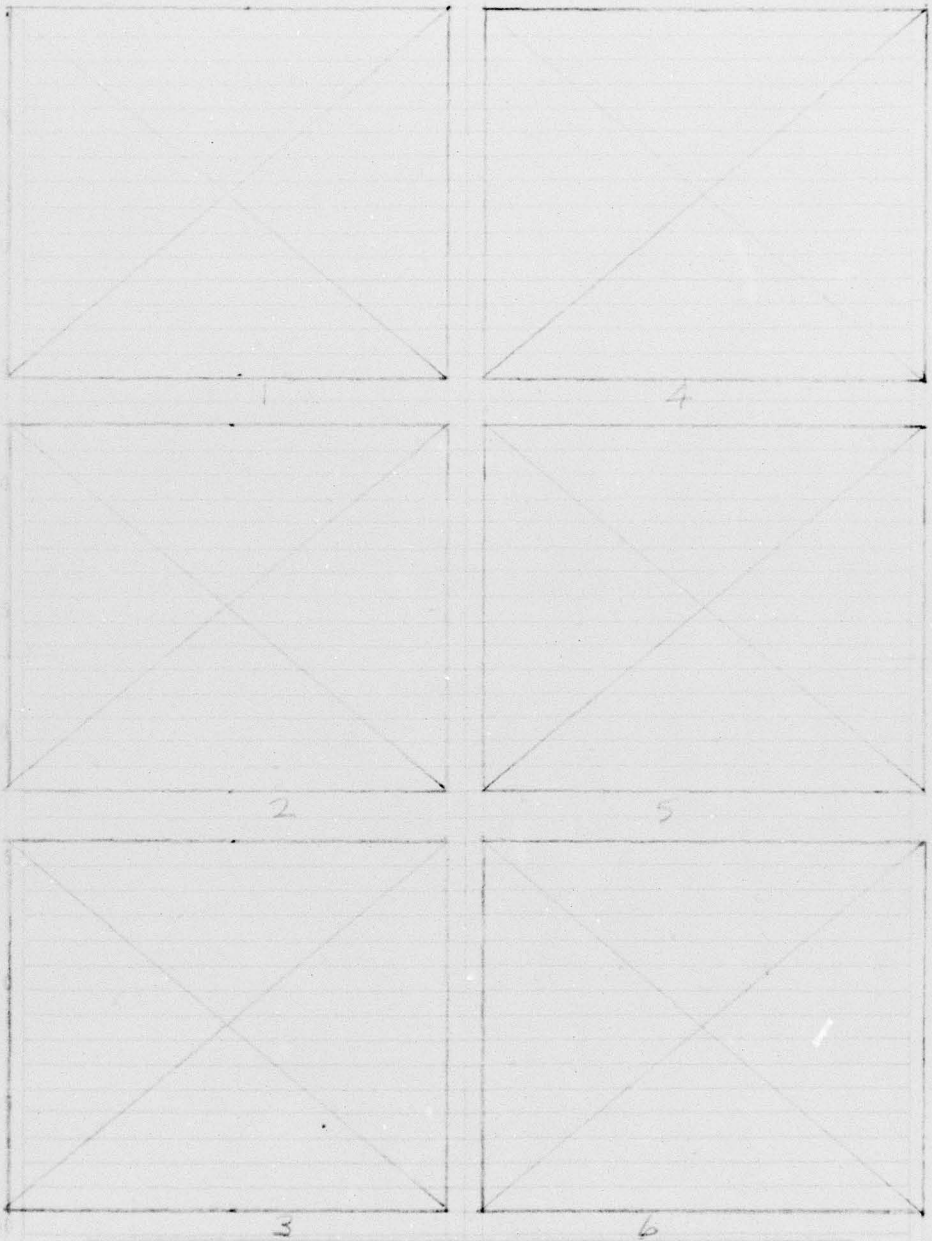


Figure 30 (m-o). Real Data With Different Specklegram Outputs

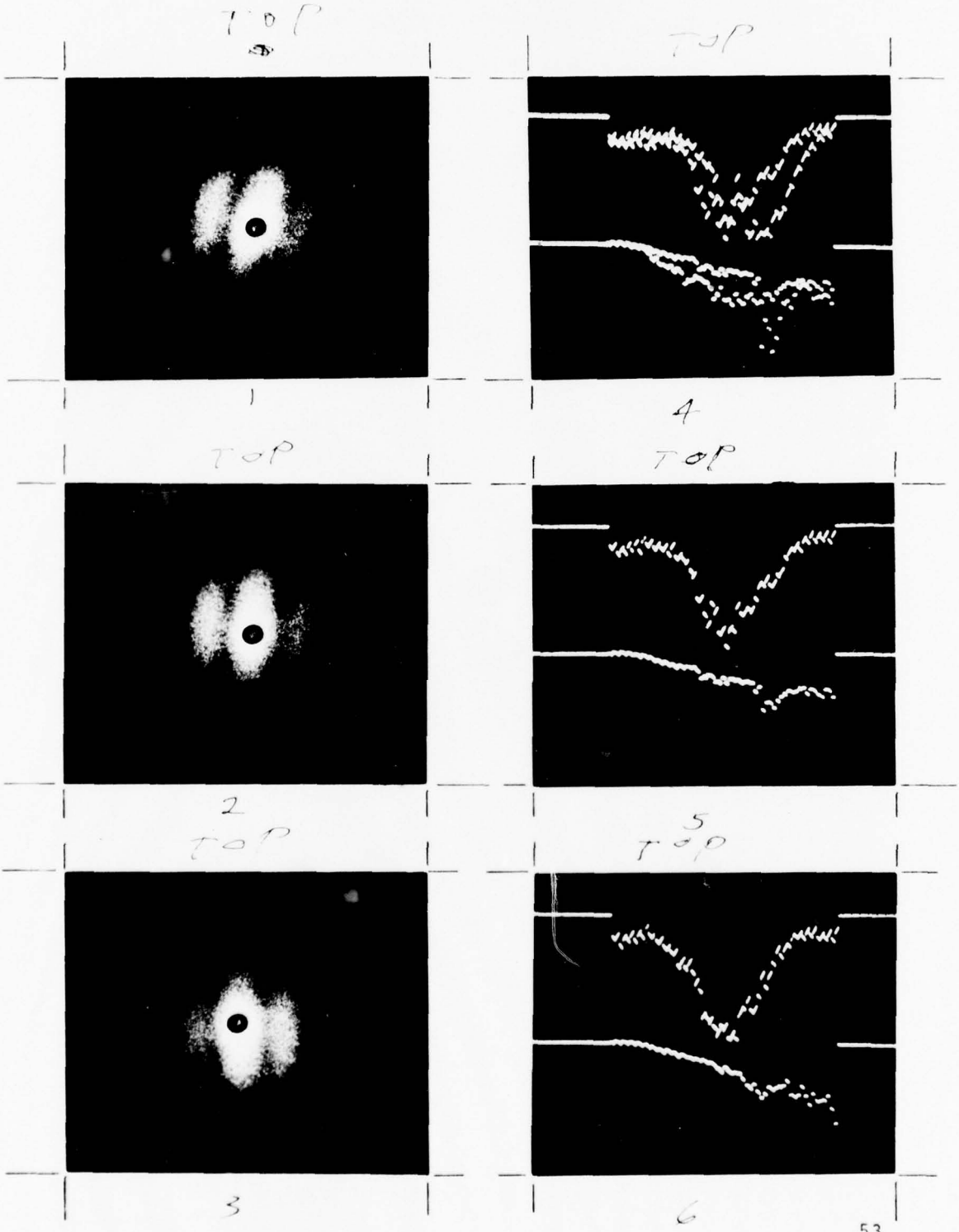


FIGURE 30. m - o

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ARRL-TR-77-203
FIG-30. m-o

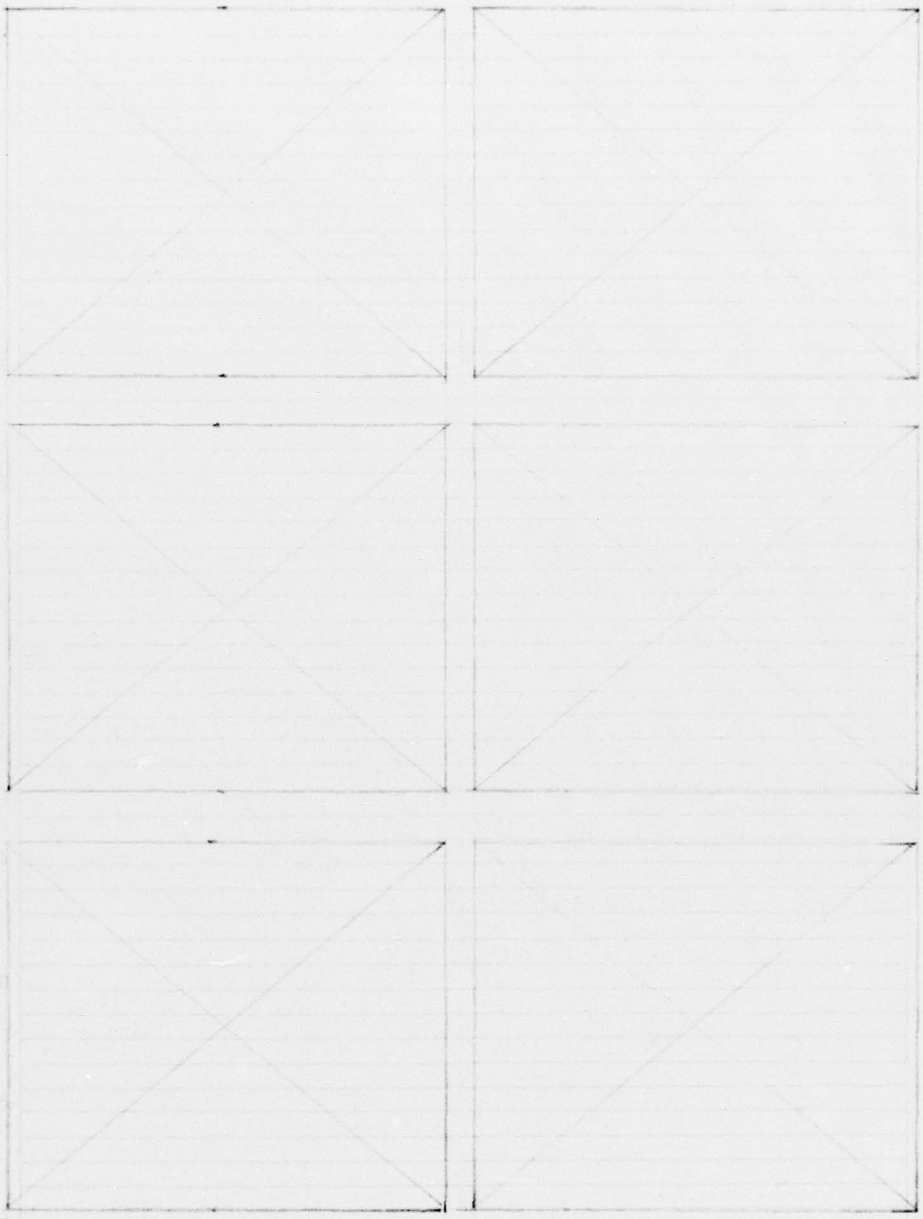


Figure 30 (p-r). Real Data With Different Specklegram Outputs

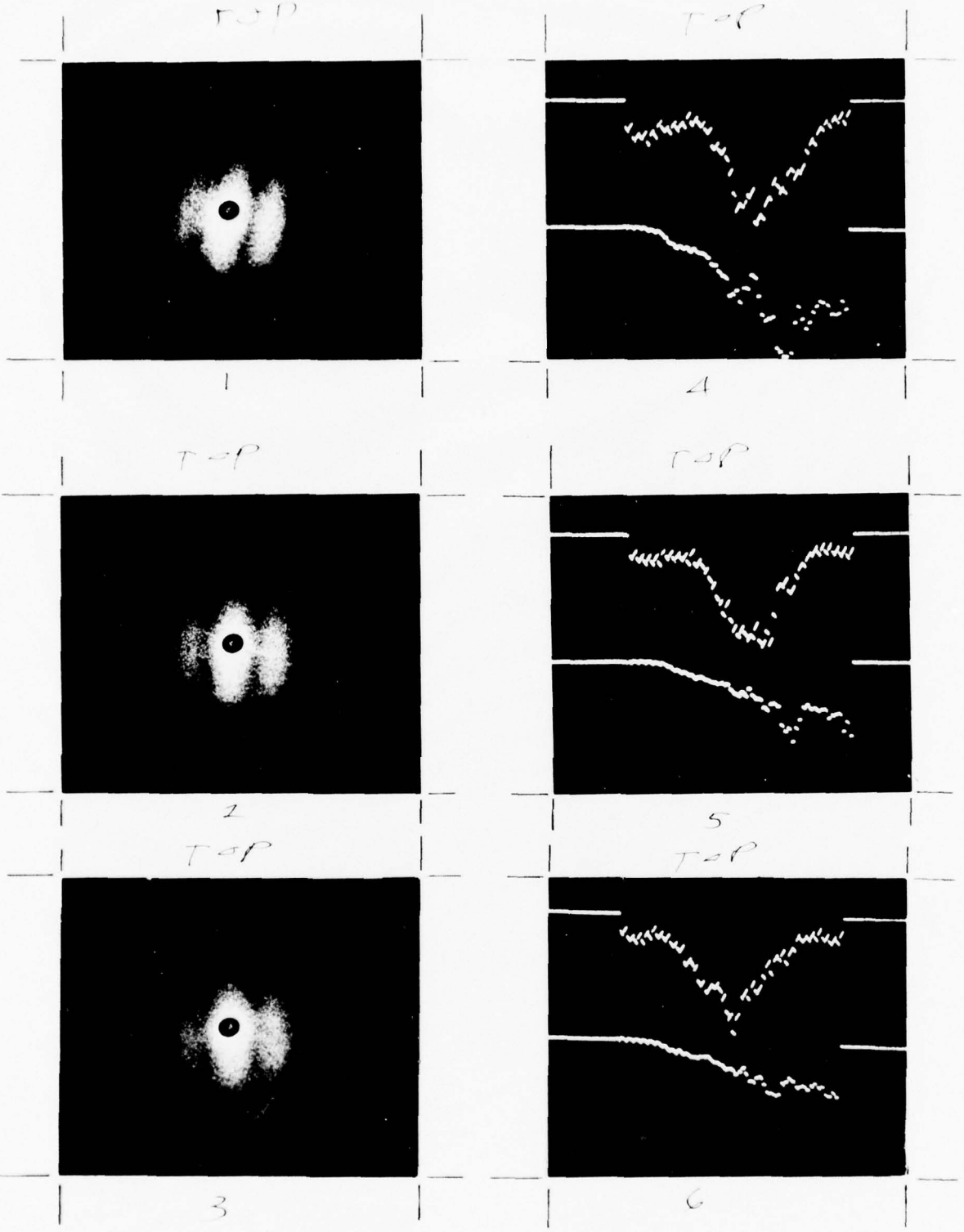


FIGURE 30. p - r

ALL 5/5
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Fig- 30. p-r
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SECTION VII

RESULTS

The results, although they did not meet the original requirements, produced some meaningful information as well as some aid toward development of a system to solve some of the problems of specklegram readout for the Air Force Flight Dynamics Laboratory.

The discussion that follows in this section pertains only to the system as it exists in its present state of development, directing itself in a time ordered fashion from the program beginning to now.

Much time was spent at the start in generating the correct electronics control signals, through the specially built logic circuitry, for activating the x-y stepping stage and the two dimensional detector array. Many capacitor and resistor changes were experimentally adjusted to allow the proper amplitude and pulse widths of the driving pulses required to operate these peripheral units optimumly.

Almost fifty hours of machine shop time was required to build the hardware to integrate much of the equipment. For instance, a specklegram holder had to be built for mounting to the x-y stage, a base was constructed to mount the x-y stage to the optical bench, a base was built for mounting the detector, and some special hardware was constructed for rack mounting the electrical circuitry and labeling the faceplate.

The system was then assembled and checked out in its final form as satisfactory and operable.

The software required most of the time from this point on. Each subroutine discussed in the software section of this report was written and rewritten until a final workable program was achieved. The data analysis section of the software program was written in two different forms: 1.) peak detection, 2.) Fast Fourier Transform. Essentially all the software for the peak detection was thrown out after it was determined to be inadequate for data analysis. Nearly all of the software progressions for both methods will be available at the contract close-out time.

