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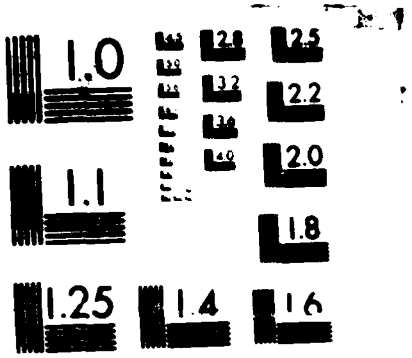
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CONTRACT REPORT BRL-CR-563

LASER BALLISTIC
SENSOR DEVELOPMENT

BOEING AEROSPACE COMPANY
MS 8C-64
PO BOX 3999
SEATTLE, WASHINGTON 98124

JANUARY, 1987

US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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A prototype instrument to determine the orientation of a projectile in free flight (i.e., roll, pitch and yaw angles) was developed at Boeing and used to perform tests at the U. S. Army Ballistic Research Laboratory (BRL) at Aberdeen Proving Ground, MD. The instrument incorporated two visible gas lasers (to provide a two color collimated illuminating beam) and a pair of galvanometer beam deflectors to generate a circular angular dither of the output beam. All three angles can be determined from the detected light reflected by a retroreflector/hologram combination mounted on the projectile. The prototype instrument was designed to make three-axis angle measurements on in-flight or in-bore spinning or non-spinning projectiles, and to make two-axis angle measurements of gun tube motion.

Tests were performed by both Boeing and BRL personnel at the Aerodynamics Range at BRL during a two-week period in August 1985. The test instrumentation was then left at BRL for additional testing by BRL personnel. A summary of the test results follows:

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19. Abstract (continued)

1) All three angles of a spinning projectile can be measured with a fixed beam and two detectors, where one detector senses fringe amplitude and the other detector senses roll, 2) The dither rate (3 kilohertz was too low for the non-spinning projectiles tests, 3) No in-bore data was obtained due to obturation, 4) Dynamic measurements of both angle and position of a gun tube were demonstrated.

As a result of the test, the following problem areas have been identified: 1) The test results show that a system with a higher dither frequency must be developed, 2) The use of two independent lasers complicate the alignment procedure. It would be more reasonable to use a two-color laser (e.g. argon ion laser), 3) Some of the data contains an intensity variation at the fundamental of the dither frequency. This could be due to the projectile lying at the edge of the "overlap" of the dithered beams. A larger beam should eliminate this problem and simplify the alignment procedure, 4) The reflection coefficient versus angle was assumed to be sinusoidal for the present data reduction algorithm. In practice, the reflection coefficient is not sinusoidal, and the shape of the function changes with relative humidity and laser wavelength. Additional development is needed on an algorithm based on a more realistic analytic model.

ACKNOWLEDGEMENTS

We would like to acknowledge the excellent support by Mr. Donald McClellan, Mr. John Carnahan and Mr. William Thompson (range personnel) during this program. The technical results obtained were due in large part to the cooperation and assistance we received.

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SUMMARY

The prototype instrument to determine the orientation of a projectile in free flight (i. e. roll, pitch and yaw angles) was developed at Boeing and used to perform tests at the U.S. Army Ballistic Research Laboratory (BRL) at Aberdeen Proving Ground, MD. The instrument incorporated two visible gas lasers (to provide a two color collimated illuminating beam) and a pair of galvanometer beam deflectors to generate a circular angular dither of the output beam. All three angles can be determined from the detected light reflected by a retroreflector/hologram combination mounted on the projectile. The prototype instrument was designed to make three-axis angle measurements on in-flight or in-bore spinning or non-spinning projectiles, and to make two-axis angle measurements of gun tube motion.

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INTRODUCTION

This document is the final report on Phase 1 of contract DAAK11-84-C-0095. The contract is the first part of a program whose goal is to develop hardware for measuring the angular orientation of projectiles in-flight and in-bore, and the angular response of gun tubes during firing. The technology, originally developed for measuring the pitch angle of models in the Boeing Transonic Wind Tunnel, was shown to be applicable to spinning projectile yaw angle measurement in a prior test program (Reference 2) at the U.S. Army Aerodynamics Range. Significant improvements to the measurement techniques were made in the present contract.

A two-laser breadboard system was assembled at Boeing for evaluation at the Ballistic Research Laboratory. The breadboard was designed to make 3-axis angle measurements on in-flight and in-bore non-spinning or spin-stabilized projectiles, and 2-axis angle measurements on gun tubes. For spin-stabilized projectiles, three-axis angle measurements were demonstrated. Signals were obtained from non-spinning projectiles, but could not be converted into meaningful information due to the inability of the breadboard optical system to measure the orientation of projectiles possessing high yawing rates. No in-bore data was obtained due to degradation of the incident laser beam quality resulting from the leakage of hot combustion gases around the projectile. Dynamic measurement of both angle and position were demonstrated for the gun tube tests.

The report contains a description of the breadboard system, the modifications required for the various measurement tasks, the test conditions, and the test results. Data reduction algorithms developed by Boeing are in Appendix B. Preliminary design information for Phase II hardware, based on the results of this evaluation, are included.

OPTICAL TEST SET-UP

The test setup consists of an optical unit and supporting electronics located in the range together with data acquisition and processing equipment placed in the control room. The optics will be discussed first.

Figure 1 shows the arrangement of optical elements on a standard 0.6x1.2 meter setup board. Red and blue lasers are used to provide orthogonal angle measurements on the projectile. The beams are combined in a dichroic cube beamsplitter and then directed to the filter-splitter. A lens in the red beam is used to adjust the beam diameter at the filter-splitter so that the red and blue beams have the same diameter when they exit the unit.

The filter-splitter is a Boeing device (U. S. Patent No. 4,329,059) that spatially filters the outgoing beam while transmitting most of the return beam energy to the photodetectors. The coaxial red and blue beams at the input to the filter-splitter are focused by a microscope objective lens onto a small elliptical mirror on a tilted glass plate which spatially filters the reflected beams and insures that the red and blue beams are collinear. The elliptical mirror is small compared to the diffraction pattern of the return beams from the reflector on the projectile, so more than 90% of the return energy passes on to the photodetectors.

A two-axis galvanometer type beam deflector generates a circular dither (or conical scan). The relay lens forms an image of the filter-combiner mirror in the focal plane of the large collimating lens. The function of the relay lens is to reduce lateral motion of the spot at the projectile. (The translation is zero in the plane where the combination of the collimating and relay lenses forms an image of a galvanometer mirror.) The output beam is collimated and reflected into the projectile path with a pair of mirrors (not shown).

The reflector assembly consists of a hologram and a cube corner reflector, as described in Reference 2, with modifications that allow 3-axis angle measurement. The hologram has a central circular holographic grating surrounded by an annular grating with equal area but orthogonal fringe orientation. Red and blue spectral filters that match the hologram profiles are sandwiched between the hologram and the reflector.

The circular dither on the outgoing beam produces orthogonal sinusoidal components to match the axes of the dual hologram. Amplitude and phase of a pair of dither frequency harmonics (for each color) are used to find the orientation of the projectile body axis. Roll about the body is proportional to the phase difference between the deflector driver and the fundamental component of the return signal.

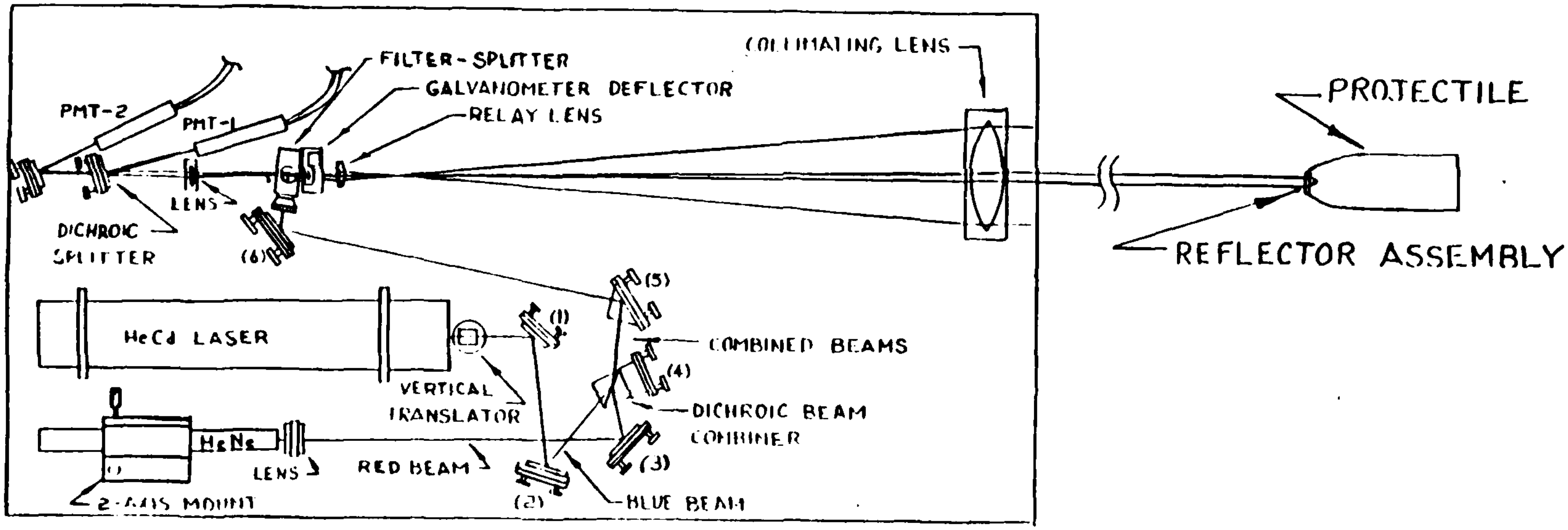


Figure 1. BRL Optical Breadboard.

DATA ACQUISITION ELECTRONICS

Figure 2 is a block diagram of the data Acquisition Electronics (DAE). The DAE was used to collect range or calibration data. The photodetectors were Hamamatsu R761 photomultipliers (PMT), a head-on type with a half inch (13mm) diameter photocathode. The PMT has ten dynode stages, typical current gain of 5.8X10E+5, and a spectral response from 185nm to 850nm, peaking at 420nm. The light entering the PMT's was optically filtered for the two optical wavelengths before application to the PMT's.

Both the red and blue signal channels are identical with the exception of the overall gain. Load resistors for the PMT's were 10k ohms. At the optical assembly each PMT output was amplified by a HP465A amplifier with a gain of 20db and filtered by a Krohn-Hite 3342 filter/amplifier. One section of the Krohn-Hite filter is used as a low pass filter with a cutoff frequency of 100Hz and a gain of 20db. The low pass section drives the high pass section resulting in a bandpass with cutoff frequencies of 100Hz and 24KHz. The high pass section of the Krohn-hite filter drives approximately 100 feet of terminated coax cable between the optical assembly and the control room. The variable gain capability of the HP467A was used to adjust the input amplitude to the tape recorder and analog-to-digital converter to approximately one volt RMS.

All timing for the system is synchronously derived from a very stable frequency source, an HP8460B signal generator operating at 576Khz. Quadrature (i.e. the two signals are out of phase by 90 degrees) signals at 3Khz drive the elevation and azimuth galvanometers.

An EMI7000 tape recorder was used to record all test data. Each signal output from the HP467A's was applied to three tape recorder channels and one channel of the ADC/Computer Interface. The gain settings of the three tape recorder channels were adjusted to accommodate signals that were the expected nominal and plus and minus 50% from nominal. Other sources of data recorded by the EMI7000 are shown in Figure 2.

The direct memory access, DMA, of the HP9836 computer was used as a transient waveform recorder to collect real time range and calibration data for immediate and future data reduction. All four channels of the ADC/Computer Interface are sampled synchronously at a 36Khz rate and data transferred to the computer by DMA at 144 kilobytes.

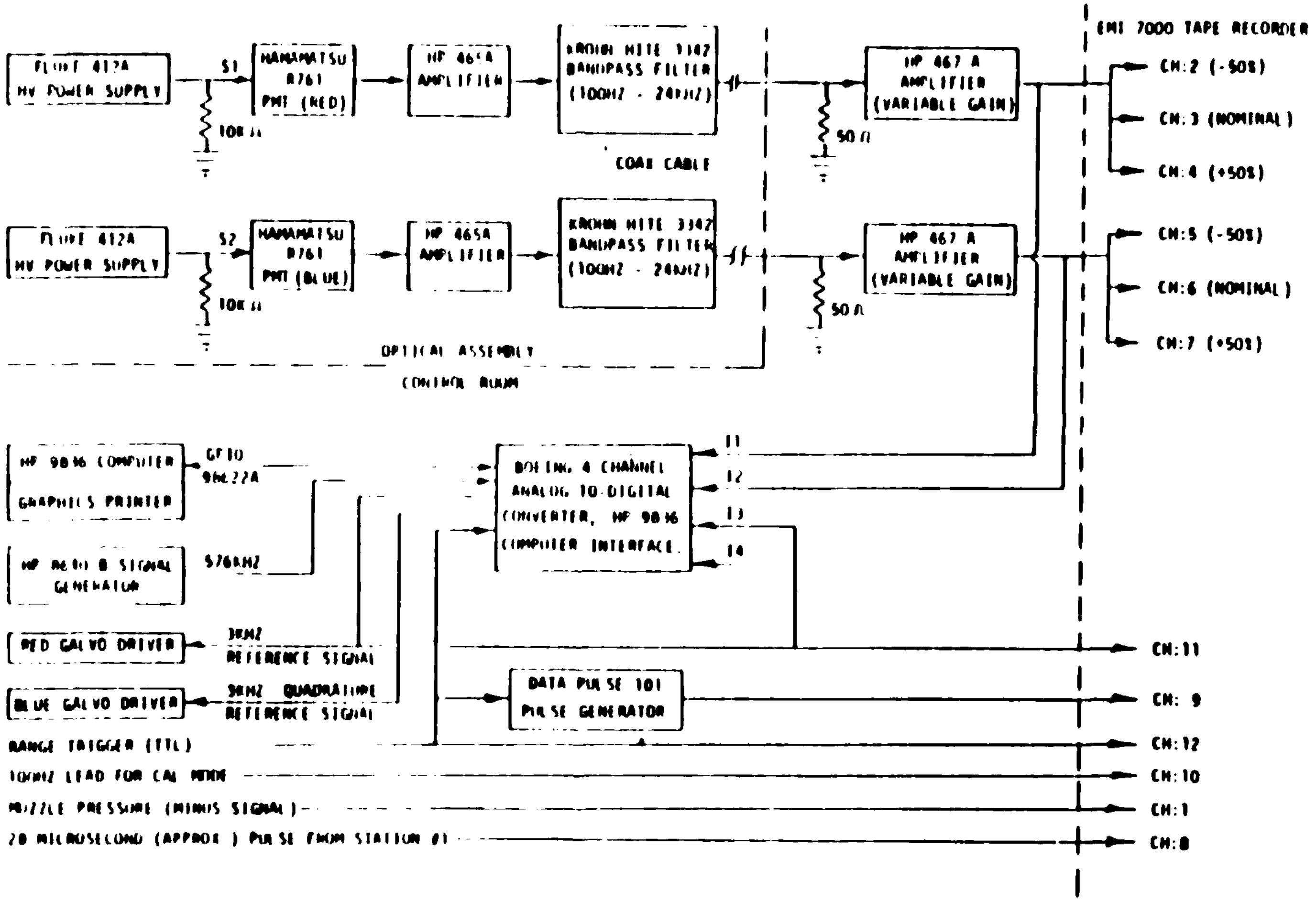


Figure 2. Block Diagram of Data Acquisition Electronics.

Initiation of range data collection was synchronized to the first positive crossing of the 3Khz signal driving the red galvanometer after a range trigger is received. This synchronization was incorporated to facilitate the phase measurement required in processing the data. When range data was collected, the red, blue, and 3Khz reference signals were sampled and stored by the computer.

Each hologram/retroreflector combination was calibrated by placing it in a test fixture which allowed it to be rotated in two orthogonal planes, simulating pitching and yawing motion. During this procedure the red and blue signals and the x and y positions of the gimbal positioning device were also sampled and stored by the computer. Appendix A contains the schematics for the data acquisition electronics.

DATA PROCESSING

Since data processing is dependent on the characteristics of the holographic grating and corner reflector combination, the reflector assembly will be described first.

The reflector assembly, Figure 3, consists of a holographic grating and a cube corner reflector. The reflector assembly is small and rugged with typical dimension of 6.4 mm diameter and 5 mm high. The input light beam is diffracted by the hologram into the zero and higher order beams. For clarity, only the zero order and one of the signed first order beams are shown in the figure. These two beams are retroreflected by the cube corner and again diffracted by the hologram. Note that the zero and first order beams are again diffracted into zero order and first order beams. The emerging composite zero order consists of a number of parallel component beams. These component beams follow different optical paths, consequently they interfere constructively or destructively, depending on relative phase difference. Figure 4 shows the modulation of the reflection coefficient due to optical interference as a function of the angle of incidence.

The resulting fringe angle of the hologram corner cube combination is dependent on the fringe angle of the hologram when it is produced, the index of refraction and height of the corner cube reflector. Figure 5 is a diagram showing the optical set up for producing the hologram. The diffraction angle for the hologram is

$$\Theta_d = 2 \sin^{-1}(\lambda/2s)$$

where λ is the wavelength of the laser source and s is the grating period.

The fringe angle for the hologram and corner cube reflector combination is approximately

$$\Theta_f = n\lambda/2h\Theta_d$$

where h is the height and n is the index of refraction of the cube corner reflector.

If the change in angle of the retroreflector is unidirectional then the amplitude of the reflection coefficient could be used to measure the angle of the retroreflector. In reality the amplitude does change due to effects other than changes in the angle of the cube corner reflector (e.g. noise, changes in laser power output). To determine the direction of change of the retroreflector angle, quadrature signals are required. With quadrature

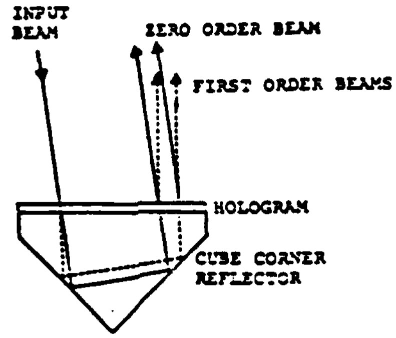


Figure 3. Reflector Assembly.

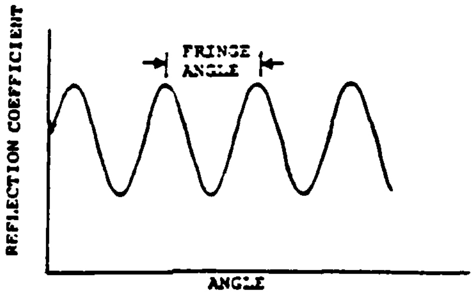


Figure 4. Reflection Coefficient.

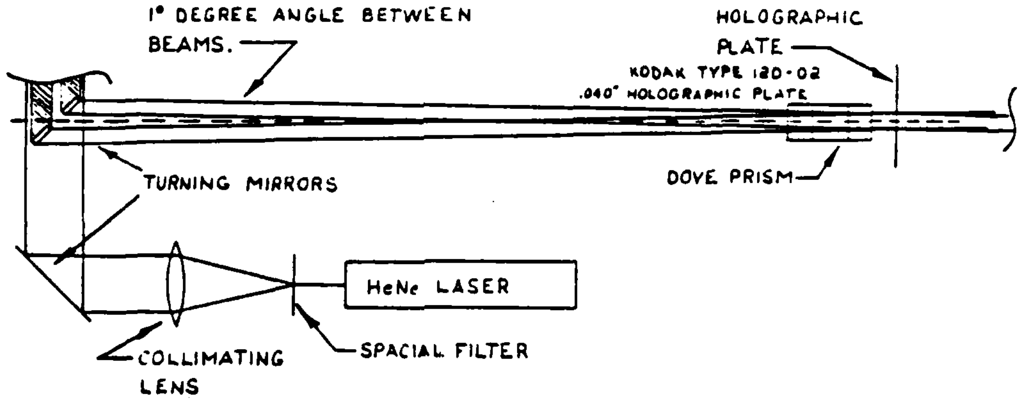


Figure 5. Technique used in making a 1^0 Diffraction Angle Hologram.

(i.e. signals are out of phase by 90°) signals phase can be measured, direction of phase change determined, and the amplitude effects which are not related to angle can be eliminated.

The spin of a spinning projectile provides the modulation which enables data reduction. For a slow spin or non-spinning projectile the laser beam is dithered (angle modulated) in order to change the incident angle of the input light beam at the retroreflector. This is accomplished by the azimuth and elevation galvanometers and beam directing optics.

Angle modulation of the beam across the fringe pattern shown in Figure 4 results in quadrature relationships existing between frequency components of the photodetector current which are harmonicly related to the modulating frequency. Figures 6 through 8 support the analytical description to follow from which the software algorithm was developed. This analytical description is for one axis only and is not as rigorous as the description for the analytic model which was developed at the end of the program.

Figure 6a represents the photodetector output (equivalent to the reflection coefficient) and Figure 6b the angle modulation at the dither frequency. Figure 6c is the photocurrent for the angle modulation shown in Figure 6b. I is the photodetector current output as a function of the angle of the corner cube reflector and $\theta_r = 2\pi$ (yaw angle)/(fringe angle). I_p is one half the peak-to-peak value of the photodetector current and t is time. m_p is the peak deviation of the angle modulation in radians and w_m the modulation frequency of the dither in radians per second.

The equations that describe the modulation effects of the dither are

$$\begin{aligned} I(\theta_r, t) &= I_p \sin(\theta_r + m_p \sin w_m t) \\ &= I_p \sin \theta_r \cos(m_p \sin w_m t) + \\ &\quad I_p \cos \theta_r \sin(m_p \sin w_m t) \\ &= I_p \sin \theta_r [J_0(m_p) + 2J_2(m_p) \cos 2 w_m t + \\ &\quad 2J_4(m_p) \cos 4 w_m t + \ldots] + \\ &\quad I_p \cos \theta_r [2J_1(m_p) \sin w_m t + 2J_3(m_p) \sin 3 w_m t + \ldots] \end{aligned}$$

where the values of $J_n(m_p)$ are determined from the graph of Bessel Functions, Figure 7. Note that the amplitudes of the odd and even harmonics above are quadrature functions. The amplitude of the odd harmonics is proportioned to the cosine of θ_r and the amplitude of the even harmonics is proportional

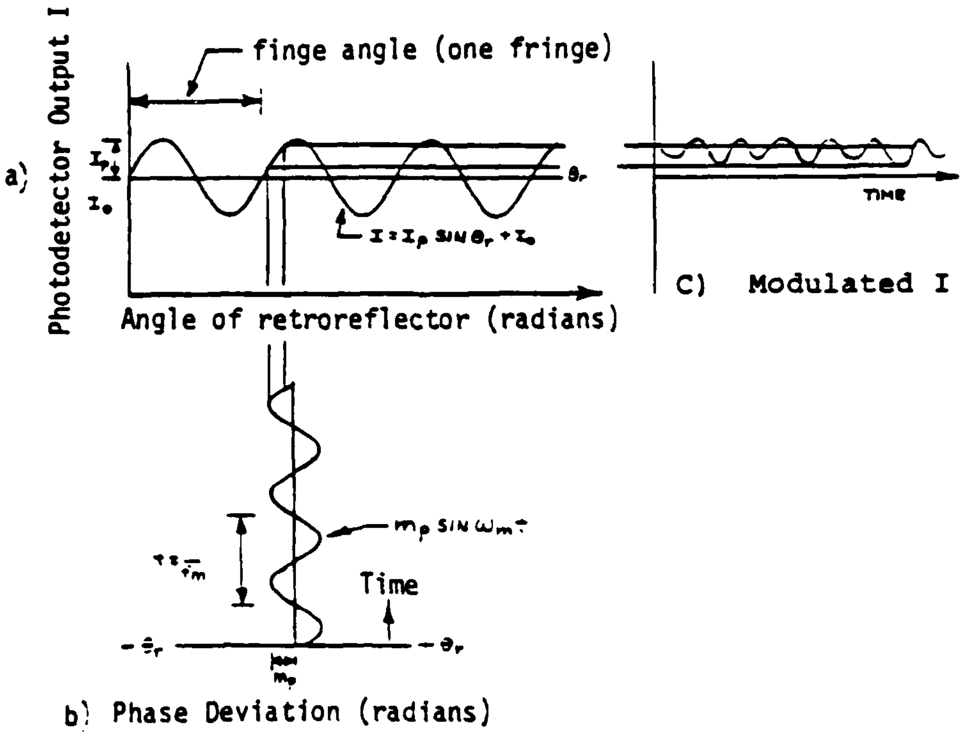


Figure 6. Angle Modulation of the Fringe Angle.

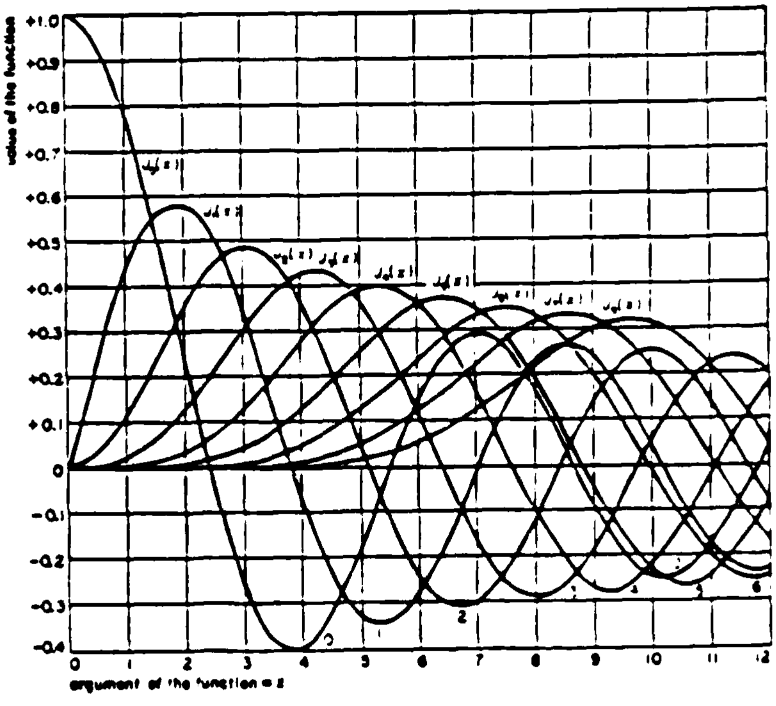


Figure 7. Bessel Functions for the first 8 orders.

to the sine of the θ_r. The fundamental and second harmonic were used in the breadboard system.

Figure 8a is the photodetector output with a graphic representation showing the relation between the fundamental and second harmonic components of a reflected beam for a small value of m_p. The figure shows the relationship between the reflected signal and the dither signal, when $\theta_r = 0, \pi, 2\pi, \cdots$. The fundamental frequency dominates the signal when $\theta_r = 0, \pi, 2\pi, \cdots$. The second harmonic dominates the signal when $\theta_r = \pi/2, 3\pi/2, 5\pi/2 \cdots$. Note the Pi radian phase reversal between the positive and negative slopes for the fundamental and the positive and negative peaks for the second harmonic. Figure 8b and c are the fundamental and second harmonic filtered from the photodetector current by bandpass filters. The amplitude factor m_p is chosen equal to approximately .27 resulting in equal peak-to-peak amplitudes for the fundamental and second harmonic. It is important to note that the waveforms of the fundamental and second harmonic are in quadrature.

