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EQUIPMENT DEVELOPMENT FOR AUTOMATIC ANTHROPOMETRIC MEASUREMENTS

by
J. P. Cater
W. E. Oakey

FINAL REPORT
for
Contract NAS 9-15038
SwRI Project 16-4630

Prepared for
NASA Lyndon B. Johnson Space Center
Houston, Texas 77058

31 March 1978

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Approved:

for Douglas N. Travers
Vice President
Electromagnetics Division

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I. INTRODUCTION

A. Purpose of the Program*

The purpose of the program was to design, construct, and test experimentally a microcomputer-controlled video-based single angle, one-plane body segment anthropometric measurement system.

B. Anthropometric Measurement

1. Conventional Anthropometric Measure Methods

The efficiency, comfort, and physical well being of the astronaut is strongly influenced by the extend to which the astronaut's body fits its surroundings. The study of this interface between man and his surroundings in relation to body dimensions and movements is a combined science of biomechanics and anthropometrics.

Quantative measurements in these sciences have, in the past, been rather primitive because of the difficulty of taking data on an unencumbered man. While static measurements such as body size, arm reach envelope, and leg reach envelope could be made using simple calipers and tape measures, no simple method existed for dynamic measurements with limb motion. In fact, to our knowledge no automated video anthropometric system had been successfully demonstrated prior to the development described herein.

Although the data from static measurements can certainly assist in design efforts for situations where people remain stationary (such as chairs), the data does not accurately describe the dynamic operational limitations of the subject. This difference is further amplified by a zero gravity environment where the neutral body posture changes and chairs are no longer useful.

Measurement of anthropometric data has in the past been performed manually by rather inefficient means. Typically, a subject is seated in a chair and required to traverse a body segment, such as an arm, incrementally through a very slow arc while a second person measures each position with a standard tape measure. The distance from each position to

* The original scope of the program was to review ergometer data from previous programs in an effort to obtain functional anthropometric information. This effort was terminated at NASA's option by Contract Amendment No. 5S, dated 15 November 1977, which changed the scope to that described herein.

a reference plane is then calculated and from the set of total movement data an angle of body segment freedom is determined. Not only is this static method of measurement subject to interpretation error, the subject under measurement must endure uncomfortable and often lengthy body positions, thus influencing accuracy of the data collection.

2. The Video Anthropometric Method

An automated procedure for measuring and recording the anthropometric active angles defined above was conceived by Dr. William Thronton, JSC, and designed and developed by SwRI under the subject contract. The small portable system delivered under this contract consists of a microprocessor controlled video data acquisition system which measures single plane active angles using television video techniques and provides the measured data on sponsor-specified preformatted data sheets. This system, using only a single video camera, observes the end limits of the movement of a pair of separated lamps and calculates the vector angle between the extreme positions.

A system sketch of the automatic single angle anthropometric measuring system with a typical test configuration is shown in Figure 1. The components shown which include the video camera, video processor, and electronic teletypewriter comprise the measuring system. The two small incandescent lamps which are affixed to the test subject using either a tape or strap mechanism obtain their power from the video processor to enable synchronization with the processor point-vector measurement technique.

To prepare a subject for the single angle data collection, two small lamps with attached flexible wires are affixed to the subject's lower arm at points A and B, elbow joint and wrist joint, respectively. The video camera viewing the subject's arm provides the microprocessor with a sequentially scanned "picture" of the lights on the test lamp. The viewed scene is divided into an approximate 256 x 256 grid as determined by the 256-line vertical line scan of the camera and a synchronized oscillator running at a frequency of 256 times the line scanning frequency of 15,750 Hz.

As the test subject moves his arm on command from the test operator, the video camera scans the lamp positions at the extreme arm movement positions and then calculates the interposing angle. The measured angle is then automatically printed out in a preformatted data sheet by the microprocessor controller on the teletypewriter operator console.

An example of the data sheet format is shown in Figure 2. The real time measured data is printed as the data is taken. The remaining text is stored in system memory and can be easily changed for other data sheet formats.

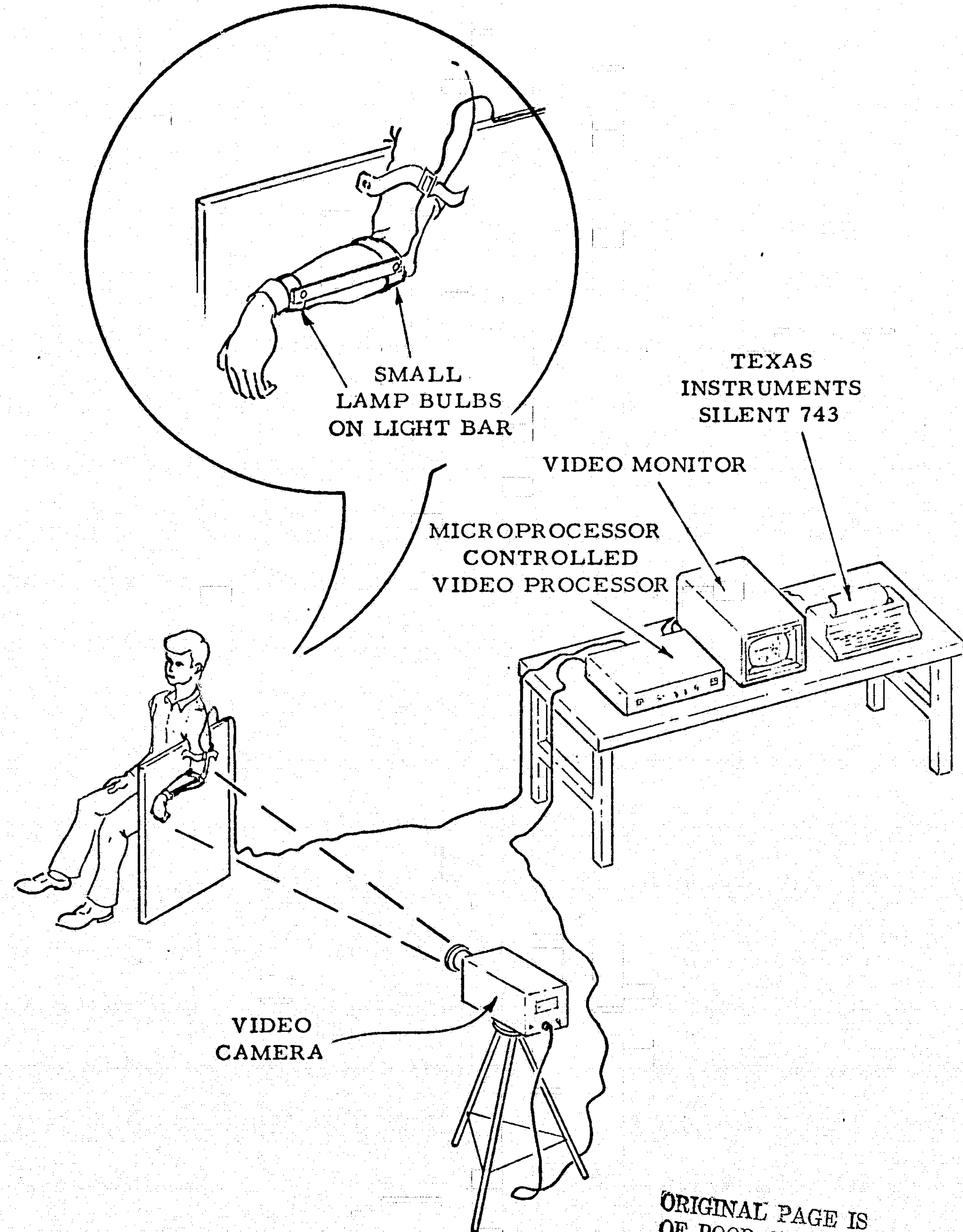

FIGURE 1

AUTOMATIC SINGLE ANGLE
ONE PLANE VIDEO MEASUREMENT SYSTEM CONFIGURATION

MUSCULOSKELETAL EXAMINATION
ANTHROPOMETRIC TEST DATA SHEET, ACTIVE ANGLES

NAME: S.S.N.:

1. NECK, HEAD		ROTATION:	R:	DEG			L:	DEG
		FLEXION:		DEG		EXTENSION:		DEG
		LATERAL FLEXION:	R:	DEG			L:	DEG
2. SHOULDER		ADDUCTION	R:	DEG		ABDUCTION	R:	DEG
		ADDUCTION	L:	DEG		ABDUCTION	L:	DEG
ROTATION:		INT.	R:	DEG		EXT.	R:	DEG
	(DOWN)	INT.	L:	DEG	(UP)	EXT.	L:	DEG
FLEX/EXT:		FLEX.	R:	DEG		EXT.	R:	DEG
	(FORWARD)	FLEX.	L:	DEG	(BACK)	EXT.	L:	DEG
3. ELBOW		FLEX.	R:	DEG		EXT.	R:	DEG
		FLEX.	L:	DEG		EXT.	L:	DEG
4. FOREARM		PRON.	R:	DEG		SUP.	R:	DEG
		PRON.	L:	DEG		SUP.	L:	DEG
5. WRIST DEVIATIONS								
		ULNAR	R:	DEG		RADIAL	R:	DEG
		ULNAR	L:	DEG		RADIAL	L:	DEG
		FLEX.	R:	DEG		EXT.	R:	DEG
	(DOWN)	FLEX.	L:	DEG	(UP)	EXT.	L:	DEG
6. HIP		FLEX.	R:	DEG		EXT.	R:	DEG
		FLEX.	L:	DEG		EXT.	L:	DEG
		ABDUCTION	R:	DEG		ABDUCTION	L:	DEG
7. KNEE		FLEX.	R:	DEG		EXT.	R:	DEG
		FLEX.	L:	DEG		EXT.	L:	DEG
8. ANKLE		PLANTAR	R:	DEG		DORSI.	R:	DEG
	(DOWN)	PLANTAR	L:	DEG	(UP)	DORSI.	L:	DEG

FIGURE 2. SAMPLE DATA SHEET

II. PROGRAM TASKS

A. Microprocessor and Controller for Digital Video System

The video anthropometric system incorporates a high speed stored program microprocessor to provide the flexibility and intelligence required by the video measurement calculations. The first major task of the subject program was to design and test the microprocessor control and computation functions required for the anthropometric measurements. The MOS Technology 6502 microprocessor employed in the NASA video anthropometric system was designed and integrated into the system to provide four primary functions during system operation:

(1) The microprocessor controls the illumination and timing of the subject lamps, thus ensuring synchronism with the measured video data. While alternating illumination between the reference and end-point lamps on the subject a total of eight times, the microprocessor assures the correct data by requiring a majority of the measured points to be within prespecified tolerance limits. Any data taken during a measurement cycle that falls outside of the tolerance limit is discarded and the remaining data tested for majority logic.

In the event that a majority position count is not obtained for a specific position, the entire data set is rejected and the operator is notified of incorrect data by an aural beep.

(2) A second function of the microprocessor controller is measuring the angle (with respect to horizontal) of the pair of lamps attached to the subject's limb. By alternating the illumination of the lamps on either end of the subject's limb, the angle of the lamp-to-lamp center line is measured with respect to horizontal and stored in a temporary memory location for a later calculation.

(3) The third microprocessor function is to measure the extreme angle of movement of the subject's limb and calculate the horizontally referenced angle as obtained in Part (2). The two horizontally referenced angles are then summed to obtain a total body segment angle.

(4) The fourth major function of the system microprocessor is to print on a pre-formatted data sheet the measured angle along with subject identification information. This allows the system operator to produce a number of complete single angle anthropometric data sheets without the need for complicated data logging and recording methods. The final data sheet format was shown previously in Figure 2.

B. System Design and Fabrication

The second major task in the program was the fabricating and packaging of the operating anthropometric test system in a transportable laboratory demonstration model. The completed single angle anthropometric measuring system is shown in Figure 3 to illustrate the major components of the integrated test system.

The four pieces of equipment shown in the figure are a Silent 700 series teletypewriter for data input and output, a standard closed circuit video camera for anthropometric data acquisition, a 5-inch television monitor for subject and test set alignment, and the video link angle computer containing the microprocessor circuitry and video interface system.

C. System Calibration and Test

The third major program task was to provide calibration data on the video system accuracy and to provide sample single angle lower arm measurement data on five randomly selected subjects using the operable transportable system. Both the calibration data and the sample data on the five subjects are shown in Section V. A and B of this report.

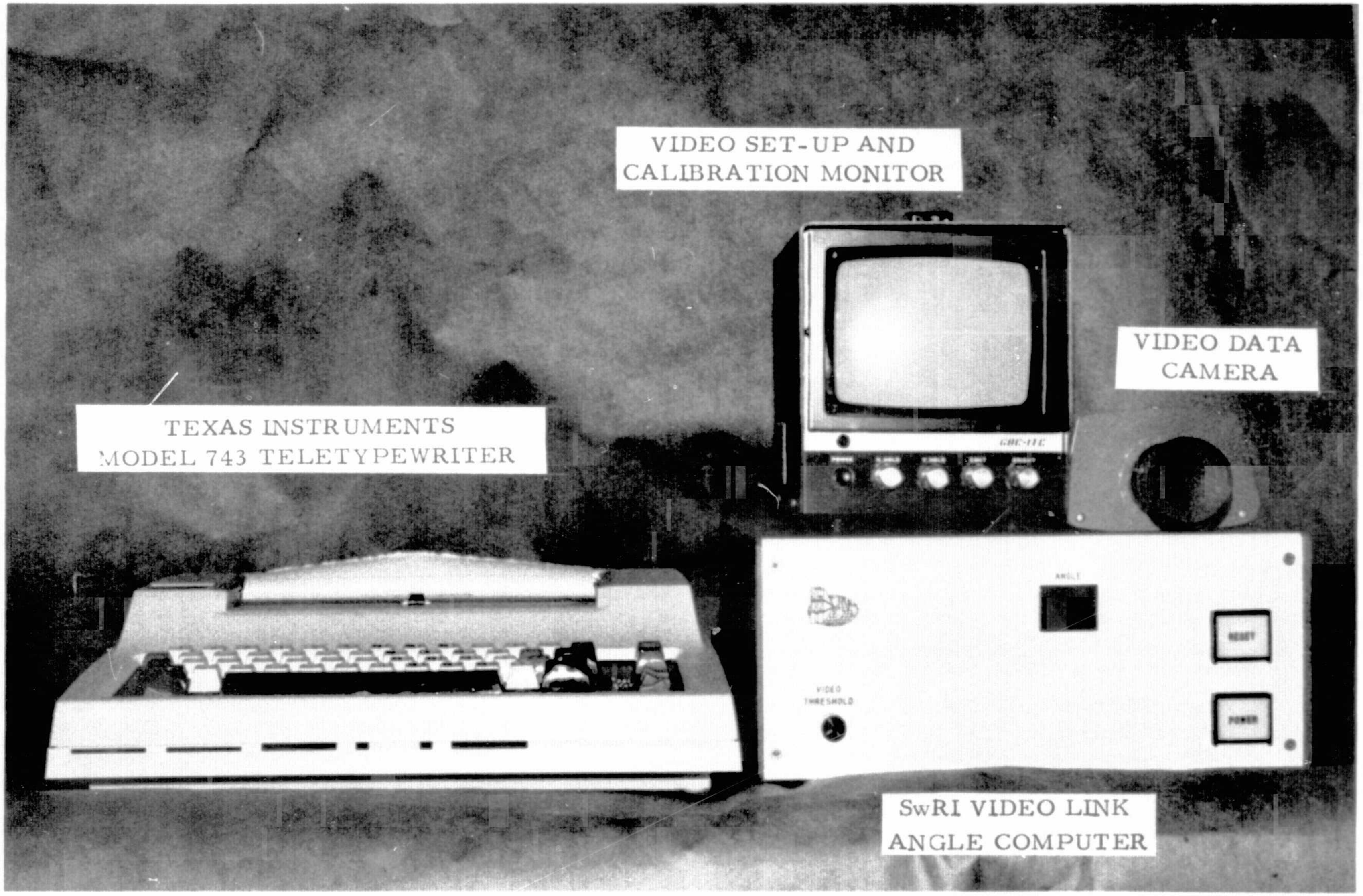

FIGURE 3. SwRI VIDEO ANTHROPOMETRIC MEASURING SYSTEM

III. TECHNICAL DISCUSSION

A. General Theory of Video Anthropometric Measurements

The concept of a video based point source illumination tracker has been designed and demonstrated by SwRI to NASA in 23 September 1976.* The principle of operation of the system is based on the ability of a video camera to sequentially scan a test subject to which small bright lights are attached and provide a temporal referenced signal which is directly proportional to the positions of the light sources in the X-Y viewing plane. Previous testing of this concept at SwRI indicates that sufficient contrast exists using small low-powered incandescent lamps in a normally lighted test chamber to provide usable data, thereby eliminating the need for a darkened or specially designed anthropometric test chamber. The use of this visual follower technique also allows the collection of anthropometric data in such environments as closed-in areas and underwater test and ergometer facilities.