SECTION VIII

CONCLUSIONS

In this section, I would like to discuss the present capability of the final system and also interject some possible solutions toward establishing a more accurate and feasible system for carrying out the initial objectives laid out for this project.

It appears that most of the objectives such as data analysis speed, automatic data input with .001-inch accuracy, and fringe angle and spacing determined by nonmechanical means, have been achieved with relatively few problems. It has been demonstrated that: 1.) a data analysis rate of 1-2 Hz is feasible in the existing software system; 2.) a .001-inch accuracy of stepping positions can be achieved under computer control at the above data analysis rate; and 3.) the detector shceme of two orthogonal linear arrays allows for the determination of angle and displacement completely independent of the fringe orientation on the detectors.

After completion of the software preliminaries and a checkout of the FFT portion of the computer program, some of the specklegram data furnished by Flight Dynamics Laboratory, was introduced for initial tests. During the testing period, various optical configuration changes were made such as varying the size of the readout laser beam and changing the image size of the specklegram fringes on the detector faces, which compensate for noise and detector optimization respectively. It was found that a beam size of approximately .25 mm was optimum to give maximum fringe contrast yet not cause too high a noise level due to large secondary speckle. It was also determined that an image size about 1-1/4 times the detector length utilized the detectors to their fullest, maintaining the best ratio between number of detectors per fringe and number of fringes per detector. For example, if 15 fringes were present across the complete halo, then approximately 12 fringes would be imaged across the 64 detector elements; thus there would be 5-1/3 detectors per fringe. For a low number of fringes (5) there would be 4 fringes projected onto the detectors thus 16 detectors per fringe.

The best results that could be obtained from the 15 fringe case would be to the nearest fourth of a fringe but since noise and other experimental errors are present, only about 1 fringe resolution can be obtained. For the case of 5 fringes in the projected halo, about a quarter of a fringe resolution is possible. The system, as it exists in its present state, can analyze data at a 2-3 point per second rate with a very low resolution accuracy.

Some thought has gone into methods of improving the system resolution which appears to be the main problem at the present time, without any major change in the overall system configuration.

The first thought which came to mind was to try to reduce the secondary speckle noise without changing the fringe resolution of the output data. Two methods of in-house experimentation are going to be performed for solving this problem. The first will be to slightly misdirect, at a high fringe rate, the readout laser beam in an optical system where the image plane is held stationary. This could be performed with a motor driven rotating wedge. The second method would be to project the output fringe pattern onto a liquid crystal dynamic diffuser, which acts as a random phase medium that is electrically controlled. A surface of this type would tend to shift the secondary speckle a small amount in a random fashion at a rapid rate. In both the above mentioned methods, the secondary speckle noise would be minimized by taking several detector scan data samples and averaging them digitally over a short period of time. This process could be done with a small amount of modification to the existing system.

Another way of analyzing the specklegram data that will be considered, uses the optical fourier transform. By using either the rotating wedge or the diffuser as a noise reduction scheme, an optical system consisting of a laser, specklegram, diffuser, fourier transform lens, D.C. Block, and appropriate detector could perform the equivalency of the digital fast fourier transform operation, in an optical train with an essentially zero time frame, thus eliminating one large time consuming aspect of the present method.

All of the above techniques are being considered in-house under project 2001-02-42 of AFAL/DHO-2. If any of the methods prove feasible then further experimentation could be performed by Flight Dynamics Laboratory approval.

APPENDIX I

A FEASIBILITY STUDY OF AUTOMATIC FRINGE COUNTING TECHNIQUES

13 November 1973

By C. Richard Lane

BACKGROUND:

As a result of structural problems associated with the C-5 aircraft, Dr. Lovelace has asked that all laboratories reflect on possible solutions to the problem of monitoring the structural integrity of critical areas on the aircraft. Based on their past experience in the area of non-destructive testing of aircraft structures, Flight Dynamic Laboratory organized an approach to provide such a monitoring system in cooperation with ARL, and AFAL. This work is presently being done under AFFDL work unit 1467-02-12 with Mr. Gene Maddux and Dr. Frank Adams as principal investigators.

The initial approach taken by FDL utilizes the recording of a double exposure speckled image of the area of the structure being monitored, where some strain is introduced between exposures. This double exposed image is then processed to make a transparency. Upon illumination by a small laser beam a set of fringes are projected which represent the correlation of the speckles at that location on the image.

These fringes can be related to the surface motion that took place between the two exposures, the structural integrity at that point.

Although this technique is limited with respect to the size, type, and depth of the flows that it can detect, it provides a good first step and is essential to more complex techniques that have potential of overcoming these limitations.

For each C-5 aircraft a large number of these specklegrams would be required (5,000 - 10,000 if one specklegram were made for each installed wing fastener) and a large number (100 - 1000) of points per specklegram would need to be analyzed. It is, thus, obvious that an automated system is required that will map the surface motion with each specklegram area.

OBJECTIVE:

The objective of the initial in-house effort within AFAL was to investigate techniques of determining the spacing and direction of a projected sample fringe pattern. This investigation included the demonstration of the techniques on a sample specklegram provided by AFFDL.

APPROACH:

As a result of past experience with similar type problems in the area of optical processing and the availability of equipment within AFAL two approaches to the problem were taken. Both approaches required that the fringe pattern be read-in automatically by one of three ways:

a. Scanning point detectors.

b. Electrically scanned linear diode arrays.

c. Electrically scanned 2-dimensional image, dissector tube.

Once the fringe information was detected, two approaches were considered to analyze the fringes and indicate the spacing and direction. The two approaches were:

a. Store the information in a memory unit, then perform a 2-dimensional fast fourier transform (FFT) to determine the spatial frequency component in both magnitude and angle. The FFT was chosen over optical transforming due to the lack of spatial coherence in the speckled fringe pattern.

b. As the information is read-in, perform a peak detection operation and average the peak spacing for scans in two directions. By means of a simple arithmetic operation the maximum spacing and direction were then determined.

Evaluation of both approaches were carried out on the sample provided.

DISCUSSION OF THE 3 DEMONSTRATION TECHNIQUES:

Two of the three demonstrations to be discussed now were done only minimally and were investigated only to the extent of being considered as a possible solution to the fringe counting problem. Although all three demonstrations were capable of providing a solution to the problem, only the third was experimented with to the desired extent. It will also be seen that the 3 demonstrations were similar enough in theory that it can be assumed that if one experiment works then all three, with proper implementation, can serve as a solution. All three techniques have been discussed and demonstrated to: Mr. G. Maddux and Dr. Frank Adams of the Flight Dynamics Laboratory.

1) On 6 August 1973 a sales representative from Tektronix Incorporated accompanied to our lab, a processing oscilloscope being considered for purchase under project 2001-04-10. The sales representative set up the processing system in the lab which consisted of a Model 7704A

oscilloscope with standard scope plug-ins, a Model 7001 Processor, a PDP 11-05, 16K core mini-computer, a CRT display terminal, and a rapid read-write tape punch. The self-scanning detector array was introduced into the system through the oscilloscope inputs. The array, scanning its 512 elements at a 200 Hz rate, was synchronized to the scope such that all 512 elements were displayed on the scope screen in one sweep (5msec). The processor portion of the system then digitizes the data displayed on the scope screen and sends it to the PDP 11 computer along with a command of which software program to implement on the data. The resulting answer can then be displayed by a curve trace on the scope screen or CRT screen of the terminal.

Due to a lack of time and the limited software programs available by the sales representative, only a fast fourier transform program was used to attack the fringe counting problem. The fringes to be measured were imaged on the reticon array and displayed on the scope. By a stroke of luck, the FFT program being demonstrated needed 512 digitized points to perform the transform, exactly the number of detectors in the scanning array. The signal being displayed is now averaged over several scans of the array and then the FFT program is called up and performed on the averaged signal and the result displayed with 512 points on the oscilloscope screen.

Two sets of fringes were experimented upon during the demonstration: An equally spaced set of .05 inch fringes; and a set of fringes generated from a specklegram.

a. Figure 2a shows the fringes imaged on the reticon and averaged 1024 times to eliminate unwanted noise. From the figure there are 21-22 fringes across the 512 elements of data, and multiplying the number of fringes by 200 Hz (the scan rate of the detector), gives the frequency that the computer actually sees.

(1) 21 x 200 = 4200 Hz = 4.2 KHz

(2) 22 x 200 = 4400 Hz = 4.4 KHz

Figure 2b illustrates the fast fourier transform of the signal of Figure 2a, and the strong peak (arrow) is printed out as 4.3 KHz, a reasonable result.

b. Figure 3a is a scope trace of a sample specklegram from FDL, one trace a single sweep and the other a trace averaged 512 times. These two traces illustrate the noise reduction capability of averaging a signal over several traces. This noise reduction factor could prove very necessary if other methods of fringe counting other than FFT, is implemented. The FFT displayed in Figure 3b shows two significant peaks of data relating to the fringe spacing. The peak indicated by the red arrow is a 200 Hz frequency spike representative of the scan rate of the reticon array. This frequency spike is a consequence of the input fringes not filling the entire aperture of the array, thus the synchronizing pulses from the clocking circuit of the array are prominent. If approximately the first 30 registers of the data in Figure 3b are set to zero (200 Hz spike), the strongest frequency then becomes the second spike and this frequency value is printed in Figure 3c with a 50mv to 20 mv vertical scale change. By examination of Figure 3a it should be obvious that 4.2 MHz represents the fringe frequency of major concern. As a simple conclusion, a software programming addition that cancels out the 200 Hz clocking rate would be incorporated and only the desired frequency peak would be predominate. By retransforming the result obtained in Figure 3c, it is seen that the same fringe spacking is preserved after cancellation of the 200 Hz peak (Figure 3d).

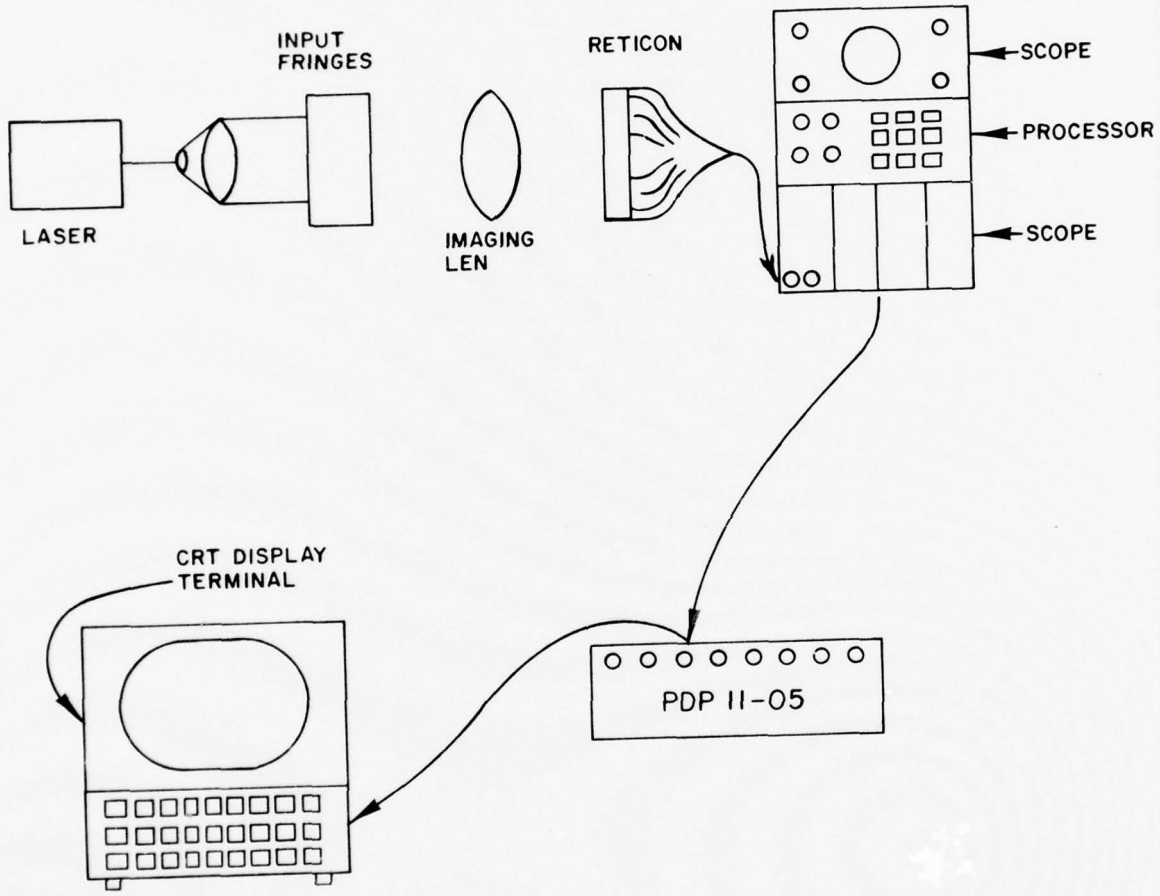

INPUT
FRINGES
RETICON
SCOPE
PROCESSOR
SCOPE
LASER
IMAGING
LEN
CRT DISPLAY
TERMINAL
PDP 11-05

Figure 1a

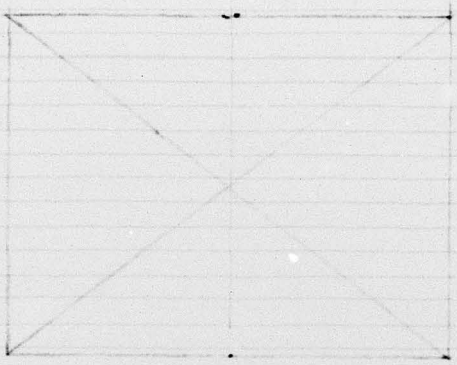


Figure 2a

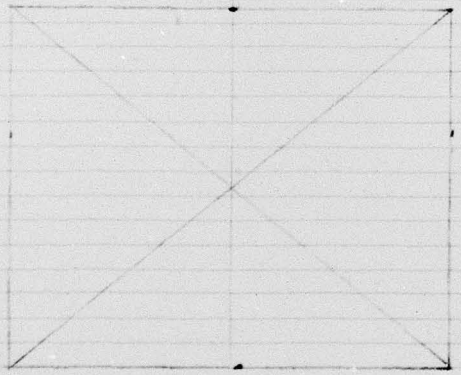


Figure 2b

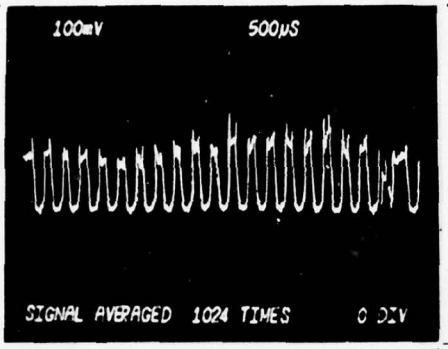


Figure 2a

5/5

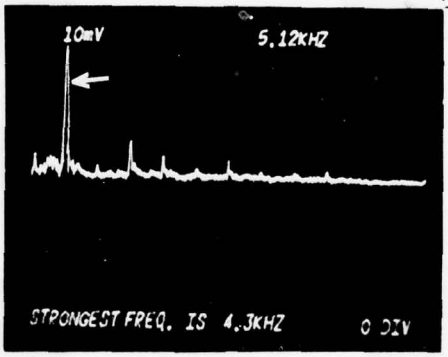


Figure 2b

5/5

AFAL-TR-77-203

FIG-2a+2b

PAGE-65

2) The second method of demonstration will be discussed only briefly since it is similar in procedure to the third demonstration with slightly more sophisticated equipment. Figure 1b shows the basic setup used for this demonstration. The primary difference between this procedure and the first demonstration procedure is that instead of calculating a fast fourier transform with a PDP 11 computer, a counting program was implemented. The program performs an adjacent register comparison to locate peak points and then checks the difference between these peak points. This approach is instrumented by two orthogonal scans across the fringe pattern with an electronically raster scanned image dissector tube. Essentially, the result is an x and y fringe spacing measurement of which an actual fringe spacing may be calculated along with a fringe angle displacement. This procedure will be discussed more thoroughly in the next demonstration. The sole purpose of this experiment was to indicate the feasibility of using an image disector tube for the fringe counting problem.