Figure 8d shows the desired quadrature terms as a function of cube corner reflector angle. To arrive at these outputs a phase comparison must be made between the fundamental and the modulating frequency for the fundamental, and between the second harmonic and twice the modulating frequency for the second harmonic. Devices such as balanced mixers used as a phase detector, followed by a suitable low pass filter, would produce the desired output. For the computer algorithm the envelope amplitude and sign is determined for each cycle of reference phase.

After amplitude and phase detection the quadrature signals of Figure 8c and d can be written as

$$E_1(\theta_r) = I_p(2J_1(m_p))\cos\theta_r$$

$$E_2(\theta_r) = I_p(2J_2(m_p))\sin\theta_r$$

where $E_1(\theta_r)$ is the detected envelope of the fundamental and $E_2(\theta_r)$ the detected envelope of the 2nd harmonic. Then

$$E_2(\theta_r)/E_1(\theta_r) = I_p\ 2J_2(m_p)\sin\theta_r / I_p\ 2J_1(m_p)\cos\theta_r$$

$$= J_2\sin\theta_r / J_1\cos\theta_r = (J_2/J_1)\tan\theta_r$$

and

$$\theta_r = \tan^{-1}[J_1E_2(\theta_r)/J_2E_1(\theta_r)]$$

The sign of the argument of the arctan identifies the quadrant for each quarter-fringe cycle. Comparison of the signs of the numerator and denominator of the present and previous measurements are used to identify quadrant boundary

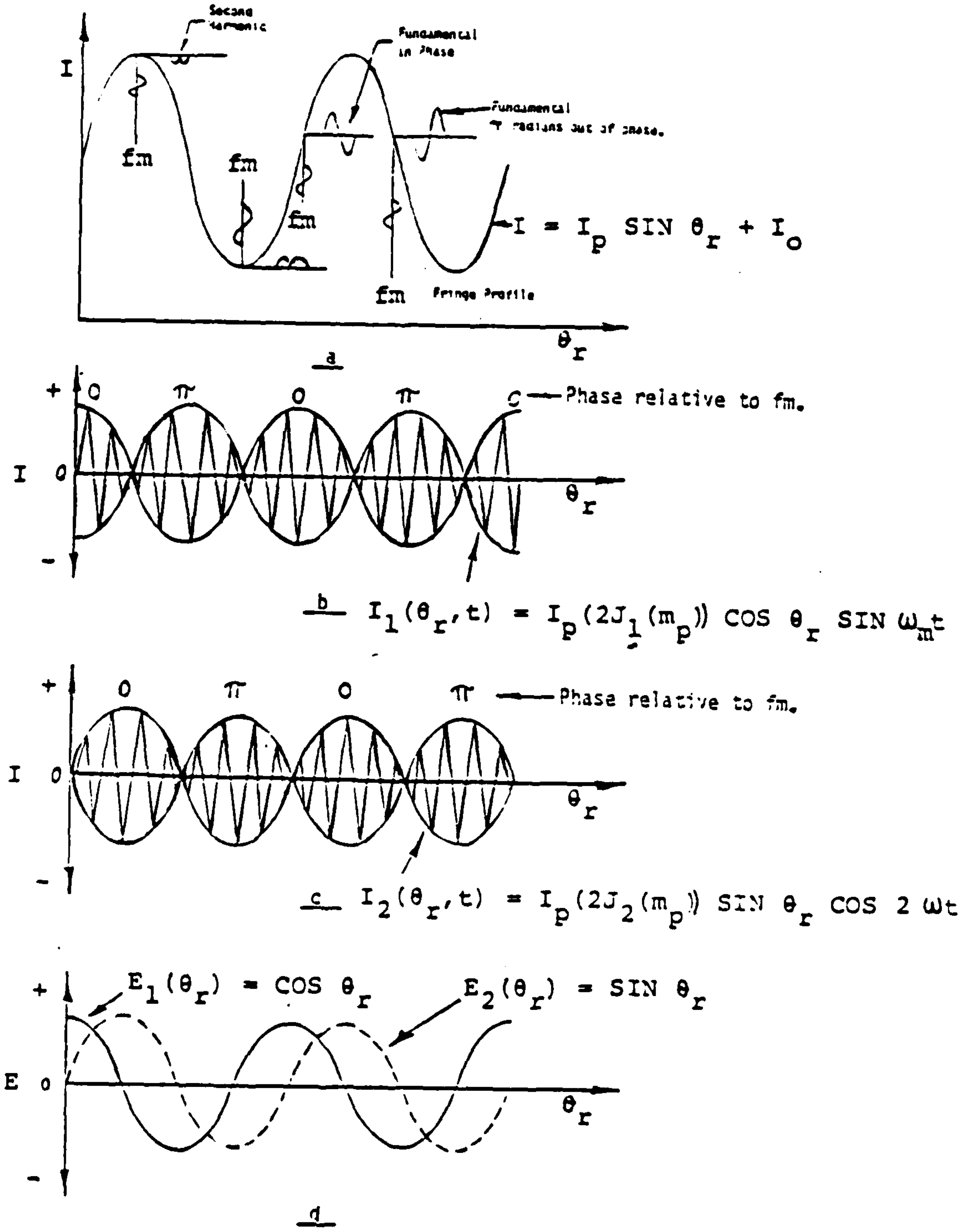


Figure 8. Modulated and Detected Waveforms.

crossings. Consequently, fractional fringe quarter cycles can be measured, and the boundary direction crossing used to sum quarter fringe cycles.

SOFTWARE DEVELOPMENT

Software was developed using the preceding analytical description. It is important to note that the software was a development effort intended for diagnostics and for the future determination of the requirements for complete data reduction by a HP9836 computer or the range computer.

The two programs (written in the BASIC language) are included as Appendix B. One software program is used for collecting and processing range data when a range trigger is received and the other is used to collect calibration data for a given hologram cube corner reflector combination. The calibration program was derived from the range program, consequently parts of the program are not integral to the calibration process. Figure 9 is the flow chart for the range data collection and processing program.

Range data consisted of the outputs from the two photomultipliers and a 3Khz reference (the 3Khz signal driving the elevation galvanometer). For each cycle of the 3Khz reference there are twelve data samples for each channel of the ADC/Computer Interface. Transfer of data was done using the Basic TRANSFER command. Data was transferred to a DMA Buffer in real time for a predetermined time after receiving a range trigger. At the end of this predetermined time, determined by the DMA Buffer size, the binary data was converted to decimal and placed in a program array for use by the program.

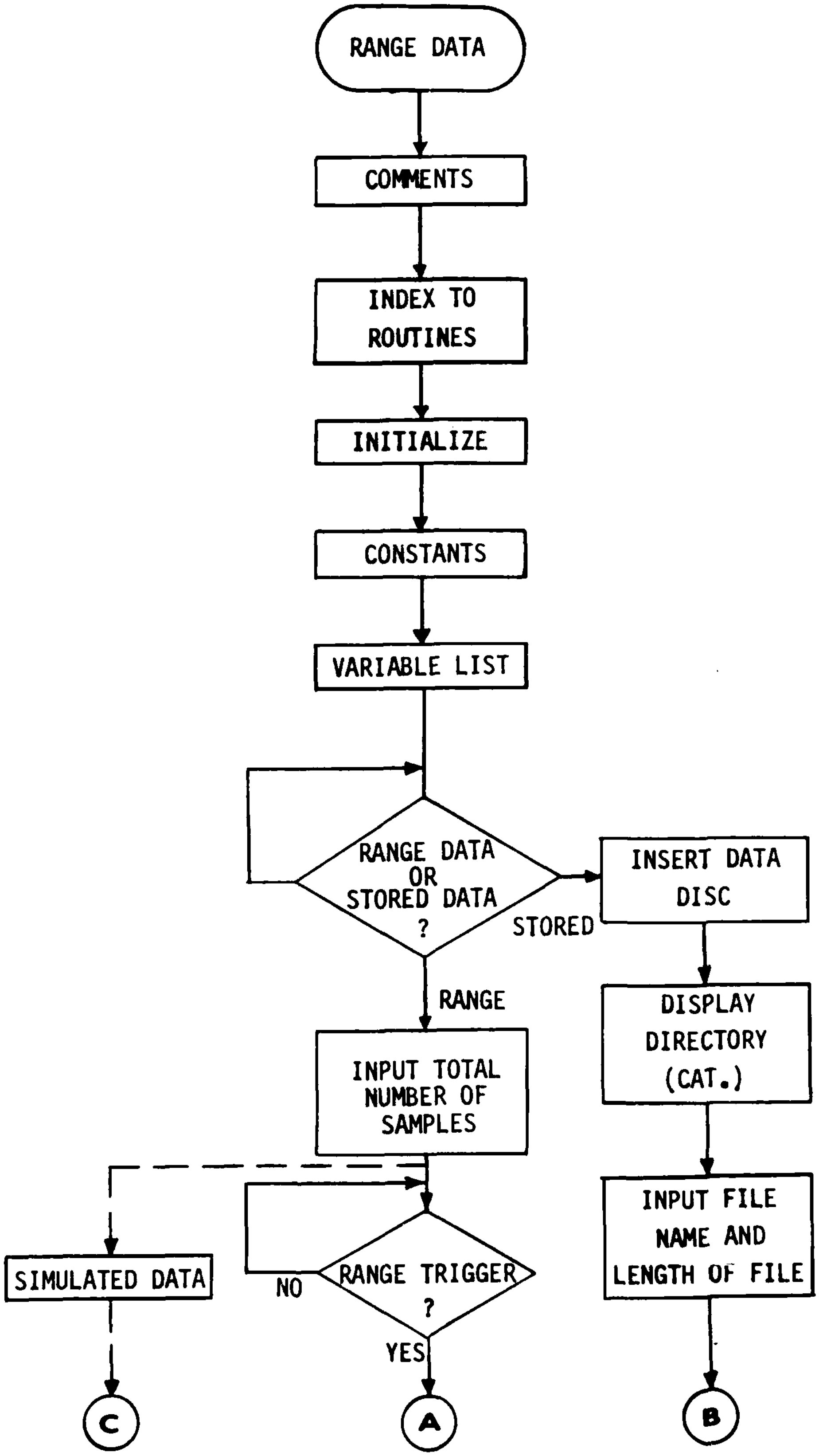
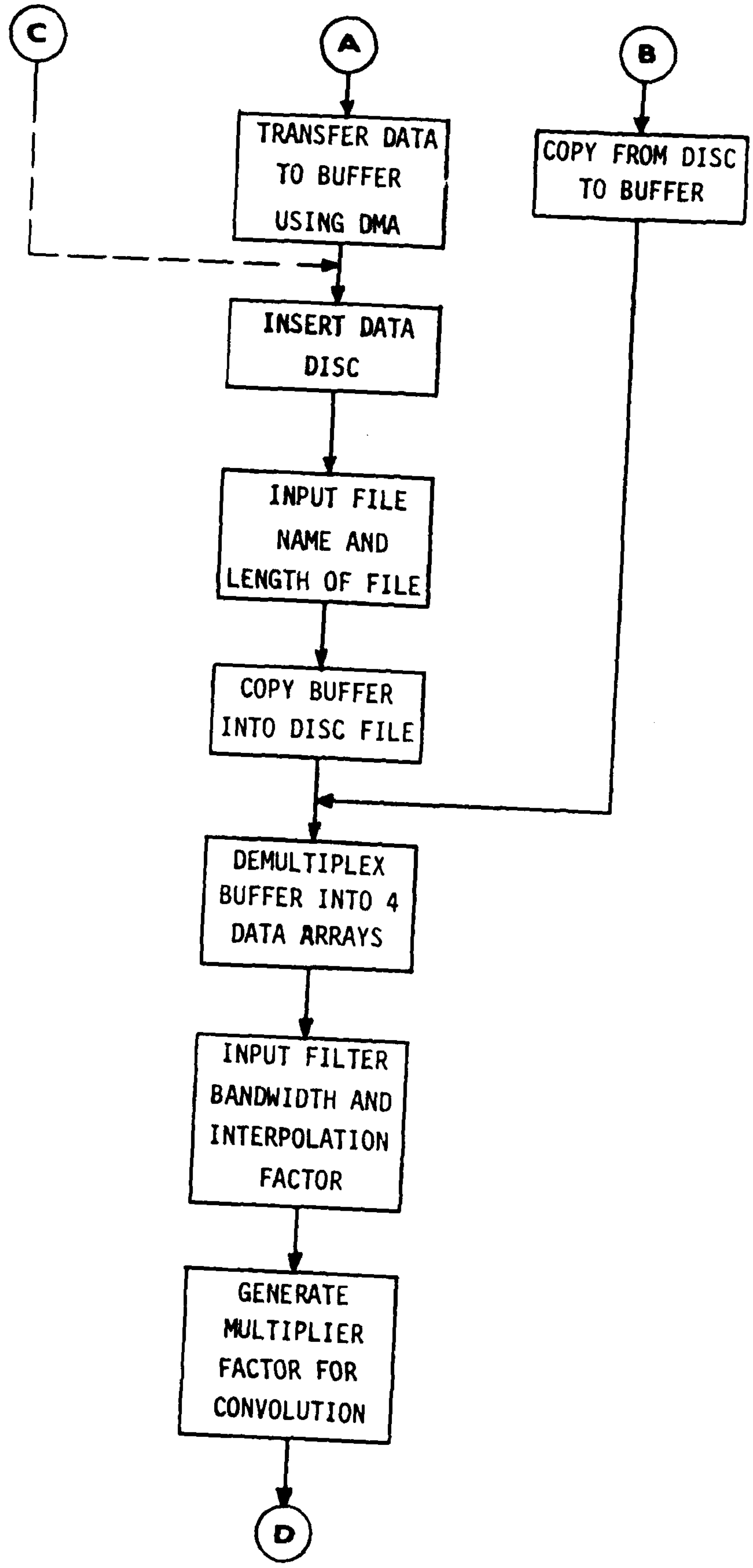


Figure 9. Computer Program Flow Chart



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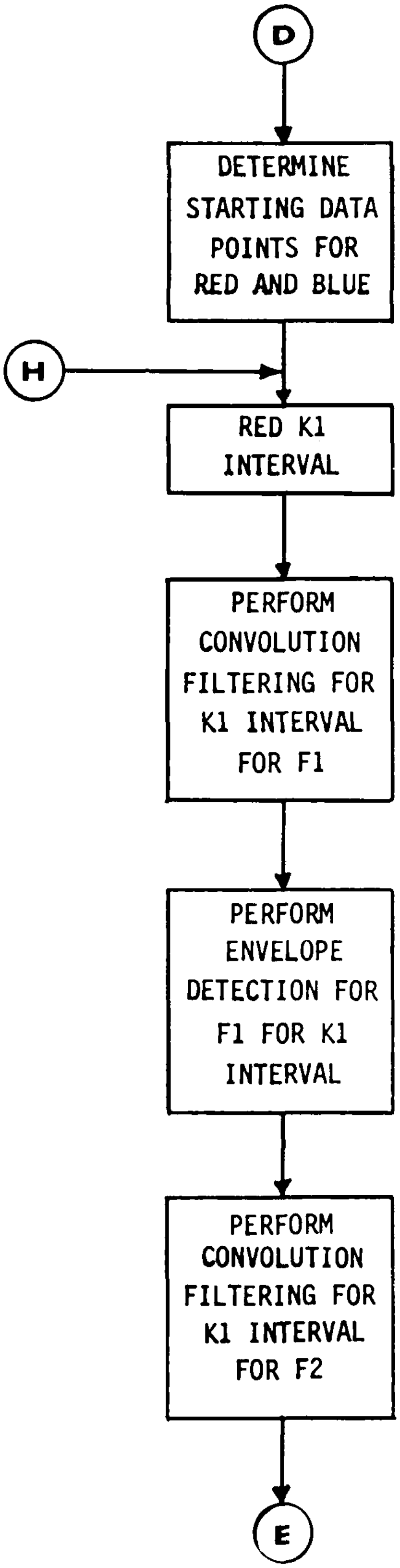
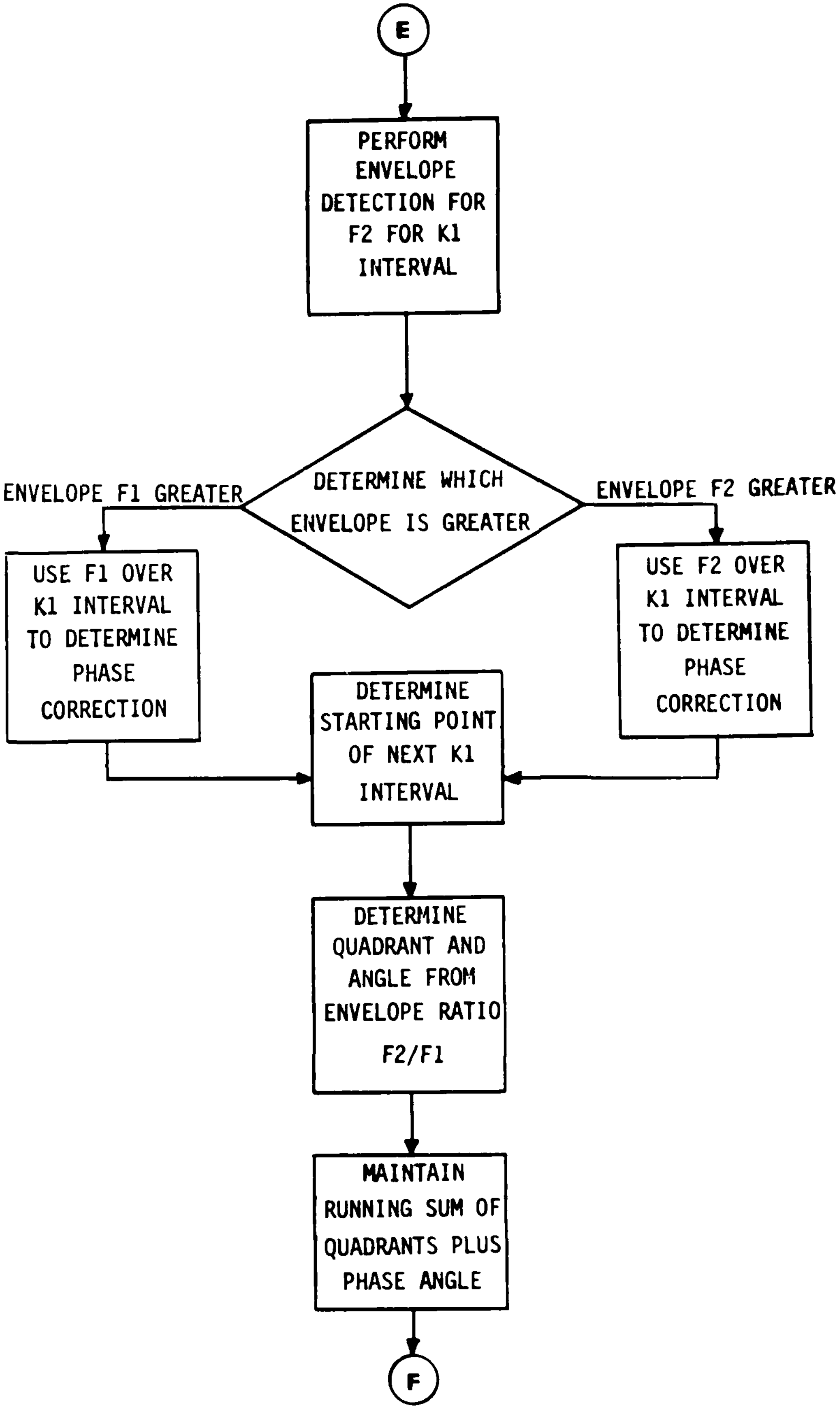


Figure 9. Computer Program Flow Chart (continued)



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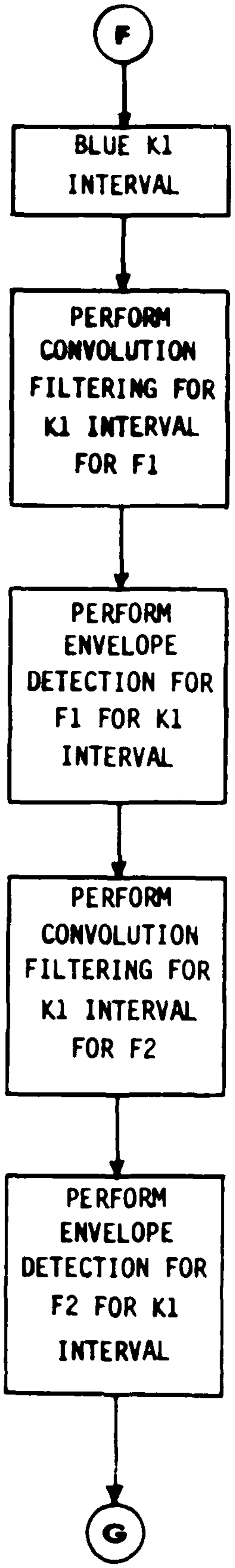

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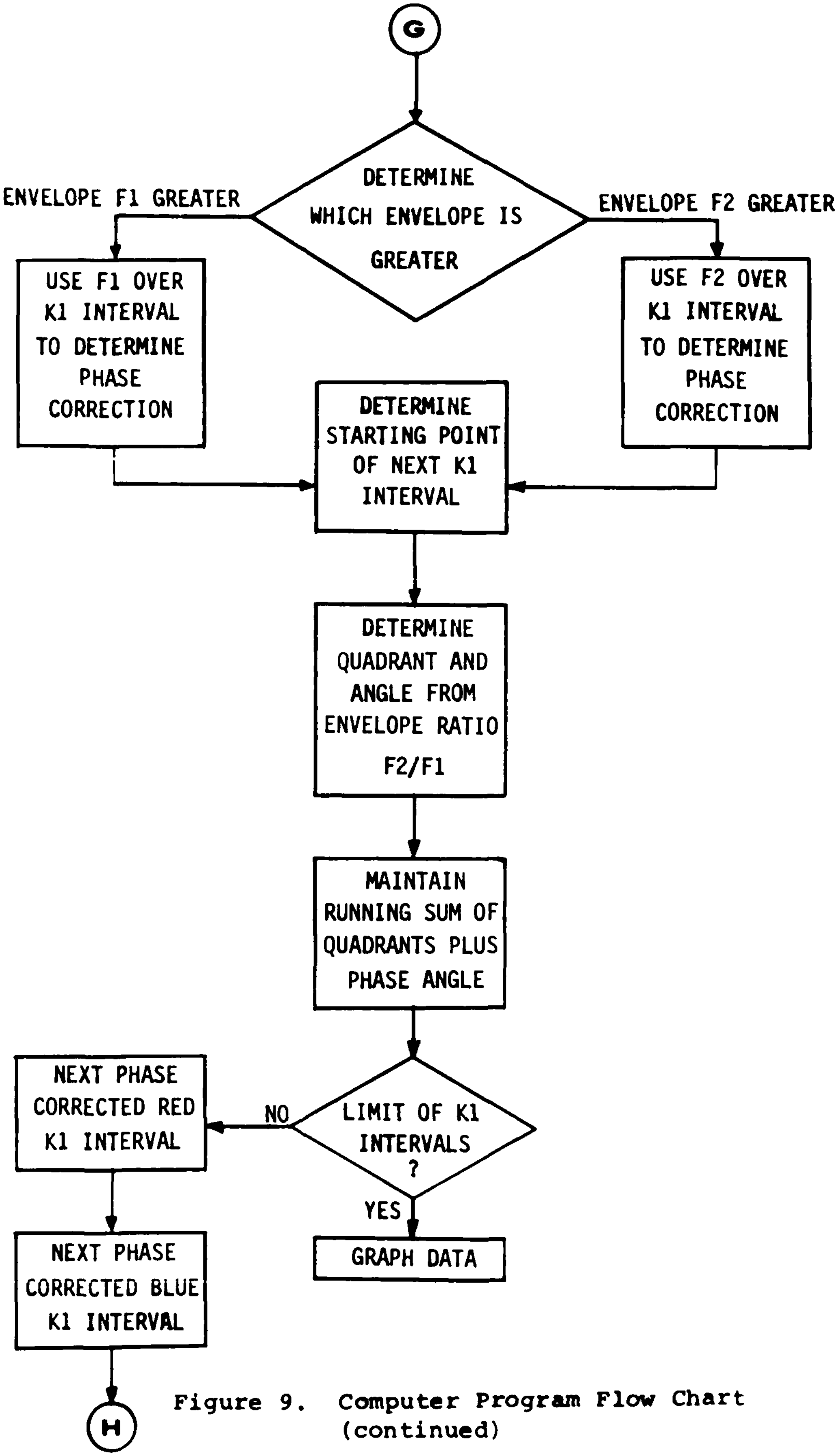


Figure 9. Computer Program Flow Chart (continued)

TEST RESULTS

The test configuration and results of tests performed jointly by BAC and BRL personnel are summarized in Table 1 below. Following the table is a discussion of the reduced data listed in the order of those rounds which produced reducible data.

TABLE 1 - ROUND FIRING SUMMARY

NO.	ROUND TYPE	DATA SET	CONFIGURATION	RESULTS
17450	30 mm spinning		Scotchlite on nose, to check for obturation	No range trigger
17452	30 mm spinning	Run-1	Single 1° hologram Red beam set for yaw Blue beam set for roll Flight path 30 m	Data on tape No range trigger
17453	30 mm spinning	Run-2	"	No data No range trigger
		Run-3	No retro, range trigger check	
		Run-4	No retro, range trigger check	
		Run-5	No retro, range trigger check	
17458	30 mm spinning	Run-6	Same as round 17452	Early range trigger No data
		Run-7	No retro, range trigger check	
17460	20 mm no spin	Run-8	2-axis, 1° hologram Cal-3A Flight path 15 m	Data on tape and in computer
17461	20 mm no spin	Run-9 Cal-4	"	"
		Run-10	No retro, range trigger check	
		Run-11	No retro, range trigger check	

TABLE 1 - ROUND FIRING SUMMARY

NO.	ROUND TYPE	DATA SET	CONFIGURATION	RESULTS
17464	30 mm	Run-12 Cal-5	Set up for in-bore measurement. Folding mirror in blast room	No data due to obturation
17465	25 mm	Run-13 Cal-6	Muzzle angle and linear displacement setup. Reflector in collar on muzzle.	Collar moved No data
17466	25 mm	Run-14 Cal-6	"	Displacement and angle data Gun moved back 16mm in last two shots
17467	25 mm	Run-15 Cal-6	"	Muzzle pressure gauge failed
17468	25 mm	Run-16	"	
17469	25 mm	Run-17	"	

Round 17452 - The purpose of this round was to test the feasibility of determining pitch, roll, and yaw angles of a spinning projectile with a fixed beam (no dither). The 30 mm round was fitted with a single 1^0 hologram and cube corner reflector. The calculated fringe angle is 6 milliradians, based on the hologram diffraction angle and the specified height of the retroreflector.

A retroreflector whose far-field pattern consisted of two spots was used to facilitate roll measurement. The optics for the blue beam were adjusted to form the far-field pattern of the return beam on a slit in front of the photomultiplier so an electrical pulse occurs each time the projectiles rolls 180^0. The reflection assembly on a spinning projectile generates a frequency modulated (fm) signal, where the number of cycles per half revolution is proportional to the total yaw angle (Reference 2). The polar angle is proportional to the time between the minimum frequency point of the fm signal (red beam) and the electrical pulse from the blue beam.