An illustration of a single angle lower arm measurement problem encountered under this program is presented in Figure 4. To prepare a subject for the single angle data collection, two subminiature lamps with attached flexible wires were affixed to the subject's lower arm at points A and B, elbow joint and wrist joint, respectively. The video camera viewing the subject's arm provided the microprocessor a sequentially scanned "picture" of the lights on the test lamp. The viewed scene was divided into an approximate 256 x 256 grid as determined by the 256-line vertical line scan of the camera and a synchronized oscillator running at a frequency of 256 times the line scanning frequency of 15,750 Hz.

Under these conditions, the points A and B in Figure 4 were viewed by the video camera in a sequential manner by first illuminating the lamp at the reference point A and determining the matrix coordinates for this point (X = 128, Y = 128). The illuminator at point B1 was then energized and the light at point A extinguished, allowing measurement of the location coordinates of point B1 in a similar manner (wrist coordinates of X = 114, Y = 100). This alternating sequence was then continued for seven additional lamp pair illuminations and the resultant coordinate points were analyzed for a majority within pre-determined limits to minimize angular measurement error.

* The video position detection circuits described in this report were initially developed in-house by SwRI in 1976 and demonstrated to NASA representatives in 23 September 1976.

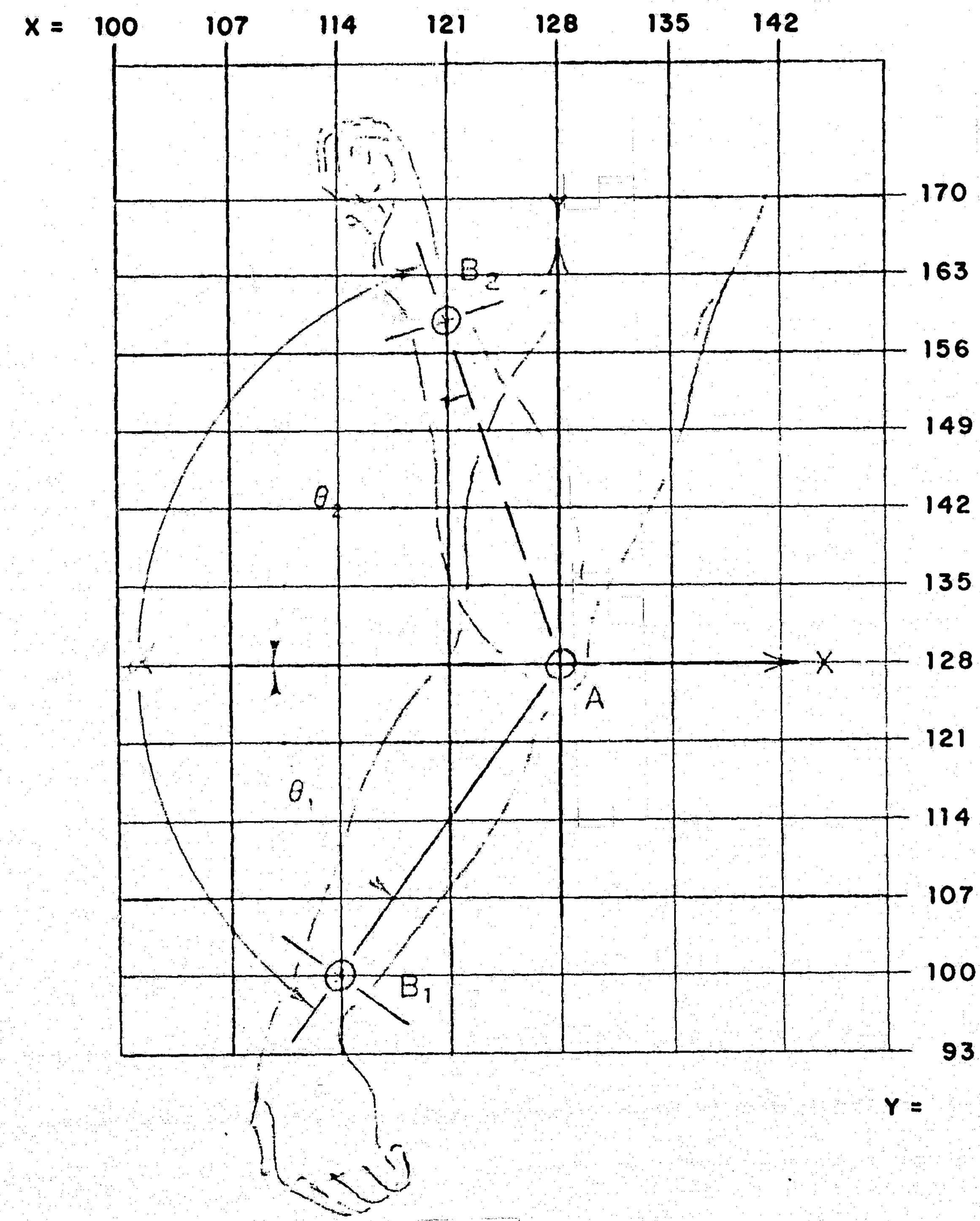

FIGURE 4

REPRESENTATION OF VIDEO X-Y COORDINATE GRID

After the grid coordinates of the two lamps at the elbow and the wrist had been measured and a majority of coordinates confirmed, the microprocessor subtracted the valid coordinates point B1 from point A and performed the division of $\Delta Y / \Delta X$, yielding the slope of the body segment with respect to the horizontal axis (S = 28 / 14 = 2). An arc tangent calculation was then performed on this slope to yield a true body segment angle in relation to the horizontal video camera plane (θ_1 = ATAN (2) = 63.4°).

The test subject then moved his lower arm to the opposite extreme of free travel and the test operator activated the data retrieval key on the input terminal to start the second phase of the data collection cycle.

Points A and B2 were sequentially activated again for eight cycles as previously described to obtain a new set of majority reference and relative extreme movement coordinates. Once these were obtained, the microprocessor computed the slope of the imaginary line connecting the extreme angle light sources together as well as the arc tangent of this slope, producing a horizontally referenced body limb extreme angle. The data collected allowed the microprocessor to calculate the total body segment arc by subtracting the lesser of the two angles from the greater angle and then normalizing this angle to less than or equal to 180°. The result of this calculation, as shown in the following equations, eliminated the effects of the reference point (A) movement in the X-Y plane and the effect of camera tilt by providing a horizontally referenced angle for each extreme of lower arm movement:

$$\theta_1 = \text{ATN} \frac{A(Y) - B_1(Y)}{A(X) - B_1(X)}$$

$$\theta_2 = \text{ATN} \frac{A(Y) - B_2(Y)}{A(X) - B_2(X)}$$

$$\alpha = \theta_1 + \theta_2$$

$$\alpha = \text{ATN} \frac{A(Y) - B_1(Y)}{A(X) - B_1(X)} + \text{ATN} \frac{A(Y) - B_2(Y)}{A(X) - B_2(X)}$$

The limitation of the measurement technique currently employed is that the active angles which are measured by the automated link angle computer must lie in a plane perpendicular to the camera lens. Departures from the prealigned measurement plane will produce errors proportional to the amount of movement of the subject's body segment in the Z plane (viewed as depth from the camera's point of view). The effect of the Z plane movement is a variable which is dependent on the distance from the test subject to the camera lens, and additionally on the offset distance of the test illumination lamp from the exact center of the X-Y viewing plane. The problem to be described is best understood by examining the graphical representation of a typical test configuration shown in Figure 5. If the upper arm of the test subject is assumed to be fixed in place using a strap mechanism, then point A should be assumed to be fixed in space with point B moveable in the X, Y, and Z planes. The X and Y movements are the desired planes of movement while the Z plane movements are undesired and will be minimized. If the test subject inadvertently moves his wrist (point B_1) away from the test fixture board to point P_1 during data collection, as shown in Figure 5, the error introduced by this movement is an elliptical function with the minor axis radius being proportional to the distance of point B in the Y direction from the exact center of the scanning field. This effect, which is produced by parallax from the camera lens, is the equivalent to the projection of a line from the center of the camera lens through point P_1 of the subject's wrist on to the perpendicular test fixture board. For the types of body measurements described herein, the error introduced by this Z plane movement will be essentially negligible if movements away from the test plane can be restricted to approximately one inch total travel over the full body segment length angle.