3) The demonstration to be discussed now utilized equipment already existing in the laboratory of AFAL/TEL and thus was readily available during a longer period of time required for a more thorough investigation. The equipment used and its configuration are illustrated in Figure 1c.

SYSTEM DESCRIPTION:

A laser is used to illuminate a set of fringes at the input plane and an imaging lens projects the fringes onto an x-y scanning aperture. The variable size aperture is scanned by two bi-directional variable speed D.C. motors which are manually started and stopped. The aperture sizes are configured such that the resolution of the system can vary from a small fraction of one fringe down to a single fringe or essentially no resolution. This aperture size variation can be used constructively to reduce noise in the system resulting in less software work and time for the computer to implement at a later stage in the processing. A digital

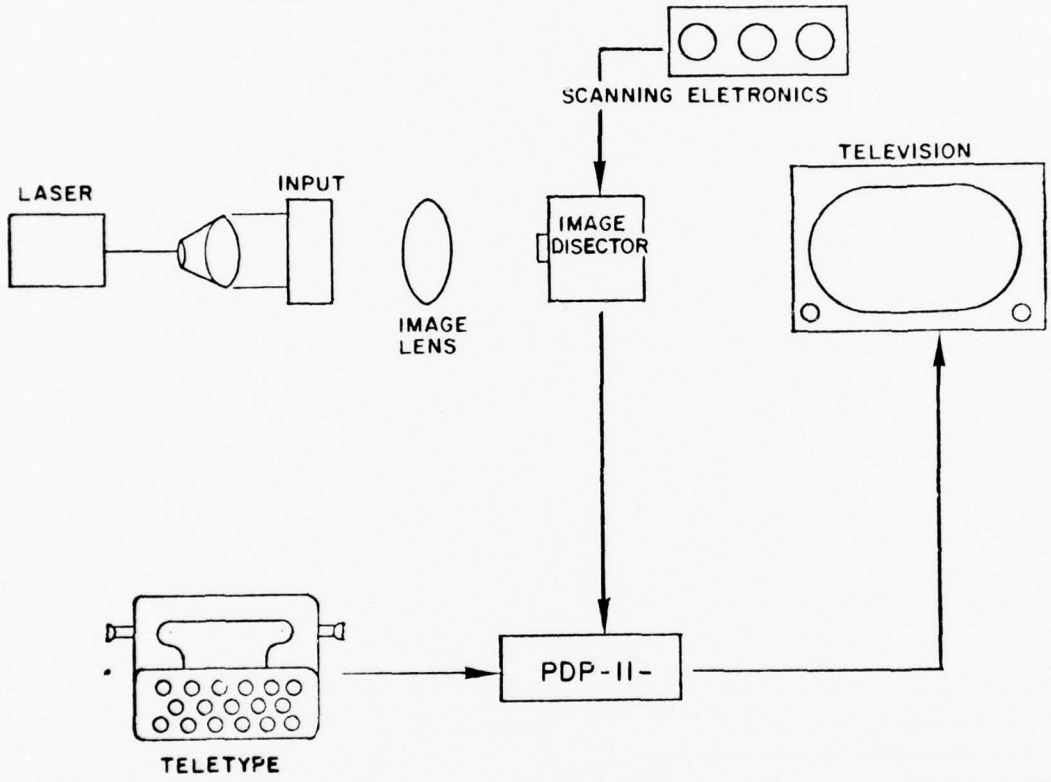

SCANNING ELETRONICS
TELEVISION
LASER
INPUT
IMAGE DISECTOR
IMAGE LENS
PDP-11-
TELETYPE

Figure 1b

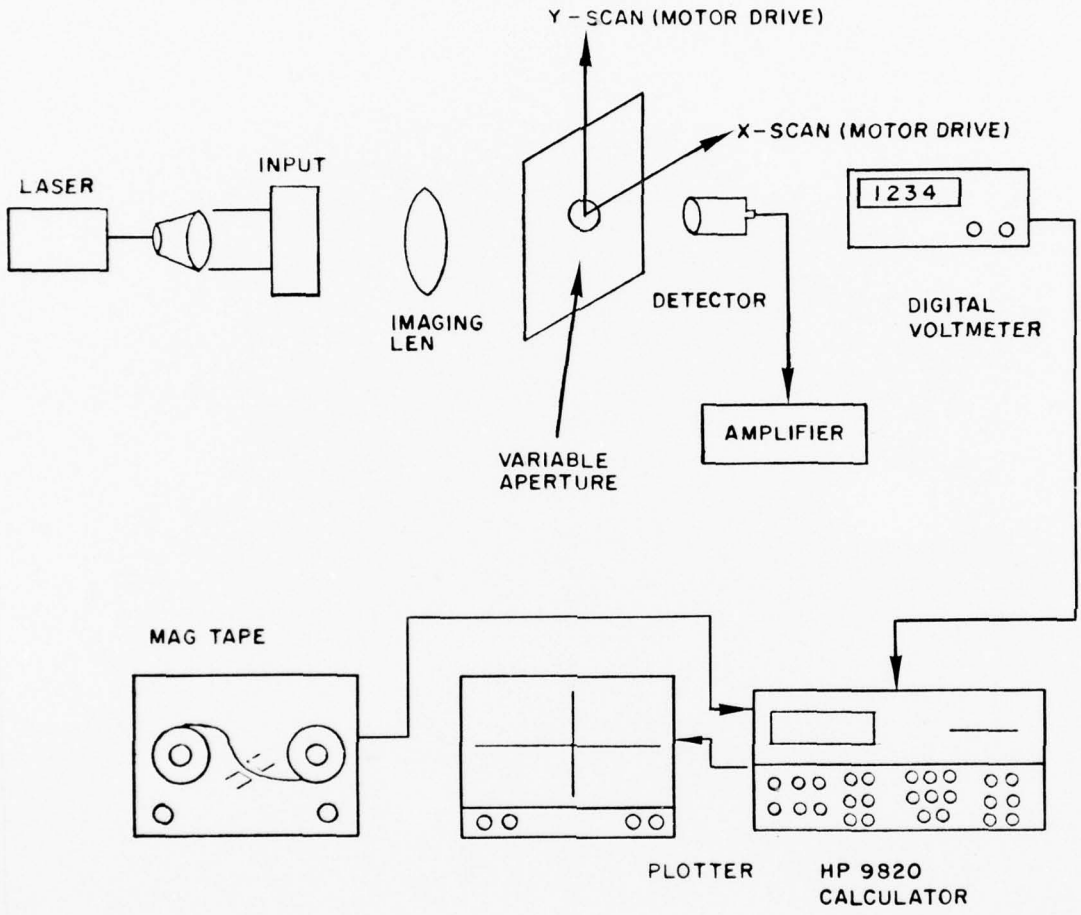

Y - SCAN (MOTOR DRIVE)
X - SCAN (MOTOR DRIVE)
LASER
INPUT
IMAGING LEN
DETECTOR
1234
DIGITAL VOLTMETER
AMPLIFIER
VARIABLE APERTURE
MAG TAPE
PLOTTER
HP 9820 CALCULATOR

Figure 1c

voltmeter is used to pick up the intensity pattern of the fringes and also serves as an analog-to-digital converter that directly interfaces with the Model 9820 Hewlett Packard Calculator. The digital voltmeter and calculator combination is extremely slow for use as a data collector since it operates at a maximum data sampling rate of 3 samples per second. This fact rules out this type of system as a final product to solve the fringe counting problem, although it strongly demonstrates the feasibility of using a similar fringe counting technique with a data reading capability of approximately 4-5 magnitudes greater. A plotter can also be tied directly to the system giving a visual description of the fringe data that the calculator will process.

SAMPLE PROCEDURE:

A good method of examining the procedure used to count the fringes would be to look at Figure 4a, b, and c, which list the calculator program, in some detail.

The first step is to image the fringe pattern onto the scanning aperture plane and position the aperture in the y direction ready to scan across the complete fringe pattern.

By simultaneously running the program and starting the y direction scan (manually), the "reads data" portion of the program begins reading in the fringe information to the designated registers R0 - through R100. Following the 25 second data read in time, the program initializes step II which normalizes the data such that the minimum voltage register is zero and all other registers are shifted about the zero level. Section III in the program finds the register with maximum value and affixes this value to the scale setting needed for plotting the 100 data registers (IV) representing the fringe pattern. The fifth portion points out the data

```
Ø:
Ø→X;FXD Ø⊦
1:
Ø→RX; IF  (X+1→X)≤
249; JMP Ø⊦
2:
Ø→X⊦
3:                          I
RED 3,A,RX; IF  (X
+1→X)≤1ØØ; JMP  Ø⊦
4:
Ø→X;RX→B;Ø→C⊦
5:
IF RX≤B;RX→B;X→C
⊦
6:                          II
IF (X+1→X)≤1ØØ;
JMP -1⊦
7:
Ø→X⊦
8:
RX-B→RX; IF  (X+1→
X)≤1ØØ; JMP Ø⊦
9:
Ø→X; JMP 9⊦
1Ø:
IF RX>R13Ø;RX→R1
3Ø⊦
11:                         III
IF (X+1→X)≤1ØØ;
JMP -1⊦
12:
SCL Ø, 1ØØ,Ø,R13Ø
;Ø→X⊦
13:
PLT X,RX;IF  (X+1
→X)≤1ØØ; JMP Ø⊦             IV
14:
PEN ;SPC 2⊦
15:
Ø→X;FXD Ø⊦
16:
IF RX>.5E-2;PRT
X; JMP 1⊦                    V
17:
IF (X+1→X)≤1ØØ;
JMP -1⊦
18:
SPC 2;PRT "THE PEAKS
ARE";PRT "AT
REGISTERS"⊦
19:
Ø→X⊦
2Ø:
IF RX≤1E-2;Ø→RX⊦             VI
21:
IF 1X+1→X)≤1ØØ;
JMP -1⊦
```

FIGURE 4a.

I } READS DATA FROM DIGITAL VOLTMETER

II } NORMALIZES THE DATA TO ZERO

III } SETS THE SCALE FOR THE PLOT

IV } PLOTS THE FRINGES

V } PRINTS THE WIDTH OF THE FRINGE PATTERN BY REGISTERS

VI } SETS SMALL VALUES OF NOISE AMPLITUDE TO ZERO

```
22:
Ø→X; 15Ø→Y⊦
23:
IF R(X+1)>RX;X+1
→RY;IF  (X+1→X)≤1
ØØ; JMP Ø⊦
24:
IF X>99; JMP 4⊦
25:
IF R(X+1)≤RX;I⊦
(X+1→X)≤1ØØ; JMP
Ø⊦
26:
IF X>99;JMP 2⊦
27:
Y+1→Y; JMP -4⊦
28:
Y→C; 15Ø→Y⊦
29:
PRT RY;IF (Y+1→Y
)≤C; JMP Ø⊦
3Ø:
Ø→R(C+1);SPC 3;
PRT "DISTANCE BE
TWEEN";PRT "FRIN
GES IN"⊦
31:
ENT "X-DIRECTION
?", B; IF B=1;
PRT "X-DIRECTION
 IS";JMP 2⊦
32:
PRT "Y-DIRECTION
 IS"⊦
33:
2ØØ→C;151→Y⊦
34:
R(Y+1)-RY→RC;C+1
→C;Y+1→Y;IF R(C-
1)>.1;JMP Ø⊦
35:
C→A;2ØØ→C⊦
36:
IF RC≤3;JMP 3⊦
37:
IF (C+1→C)>A-2;
JMP 4⊦
38:
JMP -2⊦
39:
IF C=2ØØ;R(C+1)→
RC;JMP -2⊦
4Ø:
R(C-1)→RC;JMP -3
⊦
41:
2ØØ→C⊦
```

VII — CALCULATES AND STORES THE RESISTERS WHERE PEAKS OCCUR

VIII — PRINTS THE PEAK REGISTERS

IX → ASKS FOR DIRECTION OF SCAN

X — CALCULATES DIFFERENCE BETWEEN PEAKS

XI — IF SMALL PEAKS SHOW UP, THESE STEPS SET SMALL DIFFERENCES TO ADJACENT DIFFERENCE

FIGURE 4b.

```
42:
RC+R (C+1)→R(C-1)
⊢
43:                          XII
C+1→C;IF C≤A-3;
JMP -1⊢
44:
IF B=1;JMP 2⊢
45:
Ø→R25Ø;FXD 3;
PRT  .Ø18(R(A-2)/
(A-2Ø1))→R25Ø;
PRT"     INCHES";
SPC 8; JMP 2⊢
46:                          XIII
Ø→R251;FXD 3;
PRT .Ø29(R(A-2)/
(A-2Ø1))→R251;
PRT"      INCHES";
SPC 8⊢
47:
STP  ⊢
48:
PRT "DISTANCE BE
TWEEN";PRT "FRIN
GES IS"⊢
49:
PRT R251/√(1+R25
1R251/R25ØR25Ø)→
R252⊢                        XIV
5Ø:
PRT"      INCHES";
SPC 1;PRT "AN
GLE WITH";PRT "R
ESPECT TO";PRT"
THE X-AXIS"⊢
51:
PRT ACS (R252/R2
51);PRT"
DEGREES";SPC 8⊢
52:
END ⊢
R276
```

FIGURE 4c.

XII — CALCULATES SUM OF PEAK DIFFERENCES AND STORES

XIII — CALCULATES AND PRINTS FRINGE SPACING IN BOTH THE X & Y DIRECTION

XIV — FROM X & Y FRINGE SPACING THE ACTUAL FRINGE SPACING AND DIRECTION ARE PRINTED IN INCHES AND DEGREES, RESPECTIVELY

AD-A048 210 AIR FORCE AVIONICS LAB WRIGHT-PATTERSON AFB OHIO F/G 17/8
SPECKLEGRAM DATA REDUCTION USING OPTICAL AND DIGITAL TECHNIQUES--ETC(U)
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UNCLASSIFIED AFAL-TR-77-203 NL

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registers that contain fringe data or, in other words, registers with data more than $5x10^{-2}$ in amplitude. This information merely tells the programmer if noise contained in the systems will be above a certain threshold value set by the programmer ($5x10^{-2}$ in this case), and immediately following is Section VI which sets these noise values to absolute zero. The plots and printouts in Sections III, IV, AND V are mainly used to check the program for proper operation and are normally eliminated for general purposes by the jump 9 command in statement 9 of Section III. The first printout under normal operation, performed in Section VII, calculates the registers where the peaks of the fringes occur by a method of adjacent register comparison, and a resulting printout is executed in Section VIII. An example of this printout is shown in Figures 5a and 5b. These fringes will be discussed in more detail later in the report. Section Ix of the computer program simply asks the operator the direction in which the data was scanned in from Section I, and correspondingly enters a scale factor that has been manually precalculated to convert the scanning motor speeds into a recognizable format such as inches for this case. These two scale factors show up in Section XIII of the program as .018 for the y-direction and .029 for the x-direction. In Section X the data stored in Section VII are substracted and these differences are stored again for later use in Sections XI and XII. The eleventh program section is a safety feature installed to ensure that any peaks appearing as a result of noise in the system that were not eliminated previously are thrown out to prevent a false representation of fringe count. The fringe differences are now averaged over the entire data file in Section XII and the uni-directional (y) spacing is calculated with the motor speed scale factor employed to give an answer in inches. After storing this spacing in inches the entire procedure is initiated again the x-direction, by scanning the motor drive and this time using a different scale factor. As a result of Section XIII both x and y fringe spacing information is stored in R251 and R250, respectively. Stepping to the final section (XIV) registers R250 and R251 containing the x and y information, are inserted into a simple trigonometry function to determine the fringe spacing d and fringe angle θ which are the two answers being sought (see Figure 4D).

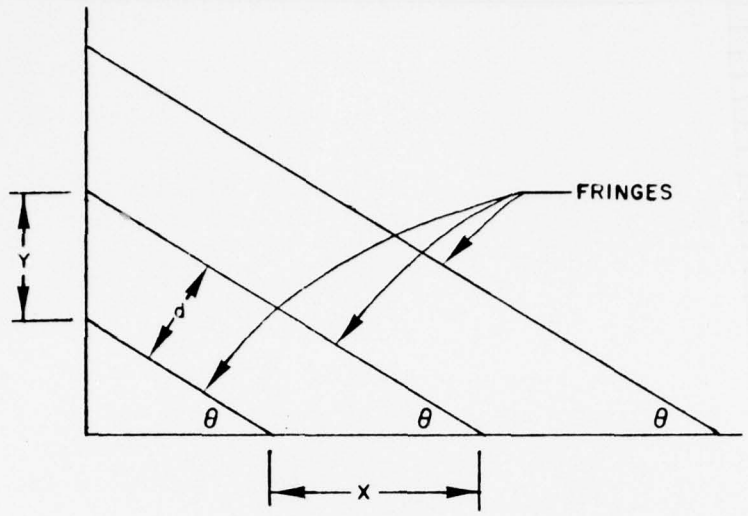


Figure 4D

Figures 5a and 5b illustrate the format in which the results were displayed. The answers of 5a were made from fringes spaced at .05 inch apart and 5b .10 inch apart, with angles for the two sets of fringes set approximately the same.