Figure 10 shows the laser measurement results of total yaw angle as a function of time. Data obtained from the analysis of a series of orthogonal spark shadowgraphs obtained for this round are shown in Figure 11. The laser measurement is quite similar in shape to the smooth curve fitted to the shadowgraph data. It is interesting that the minimum yaw points at 10m are not on the smooth curve, but they show up on both the raw shadowgraph data and the reduced laser data.

Figures 12a and b are laser and shadowgraph measurements of the horizontal and vertical yaw angle components. The square boxes on the laser curve mark the points at which the pair of far-field blue spots line up with the slit. The projectile rolls 180^0 between each pair of square boxes, thus the laser angle sensor can measure all three projectile angles.

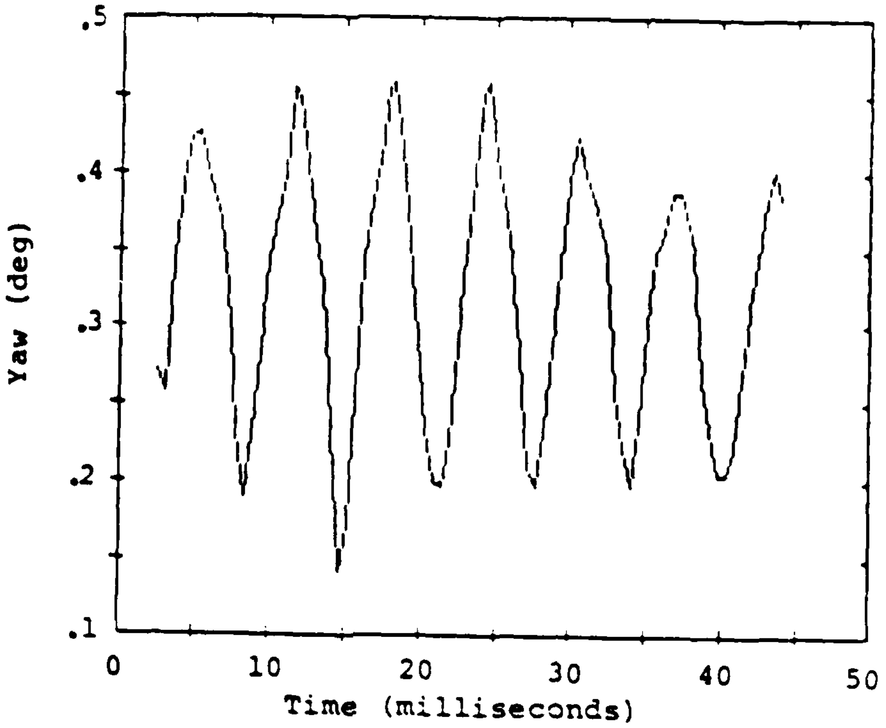


Figure 10. Total Yaw, Round 17452, Laser.

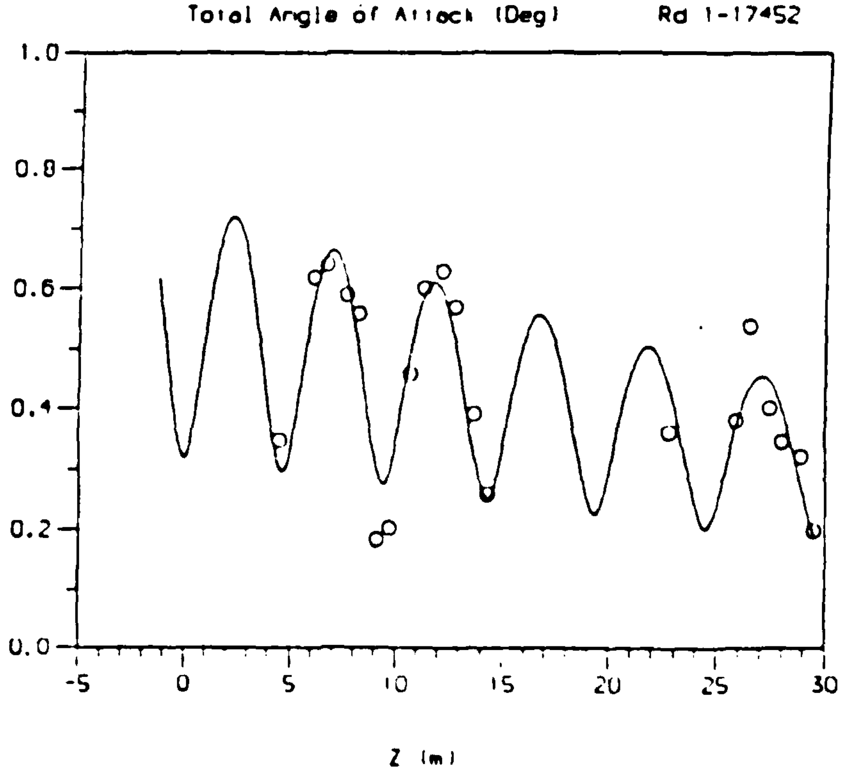
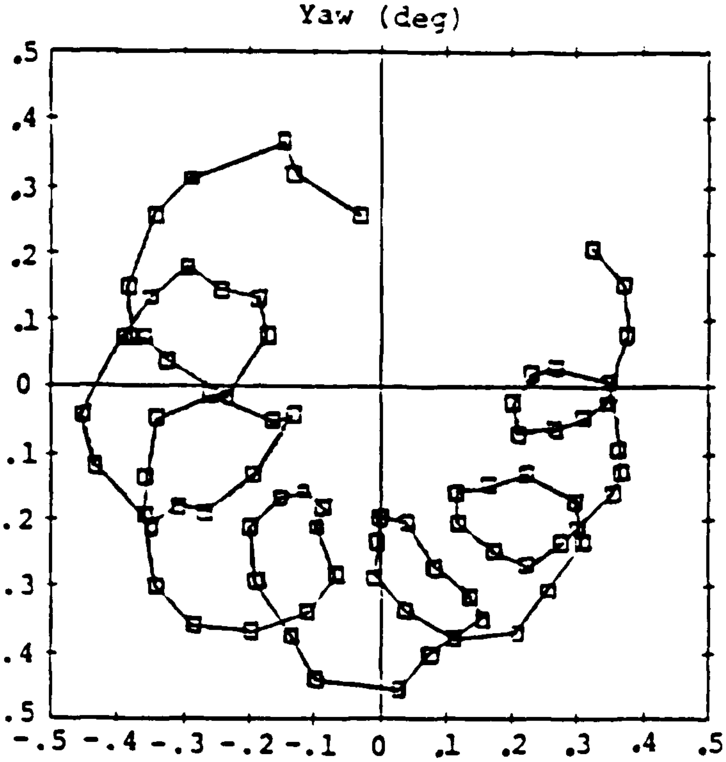
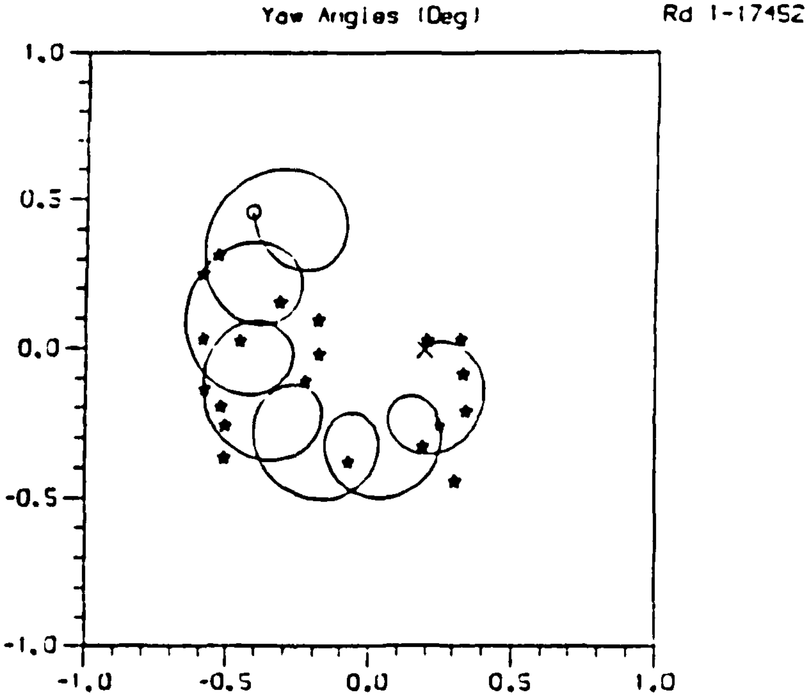


Figure 11. Total Yaw, Round 17452, Shadowgraph.



a) Laser Data

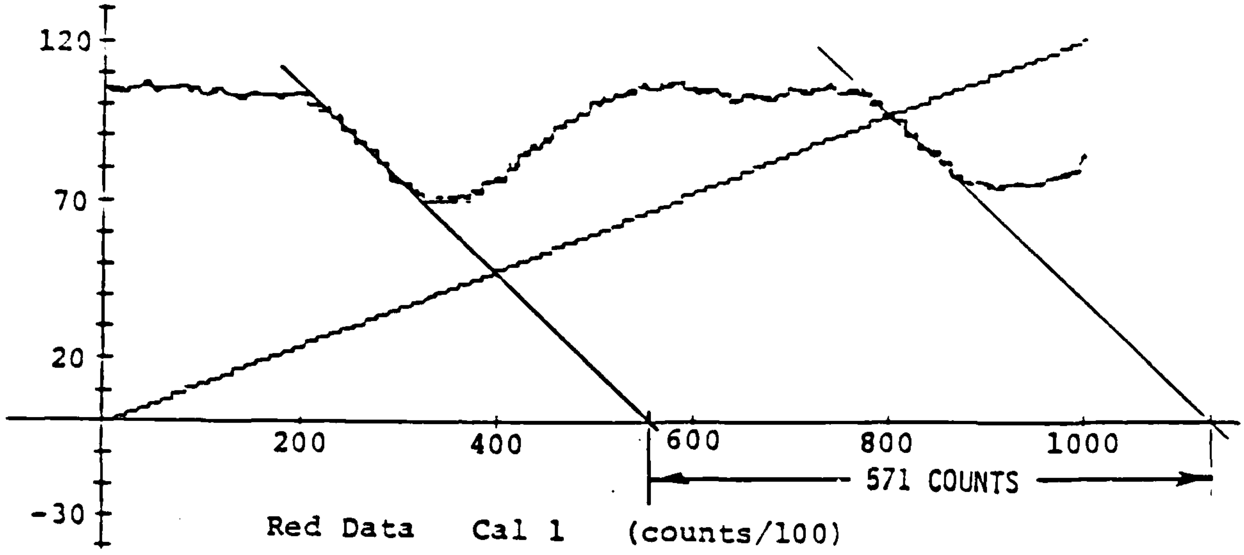


b) Shadowgraph

Figure 12. Yaw Angle, Looking Up-range, Round 17452.

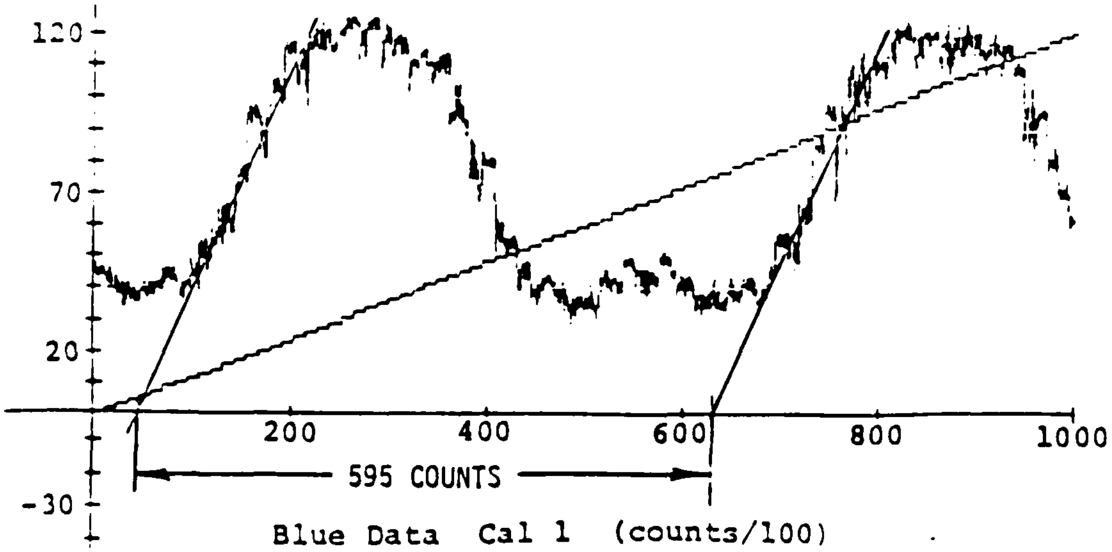
Round 17453 and 17458 - No data was acquired on these rounds due to problems with the range trigger. However, the rounds were calibrated prior to each firing. The calibration technique is described below.

The round is mounted in a precision two-axis motorized optical mount. The mount has a digital encoder that is coupled to the HP-9836 computer. The initial angle is adjusted so that the Fresnel reflection from the reflector assembly returns to the laser. The projectile is rolled so that motion on one axis produces no modulation of the fringes for the orthogonal axis. The mount is then driven slowly and the fringe pattern versus encoder counts is stored in the computer. Figured 13 and 14 show typical fringe patterns. The number of counts per fringe is found by the geometric construction shown on the figure.



1240 COUNTS = 10^{-2} rad
FRINGE ANGLE = 4.61 mrad (0.264 deg.)

Figure 13. Fringe Angle Calibration, Red.



FRINGE ANGLE = 4.80 mrad (0.275 deg.)

Figure 14. Fringe Angle Calibration, Blue.

Rounds 17460 and 17462 - The purpose of these rounds was to evaluate the use of circular dither with two laser lines to measure all three angles of a non-spinning projectile. The reflector assemblies were calibrated in the precision 2-axis mount prior to firing the rounds. The hologram configuration was the orthogonal nested holographic grating as described in the preceding section. The hologram diffraction angle was one degree.

Fringe data was obtained for both of these rounds, and the signals are quite clean. Unfortunately, the rounds were very dynamic. The fringe rate is too high for processing with the algorithm that was developed on this program. The date reduction algorithm is designed for the case where the fringe rate is small compared to the dither rate. Figure 15 shows the output of the data reduction algorithm for these rounds. Figure 16 is the range data for round 17460.

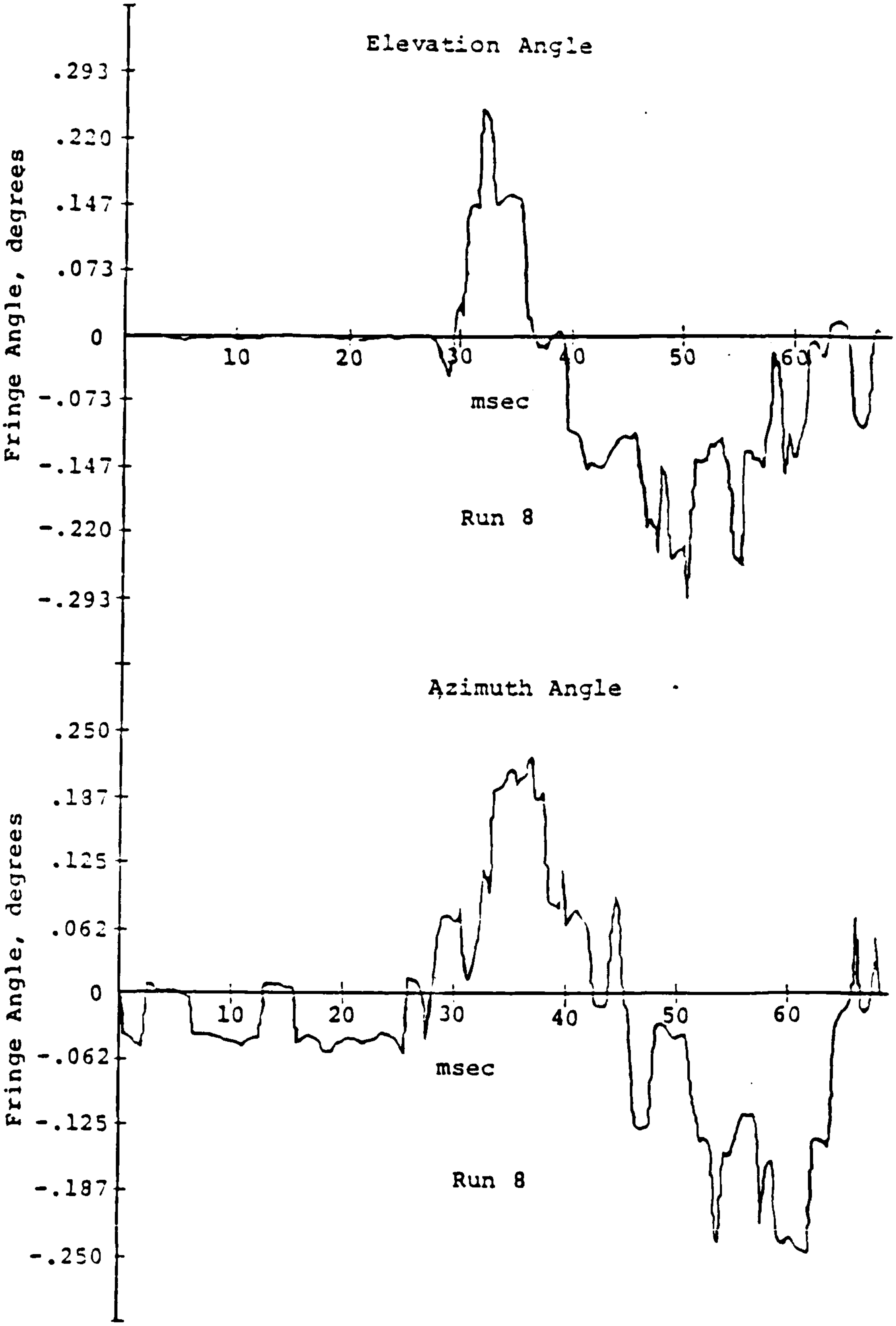


Figure 15. Computer Output, Round 17460.

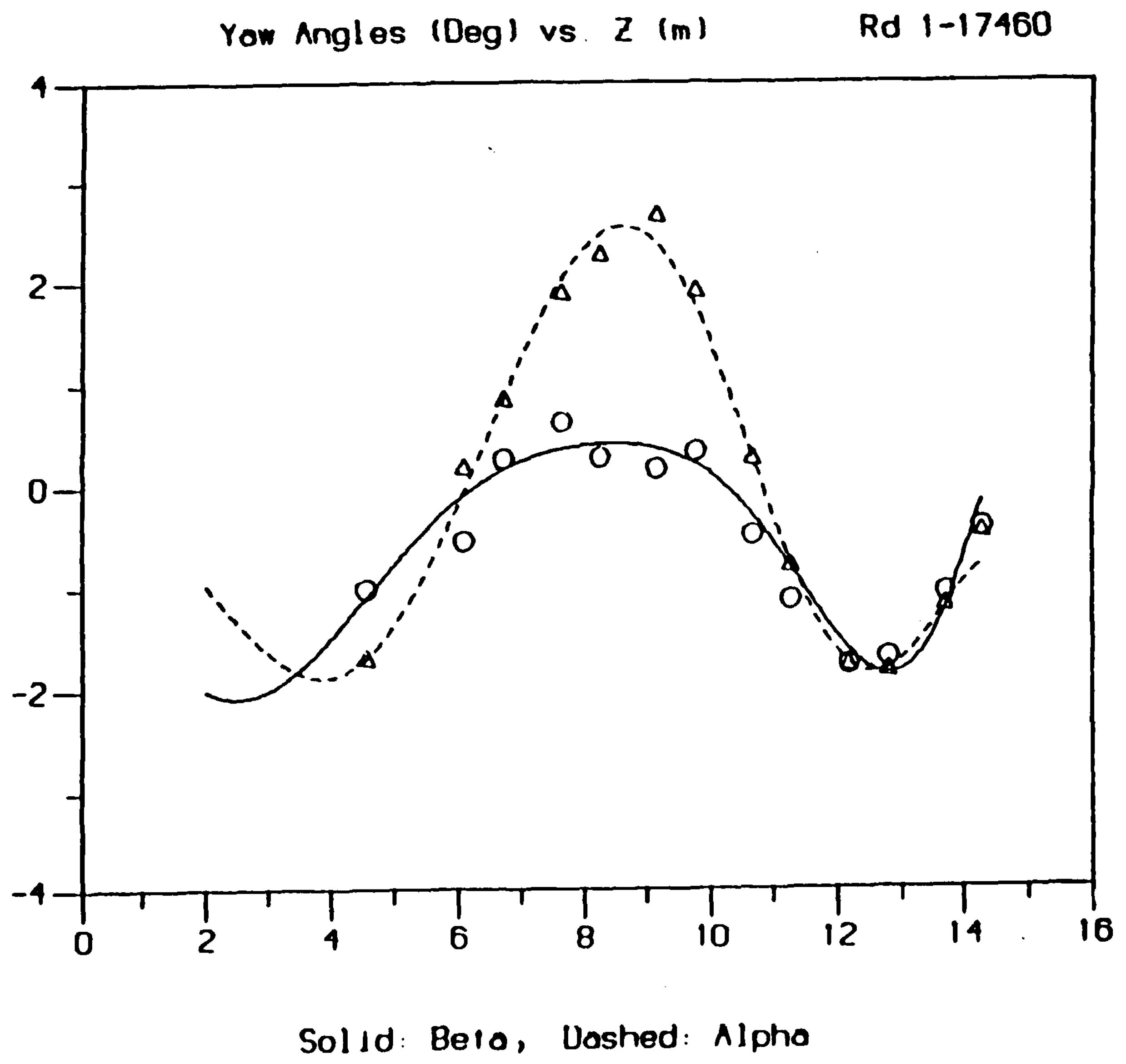


Figure 16. Yaw Angles versus Z, Round 17460.

Round 17464 - In-Bore. The optical unit was in the loading room. The laser beam passed through a 50 mm hole in the blast room wall and was directed by a pair of mirrors into the muzzle. The projectile base was fitted with a rubber seal in an attempt to prevent the passage of combustion gases. The seal failed, and no data was obtained from this round due to obscuration of the optical beam by leakage of hot combustion gases.

Rounds 17466 and 17467 - Muzzle Angle and Displacement. This setup is similar to the in-bore setup, except that the second folding mirror directed the laser beams to a reflector assembly mounted on a collar attached to the muzzle. In addition, the Boeing Dynamic Displacement Measurement System (DDMS) was used to measure the horizontal displacement of the muzzle.

Figures 17 and 18 are reduced angle data for these rounds. The blue laser measures the azimuth angle and the red laser measures the elevation angle.

DDMS counter output versus sample number is shown in Figure 19. Positive numbers correspond to displacement toward the right side of the range, looking down-range. The sample rate is 36 kHz.

The data for run 14, round 17466, indicates no motion for the first 5.6 milliseconds (200 samples), then a linear displacement of .280 millimeters in the following 2.5 milliseconds. The DDMS record then becomes flat, indicating that hot muzzle gases have passed through the beam. The hot gas destroys the lateral coherence of the signal beam, so the fringe count stops. The hot gas also affects the angle measurement system.

The displacement data can be used to estimate angular motion. Assume that the gun-tube bending follows a circular arc, then the angular change at the end of the tube is equal to the displacement divided by one-half the tube length. This results in an angle of 0.56 milliradian (0.032 degrees) for round 17466.

Proximity probes (used by BRL personnel following the above series of tests) registered a peak pointing angle of roughly 0.1 degree in the horizontal direction and a somewhat larger angle in the vertical direction.

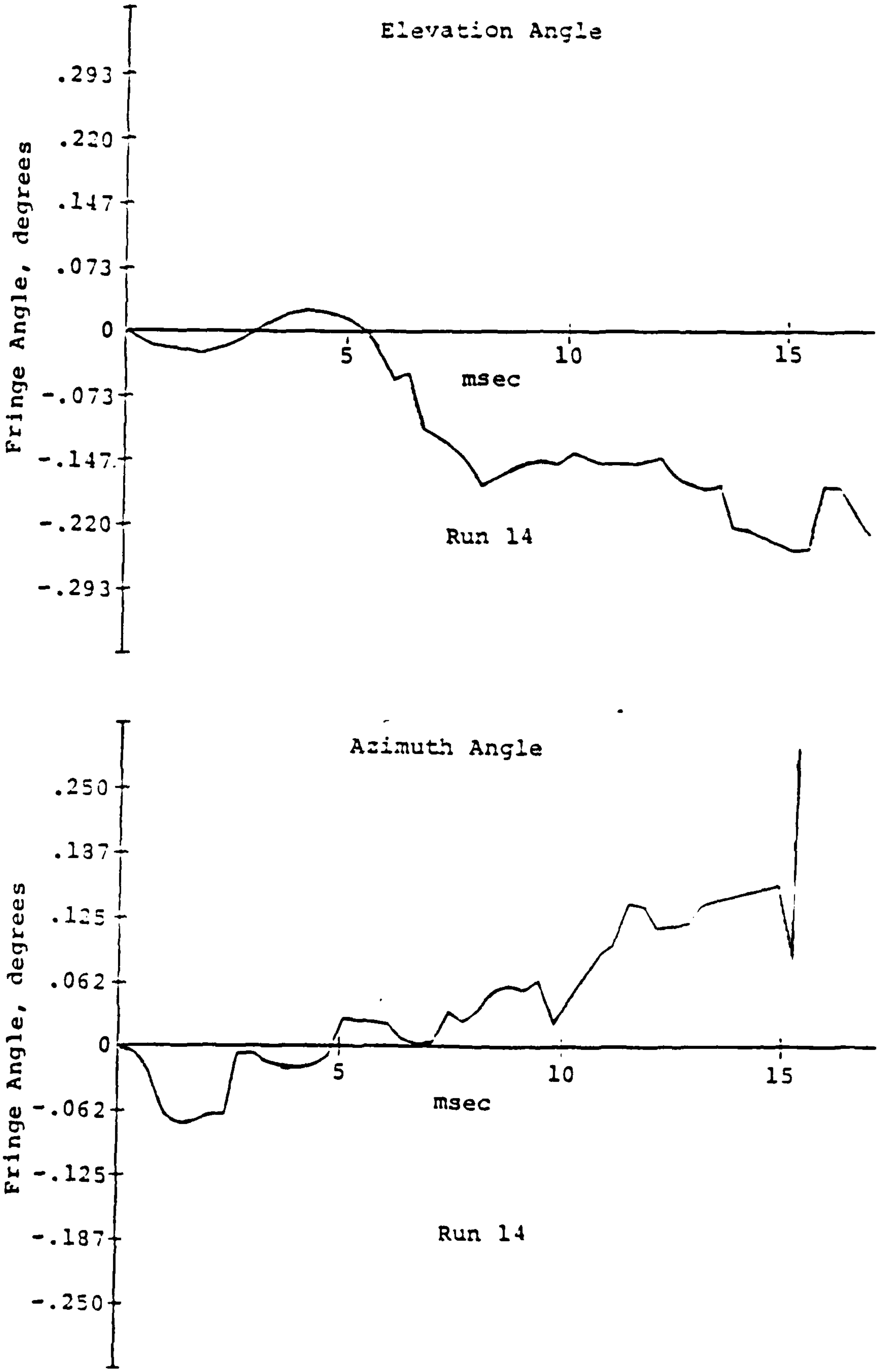


Figure 17. Muzzle Angle, Round 17466.