B. Electronic System Implementation

1. Video Interface Module

The circuitry which was used to interface the video camera to the digital microprocessor was tested in breadboard form to verify the video interface design. A block diagram of the video-to-digital interface is shown in Figure 6. The purpose of this interface is to generate an EIA standard video sync signal to control the camera scanning synchronization and provide the various control signals for the X and Y coordinate counters.

The standard horizontal scanning frequency for television signals is 15,750 Hz which provides a period per line of 63.5 μsec. The horizontal sync/blanking interval is approximately 10 μsec in length leaving 53 μsec of available data acquisition time per horizontal scan line. In order to obtain a resolution of 256 elements per scan line, the counter must be driven by an oscillator running at a frequency of approximately 4.9 MHz.

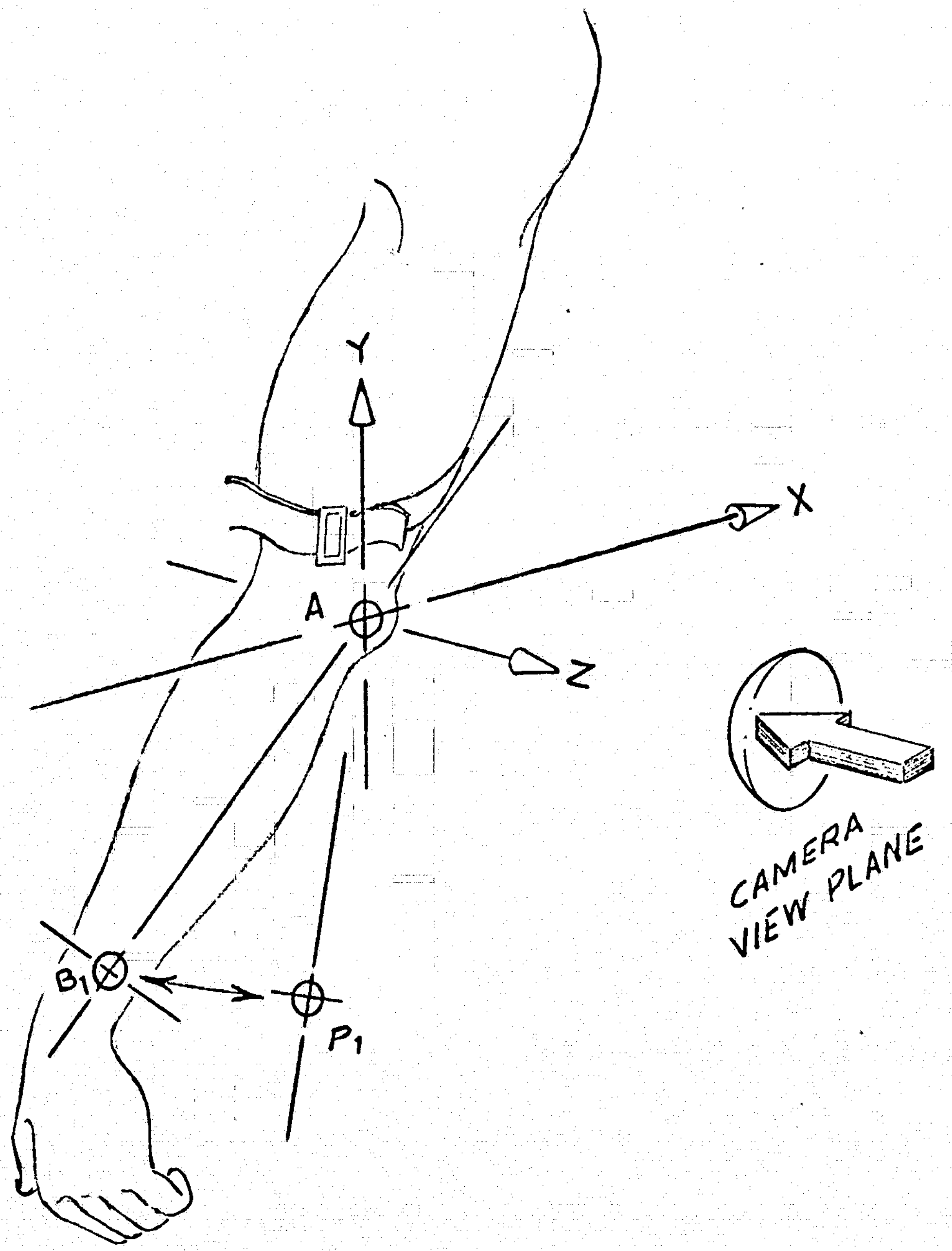

FIGURE 5

GRAPHICAL ILLUSTRATION OF PARALLAX ERROR

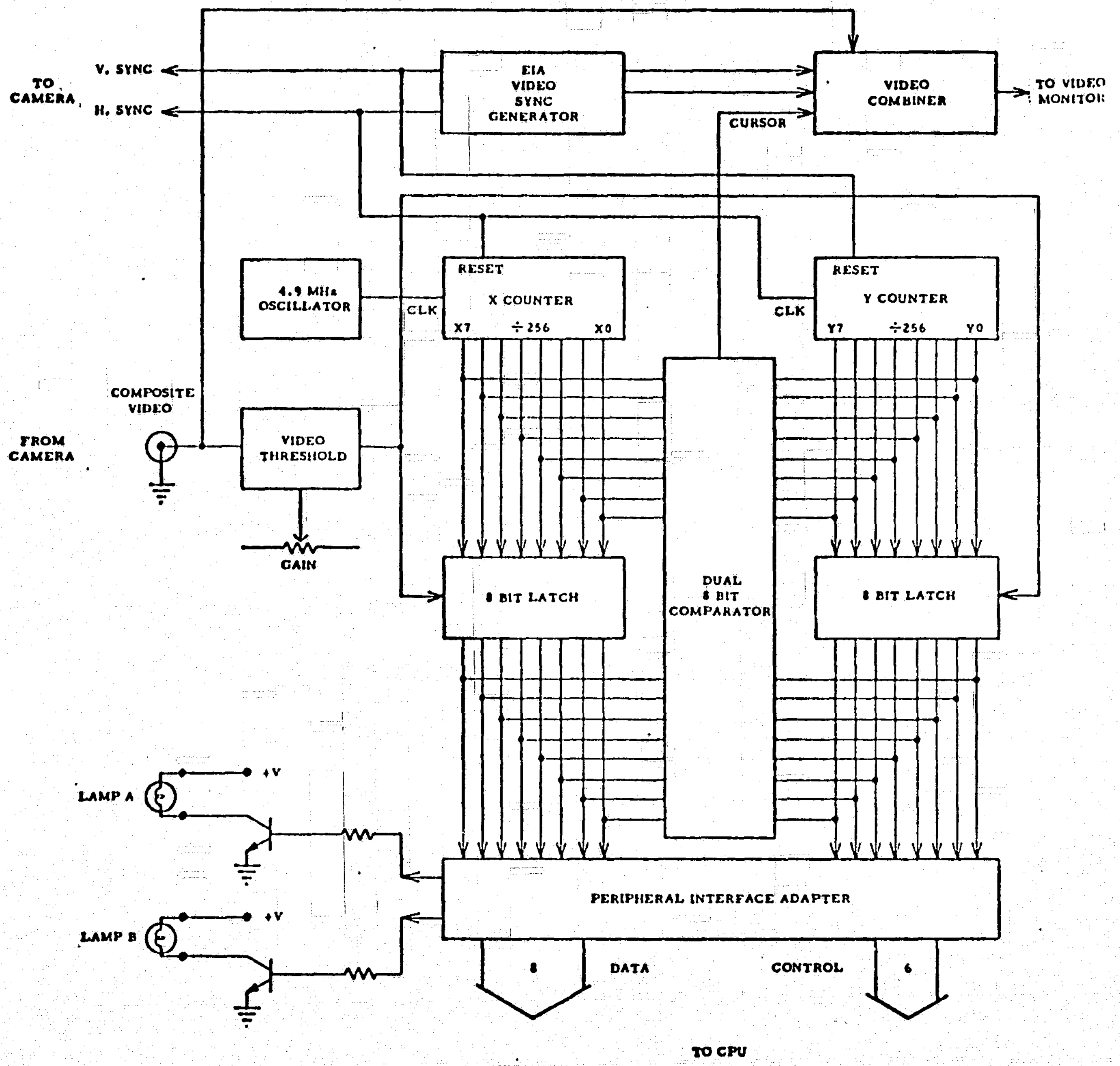

FIGURE 6

VIDEO TO DIGITAL INTERFACE BLOCK DIAGRAM

When the video signal crosses the preset adjustable threshold, the count that exists within the X and Y counter is latched into the associated 8-bit data latches. This provides a 16-bit X-Y coordinate pair for each illumination point. The 16-bit latched coordinate pair is in turn compared with the real time sequential count coming from the X and Y counters to produce a crosshair-type cursor which may be projected on the monitor television for verification of proper video tracking. The effect of this cursor during real time measurements is a double set of crosshairs superimposed over the test subject with the origins of each set of crosshairs coincident with the illuminating subminiature lamps.