Finally 6 illustrates a method for checking the fringe angles, by simply plotting the fringe pattern in the x and y direction and graphically measuring the angle offset.

THE PEAKS ARE
AT REGISTERS

x
0
13
17
21
26
30
35
39

DISTANCE BETWEEN
FRINGES IN
X-DIRECTION IS

.126

INCHES

DISTANCE BETWEEN
FRINGES IS

.099

INCHES

THE PEAKS ARE
AT REGISTERS

y
0
49
57
67
76

ANGLE WITH
RESPECT TO
THE X-AXIS

37.001

DE

DISTANCE BETWEEN
FRINGES IN
Y-DIRECTION IS

.162

INCHES

Figure 5a

THE PEAKS ARE
AT REGISTERS

0
43
47
51
y 55
59
64
68
73

DISTANCE BETWEEN
FRINGES IN
Y-DIRECTION IS

.077

INCHES

DISTANCE BETWEEN
FRINGES IS

.050

INCHES

THE PEAKS ARE
AT REGISTERS

0
14
17
19
21
23
26
x 28
30
32
35
37
39

ANGLE WITH
RESPECT TO
THE X-AXIS

40.510

DEGREES

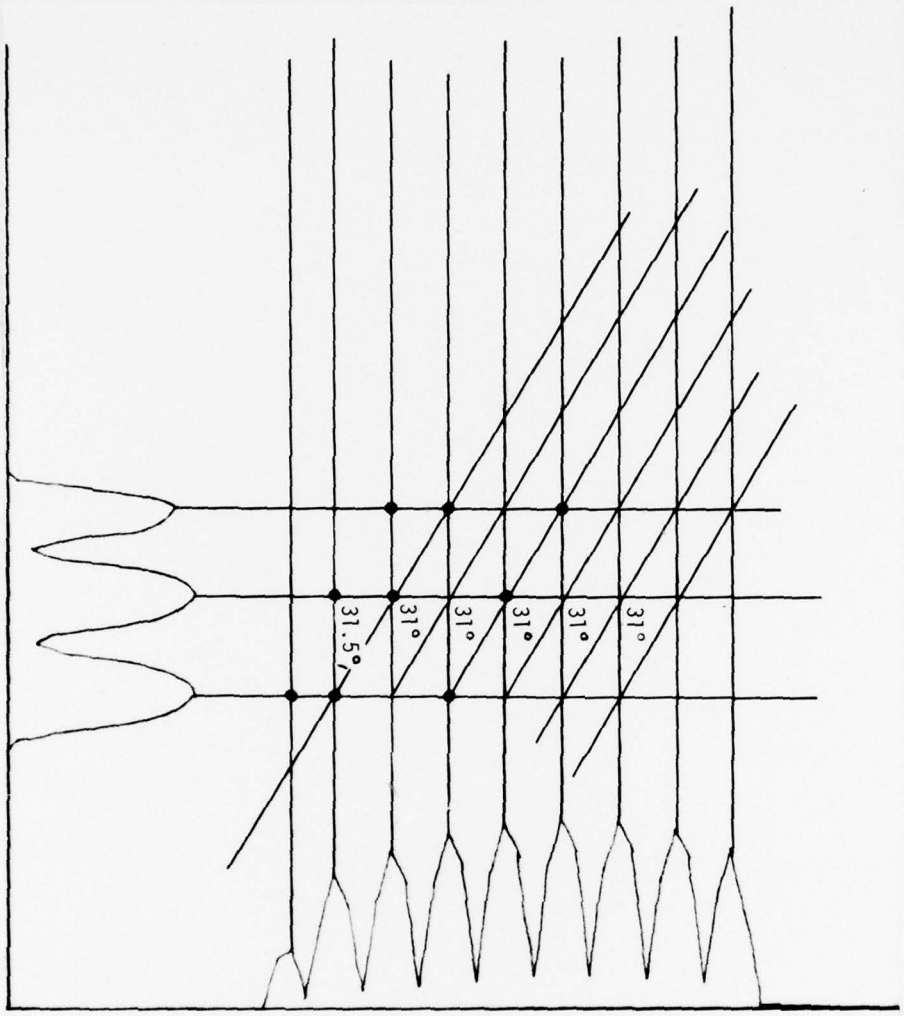
DISTANCE BETWEEN
FRINGES IN
X-DIRECTION IS

.066

INCHES

Figure 5b

```
Ø:
Ø→X;AXE Ø,Ø,Ø,ØH
1:
RED 3,A,RX;IF (X
+1→X)≤1ØØ;JMP ØH
2:
Ø→X;SCL Ø,1ØØ,Ø,
1H
3:
PLT 1.45X,RX;IF
(X+1→X)≤1ØØ;JMP
ØH
4:
STP H
5:
Ø→XH
6:
RED 3,A,RX;IF (X
+1→X)≤1ØØ;JMP ØH
7:
Ø→X;SCL Ø,1,Ø,1Ø
ØH
8:
PLT RX,.9X;IF (X
+1→X)≤1ØØ;JMP ØH
9:
END H
R395
```




```
THE PEAKS ARE
AT REGISTERS
Ø.ØØØØØØØØØE ØØ
1.4ØØØØØØØØE Ø1
2.6ØØØØØØØØE Ø1
3.6ØØØØØØØØE Ø1

DISTANCE BETWEEN
FRINGES IS
              .216
       INCHES

THE PEAKS ARE
AT REGISTERS
             Ø.ØØØ
             7.ØØØ
            11.ØØØ
            15.ØØØ
            19.ØØØ
            23.ØØØ
            27.ØØØ
            31.ØØØ
            35.ØØØ
            39.ØØØ

DISTANCE BETWEEN
FRINGES IS
              .116
       INCHES
DISTANCE BETWEEN
FRINGES IS
              .1Ø2
ANGLE WITH
RESPECT TO
THE X-AXIS
            28.237
```

Figure 6

CONCLUSION:

Our investigation as described here, indicates that several techniques may readily be applied to the type of fringe counting problem considered.

Several choices exist for reading out and for processing ("counting") fringe spacing. The choices of techniques (and optimum hardware implementation of same) depend heavily on the detailed technical and economic parameters and constraints of the application. Consideration of these details was beyond the scope of these initial feasibility investigations, since all equipment used in the demonstrations was presently available in-house.

The next logical step appears to be a design analysis to determine the optimum system configuration taking into account the detailed technical and economic factors. Following this, construction and testing of a prototype system would be appropriate.

AFAL/TEL would be pleased to undertake further work on this problem along the lines of the previous paragraph or as considered appropriate by mutual agreement of AFAL and FDL.

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VP05-01H 05-NOV-72 02:24 PAGE 1

```
                                        .TITLE SPECKLEGRAM ANALYSIS SYSTEM
                                        ;WITH DATA READ FROM RETICON
                                        ;AND STEPPING STAGE

                                        .ENABLE    AMA


000000                  R0=%0
000001                  R1=%1
000002                  R2=%2
000003                  R3=%3
000004                  R4=%4
000005                  P5=%5
000006                  SP=%6
000007                  PC=%7
177560                  KBS=177560
177562                  KBB=177562
177564                  TPS=177564
177566                  TPB=177566


000000                                  .ASECT

                        ;MAIN  PROGRAM


000500                  .=500
000500 012706 000500    START: MOV #500.SP
000504 005037 005742           CLR TRACK
000510 012700 006062           MOV #ASKAV.R0            ;PRINT AVERAGE
000514 004737 004210           JSR PC.TTYOUT
000520 012700 005762           MOV #MEAN.R0
000524 004737 004320           JSR PC.INPUT             ;ENTER NUMBER
000530 012700 005762           MOV #MEAN.R0
000534 012702 005666           MOV #KEEP.R2
000540 004737 001034           JSR PC.ASCII             ;CONVERT TO OCTAL
000544 010337 005744           MOV R3.TIMES             ;LOAD
000550 012737 000005 005736    MOV #5.XREAD             ;X
000556 012700 005776    JUMP:  MOV #XLIMIT.R0
000562 005020           CLEAR: CLR (R0)+               ;CLEAR STAGING LOCATIONS
000564 020027 006056           CMP R0.#STEPX
000570 001374                  BNE CLEAR
000572 012700 000144           MOV #XDIST.R0            ;PRINT X-DISTANCE
000576 004737 004210           JSR PC.TTYOUT
000602 012700 005776           MOV #XLIMIT.R0
000606 004737 004320           JSR PC.INPUT             ;ENTER X-DISTANCE
000612 012700 005776           MOV #XLIMIT.R0
```

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
 48 000616  012702  005666                MOV #KEEP,R2
 49 000622  004737  001034                JSR PC,ASCII              ;CONVT TO OCTAL
 50 000626  012700  005776                MOV #XLIMIT,R0
 51 000632  010310                        MOV R3,(R0)              ;LOAD
 52 000634  012700  006234                MOV #YDIST,R0
 53 000640  004737  004210                JSR PC,TTYOUT             ;PRINT "Y-DISTANCE"
 54 000644  012700  006012                MOV #YLIMIT,R0
 55 000650  004737  004320                JSR PC,INPUT             ;ENTER Y-DISTANCE
 56 000654  012700  006012                MOV #YLIMIT,R0
 57 000660  012702  005666                MOV #KEEP,R2
 58 000664  004737  001034                JSR PC,ASCII             ;CNVT TO OCTAL
 59 000670  010337  006012                MOV R3,YLIMIT
 60 000674  012700  006324                MOV #XINC,R0
 61 000700  004737  004210                JSR PC,TTYOUT             ;PRINT "X-INC"
 62 000704  012700  006026                MOV #INCX,R0
 63 000710  004737  004320                JSR PC,INPUT             ;ENTER X-INC
 64 000714  012700  006374                MOV #YINC,R0
 65 000720  004737  004210                JSR PC,TTYOUT;            PRINT "Y-INC"
 66 000724  012700  006042                MOV #INCY,R0
 67 000730  004737  004320                JSR PC,INPUT:             ENTER Y-INC
 68 000734  012737  000004  164002        MOV #4,@#164002:            SET, +DIRECTION
 69 000742  012700  006026                MOV #INCX,R0
 70 000746  012702  005666                MOV #KEEP,R2
 71 000752  004737  001034                JSR PC,ASCII:             ;X-INC TO OCTAL
 72 000756  013737  005644  006056        MOV OBUF,STEPX:             LOAD
 73 000764  012700  006042                MOV #INCY,R0
 74 000770  012702  005666                MOV #KEEP,R2
 75 000774  004737  001034                JSR PC,ASCII:             Y-STEP TO OCTAL
 76 001000  012700  006576                MOV #HEAD,R0:             PRINT HEADER
 77 001004  004737  004210                JSR PC,TTYOUT
 78 001010  013737  005644  006060        MOV OBUF,STEPY
 79 001016  004737  005132                JSR PC,ASTAGE;            GTO STAGE ROUTINE
 80 001022  012700  006460                MOV #FIN,R0
 81 001026  004737  004210                JSR PC,TTYOUT;              PRINT "SCAN COMPLETE"
 82 001032  000000                        HALT
 83
 84
 85
 86 001034  012001                ASCII:  MOV (R0)+,R1:             CONVERT ASCII TO OCTAL
 87 001036  162701  000060                SUB #60,R1
 88 001042  010122                        MOV R1,(R2)+
 89 001044  021027  000015                CMP (R0),#15
 90 001050  001371                        BNE ASCII
 91 001052  005003                        CLR R3
 92 001054  014203                        MOV -(R2),R3;             LOAD LSD
 93 001056  020227  005666                CMP R2,#KEEP
 94 001062  001465                        BEQ CMST
```


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```
SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

 95 001064  014205                        MOV -(R2),R5;          LOAD 2ND DIGIT
 96 001066  005004                        CLR R4
 97 001070  020527  000000                CMP R5,#0
 98 001074  001405                        BEQ .+14
 99 001076  062704  000012                ADD #12,R4 ;          10.
100 001102  162705  000001                SUB #1,R5
101 001106  000770                        BR .-16
102 001110  060403                        ADD R4,R3
103 001112  020227  005666                CMP R2,#KEEP
104 001116  001447                        BEQ CMST
105 001120  014205                        MOV -(R2),R5;          LOAD 3RD DIGIT
106 001122  005004                        CLR R4
107 001124  020527  000000                CMP R5,#0
108 001130  001405                        BEQ .+14
109 001132  062704  000144                ADD #144,R4;          100.
110 001136  162705  000001                SUB #1,R5
111 001142  000770                        BR .-16
112 001144  060403                        ADD R4,R3
113 001146  020227  005666                CMP R2,#KEEP
114 001152  001431                        BEQ CMST
115 001154  014205                        MOV -(R2),R5;          LOAD 5TH DIGIT
116 001156  005004                        CLR R4
117 001160  020527  000000                CMP R5,#0
118 001164  001405                        BEQ .+14
119 001166  062704  001750                ADD #1750,R4;          1000.
120 001172  162705  000001                SUB #1,R5
121 001176  000770                        BR .-16
122 001200  060403                        ADD R4,R3
123 001202  020227  005666                CMP R2,#KEEP
124 001206  001413                        BEQ CMST
125 001210  014205                        MOV -(R2),R5;          LOAD 5TH DIGIT
126 001212  005004                        CLR R4
127 001214  020527  000000                CMP R5,#0
128 001220  001405                        BEQ .+14
129 001222  062704  023420                ADD #23420,R4;          10000.
130 001226  162705  000001                SUB #1,R5
131 001232  000770                        BR .-16
132 001234  060403                        ADD R4,R3
133 001236  012701  005644        CMST:   MOV #OBUF,R1;          LOAD FINAL TO OBUF
134 001242  010311                        MOV R3,(R1)
135 001244  000207                        RTS PC
136
137
138 001246  000000                AMANIP:HALT
139 001250  012700  005604        MANIP:  MOV #RR0,R0
140 001254  005020                CLR1:   CLR (R0)+;          CLEAR WORKING REGISTERS
141 001256  020027  005704                CMP R0,#DBUF+2;       PLUS NONE,OBUF,FUNC
```


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SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
142 001262  001374                        BNE CLR1:                KEEP,FLG
143 001264  012700  007022                 MOV #FBUFAV,R0
144 001270  005020                 CLR2:   CLR (R0)+:              CLEAR FFT BUFFERS
145 001272  020027  010044                 CMP R0,#FFTBUF+410
146 001276  001374                        BNE CLR2
147 001300  012704  007434                 MOV #FFTBUF,R4
148 001304  004737  003216                 JSR PC,AREAD:            GTO READ ROUTINE
149 001310  004737  001462                 JSR PC,AFFT:            GTO FFT ROUTINE
150 001314  004737  004076                 JSR PC,AAMP:            GTO AMPLITUDE ROUTINE
151 001320  004737  004516                 JSR PC,AFREQ:            GTO FREQUENCY ROUTINE
152 001324  012700  006742                 MOV #SPC,R0
153 001330  004737  004210                 JSR PC,TTYOUT:           INSERT SPACES
154 001334  023727  005642  000001        CMP NONE,#1
155 001342  001005                        BNE HUMPS
156 001344  012700  006444                 MOV #GOOF,R0
157 001350  004737  004210                 JSR PC,TTYOUT:           PRINT "LOW
158 001354  000410                        BR NOLIST
159 001356  013700  005644         HUMPS: MOV OBUF,R0
160 001362  004737  004754                 JSR PC,OTD:             FREQUENCY TO DECIMAL
161 001366  012700  005704                 MOV #DBUF+2,R0
162 001372  004737  004210                 JSR PC,TTYOUT:           PRINT FREQUENCY
163 001376  005237  005746         NOLIST: INC RATHER
164 001402  013737  005644  005756        MOV OBUF,ROBUF
165 001410  013737  005646  005760        MOV OBUF+2,ROBUF+2
166 001416  023727  005746  000002        CMP RATHER,#2
167 001424  001310                        BNE ANANIP
168 001426  012700  006742                 MOV #SPC,R0
169 001432  004737  004210                 JSR PC,TTYOUT
170 001436  004737  003640                 JSR PC,APRINT
171 001442  012700  006756         F4:     MOV #EOL,R0
172 001446  004737  004210                 JSR PC,TTYOUT:           LF , CR
173 001452  000207                 F3:     RTS PC
174 001454  000137  000500                 JMP START
175 001460  000000                        HALT
176
177
178 001462  000000                 AFFT:   HALT
179 001464  012700  007434         FFT:    MOV #FFTBUF,R0:          FFT SUBROUTINE
180 001470  012701  007436                 MOV #FFTBUF+2,R1
181 001474  022120                 NORMAL: CMP (R1)+,(R0)+
182 001476  100001                        BPL STORE
183 001500  000775                        BR NORMAL
184 001502  162701  000002         STORE:  SUB #2,R1
185 001506  012103                 ADO:    MOV (R1)+,R3
186 001510  021103                 BDO:    CMP (R1),R3
187 001512  100375                        BPL ADO
188 001514  062701  000002                 ADD #2,R1
```


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SPECKLEGRAM ANALYSIS SYSTEM

MACRO V05-01H 05-NOV-72 02:24 PAGE 1+