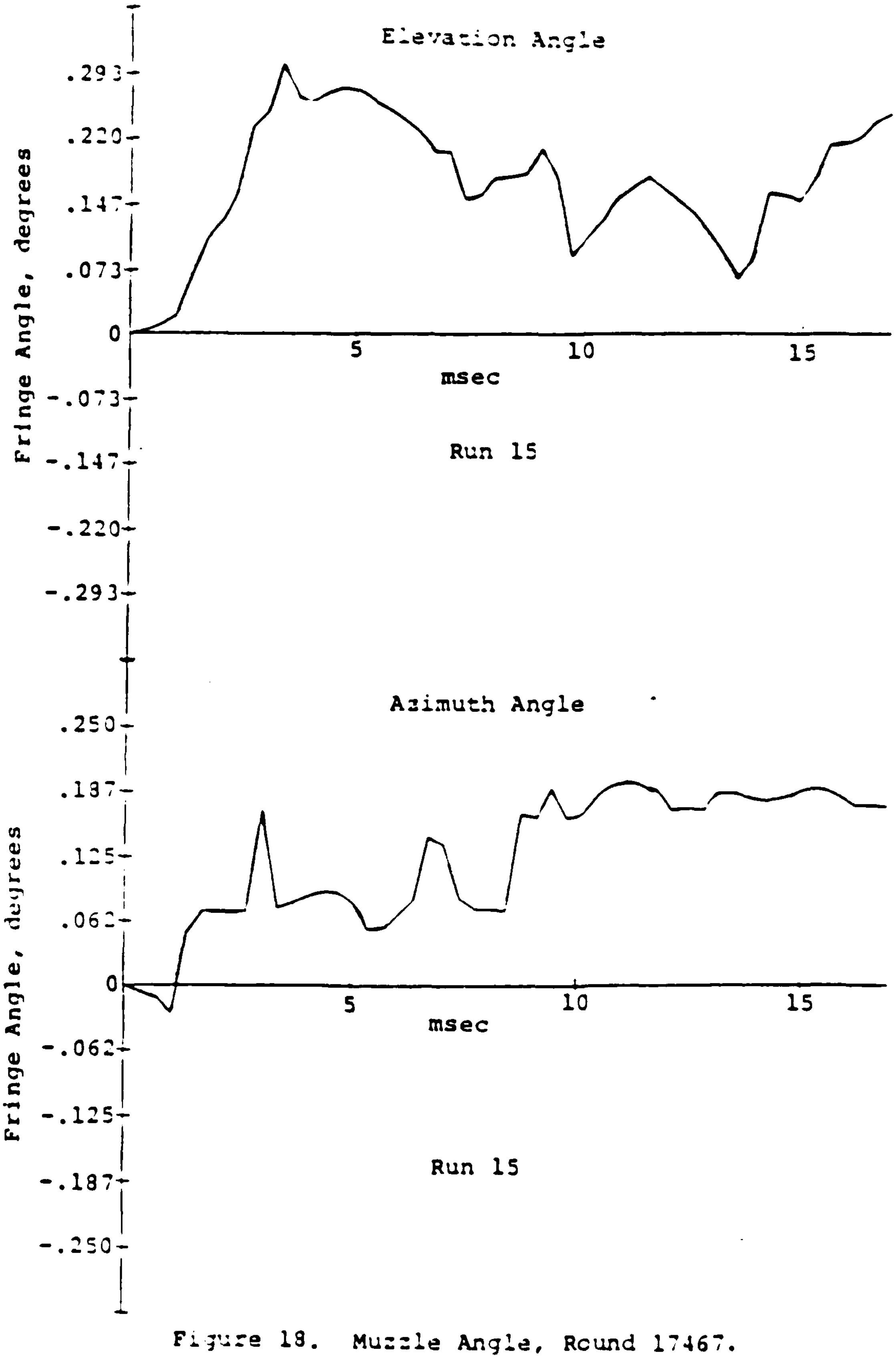


Figure 18. Muzzle Angle, Round 17467.

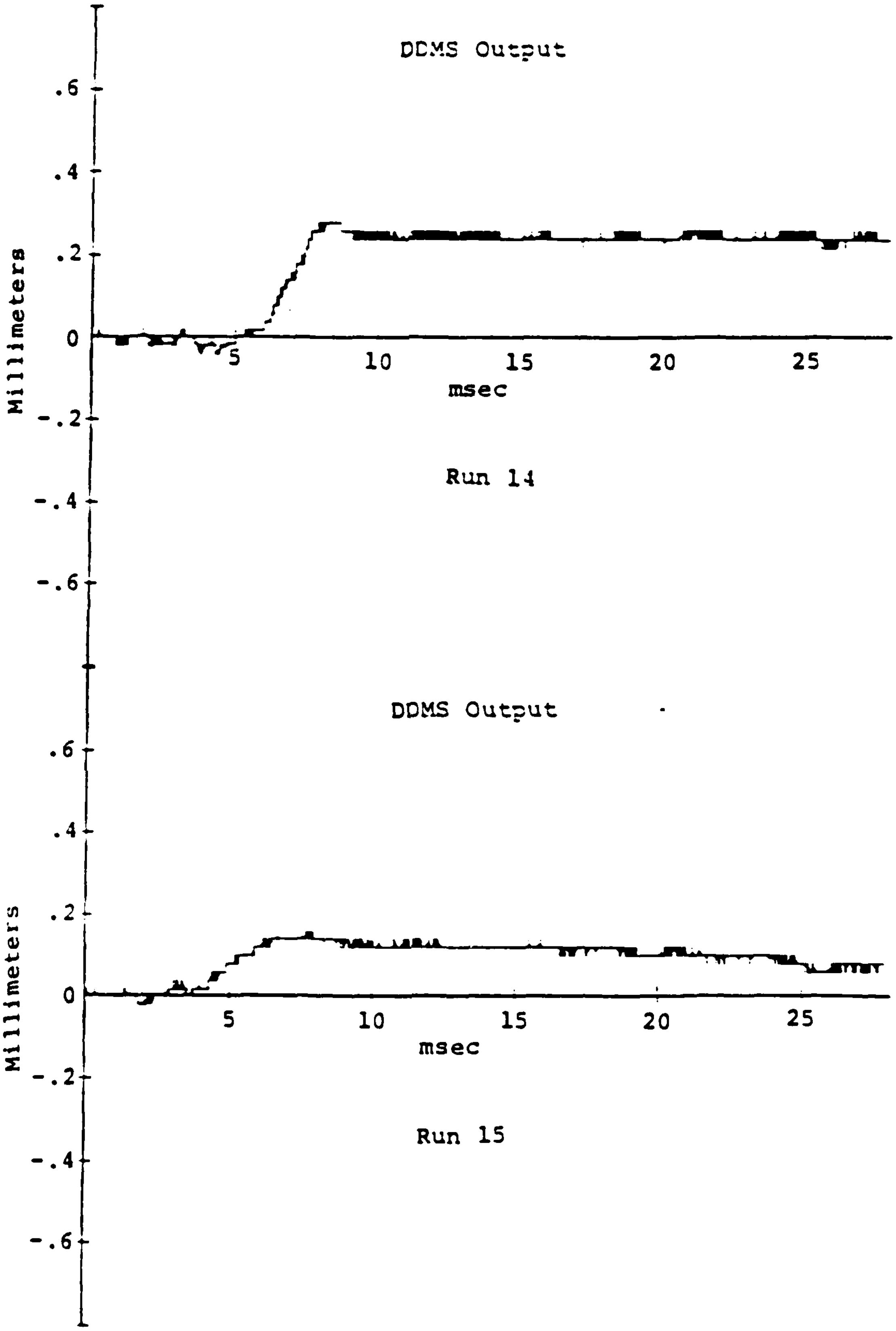


Figure 19. Muzzle Displacement, Round 17466 and 17467.

ANALYTIC MODEL

The equations relating the projectile angular motion with the output current from the photodetector will be developed in this section. The relationships for the general case (a spinning, yawing projectile observed by an optical system employing circular dither) are first derived. The simplifications that result when using a fixed laser beam or non-spinning projectile are then discussed.

A right-handed coordinate system is used in the analysis, with the X axis horizontal, the Y axis vertical and the Z axis along the range centerline. The optical centerline also coincides with the Z axis. The projectile undergoes pitching and yawing motions as a function of time, so the orientation of a projectile based coordinate system (x,y,z) may be specified by the direction cosines ($\cos\alpha_p$, $\cos\beta_p$) as shown in Figure 20-a.

The intensity of light reflected by the holographic grating/retroreflector combination placed at the nose of the projectile is a function of the angular orientation of the input laser beam relative to an axis normal to the hologram (Reference 1). It is therefore convenient to express the orientation of the body in terms of the angular coordinates

$$(u_p, v_p) = (\cos\alpha_p, \cos\beta_p)$$

where u_p and v_p may be thought of as the pitch and yaw of the projectile. The angles are chosen so that u_p is oriented perpendicular to the hologram grating lines (i.e. parallel to the direction in which light is diffracted). If the input angle is small, the reflection coefficient, $R[u_p(t)]$ is approximately a periodic function of the input angle as shown in Figure 20-b.

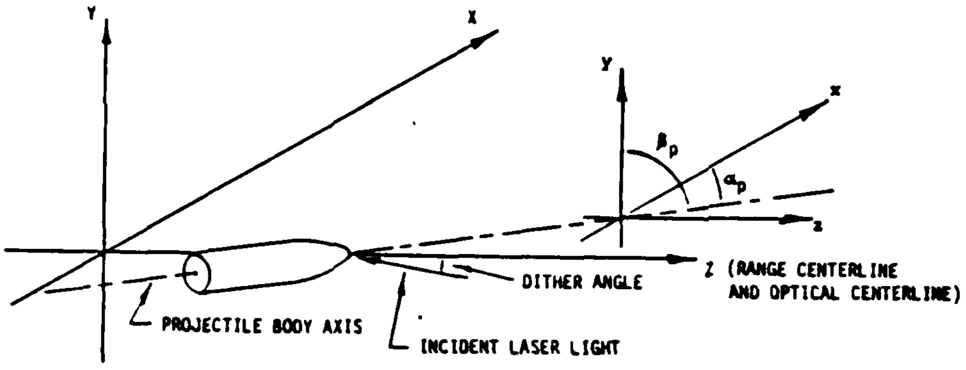
As part of the optical system, circular dither will be imparted to the laser light. Thus at any instant of time the angle between a ray representing the portion of the laser beam striking the retroreflector and the coordinate axes can be defined by the angular coordinates

$$(u_1, v_1) = (\cos\alpha_1, \cos\alpha_1)$$

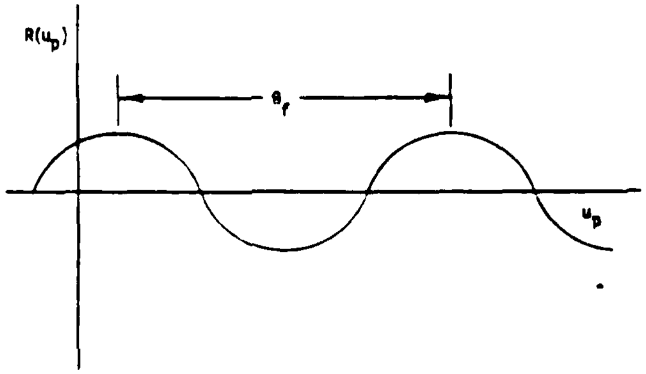
where α_1 and β_1 are the angles between the incident light and the X and Y axes respectively. Employing a trigonometric identity, the angle between the laser beam (or the body axis) and the Z axis may be expressed as

$$\gamma = \cos^{-1}(1 - \cos^2\alpha - \cos^2\beta)^{1/2}$$

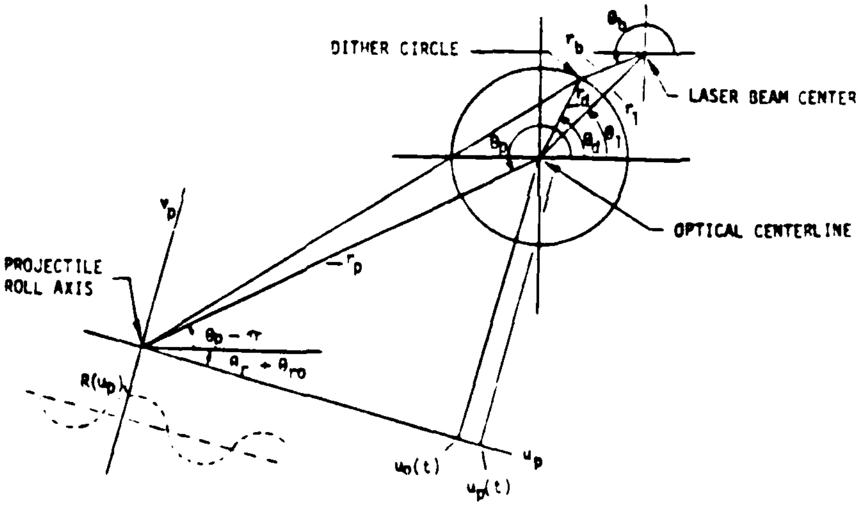
Figure 20-c illustrates the optical and projectile coordinate systems. The axes u_1 and v_1 are centered on the



a) Projectile Geometry



b) Reflector Reflection Coefficient versus Angle



c) Angular Geometry of Projectile and Laser Beam

Figure 20. Analytic Model Geometry.

optical centerline with u_1 horizontal. The body fixed projectile axes, u_p and v_p, rotate as the projectile rolls. The circle represents a circular dither of the laser beam. The polar coordinates of the center of the laser beam are (r_1, θ_1).

The circular dither can be resolved into time varying components in the projectile coordinate system

$$u_p(t) = r_d \cos(w_d t - w_r t + \theta_{do} - \theta_{ro}) + u_o(t)$$

$$v_p(t) = r_d \sin(w_d t - w_r t + \theta_{do} - \theta_{ro}) + u_o(t)$$

where r_d = angular radius of the circular dither
w_d = dither angular frequency
w_r = roll angular frequency
θ_{do} = initial dither angle
θ_{ro} = initial roll angle
$u_o(t), v_o(t)$ = position of optical axis in projectile coordinates.

The component of the dither in the u_p direction (perpendicular to the holographic grating lines) produces a modulated output, while the component in the v_p direction (parallel to the grating lines) does not.

The detector current is the product of two time varying functions. Since the intensity of the laser is not spatially uniform, as the beam is swept across the reflector (due either to the dither or the motion of the projectile) the light entering the retroreflector is amplitude modulated. The reflector further modulates the beam because the reflection coefficient, $R[u_p(t)]$, varies with the angle of incidence.

If it is initially assumed that the laser beam profile is not a function of z, then the intensity may be represented by

$$I(t) = (r_b, \theta_b)$$

where $r_b = (r_d^2 + r_1^2 - 2 r_d r_1 \cos(\theta_{do} + w_d t - \theta_1))^{1/2}$

$$\theta_b = \cos^{-1}[(r_d^2 - r_b^2 - r_1^2)/2 r_b r_1]$$

The circular dither is actually a conical scan with a fixed point at a distance z from the initial projectile position. The linear displacement of the beam with respect to the retroreflector is a function of $z - z_o$ (when $z = z_o$ there is no translation of the beam). The z axis dependence can be placed into the expression for I(t) by replacing r_1 with $r_1(t)$, where

$$r_1(t) = r_1(0) \cdot (z_0 - z(t))/z_0$$

The photodector current is therefore

$$i(t) = \rho\Gamma I(t)\, R[u_p(t)]$$

where ρ = detector responsivity (amp/watt)
Γ = optical efficiency
I = laser beam intensity

Two special cases will be considered, both assuming that the laser beam is uniform, so that I(t) is constant.

(1) The retroreflector reflection coefficient is a pure sinusoid with period θ_f.

(2) The reflection coefficient is periodic, but has higher order components.

Case 1: $R[u_p(t)] = a + b \sin(2\pi u_p(t)/\theta_f - c)$

where a = average value
b = amplitude
θ_f = angle between fringes
c = phase at $t=0$

$$u_p(t) = r_d \cos(w_d t - w_r t + \partial_{do} - \theta_{ro}) + u_o(t)$$

Let $d = \rho\Gamma I$, $k = 2\pi/\theta_f$ and $w = w_d t - w_r t + \theta_{do} - \theta_{ro}$ then the detector current is

$$i(t) = ad + bd \sin[kr_d \cos w + ku_o(t) - c]$$

Express the sine term as a sum to get

$$i(t) = ad + bd \sin(kr_d \cos w) \cos(ku_o(t) - c)$$
$$+ bd \cos(kr_d \cos w) \sin(ku_o(t) - c)$$

We can then expand the terms with sinusoidal argument using the Bessel function identities

$$\sin(z\cos\theta) = 2J_1(z)\cos\theta - 2J_3(z)\cos 3\theta + \ldots$$

$$\cos(z\cos\theta) = J_0(z) - 2J_2(z)\cos 2\theta + 2J_4(z)\cos 4\theta - \ldots$$

The first few terms are

$$i(t) = ad + bd\, J_0(kr_d) \sin(ku_o(t) - c)$$
$$+ 2bd\, J_1(kr_d) \cos w \cos(ku_o(t) - c)$$
$$- 2bd\, J_2(kr_d) \cos 2w \sin(ku_o(t) - c)$$
$$2bd\, J_3(kr_d) \cos 3w \cos(ku_o(t) - c) +$$

These harmonic components can be separated by filtering, then bidirectional changes in $u_0(t)$ can be determined by tracking the coefficients of cos $[ku_0(t)]$ and sin $[ku_0(t)]$ for a pair of even and odd harmonics. Note that the harmonic frequencies are multiples of the difference between the dither and roll frequencies. If the dither is high compared to the roll rate, roll produces a slow change in the phase of the dither.

Case 2: R(u) is periodic but not a sinusoid.

The projectile reflector must be calibrated before firing. During calibration, R(u) is measured over at least one period of θ_f. If the dither is on, the amplitudes of two adjacent harmonics are stored in a look-up table of harmonic amplitudes versus angle. If the dither is off, the table entries can be calculated as follows:

Write R(u) as a Fourier series

$$R(u) = a_0/2 + a_1 \cos(ku) + a_2 \cos(2ku) + \ldots$$

$$+ b_1 \sin(ku) + b_2 \sin(2ku) + \ldots$$

Replace u with $u + r_d \cos(w)$, then expand each term using the Bessel function identities and collect like harmonics. The first few term of the expansion and rearrangement are:

$$R_0(u) = a_0/2 + \sum_{j=1}^{m} [a_j \cos(jku) + b_j \sin(jku)]\, J_0(jkr_d)$$

$$R_1(u) = 2 \cos w \sum_{j=1}^{m} [a_j \sin(jku) - b_j \cos(jku)]\, J_1(jkr_d)$$

$$R_2(u) = 2 \cos 2w \sum_{j=1}^{m} [a_j \cos(jku) + b_j \sin(jku)]\, J_2(jkr_d)$$

$$R_3(u) = 2 \cos 3w \sum_{j=1}^{m} [a_j \sin(jku) - b_j \sin(jku)]\, J_3(jkr_d)$$

These are the harmonic amplitudes for the look-up table. The table is used to reduce the data after the round is fired.

The data is reduced in increments of the dither minus roll period. For each increment, harmonic component amplitudes can be found with the digital filtering routine in the data reduction algorithm. The look-up table is used to find the fractional angle u, where $u \leq \theta_f$. The total angle is incremented or decremented by θ_f each time u moves through the table.

PRELIMINARY DESIGN

This section contains preliminary design information for a three angle measurement system. The design addresses the limitations of the breadboard system tested at BRL, and defines the areas which require further development before a final design can be implemented.

The major limitation of the breadboard system was the dither rate. An available galvanometer deflection system was used to generate a conical scan at 3 KHz. However, in many cases the fringe rate was comparable to the dither rate. The dither rate must be much higher than the fringe rate, otherwise, the desired effect of the dither modulation is destroyed and angle information cannot be recovered. Spin stabilized rounds with fringe rates of 30 KHz have been observed in our test program. A dither rate of the order of 1 MHz would be appropriate. Oscillating mirrors (galvanometer type of resonant scanners) have a capability up to 20 KHz. Polygonal mirrors on turbine motors can generate higher scan rates, but produce linear rather than conical scans. The mechanical limit (reference 3) for a polygonal mirror is:

$$w = \frac{1}{2\pi r_o}\sqrt{\frac{8UTS}{P(3+{}_n)}}$$

where r_o = Distance from center to edge
UTS = Ultimate tensile strength
n = Poisson's ratio of material
p = Volumetric density

Substituting the values for 6061 T6 aluminum, the mechanical limit for a 5 cm diameter scanner is about 10^4 revolutions/second. If the mirror had 20 facets, the scan rate would be 200 KHz. The practical limit, due to mirror deformation and safety, is well below the mechanical limit.

Acousto-optic beam deflectors (AOD) are an alternative method for generating a conical scan. Two-axis devices are available, so a circular dither is possible. The limit is set by the transit time of a sound wave across the aperture of the device. The transit time is the amount of time required to move the deflected beam from one position to another. Typical valves for commercial deflectors are of the order of 10 microseconds. In the breadboard system the return beam was sampled at 12 positions around the dither circle. If an AOD is used with 10 microsecond transit time to sequentially deflect the beam to 12 points on a circular arc, the maximum rate would be 8.51 KHz. This rate is also inadequate for a spinning projectile.

A solution to the high dither rate requirement is to use a circular array of diode laser beams, where the diode lasers are sequentially modulated to produce a rotating optical source. Very high dither frequencies are possible with this technique. (We are currently modulating a Mitsubishi model ML 3001 diode laser at a frequency of 1 GHz.) The wavelength of laser-diodes are temperature sensitive. Diode lasers are available with fiber optic pigtails, so the lasers can be mounted on a temperature controlled heat sink and the fibers led out to form a circular array in the focal plane of the collimating lens. Two color operation is accomplished by selecting lasers so the even and odd fibers radiate in different wavelength bands, such as 830±5nm and 850 ± 5nm.

Figure 21 shows two optical configurations. Both configurations show an off-axis paraboloid mirror for collimating the beam. The beam diameter would be of the order of 30 cm, so the refracting optics as used in this program become more expensive than off-axis optics. Furthermore, the Fresnel reflection from the center of a refractor is avoided with reflecting optics.

Figure 21a is a three-axis system for measurements of spinning projectiles, using techniques verified on this program. The concept shown in Figure 21b is a circular dither system using diode laser, as described above. The first technique is lower risk and cost, since all the techniques have been demonstrated in this program.

PHASE II PROGRAM

The major task in Phase II is the design and fabrication of a three-component angular measurement system. The results of the Phase I test program made a significant impact on the requirements for the Phase II system. The major requirement is for a much higher dither rate in order to follow the dynamics of some of the projectiles. Other requirements are increased laser beam diameter, improvements in the data reduction algorithms, and increased stability of the holograms in the humid environment at BRL. The Phase II tasks are listed below:

1) Design and fabricate a three-component angular measurement system. Two variations of the three-component system are possible.

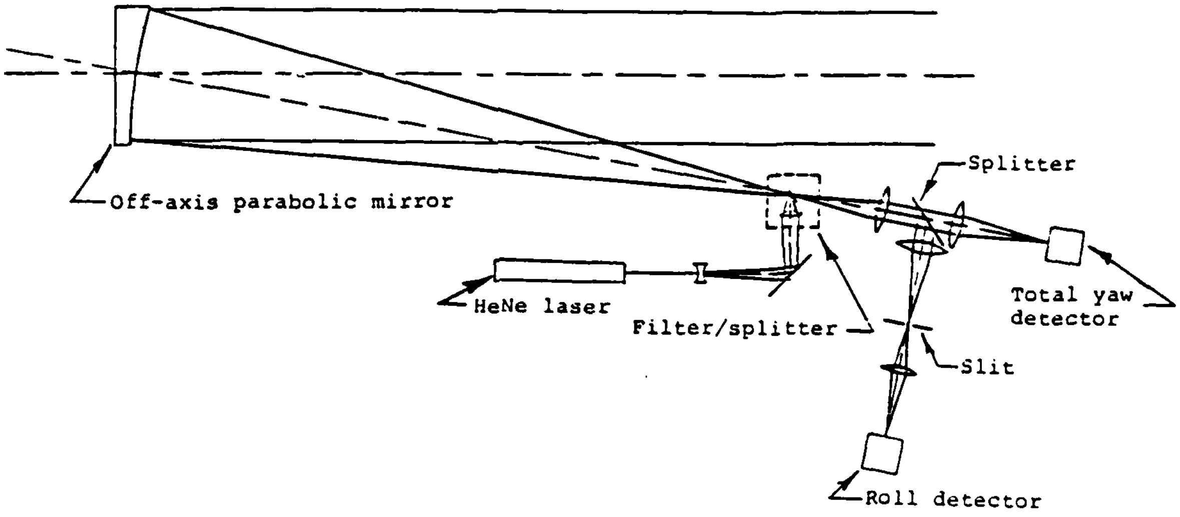
   a. Total yaw system for spinning projectiles. This technique was demonstrated on the prior contract, and improved to measure all three angles in the present contract.

   b. Three-component system with circular dither for both spinning and non-spinning projectiles. The technical difficulties are greater and the risks are higher for this system. At this time it appears that the only method for generating the required high dither rate is to use a circular array of optical fibers, each driven by a diode laser, where the relative phases of the diode lasers is adjusted to produce a conical scan. The dither generation technique should be thoroughly evaluated with a breadboard device prior to fabrication of the three-component system.