The peripheral interface adapter shown in Figure 6 is the microcomputer bus interface device, an integrated circuit of the MOS Technology 6502 microcomputer family. There are 16 bi-directional input/output ports available for use on this integrated circuit and four additional signal lines for hand shaking. Two of these signal lines are used to control the lamp illumination on the test subject's arm, providing synchronization for the computing cycle, the remaining 16 lines are used to input the X and Y coordinates to the microprocessor controller.

Figure 7 shows one of the two main component boards in the video anthropometric system computer. This wire wrapped board contains the video interface electronics, video combiner, and drive circuitry, and the teletypewriter interface electronics.

Also contained on the video interface module board are the video calibration and set up trimpots, and the cassette interface adjustment controls. In summary, the video interface module board contains all of the processor-to-external interfaces, including the latches and decoder drivers for the front panel LED angle display.

2. CPU Module

Once the digital coordinates of the reference point lamps have been produced by the video-to-digital interface, the microcomputer is used to calculate the vector coordinates of each angular line segment and the arc tangent of that line segment slope. The microprocessor controller also provides synchronization for the point illumination lamps which are affixed to the test subject.

A third function of the microprocessor controller is the automatic preformatted data sheet printout. By storing a preformatted data sheet similar to that shown in Figure 2 of Section I, the system allows the test operator to enter variable data such as names and social security numbers related to test subjects and then prints in assigned spaces the

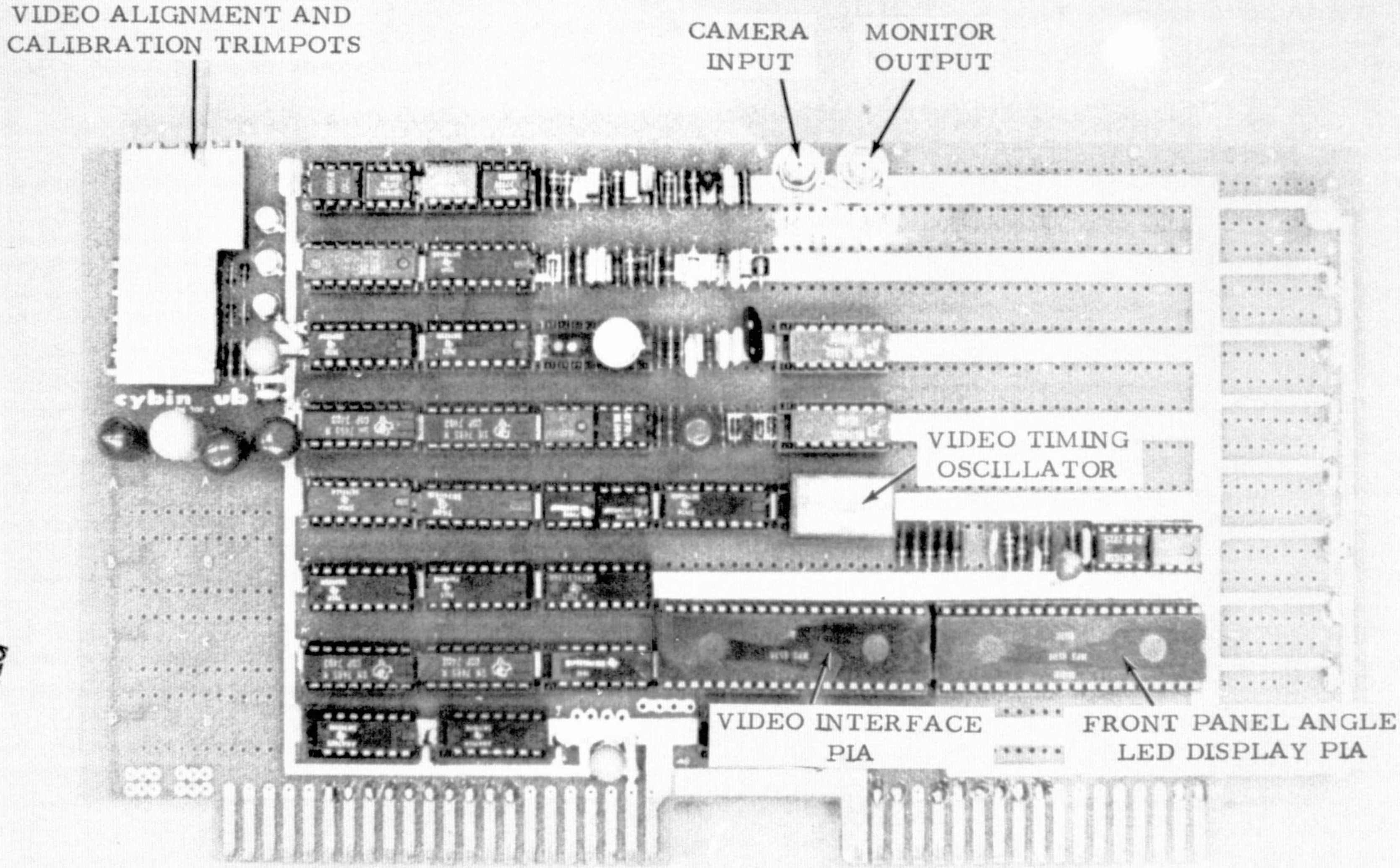

FIGURE 7. VIDEO INTERFACE MODULE

measured angles for the test subject. Spacing is also provided by the microprocessor interface timing to print a row of hyphens for each 11 inches of rolled paper output, thus providing a cut line for the individual data sheets.

A block diagram of the microprocessor controller is shown in Figure 8. The 6502 microprocessor system used in the development includes 3072 8-bit bytes of random access (RAM) and 5K bytes of read only memory (ROM). Program storage for both the data sheet printout format and the video controlling and calculating sequence are stored in programmable ROM providing a power on firmware capability for the anthropometric measurement operating system.

The CPU module is shown in Figure 9 to illustrate the placement components and circuitry associated with the central processing unit and the video link angle computer. This wire wrapped board contains 3K (3,072) 8-bit bytes of RAM and provision for 10K bytes of ultraviolet erasable programmable read only memory (EPROM) integrated circuits. Implementation of the data sheets, instruction sheet, and operating system required only 50% of the available ROM space, leaving approximately 5,000 bytes of system expansion memory.

The remaining integrated circuits and components on the central processing module are the central processing unit (MCS 6502A), the teletype monitor and timer integrated circuit (MCS6530-004), and the associated bus buffering and address decoding circuitry.

The multiposition rotary switch mounted on the upper left corner of the circuit board allows for diagnostic resetting capability of the power on restart vectors to other than the video link angle computer operating system. Rotation of this switch to positions other than the supplied position will provide access directly to the terminal interface monitor (TIM) program, giving teletype access to direct memory search and modify commands. This feature is useful primarily in system development and debugging and should be used only by experienced 6502 microprocessor programmers.

3. Peripheral Components

In addition to the SwRI video link angle computer, three other peripheral equipments are required for automatic single angle anthropometric measurements:

(1) A closed-circuit television camera.

(2) A five-inch video monitor television.

(3) The operator input/output device such as a Silent 700 teletypewriter model 743.