```
    189 001520  020127  007644              CMP R1,#FFTBUF+210
    190 001524  001371                      BNE BDO
    191 001526  020327  001000              CMP R3,#1000
    192 001532  001425                      BEQ CDO
    193 001534  003016                      BGT DROP
    194 001536  020327  000400              CMP R3,#400
    195 001542  003021                      BGT CDO
    196 001544  006303              SEE:    ASL R3
    197 001546  012700  007434              MOV #FFTBUF,R0
    198 001552  006320              UP:     ASL (R0)+
    199 001554  020027  007644              CMP R0,#FFTBUF+210
    200 001560  001374                      BNE UP
    201 001562  020327  000400              CMP R3,#400
    202 001566  003766                      BLE SEE
    203 001570  000406                      BR CDO
    204 001572  012700  007434      DROP:   MOV #FFTBUF,R0
    205 001576  006220              DOWN:   ASR (R0)+
    206 001600  020027  007644              CMP R0,#FFTBUF+210
    207 001604  001374                      BNE DOWN
    208 001606  012700  007434      CDO:    MOV #FFTBUF,R0
    209 001612  012701  007444              MOV #FFTBUF+10,R1
    210 001616  012120              SLIP:   MOV (R1)+,(R0)+
    211 001620  020027  007654              CMP R0,#FFTBUF+220
    212 001624  001374                      BNE SLIP
    213 001626  012737  000002  005626      MOV #2,RR9
    214 001634  012737  000001  005604      MOV #1,RR0
    215 001642  012737  000200  005610      MOV #200,RR2
    216 001650  005700                      TST R0
    217 001652  005001                      CLR R1
    218 001654  012700  007434              MOV #FFTBUF,R0
    219 001660  006210              SHIFT:  ASR (R0)
    220 001662  005201                      INC R1
    221 001664  020127  000003              CMP R1,#3
    222 001670  001373                      BNE SHIFT
    223 001672  005001                      CLR R1
    224 001674  062700  000002              ADD #2,R0
    225 001700  020027  010036              CMP R0,#FFTBUF+402
    226 001704  001365                      BNE SHIFT
    227 001706  005700              ALPHA:  TST R0
    228 001710  012704  007434              MOV #FFTBUF,R4
    229 001714  006224              KILL:   ASR (R4)+
    230 001716  020427  010034              CMP R4,#FFTBUF+400
    231 001722  001374                      BNE KILL
    232 001724  012737  000000  005606      MOV #0,RR1
    233 001732  006237  005610              ASR RR2
    234 001736  005700              BETA:   TST R0
    235 001740  012704  010674              MOV #COS,R4
```

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
236 001744  063704  005624                 ADD RR8,R4
237 001750  011437  005612                 MOV (R4),RR3
238 001754  012704  011000                 MOV #SIN,R4
239 001760  063704  005624                 ADD RR8,R4
240 001764  011437  005614                 MOV (R4),RR4
241 001770  013737  005606  005616  L3:    MOV RR1,RR5
242 001776  005700              GAMA:      TST R0
243 002000  013700  005616                 MOV RR5,R0
244 002004  062700  007434                 ADD #FFTBUF,R0  ;3000
245 002010  010037  005620                 MOV R0,RR6
246 002014  013701  005610                 MOV RR2,R1
247 002020  060001                         ADD R0,R1
248 002022  010137  005622                 MOV R1,RR7
249 002026  017700  003566          L5:    MOV @RR6,R0
250 002032  017701  003564                 MOV @RR7,R1
251 002036  060001                         ADD R0,R1
252 002040  010137  005632                 MOV R1,B
253 002044  013700  005620                 MOV RR6,R0
254 002050  062700  000200                 ADD #200,R0
255 002054  013701  005622                 MOV RR7,R1
256 002060  062701  000200                 ADD #200,R1
257 002064  011102                         MOV (R1),R2
258 002066  061002                         ADD (R0),R2
259 002070  010237  005634                 MOV R2,C
260 002074  013700  005620          L6:    MOV RR6,R0
261 002100  011004                         MOV (R0),R4
262 002102  013701  005622                 MOV RR7,R1
263 002106  161104                         SUB (R1),R4
264 002110  005005                         CLR R5
265 002112  013702  005612                 MOV RR3,R2
266 002116  005704                         TST R4
267 002120  100005                         BPL OTHER
268 002122  005702                         TST R2
269 002124  100020                         BPL MINUS
270 002126  005404                         NEG R4
271 002130  005402                         NEG R2
272 002132  000404                         BR  PLUS
273 002134  005702              OTHER:     TST R2
274 002136  100002                         BPL PLUS
275 002140  005402                         NEG R2
276 002142  000411                         BR MINUS
277 002144  032704  000001          PLUS:  BIT #1,R4
278 002150  001401                         BEQ AZERO
279 002152  060205                         ADD R2,R5
280 002154  006302              AZERO:     ASL R2
281 002156  006204                         ASR R4
282 002160  001371                         BNE PLUS
```

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
283 002162  005004                        CLR R4
284 002164  000407                        BR LOAD
285 002166  005704                MINUS:  TST R4
286 002170  100001                        BPL GOON
287 002172  005404                        NEG R4
288 002174  012737  000001  005664  GOON:  MOV #1.FLG
289 002202  000760                        BR PLUS
290 002204  005705                LOAD:   TST R5
291 002206  100002                        BPL FUD1
292 002210  012705  077777                MOV #77777,R5
293 002214  006205                FUD1:   ASR R5
294 002216  005204                        INC R4
295 002220  020427  000011                CMP R4,#11
296 002224  001373                        BNE FUD1
297 002226  023727  005664  000001        CMP FLG,#1
298 002234  001004                        BNE JUG
299 002236  005405                        NEG R5
300 002240  012737  000000  005664        MOV #0.FLG
301 002246  062700  000200          JUG:  ADD #200,R0
302 002252  062701  000200                ADD #200,R1
303 002256  011102                        MOV (R1),R2
304 002260  161002                        SUB (R0),R2
305 002262  013704  005614                MOV RR4,R4
306 002266  005003                        CLR R3
307 002270  005702                        TST R2
308 002272  100004                        BPL AG1
309 002274  005402                        NEG R2
310 002276  012737  000001  005664        MOV #1.FLG
311 002304  032702  000001          AG1:  BIT #1,R2
312 002310  001401                        BEQ BZERO
313 002312  060403                        ADD R4,R3
314 002314  006304                BZERO:  ASL R4
315 002316  006202                        ASR R2
316 002320  001371                        BNE AG1
317 002322  005004                        CLR R4
318 002324  005703                AG2:    TST R3
319 002326  100002                        BPL FUD2
320 002330  012703  077777                MOV #77777,R3
321 002334  006203                FUD2:   ASR R3
322 002336  005204                        INC R4
323 002340  020427  000011                CMP R4,#11
324 002344  001373                        BNE FUD2
325 002346  023727  005664  000001        CMP FLG,#1
326 002354  001004                        BNE AG3
327 002356  012737  000000  005664        MOV #0.FLG
328 002364  005403                        NEG R3
329 002366  060305                AG3:    ADD R3,R5
```


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PECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
330 002370  010537  005630          MOV R5,A
331 002374  013700  005620    L7:   MOV RR6,R0
332 002400  01.004                  MOV (R0),R4
333 002402  013701  005622          MOV RR7,R1
334 002406  161104                  SUB (R1),R4
335 002410  005005                  CLR R5
336 002412  013702  005614          MOV RR4,R2
337 002416  005704                  TST R4
338 002420  100004                  BPL MULT4
339 002422  005404                  NEG R4
340 002424  012737  000001  005664  MOV #1,FLG
341 002432  032704  000001  MULT4:  BIT #1,R4
342 002436  001401                  BEQ DZERO
343 002440  060205                  ADD R2,R5
344 002442  006302          DZERO:  ASL R2
345 002444  006204                  ASR R4
346 002446  001371                  BNE MULT4
347 002450  005004                  CLR R4
348 002452  000400                  BR CHECK
349 002454  005705          CHECK:  TST R5
350 002456  100002                  BPL FUD3
351 002460  012705  077777          MOV #77777,R5
352 002464  006205          FUD3:   ASR R5
353 002466  005204                  INC R4
354 002470  020427  000011          CMP R4,#11
355 002474  001373                  BNE FUD3
356 002476  023727  005664  000001  CMP FLG,#1
357 002504  001004                  BNE EAT
358 002506  012737  000000  005664  MOV #0,FLG
359 002514  005405                  NEG R5
360 002516  062700  000200    EAT:  ADD #200,R0
361 002522  011002                  MOV (R0),R2
362 002524  062701  000200          ADD #200,R1
363 002530  161102                  SUB (R1),R2
364 002532  013703  005612          MOV RR3,R3
365 002536  005004                  CLR R4
366 002540  005703                  TST R3
367 002542  100005                  BPL DOT
368 002544  005702                  TST R2
369 002546  100020                  BPL LOW
370 002550  005402                  NEG R2
371 002552  005403                  NEG R3
372 002554  000404                  BR HIGH
373 002556  005702          DOT:    TST R2
374 002560  100002                  BPL HIGH
375 002562  005402                  NEG R2
376 002564  000411                  BR LOW
```


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SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
377 002566  032702  000001          HIGH:  BIT #1,R2
378 002572  001401                         BEQ CZERO
379 002574  060304                         ADD R3,R4
380 002576  006303                 CZERO:  ASL R3
381 002600  006202                         ASR R2
382 002602  001371                         BNE HIGH
383 002604  005003                         CLR R3
384 002606  000407                         BR ALOAD
385 002610  005703                 LOW:    TST R3
386 002612  100001                         BPL GOONY
387 002614  005403                         NEG R3
388 002616  012737  000001  005664 GOONY:  MOV #1,FLG
389 002624  000760                         BR HIGH
390 002626  005704                 ALOAD:  TST R4
391 002630  100002                         BPL FUD4
392 002632  012704  077777                 MOV #77777,R4
393 002636  006204                 FUD4:   ASR R4
394 002640  005203                         INC R3
395 002642  020327  000011                 CMP R3,#11
396 002646  001373                         BNE FUD4
397 002650  023727  005664  000001         CMP FLG,#1
398 002656  001004                         BNE JUGGER
399 002660  005404                         NEG R4
400 002662  012737  000000  005664         MOV #0,FLG
401 002670  060405                 JUGGER: ADD R4,R5
402 002672  010511                         MOV R5,(R1)
403 002674  013777  005632  002716 L8.:    MOV B,@R6
404 002702  013700  005620                 MOV R6,R0
405 002706  062700  000200                 ADD #200,R0
406 002712  013710  005634                 MOV C,(R0)
407 002716  013777  005630  002676         MOV A,@R7
408 002724  013705  005616         L9.:    MOV R5,R5
409 002730  013702  005610                 MOV R2,R2
410 002734  010200                         MOV R2,R0
411 002736  060200                         ADD R2,R0
412 002740  005700                         TST R0
413 002742  005700                         TST R0
414 002744  060005                         ADD R0,R5
415 002746  010537  005616                 MOV R5,R5
416 002752  060205                 L10.:   ADD R2,R5
417 002754  020527  000177                 CMP R5,#177;          ;JUGGLE FFT DATA
418 002760  003002                         BGT L11.
419 002762  000137  001776                 JMP GAMA
420 002766  062737  000002  005606 L11.:   ADD #2,R1
421 002774  023737  005610  005606         CMP R2,R1
422 003002  001405                         BEQ L12.
423 003004  063737  005626  005624         ADD R9,R8
```

SPECKLEGRAM ANALYSIS SYSTEM

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```
 24 003012  000137  001736                    JMP BETA
 25 003016  062737  000001  005604  L12.:     ADD #1,RR0
 26 003024  023727  005604  000006            CMP RR0,#6
 27 003032  003007                            BGT D
 28 003034  006337  005626                    ASL RR9
 29 003040  012737  000000  005624            MOV #0,RR8
 30 003046  000137  001706                    JMP ALPHA
 31 003052  012737  000001  005610  D:        MOV #1,RP2;          FFT DONE
 32 003060  012737  000001  005604  BEGIN:    MOV #1,RR0
 33 003066  012737  000040  005606            MOV #40,RR1
 34 003074  005004                            CLR R4
 35 003076  013702  005610                    MOV RR2,R2
 36 003102  013700  005604                    MOV RR0,R0
 37 003106  013701  005606                    MOV RR1,R1
 38 003112  030102                  TEST:     BIT R1,R2
 39 003114  001401                            BEQ SLIDE
 40 003116  060004                            ADD R0,R4
 41 003120  006201                  SLIDE:    ASR R1
 42 003122  006300                            ASL R0
 43 003124  020127  000000                    CMP R1,#0
 44 003130  001370                            BNE TEST
 45 003132  020402                            CMP R4,R2
 46 003134  002420                            BLT RECLR
 47 003136  006302                            ASL R2
 48 003140  006304                            ASL R4
 49 003142  062702  007434                    ADD #FFTBUF,R2
 50 003146  062704  007434                    ADD #FFTBUF,R4
 51 003152  011203                            MOV (R2),R3
 52 003154  011412                            MOV (R4),(R2)
 53 003156  010314                            MOV R3,(R4)
 54 003160  062702  000200                    ADD #200,R2
 55 003164  062704  000200                    ADD #200,R4
 56 003170  011203                            MOV (R2),R3
 57 003172  011412                            MOV (R4),(R2)
 58 003174  010314                            MOV R3,(R4)
 59 003176  062737  000001  005610  RECLR:    ADD #1,RR2
 60 003204  023727  005610  000100            CMP RR2,#100
 61 003212  001322                            BNE BEGIN
 62 003214  000207                            RTS PC
 63
 64
 65
 66
 67
 68 003216  000000                  AREAD:    HALT
 69 003220  005002                  READ:     CLR R2;              READ DATA FROM RETICON
 70 003222  005005                            CLR R5
```