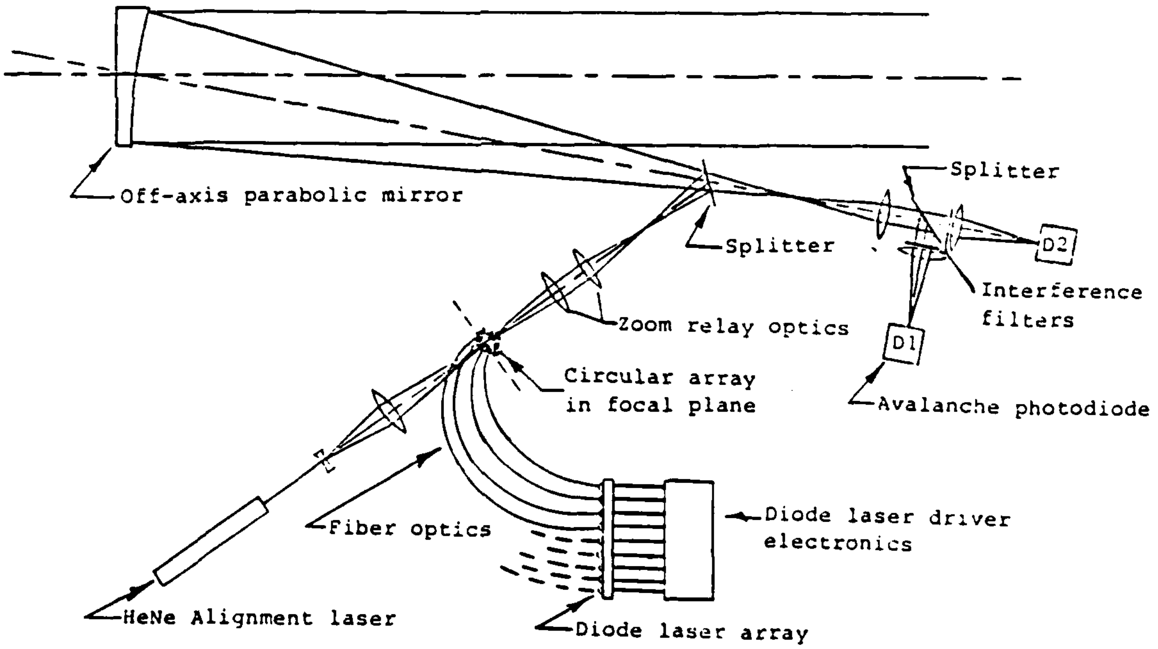
2) Data reduction algorithms

   a. No computer data reduction algorithm has been developed for 1a. Such a system would require the development of a suitable algorithm.

   b. The algorithm for 1b has partially been developed in Phase I. Additional development is required based on the results of Phase I and the analytic model developed in Phase I. One of the important problems to be addressed is the magnitude of error caused by the deviation of the reflector reflection coefficient from a sinusoid. The algorithm already developed is for the sinusoidal case, but the reflection coefficient is approximately sinusoidal only when the diffraction efficiency is low. In order to maximize the return power, it is necessary to operate with a reflection coefficient versus angle that departs significantly from a sinusoid.



a) Fixed Beam Optics



b) High Speed Circular Dither Optics

Figure 21. Laser Ballistic Sensor Configuration

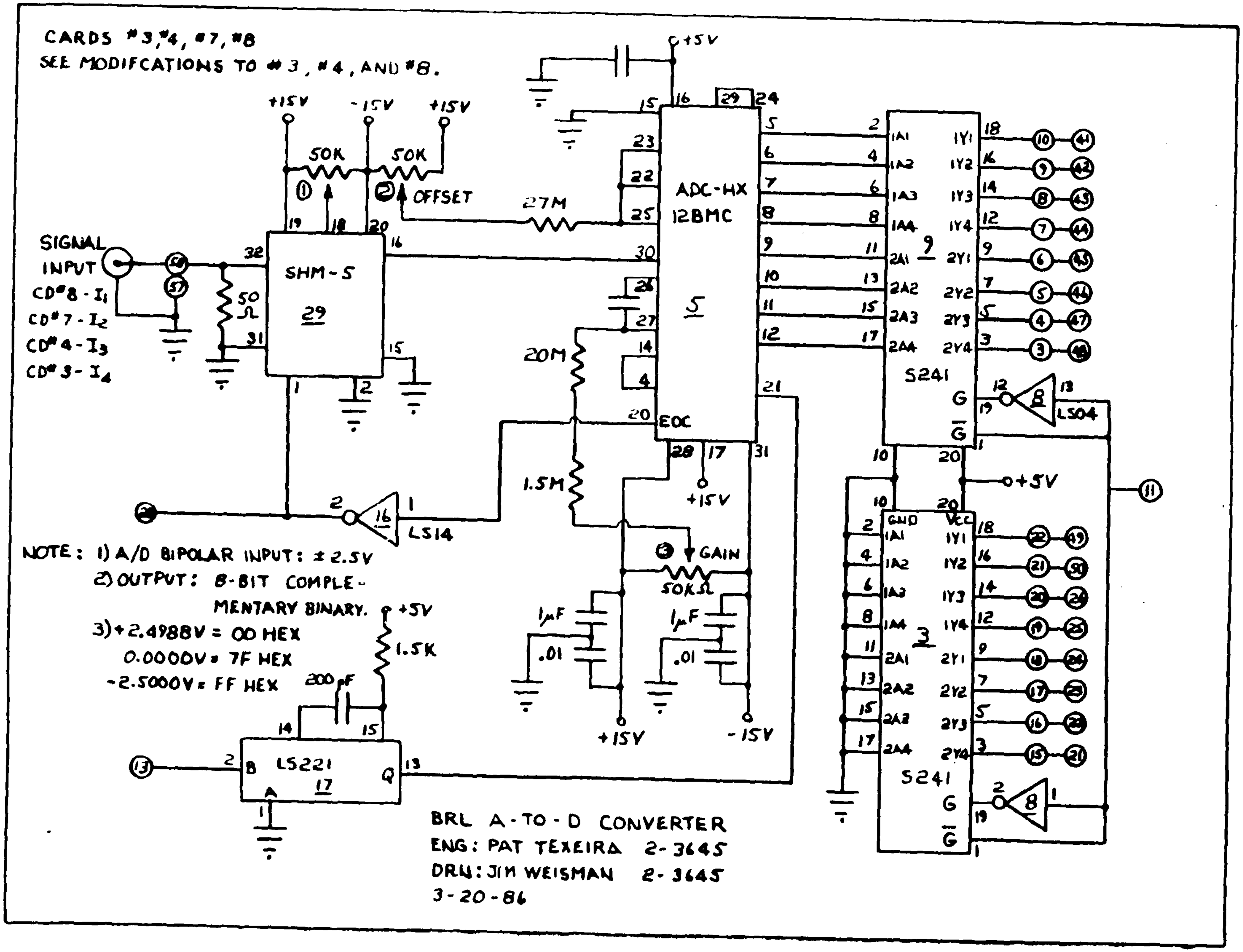
c. Algorithm development would be a joint Boeing and BRL task.

3) Investigate techniques to stabilize the holograms after fabrication. The diffraction efficiency of the holograms changed with time due to the change in relative humidity at BRL. Some of the holograms became cloudy and unusable.

4) For the system of 1b, design and fabricate signal conditioning, timing, and computer interface circuitry for an acceptable dither frequency in the range of one megahertz.

APPENDIX A

ELECTRONIC SCHEMATICS



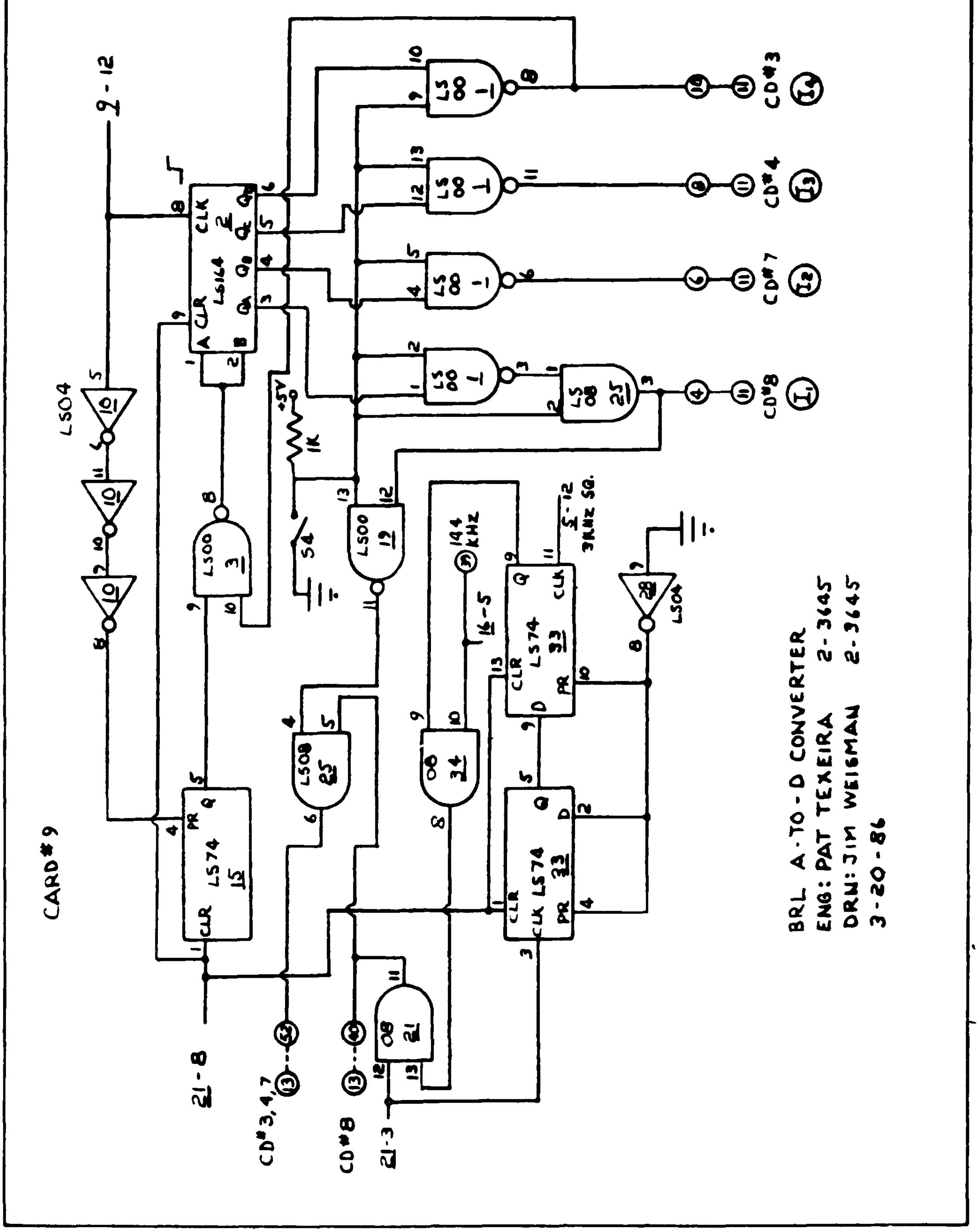
CARDS #3, #4, #7, #8
SEE MODIFCATIONS TO #3, #4, AND #8.

SIGNAL INPUT
CD#8 - I_1
CD#7 - I_2
CD#4 - I_3
CD#3 - I_4

NOTE: 1) A/D BIPOLAR INPUT: ± 2.5V
2) OUTPUT: 8-BIT COMPLEMENTARY BINARY.
3) +2.4988V = 00 HEX
0.0000V = 7F HEX
-2.5000V = FF HEX

BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRW: JIM WEISMAN 2-3645
3-20-86

SHEET 1 OF 8



BRL A-TO-D CONVERTER
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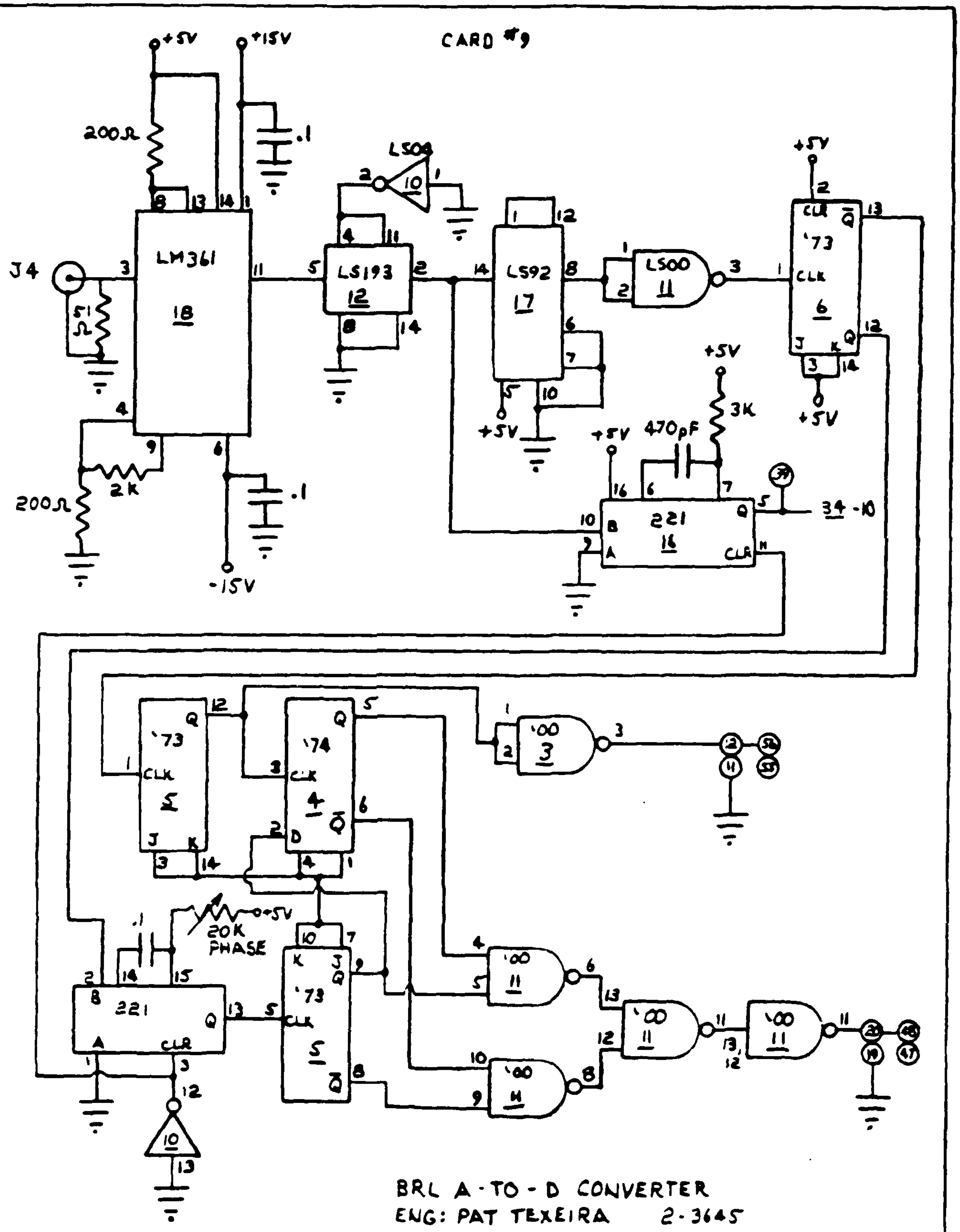
3-20-86



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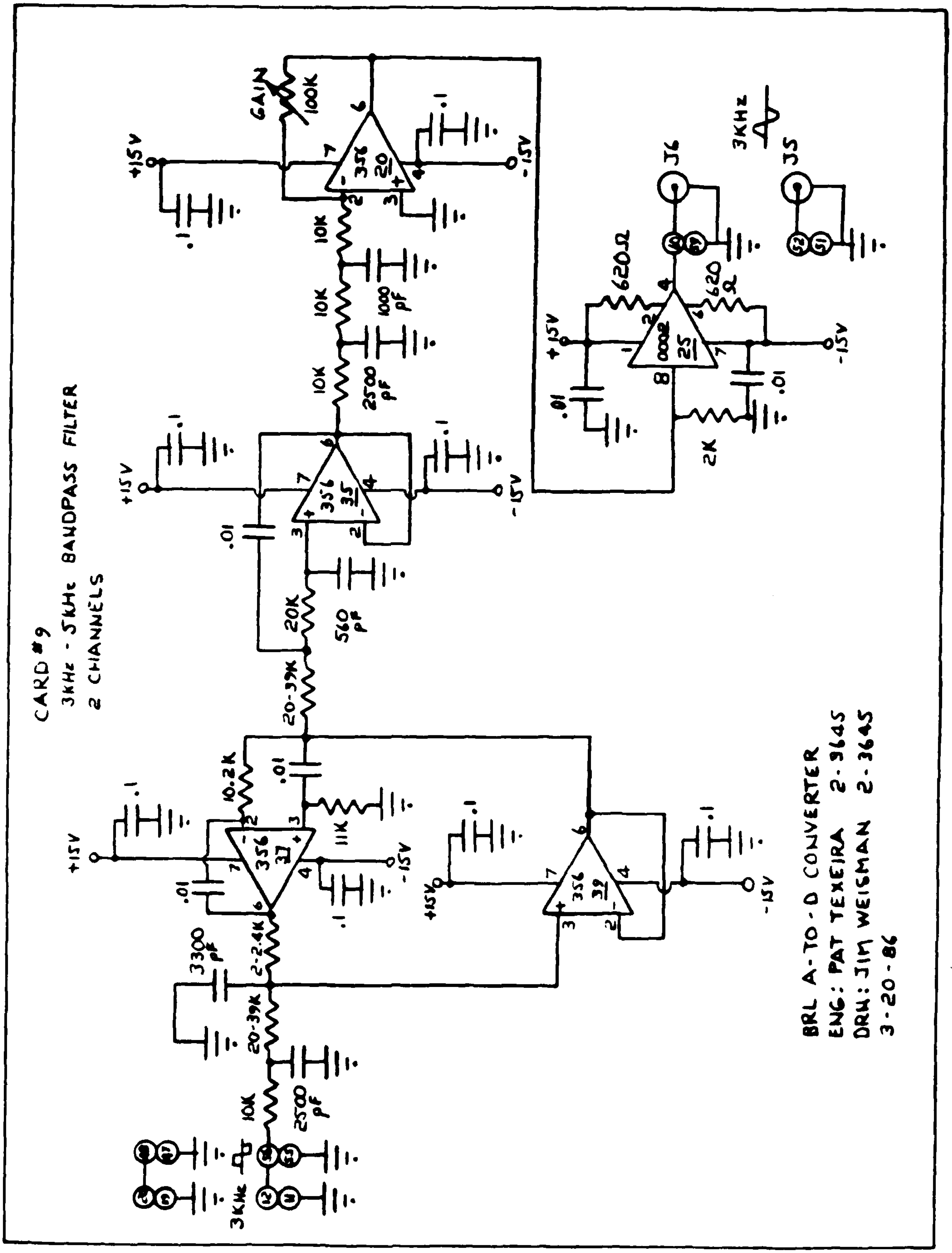
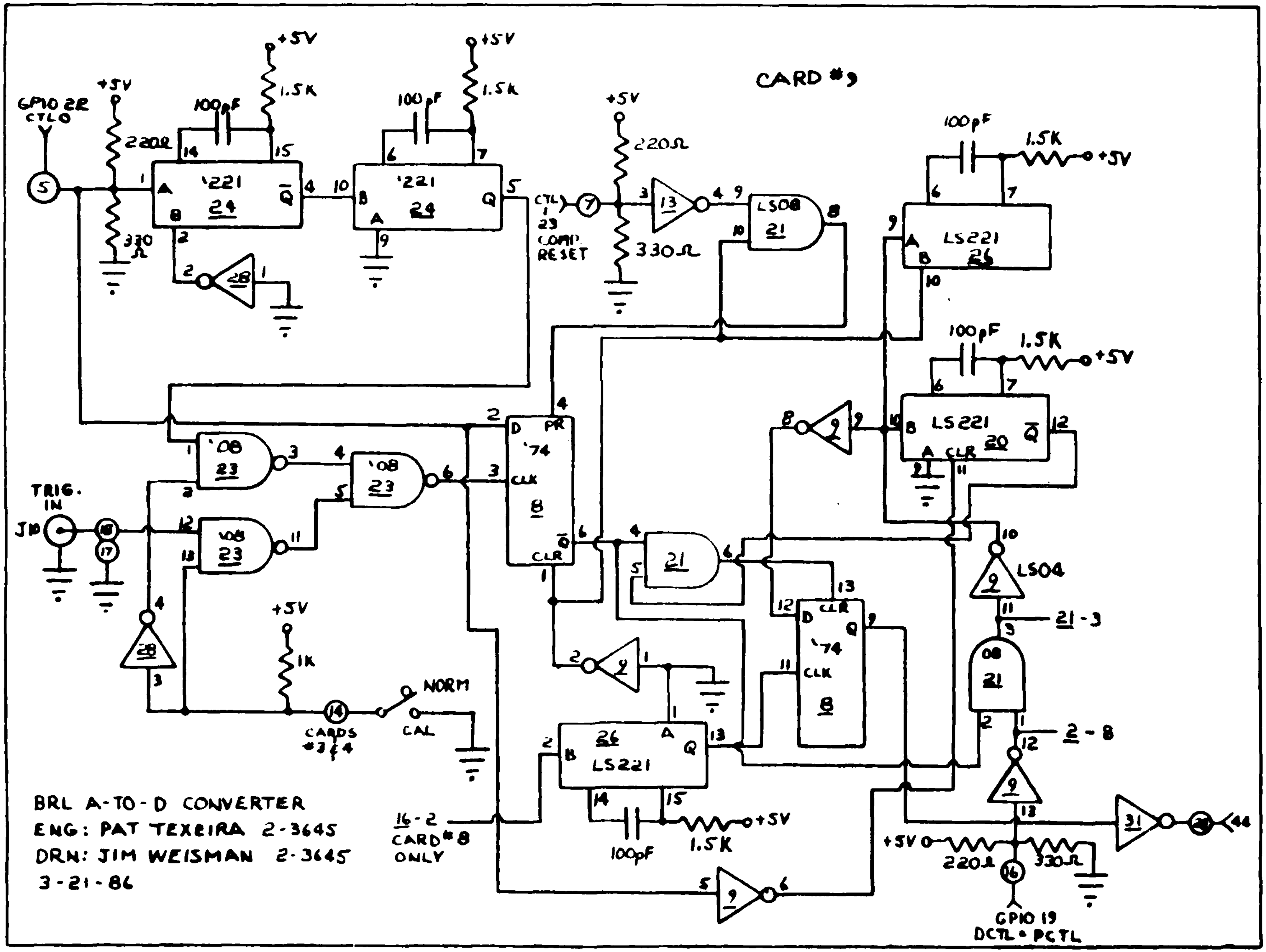
3-20-86



CARD #9
3KHz - 5KHz BANDPASS FILTER
2 CHANNELS

BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRW: JIM WEISMAN 2-3645
3-20-86

SHEET 4 OF 8



BRL A-TO-D CONVERTER
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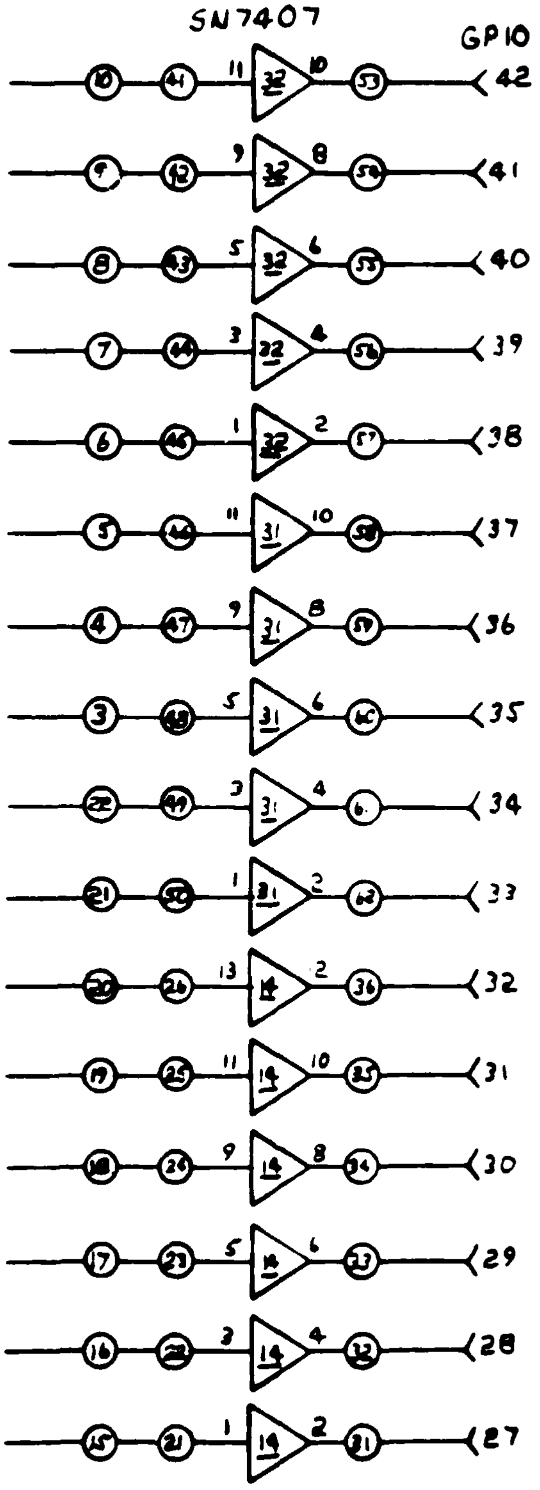
3-21-86

CARD #9



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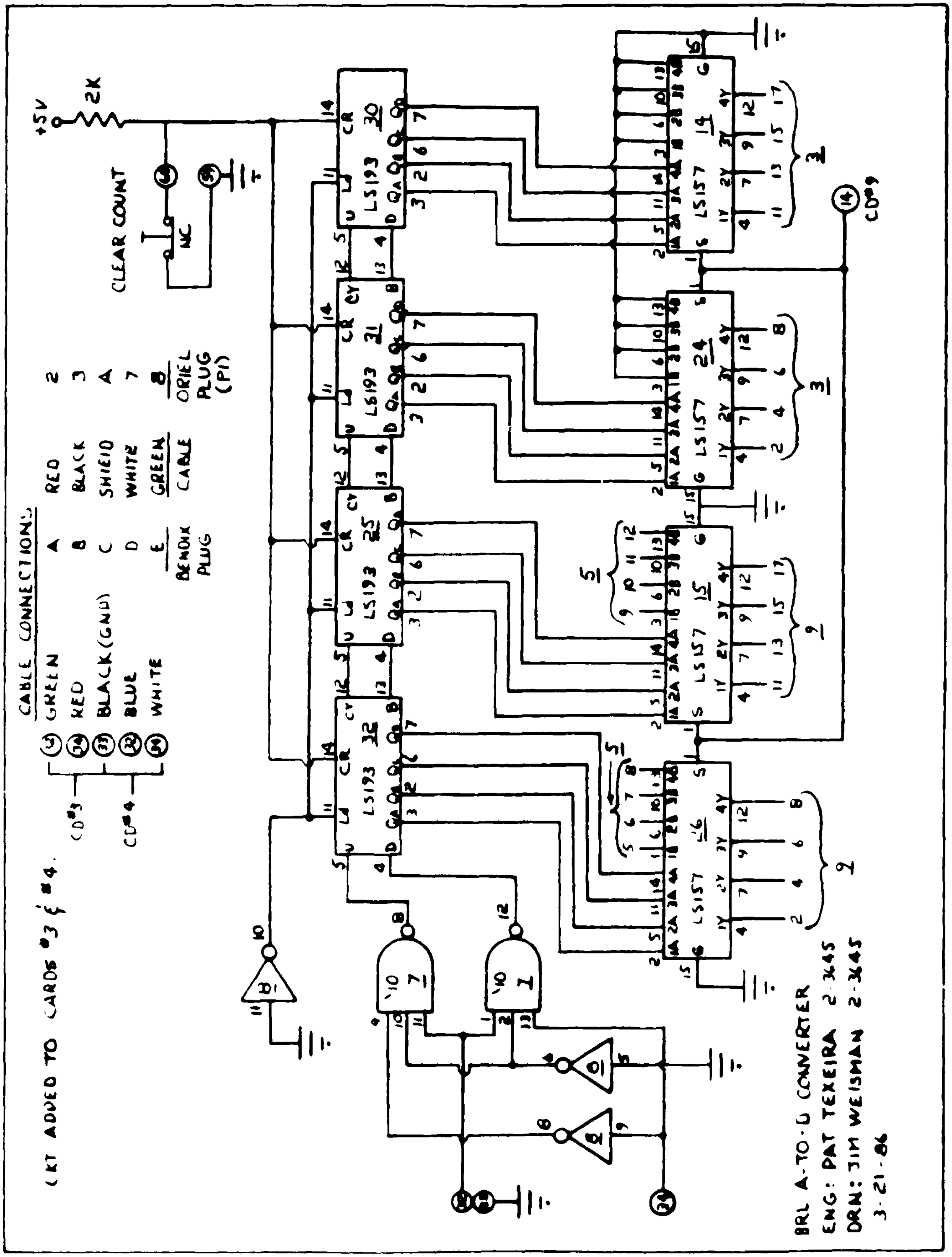
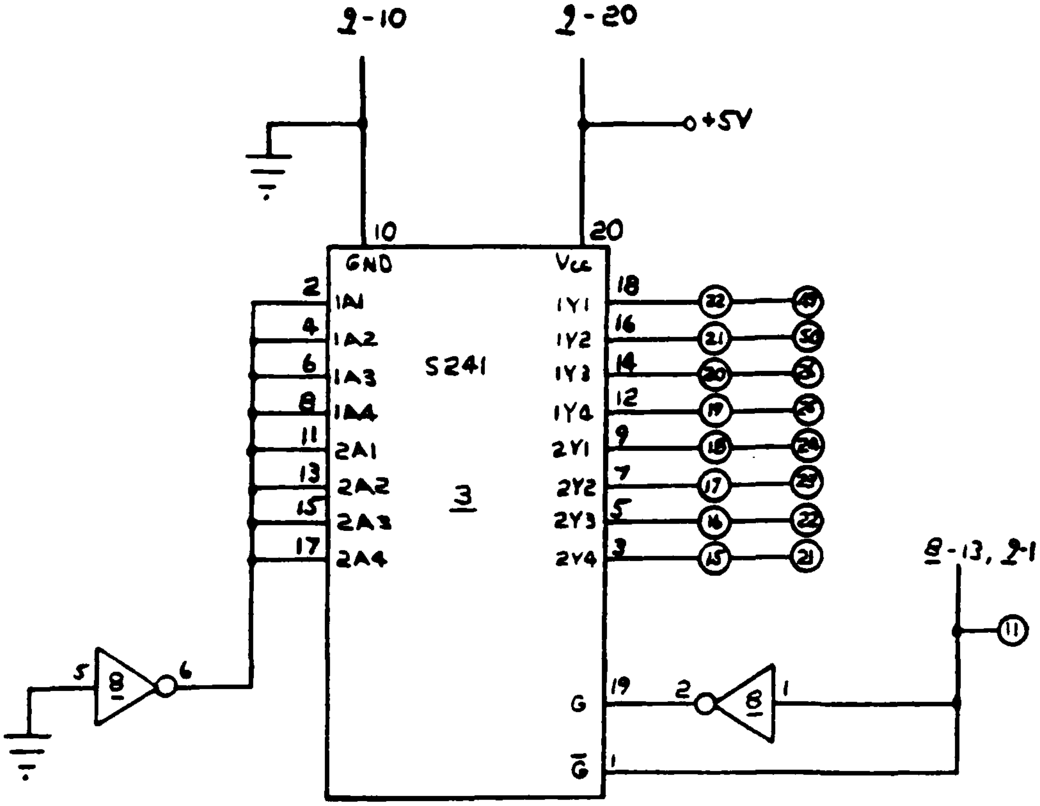
ENG: PAT TEXEIRA 2-3645
DRN: JIM WEISMAN 2-3645
3-21-86