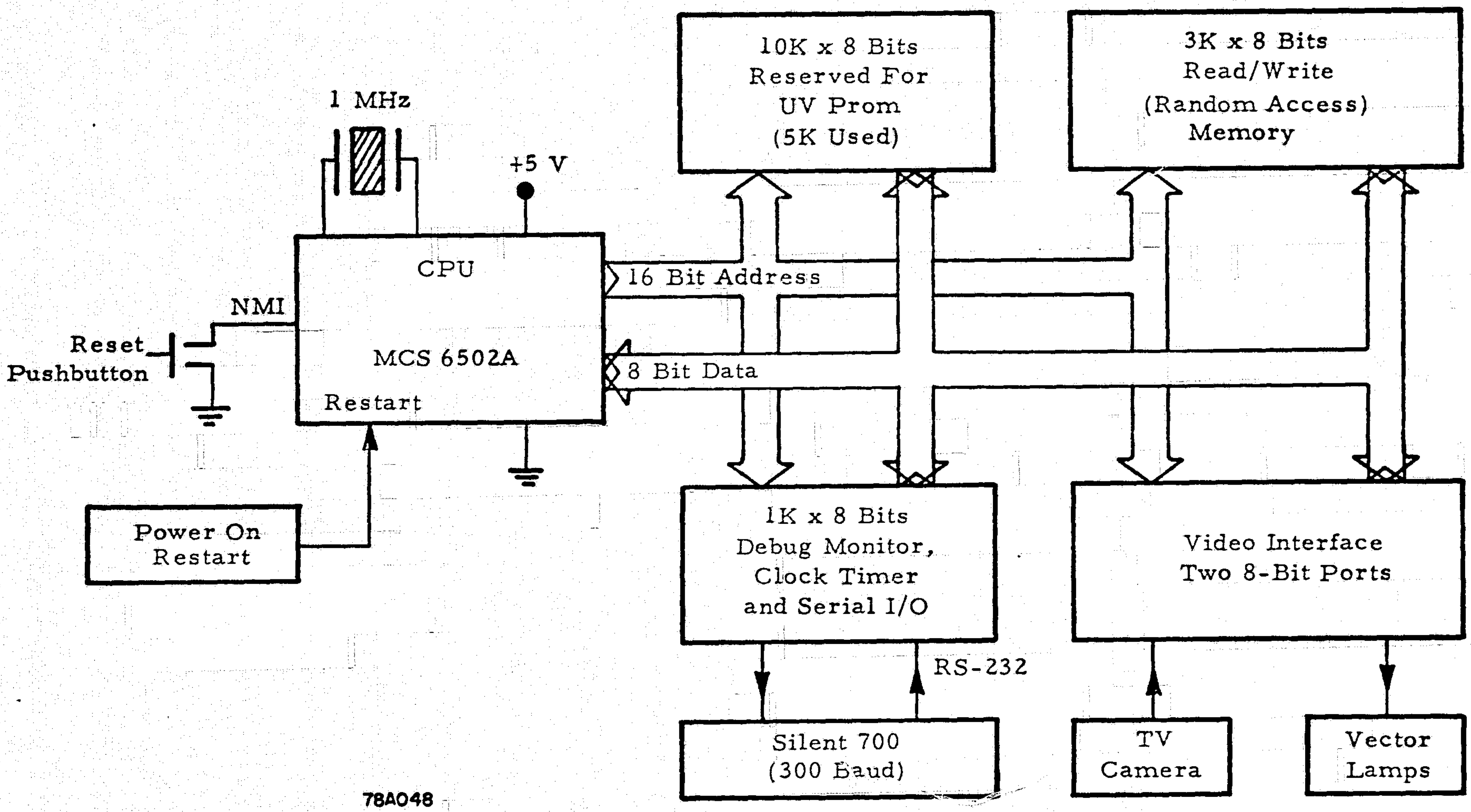

FIGURE 8. PROCESSOR BLOCK DIAGRAM

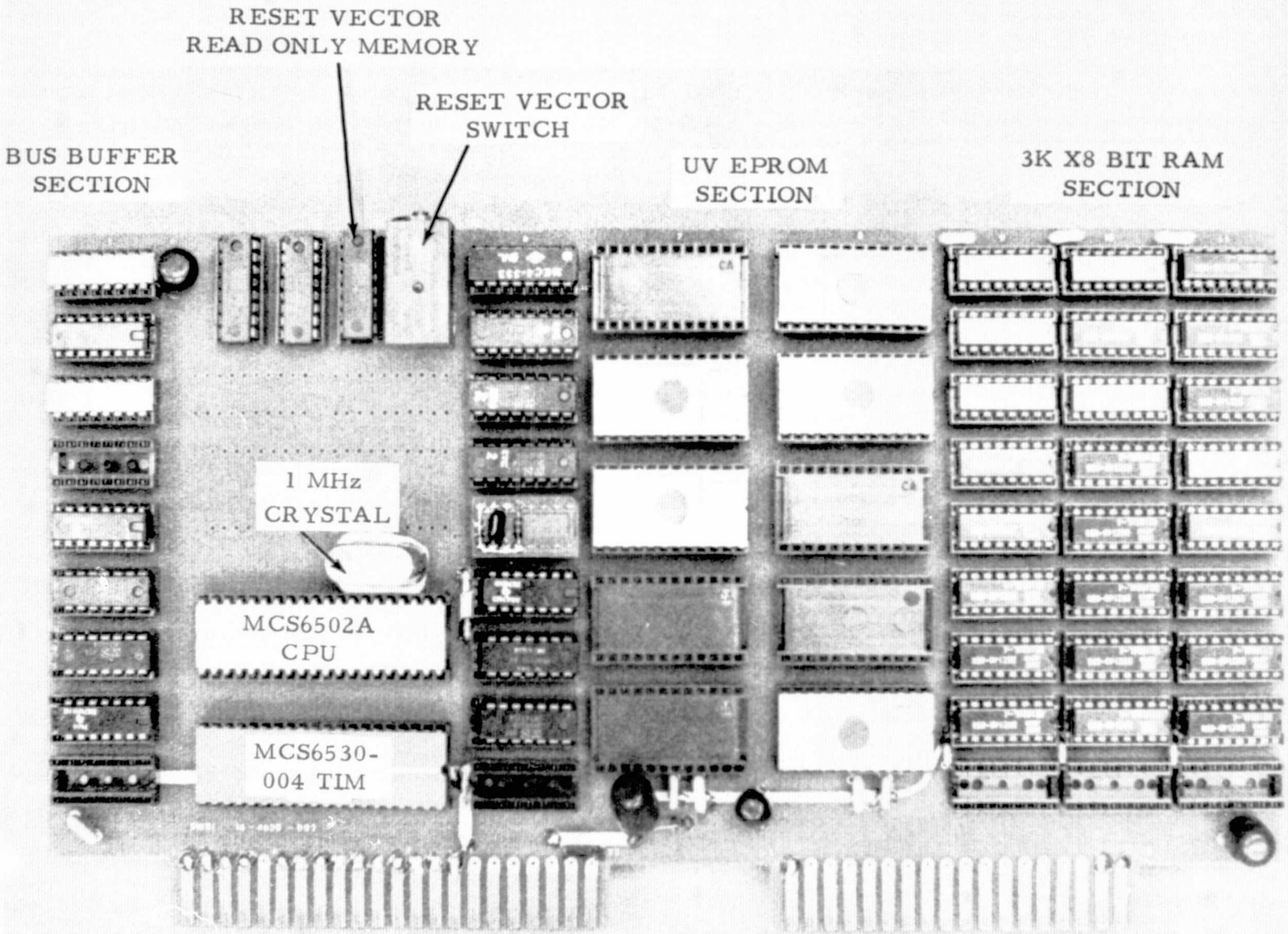

FIGURE 9. CENTRAL PROCESSING UNIT MODULE

The video camera is used to input visual link angle data from the illuminating lamps on the test subject to the video link angle computer. The camera supplied with the system is a standard RCA video camera model TC-1000. Because it is unmodified for use with the video link angle system, any standard EIA output television camera may be used with this system. The RCA camera does, however, provide adequate resolution and linearity for use with the automatic anthropometric data system. Additionally, it has been fitted with a variable iris 12 mm wide angle television closed-circuit lens to allow close-in data acquisition. The lens may be substituted with other standard angle and telephoto lenses if needed to change the camera depth of view and field of focus.

The second peripheral equipment is the five-inch GBC television monitor used for operator feedback to insure proper setting of video threshold adjustment and proper camera-to-subject optical alignment. The video monitor output from the video link angle computer is a standard EIA television interface signal and may be used with any size monitor desired. The output impedance at the video monitor connector for the video link angle computer is 75 ohms and external monitors should be adjusted to this impedance value when used with the SwRI system.