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
471 003224  012737  000004  164000  CLOCK1:MOV #4.@#164000;              CLOCK PULSE
472 003232  012737  001005  176770         MOV #1005.@#176770;             CHANNEL 2
473 003240  013700  176770          DONE1: MOV @#176770.R0
474 003244  122700  000177                 CMPB #177.R0;               DONE READING ?
475 003250  100373                         BPL DONE1
476 003252  013701  176772                 MOV @#176772.R1;              LOAD A/D
477 003256  020127  000377                 CMP R1.#377;                DO I HAVE DATA ?
478 003262  100360                         BPL CLOCK1
479 003264  020527  000002                 CMP R5.#2;                DELAY
480 003270  001402                         BEQ WAIT
481 003272  005205                         INC R5
482 003274  000753                         BR CLOCK1
483 003276  005003                  WAIT:  CLR R3
484 003300  012737  000004  164000  CLOCK2:MOV #4.@#164000;              CLOCK PULSE
485 003306  005202                         INC R2
486 003310  020227  000202                 CMP R2.#202;                SKIP DEAD TIME
487 003314  001405                         BEQ CLOCK3
488 003316  005203                  SLOW:  INC R3
489 003320  020327  000005                 CMP R3.#5;                DELAY
490 003324  001374                         BNE SLOW
491 003326  000763                         BR WAIT
492 003330  005237  005640          CLOCK3:INC SECOND;           XREAD OR YREAD
493 003334  023737  005640  005744         CMP SECOND.TIMES
494 003342  003035                         BGT CLOCK5
495 003344  012737  000004  164000  CLOCK4:MOV #4.@#164000;              CLOCK PULSE-X
496 003352  013737  005736  176770         MOV XREAD.@#176770
497 003360  013705  176770          DONE2: MOV @#176770.R5
498 003364  122705  000177                 CMPB #177.R5;               ;DONE ?
499 003370  100373                         BPL DONE2
500 003372  013724  176772          AVER:  MOV @#176772.(R4)+;             LOAD A/D
501 003376  005700                         TST R0
502 003400  005700                         TST R0
503 003402  005700                         TST R0
504 003404  005700                         TST R0
505 003406  023727  005740  000001          CMP WHICH.#1;              ;AVERAGE
506 003414  001004                         BNE LOOP1
507 003416  020427  007232                 CMP R4.#FBUFAV+210;                AVERAGE -X
508 003422  001350                         BNE CLOCK4
509 003424  000434                         BR DNREAD
510 003426  020427  007644          LOOP1:  CMP R4.#FFTBUF+210
511 003432  001344                        BNE CLOCK4
512 003434  000430                        BR DNREAD
513 003436  012737  000004  164000  CLOCK5:MOV #4.@#164000;              CLOCK PULSE-Y
514 003444  012737  000405  176770         MOV #405.@#176770
515 003452  013705  176770          DONE3: MOV @#176770.R5
516 003456  122705  000177                 CMPB #177.R5
517 003462  100373                         BPL DONE3
```

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SPECKLEGRAM ANALYSIS SYSTEM

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   518 003464  013724  176772                  MOV @#176772,(R4)+
   519 003470  023727  005740  000001           CMP WHICH,#1
   520 003476  001004                           BNE LOOP2
   521 003500  020427  007232                   CMP R4,#FBUFAV+210
   522 003504  001354                           BNE CLOCK5
   523 003506  000403                           BR DNREAD
   524 003510  020427  007644           LOOP2:  CMP R4,#FFTBUF+210
   525 003514  001350                          BNE CLOCK5
   526 003516  005237  005742           DNREAD: INC TRACK
   527 003522  023737  005742  005744           CMP TRACK,TIMFS
   528 003530  001424                           BEQ FOWARD
   529 003532  023727  005742  000001           CMP TRACK,#1
   530 003540  001412                           BEQ DUPRED
   531 003542  012702  007434                   MOV #FFTBUF,R2
   532 003546  012705  007022                   MOV #FBUFAV,R5
   533 003552  006212                  ALOOP:   ASR (R2)
   534 003554  006215                           ASR (R5)
   535 003556  062522                           ADD (R5)+,(R2)+
   536 003560  020227  007644                   CMP R2,#FFTBUF+210
   537 003564  001372                           BNE ALOOP
   538 003566  012737  000001  005740  DUPRED:  MOV #1,WHICH
   539 003574  012704  007022                   MOV #FBUFAV,R4
   540 003600  000606                           BR AREAD
   541 003602  005037  005742           FOWARD: CLR TRACK
   542 003606  005037  005740                   CLR WHICH
   543 003612  012700  007444                   MOV #FFTBUF+10,R0;        LOAD 1ST HALF DATA TO 2ND HALF
   544 003616  012701  007644                   MOV #FFTBUF+210,R1
   545 003622  011120                  CIRCLE:MOV (R1),(R0)+
   546 003624  162701  000002                   SUB #2,R1
   547 003630  020027  007544                   CMP R0,#FFTBUF+110
   548 003634  001372                           BNE CIRCLE
   549 003636  000207                           RTS PC
   550
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   555 003640  000000                  APRINT:HALT
   556 003642  005037  005752           PRINT:  CLR YDISTO
   557 003646  005037  005750                   CLR XDISTO
   558 003652  012705  000100                   MOV #100,R5
   559 003656  163705  005756                   SUB ROBUF,R5
   560 003662  005237  005750                   INC XDISTO
   561 003666  020527  000000                   CMP R5,#0
   562 003672  003371                           BGT .-14
   563 003674  012705  000100                   MOV #100,R5
   564 003700  163705  005644                   SUB OBUF,R5
```

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```
565 003704  005237  005752                  INC YDISTO
566 003710  020527  000000                  CMP R5,#0
567 003714  003371                          BGT .-14
568 003716  004737  003760                  JSR PC,AANGLE;          GTO ANGLE
569 003722  012700  005706                  MOV #DBUF+4,R0;         LOAD FOR ANGLE LIST
570 003726  004737  004210                  JSR PC,TTYOUT
571 003732  012700  006742                  MOV #SPC,R0
572 003736  004737  004210                  JSR PC,TTYOUT;          INSERT SPACES
573 003742  004737  004424                  JSR PC,ADISP            ; GTO TO DISPLACEMENT
574 003746  012700  005706                  MOV #DBUF+4,R0,
575 003752  004737  004210                  JSR PC,TTYOUT
576 003756  000207                          RTS PC
577
578
579
580
581 003760  000000              AANGLE:HALT
582 003762  005000              ANGLE: CLR R0
583 003764  013703  005752              MOV YDISTO,R3;          Y-SPACING
584 003770  013704  005750              MOV XDISTO,R4;          X-SPACING
585 003774  006303              MULT1: ASL R3;                 MULTIPLYING BY 100-8
586 003776  005200                     INC R0
587 004000  020027  000006              CMP R0,#6
588 004004  001373                      BNE MULT1
589 004006  005000                      CLR R0
590 004010  160403              DOCIR: SUB R4,R3  ;            DIVIDE Y BY X
591 004012  062700  000001              ADD #1,R0
592 004016  020327  000000              CMP R3,#0
593 004022  001372                      BNE DOCIR
594 004024  012705  010134              MOV #TANBUF,R5;         LOAD TANGENT ADDRESS
595 004030  020025              LOOKUP:CMP R0,(R5)+;           LOOK FOR ANGLE
596 004032  100376                      BPL LOOKUP
597 004034  162705  000004              SUB #4,R5
598 004040  162705  010134              SUB #TANBUF,R5;         ABSOLUTE ANGLE-DEGREES
599 004044  010537  005754              MOV R5,RATIO;           LOAD ANGLE
600 004050  006205              DIVANG:ASR R5;                 DIVIDE BY TWO
601 004052  012704  005702              MOV #DBUF,R4
602 004056  005024              DBUFCL:CLR (R4)+
603 004060  020427  005720              CMP R4,#DBUF+16
604 004064  001374                      BNE DBUFCL
605 004066  010500                      MOV R5,R0;              LOAD FOR OTD
606 004070  004737  004754              JSR PC,OTD
607 004074  000207                      RTS PC
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611
```


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SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
612 004076  000000                AAMP:  HALT
613 004100  012700  007434        AMP:   MOV #FFTBUF,R0;          REAL BUFFERS
614 004104  012701  007634               MOV #FFTBUF+200,R1;        IMAGINARY BUFFER
615 004110  005710                SQR1:  TST (R0);               IS REAL POSITIVE ?
616 004112  100001                       BPL SQR2
617 004114  005410                       NEG (R0);              IF NOT NEGATE
618 004116  005711                SQR2:  TST (R1);              IS IMAGINARY POSITIVE
619 004120  100001                       BPL SQR3
620 004122  005411                       NEG (R1);              IF NOT NEGATE
621 004124  005004                SQR3:  CLR R4
622 004126  011003                       MOV (R0),R3
623 004130  032703  000001        NOTE1: BIT #1,R3
624 004134  001401                       BEQ SQR4
625 004136  061004                       ADD (R0),R4;            SQUARE REAL PART
626 004140  006310                SQR4:  ASL (R0)
627 004142  006203                       ASR R3
628 004144  001371                       BNE NOTE1
629 004146  005005                       CLR R5
630 004150  011103                       MOV (R1),R3
631 004152  032703  000001        NOTE2: BIT #1,R3
632 004156  001401                       BEQ SQR5
633 004160  061105                       ADD (R1),R5;              SQUARE IMAGINARY PART
634 004162  006311                SQR5:  ASL (R1)
635 004164  006203                       ASR R3
636 004166  001371                       BNE NOTE2
637 004170  060405                       ADD R4,R5;              ADD REAL AND IMAGINARY
638 004172  010520                       MOV R5,(R0)+
639 004174  062701  000002               ADD #2,R1
640 004200  020027  007634               CMP R0,#FFTBUF+200
641 004204  001341                       BNE SQR1
642 004206  000207                       RTS PC
643
644
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650
651 004210  105737  177564        TTYOUT:TSTB TPS;               READY TO PRINT
652 004214  100375                       BPL TTYOUT
653 004216  012037  177566               MOV (R0)+,TPB;              ;PRINT
654 004222  021027  000000               CMP (R0),#0
655 004226  001370                       BNE TTYOUT
656 004230  000207                       RTS PC
657
658
```

SPECKLEGRAM ANALYSIS SYSTEM

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```
659
660
661 004232  021027  000123          OPER:  CMP (R0),#123;          S ?
662 004236  001003                         BNE N1
663 004240  012705  000000                  MOV #0,R5
664 004244  000207                         RTS PC
665 004246  021027  000130          N1:    CMP (R0),#130;           X ?
666 004252  001003                         BNE N2
667 004254  012705  000001                  MOV #1,R5
668 004260  000207                         RTS PC
669 004262  021027  000131          N2:    CMP (R0),#131;           Y ?
670 004266  001003                         BNE N3
671 004270  012705  000002                  MOV #2,R5
672 004274  000207                         RTS PC
673 004276  021027  000104          N3:    CMP (R0),#104;           D ?
674 004302  001003                         BNE N4
675 004304  012705  000003                  MOV #3,R5
676 004310  000207                         RTS PC
677 004312  012705  000004          N4:    MOV #4,R5
678 004316  000207                         RTS PC
679
680
681
682
683 004320  105737  177560          INPUT: TSTB KBS;              KEYBOARD READY ?
684 004324  100375                         BPL INPUT
685 004326  013704  177562                  MOV KBB,R4;             KEYBOARD TO REGISTER
686 004332  042704  177600                  BIC #177600,R4;           CLEAR PARITY BIT
687 004336  010420                         MOV R4,(R0)+
688 004340  105737  177564          ECHO:  TSTB TPS;              READY TO PRINT
689 004344  100375                         BPL ECHO
690 004346  020427  000177                  CMP R4,#177;             CHECK FOR RUBOUT
691 004352  001010                         BNE E1
692 004354  012737  000134  177566         MOV #134,TPB;             MOV / TO PRINTER
693 004362  012740  000000                  MOV #0,-(R0);             CANCEL OLD
694 004366  012740  000000                  MOV #0,-(R0)
695 004372  000752                         BR INPUT
696 004374  010437  177566          E1:    MOV R4,TPB;             PRINT NEW
697 004400  020427  000015                  CMP R4,#15
698 004404  001345                         BNE INPUT
699 004406  105737  177564          LNFD:  TSTB TPS
700 004412  100375                         BPL LNFD
701 004414  012737  000012  177566         MOV #12,TPB;              LINE FEED
702 004422  000207                         RTS PC
703
704 004424  012701  010422          ADISP:  MOV #SINBUF,R1;          LOAD SIN START ADDRESS
705 004430  063701  005754                  ADD RATIO,R1;             ADD ANGLE ADDRESS
```

SPECKLEGRAM ANALYSIS SYSTEM

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```
706 004434  011102                        MOV (R1),R2;            LOAD SIN
707 004436  013703  005750                MOV XDISTO,R3;          LOAD XSPACING
708 004442  005000                        CLR R0
709 004444  060200              MULT6:    ADD R2,R0;              MULT XSIN ANGLE
710 004446  162703  000001                SUB #1,R3
711 004452  020327  000000                CMP R3,#0
712 004456  001372                        BNE MULT6
713 004460  005003                        CLR R3
714 004462  006200              LESSOR:   ASR R0 ;                DIVIDE BY 100-8
715 004464  005203                        INC R3
716 004466  020327  000006                CMP R3,#6
717 004472  001373                        BNE LESSOR
718 004474  012704  005702                MOV #DBUF,R4;           LOAD TO CLEAR
719 004500  005024              DWIPE:    CLR (R4)+
720 004502  020427  005720                CMP R4,#DBUF+16
721 004506  001374                        BNE DWIPE
722 004510  004737  004754                JSR PC,OTD
723 004514  000207                        RTS PC
724
725
726
727 004516  000000              AFREQ:    HALT
728 004520  005037  005734      FREQ:     CLR HIDC
729 004524  023727  007632  000156        CMP FFTBUF+176,#156;      CHECK FOR HI DC
730 004532  002003                        BGE HOP
731 004534  012737  000001  005734        MOV #1,HIDC
732 004542  012700  007574      HOP:      MOV #FFTBUF+140,R0;       INITIALIZE FOR HIGHEST FREQUENCY
733 004546  005003                        CLR R3
734 004550  022003              SRCH:     CMP (R0)+,R3;           CHECK IF LAST HIGHER
735 004552  003004                        BGT HOLD
736 004554  020027  007630                CMP R0,#FFTBUF+174;          DONE ?
737 004560  003773                        BLE SRCH
738 004562  000426                        BR QUIT
739 004564  023727  005734  000001  HOLD:   CMP HIDC,#1;          CHECK HIDC SET
740 004572  001006                        BNE SKIP
741 004574  162700  000002                SUB #2,R0
742 004600  022027  000003                CMP (R0)+,#3
743 004604  003412                        BLE QUIT-6
744 004606  000405                        BR VALID
745 004610  162700  000002      SKIP:     SUB #2,R0;          SKIP FREQ SRCH FOR HIDC
746 004614  022027  000010                CMP (R0)+,#10
747 004620  003404                        BLE QUIT-6
748 004622  162700  000002      VALID:    SUB #2,R0
749 004626  010002                        MOV R0,R2
750 004630  012003                        MOV (R0)+,R3
751 004632  020027  007630                CMP R0,#FFTBUF+174
752 004636  003744                        BLE SRCH
```