CKT ADDED TO CARDS #3 & #4.
CD#3
CD#4
CABLE CONNECTIONS
GREEN A RED 2
RED B BLACK 3
BLACK (GND) C SHIELD A
BLUE D WHITE 7
WHITE E GREEN 8
BENDIX PLUG
CABLE
ORIEL PLUG (P1)
+5V
2K
CLEAR COUNT
NC
LS193
30
31
25
32
CR
CY
U
LD
D
QA
QB
QC
QD
LS157
14
24
15
16
1A 2A 3A 4A 1B 2B 3B 4B
1Y 2Y 3Y 4Y
G
S
CD#9
'10
BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRN: JIM WEISMAN 2-3645
3-21-86

MODIFICATION OF CARD #8



BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRN: JIM WEISMAN 2-3645
3-21-86

APPENDIX B

COMPUTER PROGRAM

```
10     !BRL_6_28
11     !-------------------------------------------
13     !PROGRAM FOR OBTAINING THE CALIBRATION CURVE FOR
14     !A GIVEN HOLOGRAM CORNER CUBE COMBINATION.
15     !--------------------------------------------
19  Comments:!This program uses the difference
20            !method for determining the amplitude
21            !for f2 & f1.
28            !The largest Num_samples is 32K.
31            !Graphing is included for 200 enve-
32            !lopes/graph. # of graphs depends on
33            !the number os Num_samples.
54            !Parameters of consideration: Ratios
55            !of f2/f1, degrees/count red(Dpcr),
56            !degrees/count blue(Dpcb)
57            !The doppler effect is included but
58            !not used(It was developed when this
59            !program was configured.).  It uses
60            !the parabolic fit to determine the
61            !location of the peak using the greater
62            !of the ampplitudes of f1 & f2.  The
63            !doppler correction is indepentent for
64            !the red & blue.
66            !For a/d interface- reset for counter
67            !and normal cal switch, up for cal.
68            PRINTER IS 1
70            PRINT CHR$(12)
71            PRINT TABXY(30,15),"CALIBRATION PROGRAM"
72            WAIT 3
73            PRINT TABXY(30,15),"                    "
74  Initialize:!
75     PRINTER IS 1
76     PRINT CHR$(12) !CLEAR SCREEN
77     ON ERROR GOTO Err_rout
78     OPTION BASE 0
79     GRAPHICS OFF
80     RAD
81     ON KEY 4 LABEL "GRAPH",15 GOSUB Disp_out
82     ENABLE
83     Gpio=12
84     Hpib=704
85     !CONSTANTS
86       Sf=36000 !Sample frequency
87       Gf=3000 !galvo frequency set by clock
88       K1=12  !samples at f1
89       K2=6   !samples at f2
90       K3=4   !samples at f3
91       !Signal generator frequency 576.000Khz
92     !VARIABLE LIST
93       !Num_samp : number of samples to take at 36kz rate
94       !Fb : filter bandwidth
95       !N : INT(Sf/fb)
96       !Nnn :INT (Num_samples/48)*12, used in DMA
97       !Br( ) : array, sampled data, red
98       !Bl( ) : array, sampled data, blue
99       !If1 : interpolation factor for f1
100      !If2 : interpolation factor for f2
101      !F1( ) : convolution multipling function for f1
102      !F2( ) : convolution multipling function for f2
103      !Start : starting point, determined by N
104      !Qr : starting sampled data point for next K1
```

```
105          !interval, including doppler correction, red.
106     !Qb : same as Qr except, blue
107     !Xx : Xx=1, loop for red:Xx=2 loop for blue
108     !B1( ) : Gimbal position for sample, red
109     !B2( ) : Gimbal position for sample, blue
110     !B1K1 : running sum of B1( ) in K1 interval
111     !B2K1 : running sum of B2( ) in K1 interval
112     !Filt_f1(J) : convolution elements in K1 interval, f1
113     !Filt_f2(J) : convolution elements in K1 interval, f2
114     !B1(P) : average of B1( ) in K1 interval
115     !B2(P) : average of B2( ) in k2 interval
116     !P : K1 interval of computation
117     !Ror : running sum of doppler correction, red
118     !Rob : running sum of doppler correction, blue
119     !Rotr(P) : running sum stored as a function of P
120     !Rotb(P) : running sum stored as a function of P
121     !Occr(P) : doppler correction for respective K1 interval, red
122     !Occb(P) : doppler correction for respective K1 interval, blue
123     !Qpsr : quadrant past, red
124     !Qpsb : quadrant past, blue
125     !Qptr : quadrant present, red
126     !Qptb : quadrant present, blue
127     !Qsr : running sum of quadrants, red
128     !Qsb : running sum of quadrants, blue
129     !Tar : total angle red, K1 interval
130     !Tab : total angle blue, K1 interval
131     !Ta_red(P) : total angle red, P K1 interval
132     !Ta_bl(P) : total angle blue, P K1 interval
133   !Whole quadrant update table
134   DIM Qt(5,4)
135   Qt(1,2)=1
136   Qt(1,4)=-1
137   Qt(2,1)=-1
138   Qt(2,3)=1
139   Qt(3,2)=-1
140   Qt(3,4)=1
141   Qt(4,1)=1
142   Qt(4,3)=-1
143   Qsr=10 !Quadrant sum red starts at 10
144   Qsb=10 !Quadrant sum blue starts at 10
145   ASSIGN @Gpio TO 12;WORD
146   !PRINT "      REGISTER STATUS BEFORE DMA"
147   !GOSUB Check_stat
148 Main:! Main program
149   PRINT CHR$(12)
150   GOSUB Num_samp      !# of samples to take
151      !GOSUB Test
152      !GOSUB File_data    ! Copy data from Buffer
153                         !to Disk File.
154      !GOSUB File_array
155   GOSUB Filt_bw_int  !Input filter bandwidth & interpolation factor
156   BEEP
157   INPUT "If calibration run, Type C.  else, Type S, for stored",Aa$
158   IF Aa$="C" OR Aa$="c" THEN
159      GOSUB Dma_transfer
160      GOSUB File_data
161      GOTO 174
162   END IF
163   IF Aa$="S" OR Aa$="s" THEN
164      DISP "INSERT DATA DISK - PRESS CONT TO CONTINUE'
165      PAUSE
```

```
166      CAT
167      GOSUB File_array
168      GOTO 174
169   END IF
170      BEEP
171      BEEP
172      BEEP
173      GOTO 157
174   GOSUB Mult_fun     !Generate multiplier
175                      !functions.
176   GOSUB Comp_angle   !Convolution, envelop detection, doppler correction,
177                      !& Arctan for red and blue
178   DISP
179   GOSUB Disp_out
180   GOTO 1
181 !++++++++++++++++++++++++++++++++++++++++
182 Num_samp: !Input the total number of samples
183            !to be taken. Maximum of 32K
184   BEEP
185   Num_samples=30000
186   GOTO 188
187   INPUT "TOTAL NUMBER OF SAMPLES TO BE TAKEN?",Num_samples
188   ALLOCATE REAL Ta_red(INT(Num_samples/K1)),Ta_bl(INT(Num_samples/K1)),Rot(I
NT(Num_samples/K1))
189   RETURN
190 Dma_transfer:!
191   DISP "                    COLLECTING DATA"
192   S=0
193   INTEGER Kk(0:47) BUFFER
194   ASSIGN @Buf TO BUFFER Kk(*)
195   !RESET DATA TRANSFER ELECTRONICS
196   CONTROL Gpio,2;2 !SET CTLO & CTL1 TO 0
197   CONTROL Gpio,2;0 !SET CTLO TO 1 & CTL1 TO 0
198   CONTROL Gpio,2;2 !SET CTLO & CTL1 TO 1
199 ..!END RESET
200   CONTROL @Buf,4;0
201   CONTROL Gpio,0;2
202   CONTROL Gpio,3;0
203   !SET TRANSFER LOW
204   CONTROL Gpio,2;3 !SET CLTO TO 0, XFER 0
205   !BEEP
206   TRANSFER @Gpio TO @Buf
207   FOR X=0 TO 47 STEP 4
208     Br(S)=Kk(X)-126
209     Bl(S)=Kk(X+1)+128
210     B1(S)=Kk(X+2)+1
211     B2(S)=Kk(X+3)+1
212   ! PRINT S,Br(S),Bl(S),B1(S),B2(S)
213     S=S+1
214   NEXT X
215   IF S=Nnn THEN
216     GOTO 220
217   ELSE
218     GOTO 196
219   END IF
220   CONTROL Gpio,2;2 !SET CLTO & CLT1 TO 1
221   CONTROL Gpio,1;3
222   DISP
223   !PRINT "        REGISTER STATUS AFTER DMA"
224   !GOSUB Check_stat
225   BEEP
```

```
226   RETURN
246 Filt_bw_int:!Input filter bandwidth in hertz
247   BEEP
250   INPUT "WHAT IS THE DESIRED FILTER BANDWIDTH IN HERTZ?",Fb
251   N=INT(Sf/Fb)
253   Nnn=INT(Num_samples/48)*12
254   ALLOCATE INTEGER Br(0:Nnn),INTEGER B1(0:Nnn)
255   ALLOCATE INTEGER B1(0:Nnn),INTEGER B2(0:Nnn)
256   ALLOCATE INTEGER Rotr(0:Nnn),Rotb(0:Nnn),Qccr(0:Nnn),Qccb(0:Nnn)
257   PRINT CHR$(12)
258   BEEP
262   INPUT "Real samples f1=12, interpolation factor?",If1
263   BEEP
264   INPUT "Real samples f2=6, interpolation factor?",If2
265   BEEP
266   ALLOCATE REAL Filt_f1(1:K1*If1),Filt_f2(1:K1*If2)
267   RETURN
268 Test:! Generate data - needs to be modified for this
269       !program
272   BEEP
273   INPUT "What is the Envelop Peak Amplitude?",Epa
274   BEEP
275   DISP "                       GENERATING DATA"
276   Peak_value_data=0
277   Gal_cyc_frg=200
278   Ab=0
279   ALLOCATE INTEGER Mmm(0:Num_samples-1)
280   FOR X=0 TO Num_samples-1 STEP 4
281     Ac=Epa*SIN((PI*(+Ab))/(6*Gal_cyc_frg)+(2.7)*SIN(2*PI*Ab*Gf/Sf))
282     FOR Y=X TO X+3
283       Mmm(Y)=INT(Ac)+128
284             !PRINT Y,Mmm(Y)
285       OUTPUT @Buffer USING "#,B";Mmm(Y)
286     NEXT Y
287     Ab=Ab+1
288   NEXT X
289   DISP
290   GOSUB Check_stat
291   WAIT 5
292   RETURN
293 Mult_fun: !Generation of the multiplying function.
294           !Multiplying function will be (SIN(X)/(X))*COS(Y)
295           !PRINTER IS 705
296   !ALLOCATE REAL F1(0:(N*If1)),REAL F2(0:(N*If2))
297   DIM F1(0:2000),F2(0:2000)
298   RAD
299   BEEP
300    !Generate 1/2 multiplier function for F1
301   BEEP
302   DISP "Building multiplier function for F1"
303   F1(0)=1
304             !PRINT "F1(0)=";F1(0)
305   FOR P=1 TO N*If1
306     Aa=(PI*P)/(N*If1)
307     Bb=(Aa*2*Gf)/Fb
308             !PRINT "P=";P
309             !PRINT "N=";N*If1
310             !PRINT "(PI*P)/N=";Aa
311             !PRINT "(Aa*2*GF)/FB=";Bb
312     F1(P)=(SIN(Aa)/Aa)*COS(Bb)
313             !PRINT "F1(";P;")=";F1(P)
```

```
314   NEXT P
315   DISP "Building multiplier function for F2"
316    !Generate 1/2 of multiplier function for F2
317   F2(0)=1
318            !PRINT "F2(0)=";F2(0)
319   FOR P=1 TO N*If2
320     Aa=(PI*P)/(N*If2)
321     Bb=(Aa+4*Gf)/Fb
322            !PRINT "P=";P
323            !PRINT "N=";N
324            !PRINT "(PI*P)/N=";Aa
325            !PRINT "(Aa*4*GF)/FB=";Bb
326     F2(P)=(SIN(Aa)/Aa)*COS(Bb)
327            !PRINT "F2(";P;")=";F2(P)
328   NEXT P
329   RETURN
330 !
331 !........................................
332 !Convolution and envelop detection
333 !at K1 intervals for f1 and f2.
334 !........................................
335 !
336 Comp_angle:!Filter, envelop detection,
337              !doppler correction and
338              !arctan for red & blue
340   RAD
341   Tot_angle_peak=0
342   P=0       !Initializaton of array for the out-
343             !put angle for red and blue lasers.
344      !Determine first data point to start con-
345      !volution considering the value of N and
346      !the need of a + slope for f1 for synchr-
347      !onization.
348   Quotient=(N+1) DIV K1
349   Start=(Quotient+1)+12
351   BEEP
353   DISP "                    C R U N C H I N G   D A T A"
355   PRINT "Start=";Start
356   Qq=0  !Initialize graph index. Increment
357         !Qq for each 200 computations
361   Qr=Start+2-3
362   Qb=Qr
363   FOR Xx=1 TO 2 !1=red,2=blue
364     IF Xx=1 THEN
365       Q=Qr
366     ELSE
367       Q=Qb
368     END IF
369     B1k1=0
370     B2k1=0
373 !.........................................
374 Cor_f1:!
375          !Convolution over K1 interval for
376          !F1
377 !.........................................
378     J=1
379     Peak_value_f1=0
380     FOR X=Q TO Q+K1-1
381       IF Xx=1 THEN B1k1=B1(X)+B1k1
382       IF Xx=2 THEN B2k1=B2(X)+B2k1
383       FOR C=0 TO If1-1
```

```
384          Sum_f1=0
385          IF Xx=1 THEN   !Xx=1,Red:Xx=2,Blue
386            FOR M=X TO X+N
387              Product_f1=Br(M+1)*F1((M-X)*If1-C+If1)+Br(2*X-M)*F1((M-X)*If1+C
388              Sum_f1=Sum_f1+Product_f1
389             ! PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)*
If1+C);
390             !  PRINT TAB(50);((M-X)*If1-C+If1);
391             !  PRINT TAB(60);(2*X-M-1)
392            NEXT M
393          ELSE
394            FOR M=X TO X+N
395              Product_f1=B1(M+1)*F1((M-X)*If1-C+If1)+B1(2*X-M)*F1((M-X)*If1+C
396              Sum_f1=Sum_f1+Product_f1
397             !  PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If1+C);
398             !  PRINT TAB(50);((M-X)*If1-C+If1);
399             !  PRINT TAB(60);(2*X-M-1)
400            NEXT M
401          END IF
402          Filt_f1(J)=Sum_f1
403            !PRINTER IS 705
404            !PRINT "Filt_f1(";J;")";Filt_f1(J)
405            !PRINTER IS 1
406          IF ABS(Filt_f1(J))>Peak_value_f1 THEN
407            Peak_value_f1=ABS(Filt_f1(J))
408          END IF
409          J=J+1
410        NEXT C
411      NEXT X
412      IF Xx=1 THEN B1(P)=INT(B1k1/12)
413      IF Xx=2 THEN B2(P)=INT(B2k1/12)
419          !....................................
420 Env_f1:!Envelop detection over K1
421          !interval for f1
422          !....................................
423      Diff_plus_f1=0
424      Diff_minus_f1=0
425      FOR E=If1+1 TO 5*If1+1
426        Diff_f1=Filt_f1(E)-Filt_f1(E+INT(If1*K1/2))
427        IF Diff_f1>Diff_plus_f1 THEN
428          Diff_plus_f1=Diff_f1
429        END IF
430        IF Diff_f1<Diff_minus_f1 THEN
431          Diff_minus_f1=Diff_f1
432        END IF
433             !PRINT "e=";E,"Diff_f1=";Diff_f1
434             !PRINT "Diff_plus_f1=";Diff_plus_f1
435             !PRINT "Diff_minus_f1=";Diff_minus_f1
436      NEXT E
437         !Value of Envelop at P interval for f1
438      IF Diff_plus_f1>ABS(Diff_minus_f1) THEN
439        Envelop_f1=Diff_plus_f1
440      ELSE
441        Envelop_f1=Diff_minus_f1
442      END IF
478 !..........................................
479 Con_f2:!
480            !Convolution over K1 interval for f2
481 !..........................................
483      J=1
```

```
484     Peak_value_f2=0
485     FOR X=Q TO Q+K1-1
486       FOR C=0 TO If2-1
487         Sum_f2=0
488         IF Xx=1 THEN    !Xx=1,Red:Xx=2,Blue
489           FOR M=X TO X+N
490             Product_f2=Br(M+1)*F2((M-X)*If2-C+If2)+Br(2*X-M)*F2((M-X)*If2+C)
491             Sum_f2=Sum_f2+Product_f2
492             !  PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If2+C);
493             !  PRINT TAB(50);((M-X)*If2-C+If2);
494             !  PRINT TAB(60);(2*X-M-1)
495           NEXT M
496         ELSE
497           FOR M=X TO X+N
498             Product_f2=Bl(M+1)*F2((M-X)*If2-C+If2)+Bl(2*X-M)*F2((M-X)*If2+C)
499             Sum_f2=Sum_f2+Product_f2
500             !  PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If2+C);
501             !  PRINT TAB(50);((M-X)*If2-C+If2);
502             !  PRINT TAB(60);(2*X-M-1)
503           NEXT M
504         END IF
505         Filt_f2(J)=Sum_f2
506           !PRINTER IS 705
507           !PRINT "Filt_f2(";J;")=";Filt_f2(J)
508           !PRINTER IS 1
509         IF ABS(Filt_f2(J))>Peak_value_f2 THEN
510           Peak_value_f2=ABS(Filt_f2(J))
511         END IF
512         J=J+1
513       NEXT C
514     NEXT X
520 !......................................
521 Env_f2:!Envelop detection over fract-
522          !ional interval of K1 for f2
523          !using 1/2 cycle difference
525 !......................................
526     Diff_plus_f2=0
527     Diff_minus_f2=0
528     FOR E=If2+1 TO 5*If2+1
529       Diff_f2=Filt_f2(E)-Filt_f2(E+3*If2)
530       IF Diff_f2>Diff_plus_f2 THEN
531         Diff_plus_f2=Diff_f2
532       END IF
533       IF Diff_f2<Diff_minus_f2 THEN
534         Diff_minus_f2=Diff_f2
535       END IF
536     NEXT E
540         !value of Envelop at P interval for f2
541     IF Diff_plus_f2>ABS(Diff_minus_f2) THEN
542       Envelop_f2=Diff_plus_f2
543     ELSE
544       Envelop_f2=Diff_minus_f2
545     END IF
546     !PRINT "Envelop_f2";Envelop_f2
547   !.......................................
548   !CORRECTION FOR THE DOPPLER EFFECT FOR RED
549                AND BLUE
550   !.......................................
        IF ABS(Envelop_f1)>ABS(Envelop_f2) THEN
```

```
558        FOR E=If1+1 TO 5*If1+1
560          D2=Filt_f1(E+2)-Filt_f1(E+1)
561          D1=Filt_f1(E+1)-Filt_f1(E)
562         !PRINT "D2=";D2,"D1=";D1,"(D2-D1)=";D2-D1,"E=";E
563          IF D2=0 OR SGN(D1)+SGN(D2)=0 THEN
567            GOTO 571
568          END IF
569        NEXT E
571        Dsq=D2-D1
572        Ap=Filt_f1(E)
574        Bp=D1-Dsq/2
575        Cp=Dsq/2
577        Envelop_f11=(Ap-(Bp^2)/(4*Cp))
578        !PRINT "Envelop_f11=";Envelop_f11
580        Ee=E-Bp/(2*Cp)
581        !PRINTER IS 705
590        PRINT "Ee_f1=";Ee
591        PRINTER IS 1
593        Qc=0
594        IF Ee>4*If1+1 THEN Qc=-1
595        IF Ee<2*If1+1 THEN Qc=+1
598      ELSE
617        FOR E=If2+1 TO 5*If2+1
618          D2=Filt_f2(E+2)-Filt_f2(E+1)
619          D1=Filt_f2(E+1)-Filt_f2(E)
620          !PRINT "D2=";D2,"D1=";D1."(D2-D1)=";D2-D1,"E=";E
621          IF D2=0 OR SGN(D1)+SGN(D2)=0 THEN
622            GOTO 626
623          END IF
625        NEXT E
626        Dsq=D2-D1
627        Ap=Filt_f2(E)
628        Bp=D1-Ds/2
629        Cp=Dsq/2
630        Envelop_f22=(Ap-(Bp^2)/(4*Cp))
631        !PRINT "Envelop_f22=";Envelop_f22
632        Ee=E-Bp/(2*Cp)
633        !PRINTER IS 705
635        PRINT "Ee_f2=";Ee
636        PRINTER IS 1
638        Qc=0
639        IF Ee>4*If2+1 THEN Qc=-1
640        IF Ee<2*If2+1 THEN Qc=+1
641      END IF
642      IF Xx=1 THEN
643        !PRINTER IS 705
645        Ror=Ror+Qc
646        PRINT "Ror=";Ror,
647        Rotr(P)=Ror
648        Qccr(P)=Qc
649        PRINT "Qc=";Qc
650        Qr=Qr+Qc+K1
651        PRINT "Qr=";Qr
652        PRINTER IS 1
654      ELSE
655        Rob=Rob+Qc
656        PRINT "Rob=";Rob
657        Rotb(P)=Rob
658        Qccb(P)=Qc
659        PRINT "Qc=";Qc.
660        Qb=Qb+Qc+K1
```

```
661         PRINT "Qb=";Qb
667       END IF
668       E_f1=Envelop_f1
669       E_f2=4*Envelop_f2
670       PRINT "Envelop_f2/Envelop_f1=";Envelop_f2/Envelop_f1
671         !.....................................
672 Arc_t:!Computation of the angle from the
673         !arctan(Envelop_f2/Envelop_F1) and
674         !counting of the whole quadrants
675         !.....................................
676         BEEP 500,.2
679       PRINTER IS 1
680       DEG
681       IF Xx=1 THEN ! Arc_t for Red laser
682         IF E_f1=0 THEN !Take care of divide by zero
683           IF Qpsr=1 OR Qpsr=3 THEN
684             Tar=(Qsr)*90+90
685             GOTO 716
686           ELSE
687             Tar=(Qsr)*90
688             GOTO 716
689           END IF
690         END IF
691         Ra=E_f2/E_f1
692         !Determine Quadrant & Total_angle(P)_
693         IF ABS(Ra)>=60 THEN
694           IF SGN(Ra)=1 THEN
695             Ra=60
696           ELSE
697             Ra=-60
698           END IF
699         END IF
700         IF SGN(Ra)=1 THEN !Plus Ratio
701           IF SGN(E_f1)=1 THEN ! Deno plus
702             Qptr=1
703           ELSE
704             Qptr=3
705           END IF
706           Tar=(Qt(Qpsr,Qptr)+Qsr)*90+ATN(Ra)-900
707         ELSE
708           IF SGN(E_f1)=1 THEN
709             Qptr=4
710           ELSE
711             Qptr=2
712           END IF
713           Tar=(Qt(Qpsr,Qptr)+Qsr)*90+90+ATN(Ra)-900
714         END IF
715         Qsr=Qt(Qpsr,Qptr)+Qsr
716         IF P>1 THEN Qpsr=Qptr
717         PRINTER IS 705
719         PRINT P,PROUND(Tar,-2),Qpsr,Qptr,B1(Q),B1(P)
720         PRINTER IS 1
722         Ta_red(P)=Tar
723         PRINTER IS 705
725         PRINT P,"Ta_red=";PROUND(Ta_red(P),-2),"E_F1=";E_f1,"E_F2=";E_f2
726         PRINTER IS 1
728       ELSE!Arc_t for blue laser
729         IF E_f1=0 THEN !Take care of divide by zero
730           IF Qpsb=1 OR Qpsb=3 THEN
731             Tab=(Qsb)*90+90
732             GOTO 763
```

```
733           ELSE
734             Tab=(Qsb)*90
735             GOTO 763
736           END IF
737         END IF
738         Ra=E_f2/E_f1
739         !Determine Quadrant & Total_angle(P)_
740         IF ABS(Ra)>=60 THEN
741           IF SGN(Ra)=1 THEN
742             Ra=60
743           ELSE
744             Ra=-60
745           END IF
746         END IF
747         IF SGN(Ra)=1 THEN !Plus Ratio
748           IF SGN(E_f1)=1 THEN ! Deno plus
749             Qptb=1
750           ELSE
751             Qptb=3
752           END IF
753           Tab=(Qt(Qpsb,Qptb)+Qsb)*90+ATN(Ra)-900
754         ELSE
755           IF SGN(E_f1)=1 THEN
756             Qptb=4
757           ELSE
758             Qptb=2
759           END IF
760           Tab=(Qt(Qpsb,Qptb)+Qsb)*90+90+ATN(Ra)-900
761         END IF
762         Qsb=Qt(Qpsb,Qptb)+Qsb
763         IF P>1 THEN Qpsb=Qptb
764         PRINTER IS 705
766         PRINT P,PROUND(Tab,-2),Qpsb,Qptb,B1(Q),B1(P)
767         Ta_bl(P)=Tab
768         PRINT P,"Ta_bl=";PROUND(Ta_bl(P),-2),"E_F1=";E_f1,"E_F2=";E_f2
769       END IF!For red or blue
770       PRINTER IS 1
771     NEXT Xx
772     RAD
773     PRINT
774       !This completes the angle computation
775       !for the red and blue for this K1 interval P
776     P=P+1
777       !Test to increment Qq or not
778     IF P=0 THEN
779       Qq=0
780     ELSE
781       Rmdr=P MOD 199      !P starts at 0
782       IF Rmdr=0 THEN Qq=Qq+1
783     END IF
784     !NEXT Q
785     IF Q>=Nnn-N-25-Start THEN RETURN
787     GOTO 363
788 Disp_out:!Graph data
789     Dpcr=.064          !Degrees/count gimbal red
790     Dpcb=.064          !Degrees/count gimbal blue
791     DUMP DEVICE IS 705
792     PRINTER IS 705
793     PEN 2
794     PRINT CHR$(12);     !Clear alpha & form feed
795     DISP
```

```
796    GINIT                   !Initialize
797    GRAPHICS ON             !Raster on
798    FOR Qqq=0 TO Qq !Graph index
799      FOR R=1 TO 2 !red=1, blue=2
800        PEN 2
801        WINDOW -25,200,-500,500!Set window
802        AXES 20,100
803        LORG 6
804        FOR I=0 TO 180 STEP 40
805          MOVE I,0
806          LABEL Qqq*200+I
807        NEXT I
808        !
809        LORG 8
810        FOR I=-400 TO 400 STEP 100
811          MOVE 0,I
812          LABEL I
813        NEXT I
814        !
815        LORG 5
816        MOVE 100,475
817        PEN 6
818        LABEL "ANGLE AS A FUNCTION OF ENVELOP SAMPLES"
819        MOVE 180,425
820        IF R=1 THEN
821        PEN 2
823        LABEL "RED"
824        MOVE 180, 400
825        LABEL Name$
827        PEN 6
828        END IF
829        IF R=2 THEN LABEL "BLUE"
830        MOVE 180,-400
831        LABEL Name$
833        PEN 2
834        MOVE -13,0
835        LORG 6
836        LABEL "Samp"
837        LORG 5
838        MOVE 100,-475
839        LABEL Title$;"ENVELOP SAMPLE RATE, 3KHZ"
840        PEN 0
841        MOVE 0,0
842        PEN 2
843        FOR X=0 TO 199 !graph data
844          IF R=1 THEN
845            Tb=Ta_red(Qqq*200+X+4)-Ta_red(4)
846          ELSE
847            Tb=Ta_bl(Qqq*200+X+4)-Ta_bl(4)
848          END IF
849          DRAW X,Tb
850        NEXT X
851        PEN 0
852        MOVE 0,0
853        PEN 6
854        FOR X=0 TO 199 !Graph gimbal
855          IF R=1 THEN
856            Bbb=B1(Qqq*200+X+4)*Dpcr-B1(4)*Dpcr
857          ELSE
858            Bbb=B2(Qqq*200+X+4)*Dpcb-B2(4)*Dpcb
859          END IF
```

```
860             DRAW X,-Bbb
861           NEXT X
862           PEN 0
863           PAUSE
864           !DUMP GRAPHICS
865           !PRINT CHR$(12)
866           GCLEAR
867         NEXT R
868       NEXT Qqq
869       ALPHA ON
870       PRINTER IS 1
871       DISP "STOP"
872       PAUSE
873       RETURN
874 Check_stat: !Status check on Buffer.
875       PRINT "            REGISTER STATUS @Buffer"
876       FOR X=1 TO 5
877         STATUS @Buffer,X;A
878         PRINT "REGISTER  ";X,A
879       NEXT X
880                   !DISP "PAUSE - PRESS CONTINUE TO CONTINUE"
881       BEEP
882                   !PAUSE
883       WAIT 5
884       PRINT CHR$(12)
885       RETURN
886 Err_rout:  !Routine for error recovery
887       BEEP
888       BEEP
889       BEEP
890       DISP ERRM$
891       PAUSE
892       GOSUB Disp_out
893       PAUSE
894         !
895 File data: !Transfer of data from Buffer
896                 !to disk
897         !
898       BEEP
899       DISP "INSERT A FORMATTED DATA DISK!!!!!!!! -- PRESS CONT TO CONT"
900       PAUSE
901         !Create a BDAT file for the data.
902       INPUT "NAME OF DATA FILE TO BE CREATED?",Name$
903       IF Name$="" THEN 902
904       BEEP
905       DISP "CREATING A DATA FILE"
906         !Record length is 1
907       CREATE BDAT Name$&":INTERNAL",8*Nnn+4,2
908         !Assign an I/O path
909       ASSIGN @File TO Name$&":INTERNAL"
910       GOSUB Check_stat_r
911       PRINT CHR$(12)
912       DISP "TRANSFERRING DATA FROM BUFFER TO FILE"
913       OUTPUT @File;Br(*),B1(*),B1(*),B2(*)
914       ASSIGN @File TO *
915       WAIT 5
916       DISP "TRANSFER COMPLETE"
917       WAIT 5
918       DISP
919       PRINT CHR$(12)
920       RETURN
```

```
921      !
922 File_array:  !Transfer from file to array
923      !
924  INPUT "NAME OF DATA FILE?",Name$
925  ASSIGN @File TO Name$&":INTERNAL"
926  BEEP
929  DISP "TRANSFERRING FROM DATA FILE TO AN ARRAY"
930  ENTER @File;Br(*),B1(*),B1(*),B2(*)
931  PRINT CHR$(12)
933  DISP "TRANSFER COMPLETE"
934  WAIT 3
938  !GOSUB Check_stat
939  !GOSUB Check_stat_r
940  !GOSUB Check_stat
941  DISP
942  RETURN
943 Check_stat_r: !Status check on File.
944  BEEP
945  PRINT "     REGISTER STATUS @File"
946  FOR R=1 TO 5
947   STATUS @File,R;A
948   PRINT "REGISTER  ";R,A
949  NEXT R
950      !DISP "PAUSE - PRESS CONTINUE TO CONTINUE"
951  BEEP
952      !PAUSE
953  WAIT 5
954  PRINT CHR$(12)
955  RETURN
956  END
```

```
  >   Cross Reference   <<<<

*   Numeric Variables
A                         877   878   947   948
A_to_d_reset
Aa                        306   307   312   320   321   326
Ab                        278   281   287
Ac                        281   283
Ap                        572   577   627   630
B1                        210   255   381   412   719   766   856   913   930
B1_peak
B1k1                      369   381   412
B2                        211   255   382   413   858   913   930
B2_peak
B2k1                      370   382   413
Bb                        307   312   321   326
Bb2
Bbb                       856   858   860
Bbb2
Bl                        209   254   395   498   913   930
Bp                        574   577   580   628   630   632
Br                        208   254   387   490   913   930
buffer array
bw_label
                          383   387   395   410   486   490   498   513
Check_stat
Check_stat r
Comp_angle
[illegible]
[illegible]               625   577   580   629   630   632
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]               [illegible]   562   571   574   619   621   626   [illegible]
                          561   563   571   618   621   626
Diff f1                   426   427   428   430   431
Diff f2                   529   530   531   533   534
Diff minus f1             424   430   431   438   441
Diff minus f2             527   533   534   541   544
Diff plus f1              423   427   428   438   439
Diff plus f2              526   530   531   541   542
Disp con
Disp data
Disp data
Disp data
[illegible]
dma transfer
[illegible]               740   858
[illegible]               789   856
[illegible]               628
                          [illegible]   574   [illegible]   [illegible]   [illegible]
                          [illegible]   [illegible]   436   [illegible]   [illegible]   [illegible]   558   560   [illegible]
                          572   581   [illegible]   618   619   626   627   632
[illegible]               662   682   691   701   708   726   729   738   [illegible]
                          [illegible]
[illegible]               [illegible]
[illegible]               580   590   594   595   632   [illegible]   [illegible]   640
[illegible]               [illegible]   441   [illegible]   [illegible]   [illegible]
[illegible]               [illegible]
[illegible]               [illegible]   544   [illegible]   [illegible]   670
```

```
Envelop_f22            630
Epa                    273    281
Err_rout
F1                     297 <-DEF   303    312    387    395
F2                     297 <-DEF   317    326    490    498
Fb                     250    251    307    321
File_array
File_data
Filt_bw_int
Filt_f1                266    402    406    407    426    560    561    572
Filt_f11b
Filt_f11r
Filt_f1b
Filt_f1r
Filt_f2                266    505    509    510    529    618    619    627
Filt_f22b
Filt_f22r
Filt_f2b
Filt_f2r
Gal_cyc_frg            277    281
Gf                      87    281    307    321
Gpio                    83    196    197    198    201    202    204    220    221
Hpib                    84
I                      804    805    806    807    810    811    812    813
I+1                    262    266    305    306    383    387    395    425    426    55
                       594    595
I+2                    264    266    319    320    486    490    498    528    529    61
                       639    640
[illegible]            378    402    406    407    409    483    505    509    510    51
[illegible]             88    188    266    348    380    426    485    650    660
[illegible]             89
[illegible]             90
[illegible]            193 <-DEF   194    208    209    210    211
[illegible]            386    387    392    394    395    400    489    490    495    49
                       498    503
Max_x_axes
Mmm                    279    283    285
Mn
Mult_fun
N                      251    305    306    319    320    348    386    394    489    49
                       785
Nnn                    215    253    254    255    256    785    907
Ns
Num_samp
Num_samples            185    187    188    253    279    280
Op
[illegible]      [illegible]  306    312    314    319    320    326    328  [illegible]  41
                       413    647    648    657    658    716    719    722  [illegible]  [illegible]
                       766    767    768    776    778    781
Peak_value_data        276
Peak_value_f1          379    406    407
Peak_value_f11b
Peak_value_f11r
Peak_value_f1b
Peak_value_f1r
Peak_value_f2          484    509    510
Peak_value_f22b
Peak_value_f22r
Peak_value_f2b
Peak_value_f2r
Product_f1             387    388    395    396
```

```
Product_f2           490   491   498   499
Q                    365   367   380   485   719   766   785
Qb                   362   367   660   661
Qc                   593   594   595   638   639   640   645   648   649   650
                     655   658   659   660
Qccb                 256   658