The third required ancillary equipment is the operator I/O device which is required to be a serial 300 baud RS-232 interface teletypewriter. While the teletypewriter used with the development system was the Texas Instrument Model 743 (Silent 700 version) any other standard teletypewriter with the above capabilities (such as the Teletype Model KSR-43) may be used with the existing video link angle computer system.

Since the model 743 teletypewriter used with the development system was obtained on a short-term leased basis, it was not supplied with the system.

4. Test Fixtures and Switchbox

Six test fixtures were supplied with the video anthropometric measurement system to facilitate rapid link switching during tests. The small switchbox shown in Figure 10 is used to manually select the proper fixture. The remaining test fixtures and cables are shown in Figure 11 and 12.

Each test fixture has the required pair of lamps attached, and is wired to plug into either the switchbox or the video link angle computer lamp plug. Care should be taken when using the test fixtures because the subminiature lamp envelopes and filaments are very delicate and can be easily broken in a fall to a hard floor.

FIGURE 10. ANTHROPOMETRIC TEST FIXTURE SWITCHBOX

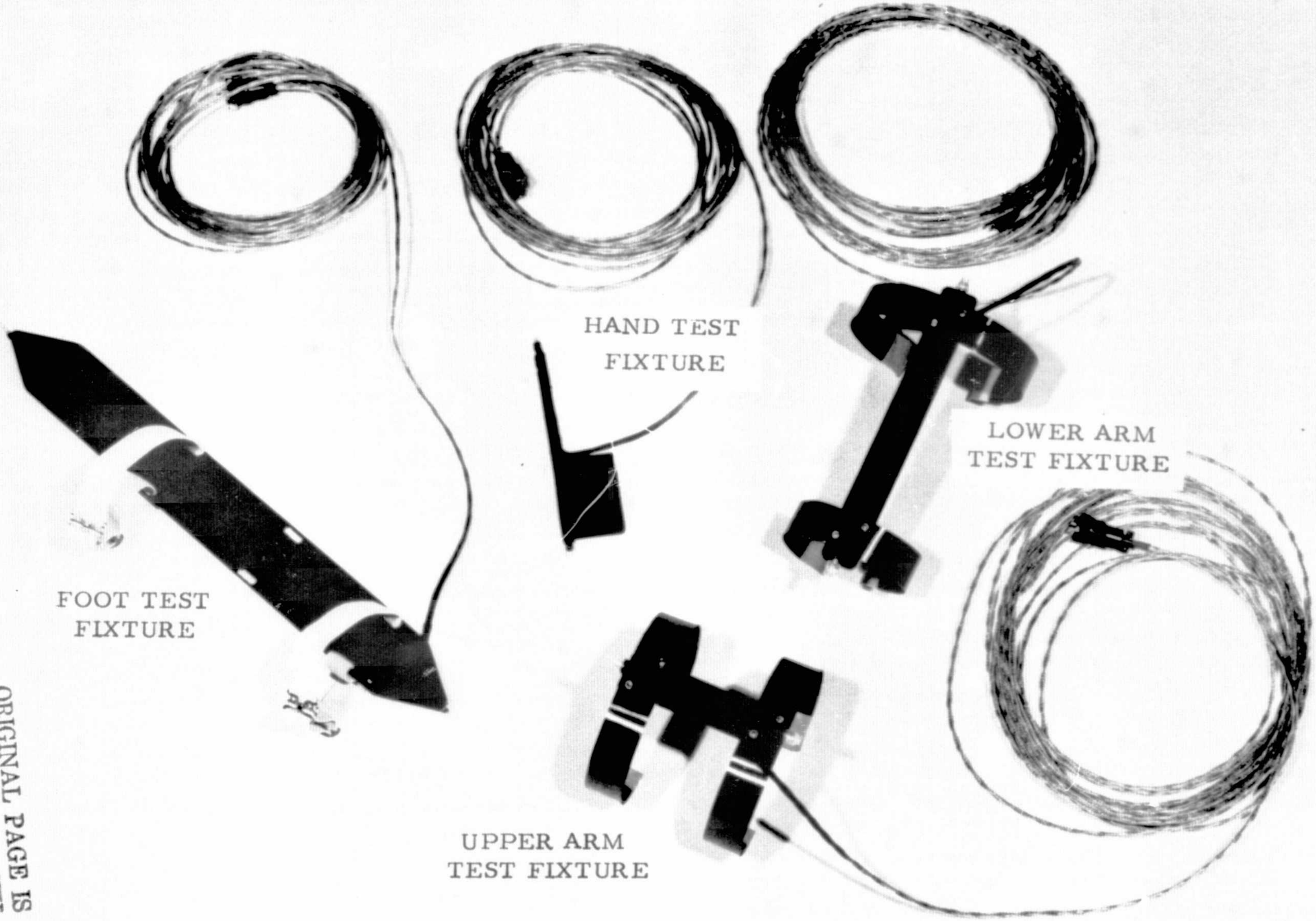

FIGURE 11. AUXILLARY ANTHROPOMETRIC TEST FIXTURES

FIGURE 12. ANTHROPOMETRIC TEST FIXTURE AND SWITCHBOX

C. Software Implementation

1. Flow Chart of Operation

The software which is resident within the video link angle computer consists of machine code programming for the MCS-6502 and requires approximately 5000 bytes of PROM. Any changes to the operating system may be made only through erasure and reprogramming of the ultraviolet EPROMs located on the main CPU board.

Figure 13 shows the flow chart of software operation which illustrates the manner in which the video link angle computer operates. At "Power-On" the computer awaits the depression of any teletypewriter key before starting to print the instruction sheet for the video data acquisition system. After the instruction sheet is completed, the data sheet for the anthropometric test subject begins and halts at the subject's name space for operator input. After the operator has completed the subject's name and typed the "Escape" key, the system moves to the social security number and awaits this entry (again followed by the "Escape" key to exit). After the above personnel data has been entered, the printing system moves to the first anthropometric test for head angles and awaits the operator command to acquire video data.

Normal operation dictates that the operator take first the reference vector by pressing the "R" key and waiting for the lamps to completely extinguish. The subject is then asked to move the link under observation to the extreme of movement (in the requested direction as specified on the data sheet) and the operator types the "E" key to command the end vector be calculated. At this point the system again awaits the operator command while displaying the calculated included angle on the front panel "Angle" display of the video link angle computer. If the angle appears to be in error the operator may elect to reacquire angle data. If the angle should be greater than 180° and is indicated less than the correct angle on the front panel ANGLE display, the operator may complement the angle by pressing the "C" key.

After the operator is satisfied that the angle displayed on the front panel of the video link angle computer is correct, he may then print the angle in the designated data space by typing the "P" key and waiting for the printout to stop at the next data point. If, at any time during system operation, the operator wishes to abort a data sheet or test subject data session, he may press the large button located on the front of the computer marked RESET which will immediately begin a new data sheet.