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```
753 004640  005037  005642          QUIT:  CLR NONE
754 004644  020327  000000                 CMP R3,#0
755 004650  001003                         BNE FOW
756 004652  005237  005642                 INC NONE
757 004656  000435                         BR OVER
758 004660  062702  000002          FOW :  ADD #2,R2;              INTERPOLATE
759 004664  011200                         MOV (R2),R0
760 004666  162702  000004                 SUB #4,R2
761 004672  021200                         CMP (R2),R0
762 004674  003003                         BGT MORE
763 004676  012705  000000                 MOV #0,R5
764 004702  000402                         BR LIST
765 004704  012705  000001          MORE:  MOV #1,R5
766 004710  062702  000002          LIST:  ADD #2,R2
767 004714  012701  007634                 MOV #FFTBUF+200,R1
768 004720  160201                         SUB R2,R1
769 004722  006201                         ASR R1
770 004724  012700  005644                 MOV #DBUF,R0
771 004730  010120                         MOV R1,(R0)+
772 004732  020527  000001                 CMP R5,#1
773 004736  001003                         BNE LESS
774 004740  012710  000053                 MOV #53,(R0)
775 004744  000402                         BR OVER
776 004746  012710  000055          LESS:  MOV #55,(R0)
777 004752  000207                 OVER:  RTS PC
778
779
780
781
782
783
784
785
786 004754  012701  005702          OTD:   MOV #DBUF,R1
787 004760  005002                         CLR R2
788 004762  020027  023420                 CMP R0,#23420;              10000.
789 004766  002405                         BLT .+14
790 004770  162700  023420                 SUB #23420,R0
791 004774  062702  000001                 ADD #1,R2
792 005000  000770                         BR .-16
793 005002  062702  000060                 ADD #60,R2;               ASCII
794 005006  010221                         MOV R2,(R1)+
795 005010  005002                         CLR R2
796 005012  020027  001750                 CMP R0,#1750;               1000.
797 005016  002405                         BLT .+14
798 005020  162700  001750                 SUB #1750,R0
799 005024  062702  000001                 ADD #1,R2
```

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SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+


800 005030  000770                        BR .-16
801 005032  062702  000060                ADD #60,R2;              ASCII
802 005036  010221                        MOV R2,(R1)+
803 005040  005002                        CLR R2
804 005042  020027  000144                CMP R0,#144
805 005046  002405                        BLT .+14
806 005050  162700  000144                SUB #144,R0;               100.
807 005054  062702  000001                ADD #1,R2
808 005060  000770                        BR .-16
809 005062  062702  000060                ADD #60,R2;              ASCII
810 005066  010221                        MOV R2,(R1)+
811 005070  005002                        CLR R2
812 005072  020027  000012                CMP R0,#12
813 005076  002405                        BLT .+14
814 005100  162700  000012                SUB #12,R0;              10.
815 005104  062702  000001                ADD #1,R2
816 005110  000770                        BR .-16
817 005112  062702  000060                ADD #60,R2;              ASCII
818 005116  010221                        MOV R2,(R1)+
819 005120  005002                        CLR R2
820 005122  062700  000060                ADD #60,R0;              LSD
821 005126  010021                        MOV R0,(R1)+;              LOAD TO DBUF
822 005130  000207                        RTS PC
823
824
825
826
827 005132  000000              ASTAGE:HALT
828 005134  005037  005730      STAGE:  CLR COLM
829 005140  005037  005724              CLR LINE
830 005144  005037  005722              CLR UNIT
831 005150  005037  005726              CLR DELAY
832 005154  012737  000001  164000  XSTEP:  MOV #1,@#164000;            X-STAGE PULSE
833 005162  062737  000001  005722          ADD #1,UNIT;             KEEP TRACK
834 005170  062737  000001  005724          ADD #1,LINE
835 005176  005237  005726      XLOOP:  INC DELAY;               DELAY
836 005202  023727  005726  000100          CMP DELAY,#100
837 005210  001372                          BNE XLOOP
838 005212  005037  005726                  CLR DELAY
839 005216  023737  005722  006056          CMP UNIT,STEPX;            DONE INC SCAN ?
840 005224  001353                          BNE XSTEP
041 005226  005037  005722                  CLR UNIT
842 005232  004737  005502                  JSR PC,POSITN;           GTO POSITN
843 005236  004737  001246                  JSR PC,@MANIP;           GTO MANIP
844 005242  005037  005746                  CLR RATHER
845 005246  013737  005776  005722          MOV XLIMIT,UNIT
846 005254  023737  005724  005722          CMP LINE,UNIT;             DONE LINE SCAN ?
```

```
PECKLEGRAM ANALYSIS SYSTEM

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 847 005262  100730                          BMI XSTEP-10
 848 005264  000443                          BR ZEROX
 849 005266  012737  000002  164000  YSTEP:  MOV #2,@#164000;        Y-STAGE PULSE
 850 005274  062737  000001  005726          ADD #1,DELAY;           KEEP TRACK
 851 005302  062737  000001  005730          ADD #1,COLM
 852 005310  005237  005722          YLOOP:  INC UNIT
 853 005314  023727  005722  000100          CMP UNIT,#100;          DELAY
 854 005322  001372                          BNE YLOOP
 855 005324  005037  005722                  CLR UNIT
 856 005330  023737  005726  006060          CMP DELAY,STEPY;        DONE Y-INC SCAN
 857 005336  001353                          BNE YSTEP
 858 005340  004737  005502                  JSR PC,POSITN;          GTO POSITN
 859 005344  004737  001246                  JSR PC,AMANIP;          GTO MANIP
 860 005350  005037  005746                  CLR RATHER
 861 005354  013737  006012  005722          MOV YLIMIT,UNIT;        DONE Y-SCAN
 862 005362  023737  005730  005722          CMP COLM,UNIT
 863 005370  003665                          BLE XSTEP-10
 864 005372  000207                          RTS PC
 865 005374  012737  000001  164002  ZEROX:  MOV #1,@#164002;        CHANGE X SIGN
 866 005402  012737  000001  164000  XZERO:  MOV #1,@#164000;        XPULSE
 867 005410  162737  000001  005724          SUB #1,LINE
 868 005416  005237  005722          DOLOOP: INC UNIT
 869 005422  023727  005722  000100          CMP UNIT,#100;          DELAY
 870 005430  001372                          BNE DOLOOP
 871 005432  005037  005722                  CLR UNIT
 872 005436  023727  005724  000000          CMP LINE,#0;            DONE ZEROING X ?
 873 005444  001356                          BNE XZERO
 874 005446  005237  005722          ROUND:  INC UNIT
 875 005452  023727  005722  040000          CMP UNIT,#40000;        DELAY
 876 005460  001372                          BNE ROUND
 877 005462  005037  005722                  CLR UNIT
 878 005466  005037  005726                  CLR DELAY
 879 005472  012737  000004  164002          MOV #4,@#164002;        CHANGE XSIGN TO +
 880 005500  000672                          BR YSTEP
 881
 882
 883 005502  012700  005702          POSITN: MOV #DBUF,R0;           LOAD POSITION BUFFER
 884 005506  005020                  DCLEAR: CLR (R0)+
 885 005510  020027  005714                  CMP R0,#DBUF+12;        CLEAR POSITN BUFFER
 886 005514  001374                          BNE DCLEAR
 887 005516  013700  005724                  MOV LINE,R0;            LOAD X-POSITION
 888 005522  004737  004754                  JSR PC,OTD;             CNVT TO DECIMAL
 889 005526  012700  005702                  MOV #DBUF,R0
 890 005532  004737  004210                  JSR PC,TTYOUT;          PRINT X-POSITION
 891 005536  013700  005730                  MOV COLM,R0;            LOAD Y-POSITION
 892 005542  004737  004754                  JSR PC,OTD;             CONVERT TO DECIMAL
 893 005546  012700  006742                  MOV #SPC,R0
```

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```
    894 005552  004737  004210                  JSR PC,TTYOUT;              INSERT SPACES
    895 005556  012700  005702                  MOV #DBUF,R0
    896 005562  004737  004210                  JSR PC,TTYOUT;               PRINT Y-POSITION
    897 005566  012700  006056                  MOV #STEPX,R0;              RELOAD X-Y STEP
    898 005572  012701  006060                  MOV #STEPY,R1
    899 005576  005037  005722                  CLR UNIT
    900 005602  000207                         RTS PC
    901
    902
    903 005604  000000                  RR0:   .WORD 0;                    FFT WORKING BUFFERS
    904 005606  000000                  RR1:   .WORD 0
    905 005610  000000                  RR2:   .WORD 0
    906 005612  000000                  RR3:   .WORD 0
    907 005614  000000                  RR4:   .WORD 0
    908 005616  000000                  RR5:   .WORD 0
    909 005620  000000                  RR6:   .WORD 0
    910 005622  000000                  RR7:   .WORD 0
    911 005624  000000                  RR8:   .WORD 0
    912 005626  000000                  RR9:   .WORD 0
    913 005630  000000                  A:     .WORD 0
    914 005632  000000                  B:     .WORD 0
    915 005634  000000                  C:     .WORD 0
    916 005636  000000                  X:     .WORD 0
    917 005640  000000                  SECOND:.WORD 0;                    0 FOR X,1 FOR Y
    918 005642  000000                  NONE:  .WORD 0
    919 005644  000000  000000          DBUF:  .WORD 0,0
    920 005650  000000  000000  000000  FUNC:  .WORD 0,0,0,0,0,0
        005656  000000  000000  000000
    921 005664  000000                  FLG:   .WORD 0
    922 005666  000000  000000  000000  KEEP:  .WORD 0,0,0,0,0,0
        005674  000000  000000  000000
    923 005702  000000  000000  000000  DBUF:  .WORD 0,0,0,0,0,0,0,0
        005710  000000  000000  000000
        005716  000000  000000
    924 005722  000000                  UNIT:  .WORD 0
    925 005724  000000                  LINE:  .WORD 0
    926 005726  000000                  DELAY: .WORD 0
    927 005730  000000                  COLM:  .WORD 0
    928 005732  000000                  SOEZ:  .WORD 0
    929 005734  000000                  HIDC:  .WORD 0
    930 005736  000000                  XREAD: .WORD 0
    931 005740  000000                  WHICH:  .WORD 0
    932 005742  000000                  TRACK: .WORD 0
    933 005744  000000                  TIMES: .WORD 0
    934 005746  000000                  RATHER:.WORD 0
    935 005750  000000                  XDISTO:.WORD 0
    936 005752  000000                  YDISTO:.WORD 0
```

```
937 005754  000000                    RATIO: .WORD 0
938 005756  000000  000000            RUBUF: .WORD 0,0
939 005762  000000  000000  000000    MEAN:  .WORD 0.0.0.0.0.0
    005770  000000  000000  000000
940 005776  000000  000000  000000    XLIMIT:.WORD 0.0.0.0.0.0
    006004  000000  000000  000000
941 006012  000000  000000  000000    YLIMIT:.WORD 0.0.0.0.0.0
    006020  000000  000000  000000
942 006026  000000  000000  000000    INCX:  .WORD 0.0.0.0.0.0
    006034  000000  000000  000000
943 006042  000000  000000  000000    INCY:  .WORD 0.0.0.0.0.0
    006050  000000  000000  000000
944 006056  000000                   .STEPX: .WORD 0
945 006060  000000                    STEPY: .WORD 0
946 006062  000015  000012  000012    ASKAV: .WORD 15.12.12
947 006070  000116  000117  000056           .WORD 116.117.56.43.40.104:     NO.* DATA AVERAGES
    006076  000043  000040  000104
948 006104  000101  000124  000101           .WORD 101.124.101.40.101.126
    006112  000040  000101  000126
949 006120  000105  000122  000101           .WORD 105.122.101.107.105
    006126  000107  000105
950 006132  000123  000040  000054           .WORD 123.40.54.40.0
    006140  000040  000000
951 006144  000015  000012  000012    XDIST: .WORD 15.12.12
952 006152  000130  000055  000124           .WORD 130.55.124.117.124:       X-TOT SCAN DISTANCE
    006160  000117  000124
953 006164  000040  000123  000103           .WORD 40.123.103.101.116
    006172  000101  000116
954 006176  000040  000104  000111           .WORD 40.104.111.123.124
    006204  000123  000124
955 006210  000101  000116  000103           .WORD 101.116.103.105.40
    006216  000105  000040
956 006222  000077  000040  000054           .WORD 77.40.54.40.0
    006230  000040  000000
957 006234  000015  000012  000012    YDIST: .WORD 15.12.12
958 006242  000131  000055  000124           .WORD 131.55.124.117.124:       Y-TOT SCAN DISTANCE
    006250  000117  000124
959 006254  000040  000123  000103           .WORD 40.123.103.101.116
    006262  000101  000116
960 006266  000040  000104  000111           .WORD 40.104.111.123.124
    006274  000123  000124
961 006300  000101  000116  000103           .WORD 101.116.103.105.40
    006306  000105  000040
962 006312  000077  000040  000054           .WORD 77.40.54.40.0
    006320  000040  000000
963 006324  000015  000012  000012    XINC:  .WORD 15.12.12
964 006332  000130  000055  000111           .WORD 130.55.111.116.103:       X-INCREMENT
```

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```
     006340  000116  000103
 965 006344  000122  000105  000115          .WORD 122,105,115,105,116
     006352  000105  000116
 966 006356  000124  000040  000077          .WORD 124,40,77,40,54
     006364  000040  000054
 967 006370  000040  000000                  .WORD 40,0
 968 006374  000015  000012  000012  YINC:   .WORD 15,12,12
 969 006402  000131  000055  000111          .WORD 131,55,111,116,103;       Y-INCREMENT
     006410  000116  000103
 970 006414  000122  000105  000115          .WORD 122,105,115,105,116
     006422  000105  000116
 971 006426  000124  000040  000077          .WORD 124,40,77,40,54
     006434  000040  000054
 972 006440  000040  000000                  .WORD 40,0
 973 006444  000114  000117  000127  GOOF:   .WORD 114,117,127,0,0,0;       LOW
     006452  000000  000000  000000
 974 006460  000015  000012  000012  FIN:    .WORD 15,12,12,12,12
     006466  000012  000012
 975 006472  000130  000055  000131          .WORD 130,55,131,40,123;        X-Y SCAN COMPLETED
     006500  000040  000123
 976 006504  000103  000101  000116          .WORD 103,101,116,40,103
     006512  000040  000103
 977 006516  000117  000115  000120          .WORD 117,115,120,114,105
     006524  000114  000105
 978 006530  000124  000105  000104          .WORD 124,105,104,15,12
     006536  000015  000012
 979 006542  000012  000012  000012          .WORD 12,12,12,12,12
     006550  000012  000012
 980 006554  000012  000012  000012          .WORD 12,12,12,12,12,12
     006562  000012  000012  000012
 981 006570  000012  000012  000000          .WORD 12,12,0
 982 006576  000015  000012  000012  HEAD:   .WORD 15,12,12,40,40
     006604  000040  000040
 983 006610  000130  000040  000040          .WORD 130,40,40,40,40
     006616  000040  000040
 984 006622  000040  000040  000040          .WORD 40,40,40,40,40,131
     006630  000040  000040  000131
 985 006636  000040  000040  000040          .WORD 40,40,40,40,40,40,40
     006644  000040  000040  000040
     006652  000040
 986 006654  000106  000122  000105          .WORD 106,122,105,121
     006662  000121
 987 006664  000040  000040  000040          .WORD 40,40,40,40,40
     006672  000040  000040
 988 006676  000130  000055  000123          .WORD 130,55,123,120,103
     006704  000120  000103
 989 006710  000040  000040  000040          .WORD 40,40,40,40
```


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:KLEGRAM ANALYSIS SYSTEM

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     006716  000040
 990 006720  000131  000055  000123          .WORD 131.55.123.120.103
     006726  000120  000103
 991 006732  000015  000012  000012          .WORD 15.12.12.0
     006740  000000
 992 006742  000040  000040  000040  SPC:    .WORD 40.40.40.40.40.0;          5 SPACES
     006750  000040  000040  000000
 993 006756  000015  000012  000000  EOL:    .WORD 15.12.0.0.0.0;             CR.LF
     006764  000000  000000  000000
 994 006772  000106  000122  000105  CYCLES:.WORD 106.122.105.121.125.105;  FREQUENCY
     007000  000121  000125  000105
 995 007006  000116  000103  000131          .WORD 116.103.131.75.40.0
     007014  000075  000040  000000
 996 007022  000000                  FBUFAV:.WORD 0;                          FFT BUFFERS
 997         007434                          .=.+410
 998 007434  000000                  FFTBUF:.WORD 0
 999         010046                          .=.+410
1000 010046  000015  000012  000012  DATA:   .WORD 15.12.12
1001 010054  000114  000111  000123          .WORD 114.111.123.124.105;       LISTED ?
     010062  000124  000105
1002 010066  000104  000040  000077          .WORD 104.40.77.40.0
     010074  000040  000000
1003 010100  000015  000012  000012  QUES:   .WORD 15.12.12
1004 010106  000117  000125  000124          .WORD 117.125.124.120.125.124;   OUTPUT
     010114  000120  000125  000124
1005 010122  000040  000077  000040          .WORD 40.77.40.0.0
     010130  000000  000000
1006
1007
1008
1009 010134  000000  000001  000002  TANBUF:.WORD 0.1.2.3.4.5
     010142  000003  000004  000005
1010 010150  000006  000007  000010          .WORD 6.7.10.12.13.14
     010156  000012  000013  000014
1011 010164  000015  000016  000017          .WORD 15.16.17.21.22
     010172  000021  000022
1012 010176  000023  000024  000026          .WORD 23.24.26.27.30
     010204  000027  000030
1013 010210  000031  000033  000034          .WORD 31.33.34.35.37
     010216  000035  000037
1014 010222  000040  000042  000043          .WORD 40.42.43.44.46
     010230  000044  000046
1015 010234  000047  000051  000053          .WORD 47.51.53.54.56
     010242  000054  000056
1016 010246  000060  000062  000063          .WORD 60.62.63.65.67
     010254  000065  000067
1017 010260  000071  000073  000075          .WORD 71.73.75.100.102
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      010266  000100  000102
1018  010272  000104  000107  000111          .WORD 104,107,111,114,117
      010300  000114  000117
1019  010304  000121  000124  000130          .WORD 121,124,130,133,136
      010312  000133  000136
1020  010316  000142  000146  000152          .WORD 142,146,152,156,163
      010324  000156  000163
1021  010330  000170  000175  000203          .WORD 170,175,203,211,217
      010336  000211  000217
1022  010342  000226  000236  000246          .WORD 226,236,246,257,271
      010350  000257  000271
1023  010354  000304  000321  000337          .WORD 304,321,337,356,400
      010362  000356  000400
1024  010366  000425  000455  000511          .WORD 425,455,511,552,624
      010374  000552  000624
1025  010400  000707  001011  001140          .WORD 707,1011,1140,1333,1623
      010406  001333  001623
1026  010412  002305  003450  007122          .WORD 2305,3450,7122,0
      010420  000000
1027
1028
1029
1030  010422  000000  000001  000002  SINBUF:.WORD 0,1,2,4,5,6
      010430  000004  000005  000006
1031  010436  000007  000010  000012          .WORD 7,10,12,13,14,15
      010444  000013  000014  000015
1032  010452  000016  000017  000020          .WORD 16,17,20,21,22,23
      010460  000021  000022  000023
1033  010466  000024  000025  000026          .WORD 24,25,26,27,31,32
      010474  000027  000031  000032
1034  010502  000033  000034  000035          .WORD 33,34,35,36,37,37
      010510  000036  000037  000037
1035  010516  000040  000041  000042          .WORD 40,41,42,43,44,45
      010524  000043  000044  000045
1036  010532  000046  000047  000050          .WORD 46,47,50,51,51,52
      010540  000051  000051  000052
1037  010546  000060  000061  000061          .WORD 60,61,61,62,63,63
      010554  000062  000063  000063
1038  010562  000064  000065  000065          .WORD 64,65,65,66,66,67
      010570  000066  000066  000067
1039  010576  000067  000070  000071          .WORD 67,70,71,71,72,72
      010604  000071  000072  000072
1040  010612  000072  000073  000073          .WORD 72,73,73,74,74,74
      010620  000074  000074  000074
1041  010626  000075  000075  000075          .WORD 75,75,75,76,76,76
      010634  000076  000076  000076
1042  010642  000076  000077  000077          .WORD 76,77,77,77,77,77
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SPECKLEGRAM ANALYSIS SYSTEM