Qccr                 256   648
Qj
Qpsb                 730   753   760   762   763   766
Qpsr                 683   706   713   715   716   719
Qptb                 749   751   753   756   758   760   762   763   766
Qptr                 702   704   706   709   711   713   715   716   719
Qq                   356   779   782   798
Qqq                  798   806   845   847   856   858   868
Qr                   361   362   365   650   651
Qsb                  144   731   734   753   760   762
Qsr                  143   684   687   706   713   715
Qt                   134 <-DEF   135   136   137   138   139   140   141   14
                     706   713   715   753   760   762
Quotient             349   349
R                    799   820   829   844   855   867   946   947   948   949
Ra                   691   693   694   695   697   700   706   713   738   74
                     741   742   744   747   753   760
Range_stored
Smar                 781   782
Rob                  655   656   657
Ror                  645   646   647
Rot                  188
Rotb                 256   657
Rotr                 256   647
[illegible]          190   208   209   210   211   213   215
[illegible]           86   251   281
Ssp
Start                349   355   361   785
Sum_f1               384   388   396   402
Sum_f2               487   491   499   505
Sys_del_b
Sys_del_red
Ta_bl                188   767   768   847
Ta_red               188   722   725   845
Tat                  731   734   753   760   766   767
Tar                  684   687   706   713   719   722
Tb                   845   847   849
Test_data
[illegible]
Tot_angle_peak       341
[illegible]
                     207   208   209   210   211   214   280   282   288   38
                     381   382   386   387   394   395   411   485   489   49
                     497   498   514   843   845   847   849   850   854   85
                     859   860   861   876   877   878   879
[illegible]                384   385   386   389   412   413   488   64    [illegible]
[illegible]
[illegible]          282   283   285   286
[illegible]

[illegible] variables
[illegible]          [illegible]
[illegible]          [illegible]   9[illegible]   90[illegible]   907   909   924   92
[illegible]          8[illegible]
```

```
*   I/O Path Names
@Buf                       194    200    206
@Buffer                    285    877
@File                      909    913    914    925    930    947
@Gpio                      145    206

*   Line Labels
A_to_d_reset
Arc_t                      672 <-DEF
Buffer_array
Bw_label
Check_stat                 290    874 <-DEF
Check_stat_r               910    943 <-DEF
Comments                    19 <-DEF
Comp_angle                 176    336 <-DEF
Con_f1                     374 <-DEF
Con_f2                     479 <-DEF
Constants
Disp_con
Disp_data
Disp_data_1
Disp_data_2
Disp_out                    81    179    788 <-DEF    892
Dma_transfer               159    190 <-DEF
Doppler_cor
Env_f1                     420 <-DEF
Env_f2                     521 <-DEF
Err_rout                    77    886 <-DEF
File_array                 167    922 <-DEF
File_data                  160    895 <-DEF
Filt_bw_int                155    246 <-DEF
Index
Initialize                  74 <-DEF
Main                       148 <-DEF
Mult_fun                   174    293 <-DEF
Num_samp                   150    182 <-DEF
Range_stored
Test                       268 <-DEF
Test_data
Var_list

*   Line Numbers
     [illegible]           180
     4
     [illegible]
     [illegible]
    11
    [illegible]
    [illegible]
    24
    [illegible]            [illegible]
    [illegible]            [illegible]    [illegible]
    [illegible]
    [illegible]            [illegible]
    [illegible]
    [illegible]            [illegible]
    [illegible]
    [illegible]
    [illegible]
    [illegible]            [illegible]
```

```
 221
 226
 240
 245
 249
 363                 787
 372
 390
 524
 526
 540
 546
 548
 562
 571                 567
 578
 600
 626                 622
 634
 635
 643
 679
 686
 691
 716                 685   688
 729
 738
 76[illegible]                 [illegible]   739
 81[illegible]
 [illegible]
 82[illegible]
 [illegible]
 8[illegible]
 8[illegible]
 8[illegible]
 [illegible]
 9[illegible]              [illegible]
 9[illegible]
 [illegible]
 [illegible]
1[illegible]
1274

[illegible]
```

```
          !BRL_E_IR
    !::::::::::::::::::::::::::::::::::::::::::::::
    Comments:!PROGRAM FOR DATA ACQUISITION AND
             !DATA PROCESSING OF RANGE DATA.
14  !______________________________________________
19           !This program uses the difference
             !method for determining the amplitude
             !for f1 & f2.
             !Graphing is included for 200 enve-
             !lopes/graph. # of graphs depends on
             !the number os Num_samples.
             !Parameters of consideration: Ratios
             !of f2/f1, degrees/count red(Dpcr),
57           !The phase correction, doppler
             !effect is included.
             !The parabolic fit is used to deter-
             !mine the location of the peak using
             !the greater of the amplitudes of f1
             !& f2. The phase correction is
             !independent for the red & blue.
             !AD Interface - Switch position NORMAL.
             PRINTER IS 1
             PRINT CHR$(12)
             PRINT TABXY(9,8),"RANGE PROGRAM"
             WAIT
             PRINT CHR$(12)
             PRINT TABXY(3,15),"
             !::::::::::::::::::::::::::::::::::::
    Index    !INDEX TO ROUTINE
             !____________________________________
             !Comments
             !Index
             !Initialize
             !Constants
             !Variables
             !Menu
             !Num_samples
             !Dma transfer
             [illegible]
             [illegible]
             [illegible]
             !Buffer array
             [illegible]
             !Get data
                        :::::::::::::::::::::
```

```
115   GRAPHICS OFF
116   RAD
117   ON KEY 4 LABEL "GRAPH",15 GOSUB Disp_out
118   ENABLE
119   Gpio=12
120   Hpib=704
121 !::::::::::::::::::::::::::::::::::::::::::::::
123 Constants:!
124 !_____________________________________________
126      Sf=36000 !Sample frequency
127      Gf=3000 !galvo frequency set by clock
128      K1=12  !samples at f1
129      K2=6   !samples at f2
130      K3=4   !samples at f3
131      Sys_del_red=-0!-3 for data acquisition
132                    !+0 for Test_data
134      Sys_del_bl=-0 !-3 for data acquisition
135                    !+0 for Test_data
137      !Signal generator frequency 576.000kHz
138 !::::::::::::::::::::::::::::::::::::::::::::::
139 Var_list:!Variable list
140 !_____________________________________________
141      !Num_samp : number of samples to take at 36kHz rate
142      !Fb : filter bandwidth
143      !N : INT(Sf/fb)
144      !Ns :INT (Num_samples/4)
145      !Br( ) : array, sampled data, red
146      !Bl( ) : array, sampled data, blue
147      !If1 : interpolation factor for f1
148      !If2 : interpolation factor for f2
149      !F1( ) : convolution multipling function for f1
150      !F2( ) : convolution multipling function for f2
151      !Start : starting point, determined by N
152      !Qr : starting sampled data point for next K1
153           !interval, including doppler correction, red.
154      !Qb : same as Qr except, blue
155      !Xx : Xx=1, loop for red;Xx=2 loop for blue
156      !B1( ) : spare input
157      !B2( ) : spare input
158      !Filt_f1(J) : convolution elements in K1 interval, f1
159      !Filt_f2(J) : convolution elements in K1 interval, f2
160      !B1(P) : average of B1( ) in K1 interval
161      !B2(P) : average of B2( ) in k2 interval
162      !P : K1 interval of computation
163      !Ror : running sum of doppler correction, red
164      !Rob : running sum of doppler correction, blue
165      !Rotr(P) : running sum stored as a function of P
166      !Rotb(P) : running sum stored as a function of P
167      !Occr(P) : doppler correction for respective K1 interval, red
168      !Occb(P) : doppler correction for respective K1 interval, blue
169      !Qpsr : quadrant past, red
170      !Qpsb : quadrant past, blue
171      !Qptr : quadrant present, red
172      !Qptb : quadrant present, blue
173      !Qsr : running sum of quadrants, red
174      !Qsb : running sum of quadrants, blue
175      !Tar : total angle red, K1 interval
176      !Tab : total angle blue, K1 interval
177      !Ta_red(P) : total angle red, P K1 interval
178      !Ta_bl(P) : total angle blue, P K1 interval
179   !Whole quadrant update table
```

```
180   DIM Qt(4,4)
181   Qt(1,2)=1
182   Qt(1,4)=-1
183   Qt(2,1)=-1
184   Qt(2,3)=1
185   Qt(3,2)=-1
186   Qt(3,4)=1
187   Qt(4,1)=1
188   Qt(4,3)=-1
189   Qsr=10 !Quadrant sum red starts at 10
190   Qsb=10 !Quadrant sum blue starts at 10
191   ASSIGN @Gpio TO 12
192   !PRINT "      REGISTER STATUS BEFORE DMA"
193   !GOSUB Check_stat
194 !::::::::::::::::::::::::::::::::::::::::::::
195 Main:! Main program
196 !
197   PRINT CHR$(12)
198   GOSUB A_to_d_reset
199   GOSUB Range_stored
200   BEEP
201   GOSUB Mult_fun     !Generate multiplier
202                      !functions.
203   BEEP
204   GOSUB Comp_angle   !Convolution, envelop detection, doppler correction,
205                      !& Arctan for red and blue
206   DISP
207   GOSUB Disp_out
208   GOTO 1
209 !::::::::::::::::::::::::::::::::::::::::::::
210 Range_stored:!
211 !
213  INPUT "RANGE DATA, Type R/r : STORED DATA?, Type S/s",Aa$
214   IF Aa$="R" OR Aa$="r" THEN
215      GOSUB Num_samp
216      !GOSUB Dma_transfer
217      GOSUB Test_data
219      GOSUB File_data
220      GOSUB Buffer_array
221      GOSUB Filt_bw_int
222      RETURN
223   END IF
224   IF Aa$="S" OR Aa$="s" THEN
225      GOSUB File_array
226      GOSUB Buffer_array
227      GOSUB Filt_bw_int
228      RETURN
229   END IF
230      BEEP
231      BEEP
232      BEEP
233   GOTO 213
234 !::::::::::::::::::::::::::::::::::::::::::::
235 Num_samp: !Input the total number of samples
236 !
237             !to be taken. Maximum of 32K
238   BEEP
239   INPUT "TOTAL NUMBER OF SAMPLES TO BE TAKEN?",Num_samples
240   Ns=INT(Num_samples/4)
241   ALLOCATE INTEGER Br(0:Ns),INTEGER Bl(0:Ns)
242   ALLOCATE INTEGER B1(0:Ns),INTEGER B2(0:Ns)
```

```
243   ALLOCATE INTEGER Rotr(0:Ns),Rotb(0:Ns),Qccr(0:Ns),Qccb(0:Ns)
245   ALLOCATE REAL Ta_red(INT(Num_samples/K1)),Ta_bl(INT(Num_samples/K1)),Rot(I
NT(Num_samples/K1))
246   !Create an un-named buffer so greater than
247   !32k can be collected.
248   ASSIGN @Buffer TO BUFFER [Num_samples]
249   RETURN
250 Dma_transfer:!
251   CONTROL @Buffer,4;0
252   CONTROL Gpio,0;2
253   CONTROL Gpio,3;0
254   !SET TRANSFER LOW
255   CONTROL Gpio,2;3 !SET CLT0 TO 0, XFER 0
256   BEEP
257   DISP "       WAITING FOR RANGE TRIGGER"
258   TRANSFER @Gpio TO @Buffer;COUNT Num_samples
259   CONTROL Gpio,2;2 !SET CLT0 & CLT1 TO 1
260   CONTROL Gpio,1;3
261   !PRINT "       REGISTER STATUS AFTER DMA"
262   !GOSUB Check_stat
263   BEEP
264   RETURN
265 Filt_bw_int:!Input filter bandwidth in hertz
266   BEEP
267   INPUT "WHAT IS THE DESIRED FILTER BANDWIDTH IN HERTZ?",Fb
268   N=INT(Sf/Fb)
269   PRINT CHR$(12)
270   BEEP
271   INPUT "Real samples f1=12, interpolation factor?",If1
272   BEEP
273   INPUT "Real samples f2=6, interpolation factor?",If2
274   BEEP
275   ALLOCATE REAL Filt_f1(1:K1*If1),Filt_f2(1:K1*If2)
276   RETURN
277 Test:! Generate data - needs to be modified for this
278      !program
279   BEEP
280   INPUT "What is the Envelop Peak Amplitude?",Epa
281   BEEP
282   DISP "                         GENERATING DATA"
283   Peak_value_data=0
284   Gal_cyc_frg=200
285   Ab=0
286   ALLOCATE INTEGER Mmm(0:Num_samples-1)
287   FOR X=0 TO Num_samples-1 STEP 4
288     Ac=Epa*SIN((PI*(+Ab))/(6*Gal_cyc_frg)+(2.7)*SIN(2*PI*Ab*Gf/Sf))
289     FOR Y=X TO X+3
290       Mmm(Y)=INT(Ac)+128
291           !PRINT Y,Mmm(Y)
292       OUTPUT @Buffer USING "#,B";Mmm(Y)
293     NEXT Y
294     Ab=Ab+1
295   NEXT X
296   DISP
298   WAIT 5
299   RETURN
300 !:::::::::::::::::::::::::::::::::::::::::::::
301 Mult_fun: !Generation of the multiplying function.
302 !______________________________________________
303           !Multiplying function will be (SIN(X)/(X))*COS(Y)
304           !PRINTER IS 705
```

```
305   !ALLOCATE REAL F1(0:(N*If1)),REAL F2(0:(N*If2))
306   DIM F1(0:2000),F2(0:2000)
307   RAD
308   BEEP
309    !Generate 1/2 multiplier function for F1
310   BEEP
311   DISP "Building multiplier function for F1"
312   F1(0)=1
313                  !PRINT "F1(0)=";F1(0)
314   FOR P=1 TO N+If1
315     Aa=(PI*P)/(N*If1)
316     Bb=(Aa*2*Gf)/Fb
317                  !PRINT "P=";P
318                  !PRINT "N=";N*If1
319                  !PRINT "(PI*P)/N=";Aa
320                  !PRINT "(Aa*2*GF)/FB=";Bb
321     F1(P)=(SIN(Aa)/Aa)*COS(Bb)
322                  !PRINT "F1(";P;")=";F1(P)
323   NEXT P
324   DISP "Building multiplier function for F2"
325    !Generate 1/2 of multiplier function for F2
326   F2(0)=1
327                  !PRINT "F2(0)=";F2(0)
328   FOR P=1 TO N+If2
329     Aa=(PI*P)/(N*If2)
330     Bb=(Aa*4*Gf)/Fb
331                  !PRINT "P=";P
332                  !PRINT "N=";N
333                  !PRINT "(PI*P)/N=";Aa
334                  !PRINT "(Aa*4*GF)/FB=";Bb
335     F2(P)=(SIN(Aa)/Aa)*COS(Bb)
336                  !PRINT "F2(";P;")=";F2(P)
337   NEXT P
338   RETURN
339 !.
340 !...........................................
341 !Convolution and envelop detection
342 !at K1 intervals for f1 and f2.
343 !...........................................
344 !:::::::::::::::::::::::::::::::::::::::::::
345 Comp_angle:!Filter, envelop detection,
348                 !doppler correction and
349                 !arctan for red & blue
350 !___________________________________________
352   RAD
353   Tot_angle_peak=0
354   P=0        !Initializaton of array for the out-
355              !put angle for red and blue lasers.
356      !Determine first data point to start con-
357      !volution considering the value of N and
358      !the need of a + slope for f1 for synchr-
359      !onization.
360   Quotient=(N+1) DIV K1
361   Start=(Quotient+1)+12
362   BEEP
363   DISP "                C R U N C H I N G   D A T A"
364   PRINT "Start=";Start
365   Qq=0  !Initialize graph index. Increment
366         !Qq for each 200 computations
370   Qr=Start+2+Sys_del_red
371   Qb=Start+2+Sys_del_bl
```

```
372   FOR Xx=1 TO 2 !1=red,2=blue
374     IF Xx=1 THEN
375       Q=Qr
376     ELSE
377       Q=Qb
378     END IF
379 !::::::::::::::::::::::::::::::::::::::::::::
380 Con_f1:!
381          !Convolution over K1 interval for
382          !F1
383 !_____________________________________________
384     J=1
385     Peak_value_f1=0
388     FOR X=Q TO Q+K1-1
392       FOR C=0 TO If1-1
393         Sum_f1=0
394         IF Xx=1 THEN    !Xx=1,Red:Xx=2,Blue
395           FOR M=X TO X+N
396             Product_f1=Br(M+1)*F1((M-X)*If1-C+If1)+Br(2*X-M)*F1((M-X)*If1+C)
397             Sum_f1=Sum_f1+Product_f1
398            ! PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)*
If1+C);
399            !  PRINT TAB(50);((M-X)*If1-C+If1);
400            !  PRINT TAB(60);(2*X-M-1)
401           NEXT M
402         ELSE
403           FOR M=X TO X+N
404             Product_f1=Bl(M+1)*F1((M-X)*If1-C+If1)+Bl(2*X-M)*F1((M-X)*If1+C)
405             Sum_f1=Sum_f1+Product_f1
406            !  PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If1+C);
407            !  PRINT TAB(50);((M-X)*If1-C+If1);
408            !  PRINT TAB(60);(2*X-M-1)
409           NEXT M
410         END IF
411         Filt_f1(J)=Sum_f1
413         !PRINTER IS 705
414         !PRINT "Filt_f1(";J;"=)";Filt_f1(J)
417         !PRINTER IS 1
418         IF ABS(Filt_f1(J))>Peak_value_f1 THEN
419           Peak_value_f1=ABS(Filt_f1(J))
420         END IF
421         J=J+1
422       NEXT C
423     NEXT X
424 !::::::::::::::::::::::::::::::::::::::::::::
425 Env_f1:!Envelop detection over K1
426         !interval for f1
427 !_____________________________________________
428     Diff_plus_f1=0
429     Diff_minus_f1=0
430    FOR E=If1+1 TO 5*If1+1
431       Diff_f1=Filt_f1(E)-Filt_f1(E+INT(If1*K1/2))
432       IF Diff_f1>Diff_plus_f1 THEN
433         Diff_plus_f1=Diff_f1
434       END IF
435       IF Diff_f1<Diff_minus_f1 THEN
436         Diff_minus_f1=Diff_f1
437       END IF
438            !PRINT "e=";E,"Diff_f1=";Diff_f1
439            !PRINT "Diff_plus_f1=";Diff_plus_f1
```

```
440           !PRINT "Diff_minus_f1=";Diff_minus_f1
441      NEXT E
442         !Value of Envelop at P interval for f1
443      IF Diff_plus_f1>ABS(Diff_minus_f1) THEN
444        Envelop_f1=Diff_plus_f1
445      ELSE
446        Envelop_f1=Diff_minus_f1
447      END IF
448 !::::::::::::::::::::::::::::::::::::::::::::
449 Con_f2:!
450         !Convolution over K1 interval for F2
451 !____________________________________________
452      J=1
453      Peak_value_f2=0
454      FOR X=Q TO Q+K2-1
455        FOR C=0 TO If2-1
456          Sum_f2=0
457          IF Xx=1 THEN   !Xx=1,Red:Xx=2,Blue
458            FOR M=X TO X+N
459              Product_f2=Br(M+1)*F2((M-X)*If2-C+If2)+Br(2*X-M)*F2((M-X)*If2+C)
460              Sum_f2=Sum_f2+Product_f2
461           !  PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If2+C);
462           !  PRINT TAB(50);((M-X)*If2-C+If2);
463           !  PRINT TAB(60);(2*X-M-1)
464            NEXT M
465          ELSE
466            FOR M=X TO X+N
467              Product_f2=Bl(M+1)*F2((M-X)*If2-C+If2)+Bl(2*X-M)*F2((M-X)*If2+C)
468              Sum_f2=Sum_f2+Product_f2
469           !  PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If2+C);
470           !  PRINT TAB(50);((M-X)*If2-C+If2);
471           !  PRINT TAB(60);(2*X-M-1)
472            NEXT M
473          END IF
474          Filt_f2(J)=Sum_f2
475          !PRINTER IS 705
476          !PRINT "Filt_f2(";J;")=";Filt_f2(J)
477          !PRINTER IS 1
478          IF ABS(Filt_f2(J))>Peak_value_f2 THEN
479            Peak_value_f2=ABS(Filt_f2(J))
480          END IF
481          J=J+1
482        NEXT C
483      NEXT X
484 !::::::::::::::::::::::::::::::::::::::::::::::
485 Env_f2:!Envelop detection over fract-
486         !ional interval of K1 for f2
487         !using 1/2 cycle difference
488 !______________________________________________
489      Diff_plus_f2=0
490      Diff_minus_f2=0
492      FOR E=If2+1 TO 5*If2+1
493        Diff_f2=Filt_f2(E)-Filt_f2(E+3*If2)
494        IF Diff_f2>Diff_plus_f2 THEN
495          Diff_plus_f2=Diff_f2
496        END IF
497        IF Diff_f2<Diff_minus_f2 THEN
498          Diff_minus_f2=Diff_f2
499        END IF
```

```
500      NEXT E
501         !Value of Envelop at P interval for f2
502      IF Diff_plus_f2>ABS(Diff_minus_f2) THEN
503        Envelop_f2=Diff_plus_f2
504      ELSE
505        Envelop_f2=Diff_minus_f2
506      END IF
507      !PRINT "Envelop_f2";Envelop_f2
510 !::::::::::::::::::::::::::::::::::::::::::::::::
511 Doppler_cor:!
512 !_______________________________________________
513 !...............................................
514 ! CORRECTION FOR THE DOPPLER EFFECT FOR RED
515 !                AND BLUE
516 !...............................................
517      IF ABS(Envelop_f1)>ABS(Envelop_f2) THEN
518        FOR E=If1+1 TO 5*If1+1
519          D2=Filt_f1(E+2)-Filt_f1(E+1)
520          D1=Filt_f1(E+1)-Filt_f1(E)
521         !PRINT "D2=";D2,"D1=";D1,"(D2-D1)=";D2-D1,"E=";E
522          IF D2=0 OR SGN(D1)+SGN(D2)=0 THEN
523            GOTO 526
524          END IF
525        NEXT E
526        Dsq=D2-D1
527        Ap=Filt_f1(E)
528        Bp=D1-Dsq/2
529        Cp=Dsq/2
530        Envelop_f11=(Ap-(Bp^2)/(4*Cp))
531        !PRINT "Envelop_f11=";Envelop_f11
532        Ee=E-Bp/(2*Cp)
533        !PRINTER IS 705
534  !!!! PRINT "Ee_f1=";Ee
535        PRINTER IS 1
536        Qc=0
537        IF Ee>4*If1+1 THEN Qc=-1
538        IF Ee<2*If1-1 THEN Qc=+1
539      ELSE
540        FOR E=If2+1 TO 5*If2+1
541          D2=Filt_f2(E+2)-Filt_f2(E+1)
542          D1=Filt_f2(E+1)-Filt_f2(E)
543          !PRINT "D2=";D2,"D1=";D1,"(D2-D1)=";D2-D1,"E=";E
544          IF D2=0 OR SGN(D1)+SGN(D2)=0 THEN
545            GOTO 548
546          END IF
547        NEXT E
548        Dsq=D2-D1
549        Ap=Filt_f2(E)
550        Bp=D1-Ds/2
551        Cp=Dsq/2
552        Envelop_f22=(Ap-(Bp^2)/(4*Cp))
553        !PRINT "Envelop_f22=";Envelop_f22
554        Ee=E-Bp/(2*Cp)
555        !PRINTER IS 705
556 !!!!  PRINT "Ee_f2=";Ee
557        PRINTER IS 1
558        Qc=0
559        IF Ee>4*If2+1 THEN Qc=-1
560        IF Ee<2*If2-1 THEN Qc=+1
561      END IF
562      IF Xx=1 THEN
```

```
563       Ror=Ror+Qc
564  !!!! PRINT "Ror=";Ror,
565       Rotr(P)=Ror
566       Qccr(P)=Qc
567       !PRINTER IS 705
568  !!!! PRINT "Qc=";Qc
569       PRINTER IS 1
570       Qr=Qr+Qc+K1
571  !!!! PRINT "Qr=";Qr
572     ELSE
573       Rob=Rob+Qc
574  !!!! PRINT "Rob=";Rob
575       Rotb(P)=Rob
576       Qccb(P)=Qc
577       !PRINTER IS 705
578 !!!!  PRINT "Qc=";Qc
579       PRINTER IS 1
580       Qb=Qb+Qc+K1
581 !!!!  PRINT "Qb=";Qb
582       PRINT
583     END IF
584     E_f1=Envelop_f1
585     E_f2=Envelop_f2
586 !!!!PRINT "Envelop_f2/Envelop_f1=";Envelop_f2/Envelop_f1
587 !:::::::::::::::::::::::::::::::::::::::::::::::
588 Arc_t:!Computation of the angle from the
589       !arctan(Envelop_f2/Envelop_F1) and
590       !counting of the whole quadrants
591 !_______________________________________________
592       BEEP 500,.2
593     PRINTER IS 1
594     DEG
595     IF Xx=1 THEN ! Arc_t for Red laser
596       IF E_f1=0 THEN !Take care of divide by zero
597         IF Qpsr=1 OR Qpsr=3 THEN
598           Tar=(Qsr)*90+90
599           GOTO 634
600         ELSE
601           Tar=(Qsr)*90
602           GOTO 634
603         END IF
604       END IF
605       Ra=E_f2/E_f1
606       !PRINTER IS 705
607 !!!!  PRINT Ra
608       PRINTER IS 1
609       !Determine Quadrant & Total_angle(P)_
610       IF ABS(Ra)>=60 THEN
611         IF SGN(Ra)=1 THEN
612           Ra=60
613         ELSE
614           Ra=-60
615         END IF
616       END IF
617       IF SGN(Ra)=1 THEN !Plus Ratio
618         IF SGN(E_f1)=1 THEN ! Deno plus
619           Qptr=1
620         ELSE
621           Qptr=3
622         END IF
623         Tar=(Qt(Qpsr,Qptr)+Qsr)*90+ATN(Ra)-900
```

```
624        ELSE
625          IF SGN(E_f1)=1 THEN
626            Qptr=4
627          ELSE
628            Qptr=2
629          END IF
630          Tar=(Qt(Qpsr,Qptr)+Qsr)*90+90+ATN(Ra)-900
631        END IF
632        Qsr=Qt(Qpsr,Qptr)+Qsr
633        IF P>1 THEN Qpsr=Qptr
634        !RINTER IS 705
635 !!!!   PRINT P,PROUND(Tar,-2),Qpsr,Qptr,B1(Q),B1(P)
636        PRINTER IS 1
638        PRINT
639        Ta_red(P)=Tar
641 !!!!   PRINT P,"Ta_red=";PROUND(Ta_red(P),-2),"E_F1=";E_f1,"E_F2=";E_f2
642        PRINTER IS 1
643      ELSE!Arc_t for blue laser
644        IF E_f1=0 THEN !Take care of divide by zero
645          IF Qpsb=1 OR Qpsb=3 THEN
646            Tab=(Qsb)*90+90
647            GOTO 679
648          ELSE
649            Tab=(Qsb)*90
650            GOTO 679
651          END IF
652        END IF
653        Ra=E_f2/E_f1
654        !Determine Quadrant & Total_angle(P)_
655        IF ABS(Ra)>=60 THEN
656          IF SGN(Ra)=1 THEN
657            Ra=60
658          ELSE
659            Ra=-60
660          END IF
661        END IF
662        IF SGN(Ra)=1 THEN !Plus Ratio
663          IF SGN(E_f1)=1 THEN ! Deno plus
664            Qptb=1
665          ELSE
666            Qptb=3
667          END IF
668          Tab=(Qt(Qpsb,Qptb)+Qsb)*90+ATN(Ra)-900
669        ELSE
670          IF SGN(E_f1)=1 THEN
671            Qptb=4
672          ELSE
673            Qptb=2
674          END IF
675          Tab=(Qt(Qpsb,Qptb)+Qsb)*90+90+ATN(Ra)-900
676        END IF
677        Qsb=Qt(Qpsb,Qptb)+Qsb
678        IF P>1 THEN Qpsb=Qptb
679       !PRINTER IS 705
680        PRINT
682 !!!!   PRINT P,PROUND(Tab,-2),Qpsb,Qptb,B1(Q),B1(P)
683        PRINTER IS 1
685        Ta_bl(P)=Tab
686 !!!!   PRINT P,"Ta_bl=";PROUND(Ta_bl(P),-2),"E_F1=";E_f1,"E_F2=";E_f2
687      END IF!For red or blue
688      PRINTER IS 1
```

```
689   RAD
690   NEXT Xx
691   RAD
692   PRINT
693     !This completes the angle computation
694     !for the red and blue for this K1 interval P
695   P=P+1
696   PRINT P
698     !Test to increment Qq or not
699   IF P=0 THEN
700     Qq=0
701   ELSE
702     Rmdr=P MOD 199     !P starts at 0
703     IF Rmdr=0 THEN Qq=Qq+1
704   END IF
705   !Q>Ns-48, either red/blue will exit to Main
706   IF Q>=Ns-48 THEN RETURN
707   GOTO 372
708 Disp_out:!Graph data
709   DUMP DEVICE IS 705
710   PRINTER IS 705
711   PEN 2
712 !!PRINT CHR$(12);    !Clear alpha & form feed
713   DISP
714   GINIT              !Initialize
715   GRAPHICS ON        !Raster on
716   FOR Qqq=0 TO Qq !Graph index
717     FOR R=1 TO 2 !red=1, blue=2
718       PEN 2
719       WINDOW -7,50,-500,500 !Set window
720       AXES 10,100
721       LORG 6
722       FOR I=0 TO 50 STEP 10
723         MOVE I,0
724         LABEL Qqq*200+I
725       NEXT I
726      !
727       LORG 8
728       FOR I=-400 TO 400 STEP 100
729         MOVE 0,I
730         LABEL I
731       NEXT I
732      !
733       LORG 5
734       MOVE 25,475
735       PEN 6
736       LABEL "ANGLE AS A FUNCTION OF ENVELOP SAMPLES"
737       MOVE 18,425
738       IF R=1 THEN
739       PEN 2
740       LABEL "RED"
741       MOVE 18,-400
742       LABEL Name$
743       PEN 6
744       END IF
745       IF R=2 THEN LABEL "BLUE"
746       MOVE 18,-400
747       LABEL Name$
748       PEN 2
749       MOVE -4,0
750       LORG 6
```

```
751       LABEL "Samp"
752       LORG 5
753       MOVE 25,-475
754       LABEL Title$;"ENVELOP SAMPLE RATE, 3KHZ"
755       PEN 0
756       MOVE 0,0
757       PEN 2
758       FOR X=0 TO 50  !graph data
759         IF R=1 THEN
760           Tb=Ta_red(Qqq*200+X+4)-Ta_red(4)
761         ELSE
762           Tb=Ta_bl(Qqq*200+X+4)-Ta_bl(4)
763         END IF
764         DRAW X,Tb
765       NEXT X
766       PEN 0
767       MOVE 0,0
768       PEN 0
769       PAUSE
770       !DUMP GRAPHICS
771       !PRINT CHR$(12)
772       GCLEAR
773     NEXT R
774   NEXT Qqq
775   ALPHA ON
776   PRINTER IS 1
777   DISP "PAUSE"
778   PAUSE
779   RETURN
780 !:::::::::::::::::::::::::::::::::::::::::::::
781 Err_rout:  !Routines for error recovery
782 !____________________________________________
783   BEEP
784   BEEP
785   BEEP
786   DISP ERRM$
787   PAUSE
788   GOSUB Disp_out
789   PAUSE
790 !:::::::::::::::::::::::::::::::::::::::::::::
791 Buffer_array:!Transfer of data from buffer to          array.
792 !____________________________________________
793      PRINT CHR$(12)
794      DISP "TRANSFERRING DATA FROM BUFFER TO 4 ARRAYS"
795    CONTROL @Buffer,5;1
796    FOR X=1 TO Ns-1
797      ENTER @Buffer USING "#.B";Zzz
798      Br(X-1)=Zzz-128
799      ENTER @Buffer USING "#.B";Zzz
800      Bl(X-1)=Zzz-128
801      ENTER @Buffer USING "#,B";Zzz
902      B1(X-1)=Zzz-128
803      ENTER @Buffer USING "#,B";Zzz
804      B2(X-1)=Zzz-128
805           !PRINT X-1,Br(X-1),Bl(X-1),B1(X-1),B2(X-1)
806    NEXT X
807    DISP "TRANSFER COMPLETE"
808    WAIT 2
809    PRINT CHR$(12)
810   RETURN
911 !:::::::::::::::::::::::::::::::::::::::::::::
```

```
812 File_data: !Transfer of data from Buffer
               !to disk
814 !__________________________________________
815  BEEP
816  DISP "INSERT A FORMATTED DATA DISK! - PRESS CONT TO CONT"
817  PAUSE
818  INPUT "NAME OF DATA FILE TO BE CREATED?",Name$
819  IF Name$="" THEN 818
820  BEEP
821  DISP "CREATING A DATA FILE"
822    !Record length is 1
823  CREATE BDAT Name$&":INTERNAL",Num_samples,1
824    !Assign an I/O path
825  ASSIGN @File TO Name$&":INTERNAL"
826  PRINT CHR$(12)
827  DISP "TRANSFERRING DATA FROM BUFFER TO FILE"
828  TRANSFER @Buffer TO @File;COUNT Num_samples
829  WAIT 5
830  DISP "TRANSFER COMPLETE"
831  WAIT 5
832  DISP
833  RETURN
834 !::::::::::::::::::::::::::::::::::::::::::::
835 File_array:  !Transfer from file to array
836 !__________________________________________
837    BEEP
838    PRINT CHR$(12)
839    DISP "INSERT DATA DISK -- PRESS CONT TO CONT"
840    PAUSE
841    CAT
842    BEEP
843    INPUT "WHAT FILE?",Name$
844    INPUT "Rec/File for file?",Num_samples
845    GOSUB 240
846    ASSIGN @File TO Name$&":INTERNAL"
847      !Reset file pointer to 1
848    CONTROL @File,5;1
849      !Reset buffer pointer to 1
850    CONTROL @Buffer,5;1
851    DISP "TRANSFERRING FROM DATA FILE TO BUFFER ARRAY"
852    TRANSFER @File TO @Buffer;COUNT Num_samples
853    DISP "TRANSFER COMPLETED"
854      !Reset buffer pointer to 1
855    CONTROL @Buffer,5;1
856      !Close @file
857    ASSIGN @File TO *
858    WAIT 2
859    PRINT CHR$(12)
860    DISP
861  RETURN
862 !::::::::::::::::::::::::::::::::::::::::::::
863 A_to_d_reset:  !
864 !__________________________________________
865    !RESET DATA TRANSFER ELECTRONICS
866    CONTROL Gpio,2;2 !SET CTLO & CTL1 TO 0
867    CONTROL Gpio,2;0 !SET CTLO TO 1 & CTL1 TO 0
868    CONTROL Gpio,2;2 !SET CTLO & CTL1 TO 1
869    !END RESET
870    RETURN
876 !::::::::::::::::::::::::::::::::::::::::::::
1180 Test_data:! Generate test data
```

```
1181 !--------------------------------------------------------------
1183     !PRINTER IS 705
1184   PRINT CHR$(12)
1185   DISP
1187   BEEP
1188   INPUT "What is the Envelop Peak Amplitude?",Epa
1189   BEEP
1190   DISP "                              GENERATING DATA"
1191   Peak_value_data=0
1192   Gal_cyc_frg=200
1193   Ab=0
1194   ALLOCATE INTEGER Mmm(0:Ns*4-1)
1195   FOR X=0 TO Ns*4-1 STEP 4
1196     Ac=Epa*SIN((PI*(+Ab))/(6*Gal_cyc_frg)+2.7*SIN(2*PI*Ab*Gf/Sf))
1199     FOR Y=X TO X+3
1200       Mmm(Y)=INT(Ac)+128
1201           !PRINT Y,Mmm(Y)
1202       OUTPUT @Buffer USING "#,B":Mmm(Y)
1203     NEXT Y
1204     Ab=Ab+1
1205   NEXT X
1208   DISP
1209   RETURN
1216   END
```