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      010650  000077  000077  000077
 1043 010656  000077  000077  000077          .WORD 77.77.77.77.77.100.0
      010664  000077  000077  000100
      010672  000000
 1044
 1045
 1046
 1047 010674  001000  000775  000766  COS:    .WORD 1000.775.766.752.731:      COSINE TABLE
      010702  000752  000731
 1048 010706  000704  000652  000622         .WORD 704.652.622.552.505
      010714  000552  000505
 1049 010720  000435  000361  000304          .WORD 435.361.304.224.144
      010726  000224  000144
 1050 010732  000062  000000                  .WORD 62.0
 1051 010736  177716  177634  177554          .WORD 177716.177634.177554.177474.177417
      010744  177474  177417
 1052 010750  177343  177273  177226          .WORD 177343.177273.177226.177156.177126
      010756  177156  177126
 1053 010762  177074  177047  177026          .WORD 177074.177047.177026.177012.177002
      010770  177012  177002
 1054 010774  177000  177000                  .WORD 177000.177000
 1055
 1056
 1057
 1058 011000  000000  000062  000144  SIN:    .WORD 0.62.144.224.304:          SIN TABLE
      011006  000224  000304
 1059 011012  000361  000435  000505          .WORD 361.435.505.552.622
      011020  000552  000622
 1060 011024  000652  000704  000731          .WORD 652.704.731.752.766
      011032  000752  000766
 1061 011036  000775  001000  000775          .WORD 775.1000.775.766.752
      011044  000766  000752
 1062 011050  000731  000704  000652          .WORD 731.704.652.622.552
      011056  000622  000552
 1063 011062  000505  000435  000361          .WORD 505.435.361.304.224
      011070  000304  000224
 1064 011074  000144  000062  000000          .WORD 144.62.0
 1065
 1066
 1067         000500'                         .END START
```


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SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+
SYMBOL TABLE

A	005630	AAMP	004076	AANGLE	003760
ADISP	004424	ADO	001506	AFFT	001462
AFREQ	004516	AG1	002304	AG2	002324
AG3	002366	ALOAD	002626	ALOOP	003552
ALPHA	001706	AMANIP	001246	AMP	004100
ANGLE	003762	APRINT	003640	AREAD	003216
ASCII	001034	ASKAV	006062	ASTAGE	005132
AVER	003372	AZERO	002154	B	005632
BDO	001510	BEGIN	003060	BETA	001736
BZERO	002314	C	005634	CDO	001606
CHECK	002454	CIRCLE	003622	CLEAR	000562
CLOCK1	003224	CLOCK2	003300	CLOCK3	003330
CLOCK4	003344	CLOCK5	003436	CLR1	001254
CLR2	001270	CMST	001236	COLM	005730
COS	010674	CYCLES	006772	CZERO	002576
D	003052	DATA	010046	DBUF	005702
DBUFCL	004056	DCLEAR	005506	DELAY	005726
DIVANG	004050	DNREAD	003516	DOCIR	004010
DOLOOP	005416	DONE1	003240	DONE2	003360
DONE3	003452	DOT	002556	DOWN	001576
DROP	001572	DUPRED	003566	DWIPE	004500
DZERO	002442	EAT	002516	ECHO	004340
EOL	006756	E1	004374	FBUFAV	007022
FFT	001464	FFTBUF	007434	FIN	006460
FLG	005604	FOW	004660	FOWARD	003602
FREQ	004520	FUD1	002214	FUD2	002334
FUD3	002464	FUD4	002636	FUNC	005650
F3	001452	F4	001442	GAMA	001776
GOOF	006414	GOON	002174	GOONY	002616
HEAD	006576	HIDC	005734	HIGH	002566
HOLD	004564	HOP	004542	HUMPS	001356
INCX	006026	INCY	006042	INPUT	004320
JUG	002246	JUGGER	002670	JUMP	000556
KBB =	177562	KBS =	177560	KEEP	005666
KILL	001714	LESS	004746	LESSOR	004462
LINE	005724	LIST	004710	LNFD	004406
LOAD	002204	LOOKUP	004030	LOOP1	003426
LOOP2	003510	LOW	002610	L10.	002752
L11.	002766	L12.	003016	L3	001770
L5	002026	L6	002074	L7	002374
L8.	002674	L9.	002724	MANIP	001250
MEAN	005762	MINUS	002166	MORE	004704
MULT1	003774	MULT4	002432	MULT6	004444
NOLIST	001376	NONE	005642	NORMAL	001474
NOTE1	004130	NOTE2	004152	N1	004246
N2	004262	N3	004276	N4	004312
OBUF	005644	OPER	004232	OTD	004754

```
SPECKLEGRAM ANALYSIS SYSTEM

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SYMBOL TABLE

OTHER   002134          OVER    004752          PC     =%000007
PLUS    002144          POSITN  005502          PRINT   003642
QUES    010100          QUIT    004640          RATHER  005746
RATIO   005754          READ    003220          RECLR   003176
ROBUF   005756          ROUND   005446          RR0     005604
RR1     005606          RR2     005610          RR3     005612
RR4     005614          RR5     005616          RR6     005620
RR7     005622          RR8     005624          RR9     005626
R0     =%000000         R1     =%000001         R2     =%000002
R3     =%000003         R4     =%000004         R5     =%000005
SECOND  005640          SEE     001544          SHIFT   001660
SIN     011000          SINBUF  010422          SKIP    004610
SLIDE   003120          SLIP    001616          SLOW    003316
SP     =%000006         SPC     006742          SQCZ    005732
SQR1    004110          SQR2    004116          SQR3    004124
SQR4    004140          SQR5    004162          SRCH    004550
STAGE   005134          START   000500          STEPX   006056
STEPY   005060          STORE   001502          TANBUF  010134
TEST    003112          TIMES   005744          TPB    = 177566
TPS    = 177564         TRACK   005742          TTYOUT  004310
UNIT    005722          UP      001552          VALID   004622
WAIT    003276          WHICH   005740          X       005636
XDIST   006144          XDISTO  005750          XINC    006324
XLIMIT  005776          XLOOP   005176          XREAD   005736
XSTEP   005154          XZERO   005402          YDIST   006234
YDISTO  005752          YINC    006374          YLIMIT  006012
YLOOP   005310          YSTEP   005266          ZEROX   005374

. ABS.  011102     000
        000000     001

ERRORS DETECTED:  0
FREE CORE:  4851. WORDS
DC:RL.OBJ,LP:LIST<DT1:RL.SRC
```


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APPENDIX III

SYSTEM OPERATING INSTRUCTION

OPERATING PROCEDURES:

I. The initial set-up should be performed as follows:

1. A 15 milliwatt or greater He-Ne laser should be aligned on the centerline of an optical bench, 8.75 inch above the surface of the bench, with all of the optics centered on this beam.

2. Set up the beam-reducing optics as described in the Optical Setup Section of this report and insert an optical attenuator immediately following these optics.

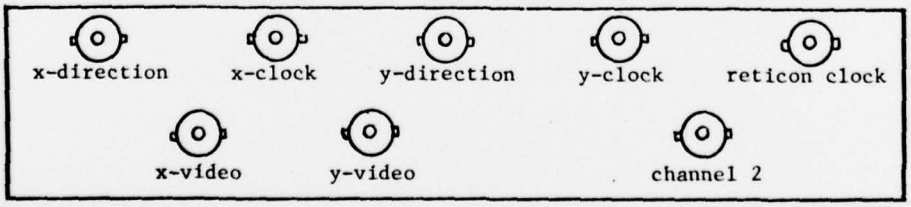
3. Place the x-y stage as close to the attenuator as needed.

4. Align a ground glass screen, with a D.C. spot block, so that the D.C. component of the fringe halo image falls on the block. Position the ground glass in the optical axis direction so that a fringe halo of 2-4 inches in diameter exists.

5. An imaging lens (f=28mm) should be centered on the optical axis and positioned to image the fringe pattern onto the detectors. The distances between the lens and the detector all depend upon the image aperture of the specklegram recording system. Essentially for the fringe spacing of a given specklegram to be analyzed accurately, the readout halo size depends on the recording aperture.

6. Connect the x-y stage cables to the appropriate x-y Aerotek Drive Units via the 8 pin connector plugs.

7. A labeled BNC wiring panel is attached to the top back of the rack mounting cart and is illustrated below.



A list of to and from BNC connections are shown in the following table:

WIRING DIAGRAM	
FROM	TO
Aerotek Drive-(x) DIR	Panel - x - direction
Aerotek Drive-(x) CL	Panel - x - clock
Aerotek Drive-(y) DIR	Panel - y - direction
Aerotek Drive-(y) CL	Panel - y - clock
Reticon -x video	Panel - x - video
Reticon -y video	Panel - y - video
Reticon -Ext. clock	Panel - reticon clock
Reticon -EOS	Panel - channel 2

8. AC connections from the Aerotek Drive Units, PDP 11 computer, off-on indicator light, and control electronics panels should be plugged into the AC terminal strip in the lower rear of the rack mounting cart.

9. Connect the teletype I/O to the computer I/O cable and plug the teletype into a wall socket.

10. Turn on all equipment and check out this equipment with a test paper tape given to you by AFAL/DHO-2.

II. AFTER CHECK-OUT (Initializing for a read sequence)

1. Place Specklegram into 4 inch by 5 inch holder.
2. Align the readout beam to the upper right hand corner of the specklegram plate, (facing the plate), by setting the local-remote switch on the x drive unit to the local position and pushing the slew button until the upper right hand x position is reached. The + or - switch will be set according to the initial position of the plate before setting up. The slew speed can also be changed by the small potentiometer on the front panel. Repeat for the y-position.
3. Reset the x and y digital display to zero by depressing the reset button and switch the remote-local switches to the remote position. The system is now ready for computer control operation.

4. Load the control program through the paper tape reader on the teletype by the following procedure:

A.) If the Bootstrap loader is not contained in core-memory, a hand loading procedure is as follows:

a.) Toggle in 017744 onto the computer switches and hit LOAD ADDR Button.

b.) Toggle 016701 and hit the DEP button and continue DEP operations on these numbers: 000026, 012702, 000352, 005211, 105711, 100376, 116162, 000002, 017400, 005267, 177756, 000765, 177560, 000000.

B.) Set the ABSOLUTE LOADER paper tape into the reader with the leader section in the reader section, and set the reader switch to the top position called START.

C.) 017744 and LOAD ADDR then START. The Absolute loader should now pass through the reader and stop when finished.

D.) Load the Control tape into the reader with the leader positioned in the reader section, and set the read switch up.

E.) 017500 and LOAD ADDR then START. The control tape should now pass through the reader and stop when finished. The control program is now loaded.

5. Make sure all connections are made and all power switches are activated. The program is now ready to run.

6. 000500 and LOAD ADDR, then START.

7. The teletype will now ask initializing questions before displaying specklegram data and these questions can be answered as described in the Software Section of this report. When the data run is finished, the teletype will print "SCAN COMPLETED".

8. If, before shutdown, another plate is to be analyzed, only the following steps have to be repeated:

II. - 1,2,3,6

9. The computer can be stopped during any phase of operation by simply hitting the HALT Button and after a data run there is no specific shutdown sequence except that the HALT button should be activated before shutting any other power off.

10. Once the procedures of Sections I and II of the operating procedures have been performed complete, only steps II. - 1, 2, 3, 4B, 4C, 4D, 4E, 5, and 6 have to be repeated.

APPENDIX IV

A TYPICAL SPECKLEGRAM EXPOSURE AND READOUT

Appendix V is designed to inform the reader in brief of a typical experiment run through from initial exposure to final readout, with the understanding that specific details can be obtained from the references listed at the end of the report.

1. EXPOSURE

In recording speckelgram data, if the laser has a wavelength of 5140 angstroms and the lens has an f-number equal to 2, then the speckle size projected onto the film plane is approximately 1 micrometer, which is defined as the minimum speckle size for our purposes. This minimum sets one parameter related to the system resolution. The next question related to the system resolution is what is the maximum and minimum shift that can be tolerated? Sampling Theory requires that the shift be greater than 2 speckle sizes (2 micrometers). The maximum shift is defined by requiring the shift not to be larger than the readout beam size (.5 to 1 millimeter). The reason for this maximum is that the surface across the reading aperture can be shifted in only one direction with the randomness of the speckle remaining unchanged. The exposure time required on the film plane is proportional to the film sensitivity and for a typical film (Kodak 649-F), 500 ergs/cm^2 is needed. Assuming now for simplicity a square centimeter of gray steel (55% reflectivity) as a specimen, a 50 milliwatt laser as an illuminator source, in which all of the light intercepts the 1 cm^2 area, and a cosine reflection distribution from the specimen with 1% of the reflected light reaching the imaging lens, a typical exposure might be as follows:

$$1000 \text{ ergs} = 10^{-4} \text{ watt-sec}$$

$$500 \text{ ergs} = .05 \text{ milliwatt-sec}$$

$$.05/50/.55/.01 = .18 \text{ seconds}$$

The .18 second exposure time assumes ideal conditions, thus optical losses in the system would require more exposure time.

The processing required is the standard film process:

1. Develop (D-19) - 6 minutes
2. Stop (Stop Bath) -30 seconds
3. Fix (Rapid Fixer) - 5 minutes

The plate is now ready for readout.

2. READOUT

Readout techniques used for extracting the fringe information from a specklegram and a typical fringe halo are, for the purposes of this report, as follows. A 1 mm readout beam diameter is chosen, thus providing a maximum of 13000 data points on one 4 inch by 5 inch film plate. Since the readout procedure for each point is the same, the procedure for only one point will be discussed. The halo containing the fringe information is defined as a conical ray of light diverging from the center of the readout beam with a cone angle directly calculatable from the recorded speckle size as follows:

$$2\lambda/D = \theta$$

where D=the speckle size. If D=1 micrometer and λ = .5 micrometer, then θ = 1 radian.

Since the recording speckles are arranged in a random fashion and the speckle shift is in only one direction over the area defined by a 1 mm aperture, then the analogy can be made that the random speckle shift acts similarly to a double slit optical configuration.

The equation for the double slit is

$$n\lambda = 2d \sin \theta$$

where n is the order of the fringe, λ is the wavelength of light, d is the distance between slits (or speckle correlation shift) and θ the angle of the fringe transmission.

This says that the first dark fringe should be located at an angle of

$$\theta \approx \lambda/2d$$

if θ is a small angle.

It should be obvious at this point that the specklegram strain analysis technique is an excellent tool for looking at in-plane displacements or strains parrallel to the recording surface, while holographic interferometry best applied to out-of-plane measurements; thus the two techniques should complement each other for solving many strain and stress problems existent in the Air Force.

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