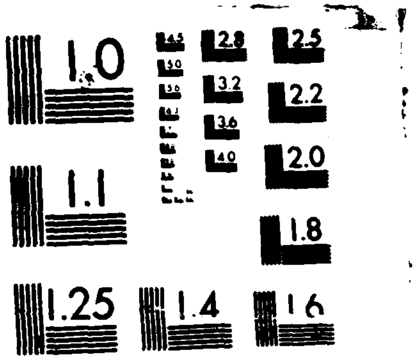
```
           Cross Reference   <<<<<

 *   Numeric Variables

[illegible]_reset
Aa                     315    316    321    329    330    335
At                     285    288    294   1193   1196   1204
A[illegible]           288    290   1196   1200
A[illegible]           527    530    549    552
B[illegible]           242    802
B[illegible]_peak
[illegible]
B[illegible]           242    804
B[illegible]_peak
[illegible]
B[illegible]           316    321    330    335
Bb[illegible]
Bbt
Bbtl
B[illegible]           241    404    467    800
Bp                     528    530    532    550    552    554
Br                     241    396    459    798
Buffer_array
Bw_label
C                      392    396    404    422    455    459    467    482
Check_stat
Check_stat_r
Comp_angle
Con_f2
Cp                     529    530    532    551    552    554
Csbf1
Csbf2
Csrf1
Csrf2
D1                     520    522    526    528    542    544    548    550
D2                     519    522    526    541    544    546
Diff_f1                431    432    433    435    436
Diff_f2                493    494    495    497    498
Diff_minus_f1          429    435    436    443    446
Diff_minus_f2          490    497    498    502    505
Diff_plus_f1           428    432    433    443    444
Diff_plus_f2           489    494    495    502    503
Disp_con
Disp_data
Disp_data_1
Disp_data_2
Disp_out
Dma_transfer
Dpcb
Dpcr
Ds                     550
Dsq                    526    528    529    548    551
E                      430    431    441    492    493    500    518    519    5
                       527    532    540    541    542    547    549    554
E_f1                   584    596    605    618    625    644    653    663    6
E_f2                   585    605    653
Ee                     532    537    538    554    559    560
Endcat
Envelop_f1             444    446    517    584
Envelop_f11            530
Envelop_f2             503    505    517    585
```

AD-A179 742   LASER BALLISTIC SENSOR DEVELOPMENT(U) BOEING AEROSPACE   2/2
CO SEATTLE WA C R POND ET AL JAN 87 BRL-CR-563
DAAK11-84-C-0095

UNCLASSIFIED   F/G 9/3   NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

```
Envelop_f22          552
Epa                  280   288  1188  1196
Err_rout
F1                   306 <-DEF   312   321   396   404
F2                   306 <-DEF   326   335   459   467
Fb                   267   268   316   330
File_array
File_data
Filt_bw_int
Filt_f1              275   411   418   419   431   519   520   527
Filt_f11b
Filt_f11r
Filt_f1b
Filt_f1r
Filt_f2              275   474   478   479   493   541   542   549
Filt_f22b
Filt_f22r
Filt_f2b
Filt_f2r
Gal_cyc_frg          284   288  1192  1196
Gf                   127   288   316   330  1196
Gpio                 119   252   253   255   259   260   866   867   868
Hpib                 120
I                    722   723   724   725   728   729   730   731
If1                  271   275   314   315   392   396   404   430   431   518
                     537   538
If2                  273   275   328   329   455   459   467   492   493   540
                     559   560
J                    384   411   418   419   421   452   474   478   479   481
K1                   128   245   275   360   388   431   570   580
K2                   129   454
K3                   130
Kk
M                    395   396   401   403   404   409   458   459   464   466
                     467   472
Max_x_axes
Mmm                  286   290   292  1194  1200  1202
Mn
Mult_fun
N                    268   314   315   328   329   360   395   403   458   466
Nnn
Ns                   240   241   242   243   706   796  1194  1195
Num_samp
Num_samples          239   240   245   248   258   286   287   823   828   844
                     852
Op
P                    314   315   321   323   328   329   335   337   354   565
                     566   575   576   633   639   678   685   695   696   699
                     702
Peak_value_data      283  1191
Peak_value_f1        385   418   419
Peak_value_f11b
Peak_value_f11r
Peak_value_f1b
Peak_value_f1r
Peak_value_f2        453   478   479
Peak_value_f22b
Peak_value_f22r
Peak_value_f2b
Peak_value_f2r
Product_f1           396   397   404   405
```

```
Product_f2              459   460   467   468
Q                       375   377   388   454   706
Qb                      371   377   580
Qc                      536   537   538   558   559   560   563   566   570   573
                        576   580
Qccb                    243   576
Qccr                    243   566
Qi
Qpsb                    645   668   675   677   678
Qpsr                    597   623   630   632   633
Qptb                    664   666   668   671   673   675   677   678
Qptr                    619   621   623   626   628   630   632   633
Qq                      365   700   703   716
Qqq                     716   724   760   762   774
Qr                      370   375   570
Qsb                     190   646   649   668   675   677
Qsr                     189   598   601   623   630   632
Qt                      180 <-DEF   181   182   183   184   185   186   187   188
                        623   630   632   668   675   677
Quotient                360   361
R                       717   738   745   759   773
Ra                      605   610   611   612   614   617   623   630   653   655
                        656   657   659   662   668   675
Range_stored
Rmdr                    702   703
Rob                     573   575
Ror                     563   565
Rot                     245
Rotb                    243   575
Rotr                    243   565
S
Sf                      126   268   288  1196
Ssp
Start                   361   364   370   371
Sum_f1                  393   397   405   411
Sum_f2                  456   460   468   474
Sys_del_bl              134   371
Sys_del_red             131   370
Ta_bl                   245   685   762
Ta_red                  245   639   760
Tab                     646   649   668   675   685
Tar                     598   601   623   630   639
Tb                      760   762   764
Test_data
Tic_m_x
Tot_angle_peak          353
Tt
X                       287   289   295   388   395   396   403   404   423   454
                        458   459   466   467   483   758   760   762   764   765
                        796   798   800   802   804   806  1195  1199  1205
Xx                      372   374   394   457   562   595   690
Y                       289   290   292   293  1199  1200  1202  1203
Z
Zzz                     797   798   799   800   801   802   803   804

+   String Variables
Aa$                     213   214   224
Name$                   742   747   818   819   823   825   843   846
Title$                  754

+   I/O Path Names
```

```
@Buf
@Buffer                248   251   258   292   795   797   799   801   803   828
                       850   852   855  1202
@File                  825   828   846   848   852   857
@Gpio                  191   258

*   Line Labels
A_to_d_reset           198   863 <-DEF
Arc_t                  588 <-DEF
Buffer_array           220   226   791 <-DEF
Bw_label
Check_stat
Check_stat_r
Comments                11 <-DEF
Comp_angle             204   345 <-DEF
Con_f1                 380 <-DEF
Con_f2                 449 <-DEF
Constants              123 <-DEF
Disp_con
Disp_data
Disp_data_1
Disp_data_2
Disp_out               117   207   708 <-DEF   788
Dma_transfer           250 <-DEF
Doppler_cor            511 <-DEF
Env_f1                 425 <-DEF
Env_f2                 485 <-DEF
Err_rout               113   781 <-DEF
File_array             225   835 <-DEF
File_data              219   812 <-DEF
Filt_bw_int            221   227   265 <-DEF
Index                   81 <-DEF
Initialize             109 <-DEF
Main                   195 <-DEF
Mult_fun               201   301 <-DEF
Num_samp               215   235 <-DEF
Range_stored           199   210 <-DEF
Test                   277 <-DEF
Test_data              217  1180 <-DEF
Var_list               139 <-DEF

*   Line Numbers
     1                 208
     4
     5
     9
    11
    13
    17
    24
   157
   174
   180
   188
   194
   196
   202
   213                 233
   214
   220
   221
```

```
   226
   240                 845
   245
   249
   363
   372                 707
   390
   524
   526                 523
   540
   546
   548                 545
   562
   571
   576
   600
   626
   634                 599   602
   635
   648
   679                 647   650
   686
   691
   716
   729
   736
   763
   816
   818                 819
   820
   827
   830
   858
   884
   895
   902
   907
   911
   951
  1254
  1274

*   SUB Subprograms
Endcat

Unused entries =     3
```

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