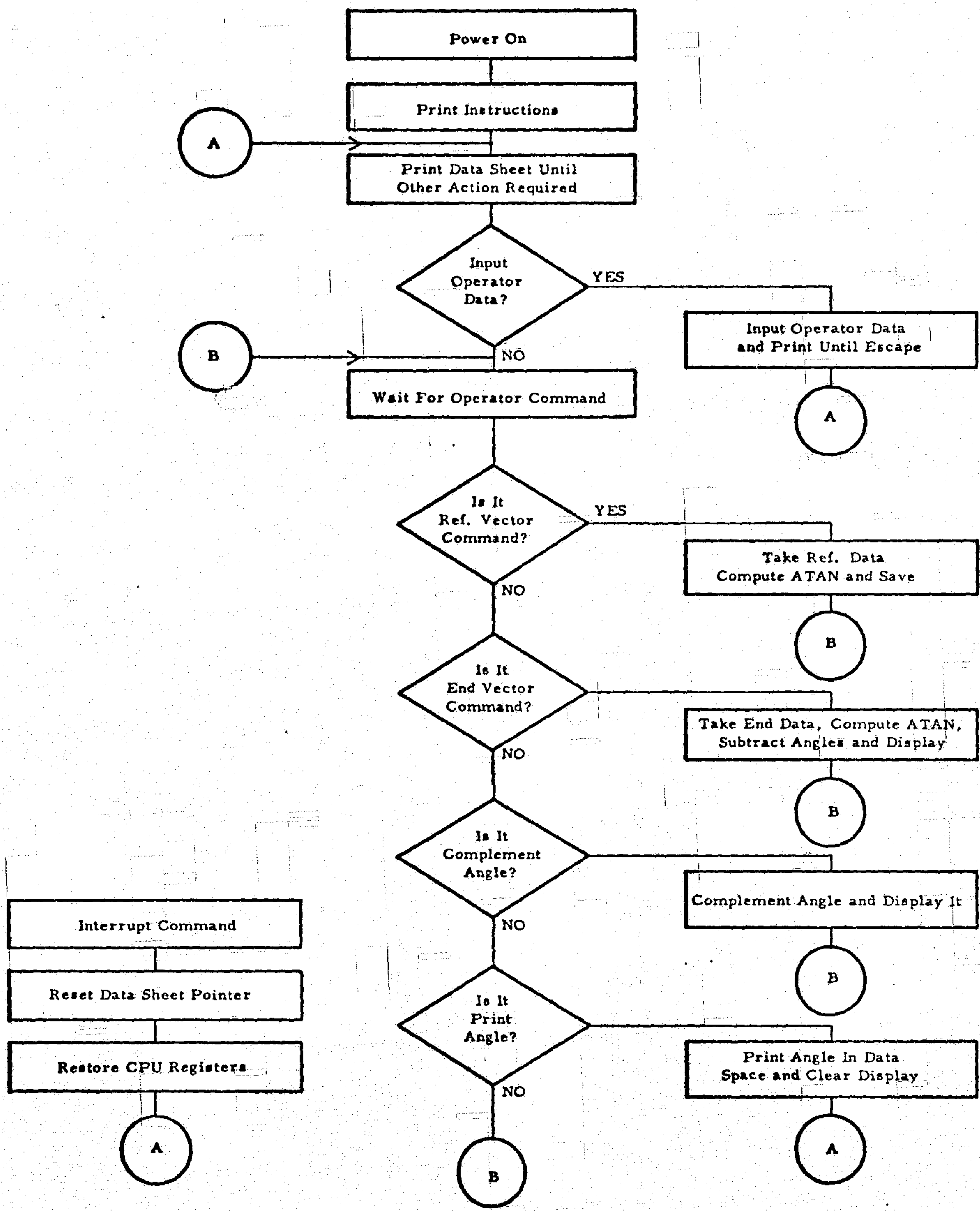

FIGURE 13. VIDEO LINK ANGLE COMPUTER SOFTWARE FLOWCHART

2. Software Design Philosophy

The 6502 video link angle computer operating software has been designed in modular form to allow ease of modification for future changes and system additions. This design philosophy was executed by the use of multiple subroutine calls from a main line program which is designed to control the major sequence of operation of the system. Not only does this type of design allow for ease of program modification at a later time, it also provides for multiple operator assistance in the initial programming of the operating software.

The data sheet formatted PROM is stored in the system as a separate memory group and is located in memory from 0C00 to 1000_H. The major program operation software begins at memory location 2800_H and extends through memory to $2C6F_H$. The machine code of the described software may be found in the operating system software listing in the Appendix.

IV. SYSTEM OPERATING PROCEDURES

The video link angle computer system is operated by first turning on the teletypewriter and then activating the POWER pushbutton on the front panel of the video link angle computer. In a similar manner the closed-circuit television camera and monitor should be turned on by switching their appropriate power switch to on. The teletypewriter should be set to full duplex, upper case, 300 baud operation.

The system is now ready to begin the printout of the instruction sheet which is obtained by depressing any key on the teletypewriter keyboard. A copy of the brief instruction sheet printed by the system is shown in Figure 14. At the end of the instruction sheet printout, the system will halt and await the depression of the "S" key to start data sheet printout. During the data sheet printout, the teletypewriter will halt several times awaiting operator input for the test subject's name and social security number. After the operator has entered each of these required pieces of data, he may exit to the operating system for continuation of the data sheet by depression of the "Escape" key on the teletypewriter keyboard. After the name and social security number has been entered by the operator, the computer will proceed to type the heading for the first data point and stop at the first awaiting data space. The following procedures should be observed while taking data throughout the remainder of the data sheet:

(1) When the printout first stops at a new data space, the operator should position the test subject's link in the reference position and type "R". During the time the lamps are illuminated the test subject should remain stationary.

(2) After the lamps have extinguished, the test subject should move the link to the extreme angle position and the operator should type "E" for the extreme angle position data.

(3) If the typewriter emits a beep or bell after typing either of the above keys, the computer is indicating that excessive subject movement or ambient reflection has occurred during the data acquisition period. The operator should adjust the VIDEO THRESHOLD control for proper data acquisition by watching the crosshairs on the video monitor track the flashing lamps. The same measurement may be repeated until the proper conditions have been achieved and the ANGLE display on the front of the video link angle computer shows the proper computed interior angle of the link movement.

NASA VIDEO LINK ANGLE COMPUTER SYSTEM
BY SOUTHWEST RESEARCH INSTITUTE ; SAN ANTONIO, TX

INSTRUCTIONS:

1. DATA SHEET WILL AUTOMATICALLY PRINT OUT

2. TO END NAME AND S.S.N ENTRY, PRESS ESCAPE KEY ON KEYBOARD

3. WHEN VIDEO DATA INPUT IS REQUIRED, PRINTER WILL STOP

4. ALIGN LIGHT BAR WITH REFERENCE LINK POSITION AND TYPE "R". (DO NOT MOVE LIGHT BAR WHILE LIGHTS ARE ACTIVE)

5. MOVE LINK TO EXTREME ANGLE POSITION, ALIGN LIGHT BAR, AND TYPE "E".

6. IF BEEP OCCURS AFTER TYPING "R" OR "E", EITHER THE CAMERA IRIS OR VIDEO THRESHOLD CONTROL SHOULD BE ADJUSTED UNTIL THE VIDEO CROSSHAIRS FAITHFULLY TRACK THE LIGHTS. THEN REPEAT SAME MEASUREMENT.

7. WHEN MEASUREMENT IS COMPLETE, THE LINK ANGLE WILL APPEAR IN THE "ANGLE" WINDOW. TO PRINT THIS ANGLE IN THE AWAITING DATA SPACE, TYPE "P". IF DESIRED THE ANGLE MAY BE RECOMPUTED BE- FORE PRINTING BY REPEATING STEPS 4 AND 5.

8. TO ABORT CURRENT DATA SHEET AND START OVER, DEPRESS "RESET" BUTTON ON FRONT PANEL.

KEY REFERENCE:

ESCAPE= ENDS ENTRY OF NAME OR S.S.N.
R   = REFERENCE ANGLE POSITION
E   = EXTREME ANGLE POSITION
P   = PRINT ANGLE IN DATA SPACE

TEAR OFF THIS SHEET FOR REFERENCE, THEN TYPE "S" TO START DATA SHEET PRINTOUT

FIGURE 14. INSTRUCTION SHEET PRINTOUT

(4) When the link angle measurement is complete, the link angle will appear in the ANGLE window. To print this angle in the awaiting data space, the operator should type "P". If the angle does not appear to be consistant with that observed by the operator, he may repeat steps (1) and (2) above until the desired data is shown in the ANGLE window. The "P" key may then be depressed to print the correct angle.

(5) If the link angle taken is likely to be greater than 180°, such as in shoulder flexion and abduction, the angle displayed in the ANGLE display window may be the 360° complement of the true measured angle. The "C" key is provided for operator complementation of this angle for printout in the awaiting data space. By repeatedly depressing the complement key, the angle may be switched between the computed angle and its complement for the appropriate angle printout.

(6) The operator may, at any time during the operation of the video link angle computer, abort the current operation and begin a new data sheet by depression of the front panel reset pushbutton.

The use of each anthropometric test fixture supplied with the system is determined by the measurement being made. A total of six fixtures have been supplied with the system and are designed for such link angle measurements as head, arm, hand, and foot movement. The use of the test fixture switchbox in conjunction with the video link angle computer allows rapid operator switching between the various ancillary test fixtures.

Figure 15 shows an internal top view of the video link angle computer. Indicators point to the various fuseholders and input/output connectors. Since the lamp fuse is inside the cabinet, it gives no visible indication of being blown, except that the lamp fixtures do not light during a test cycle.

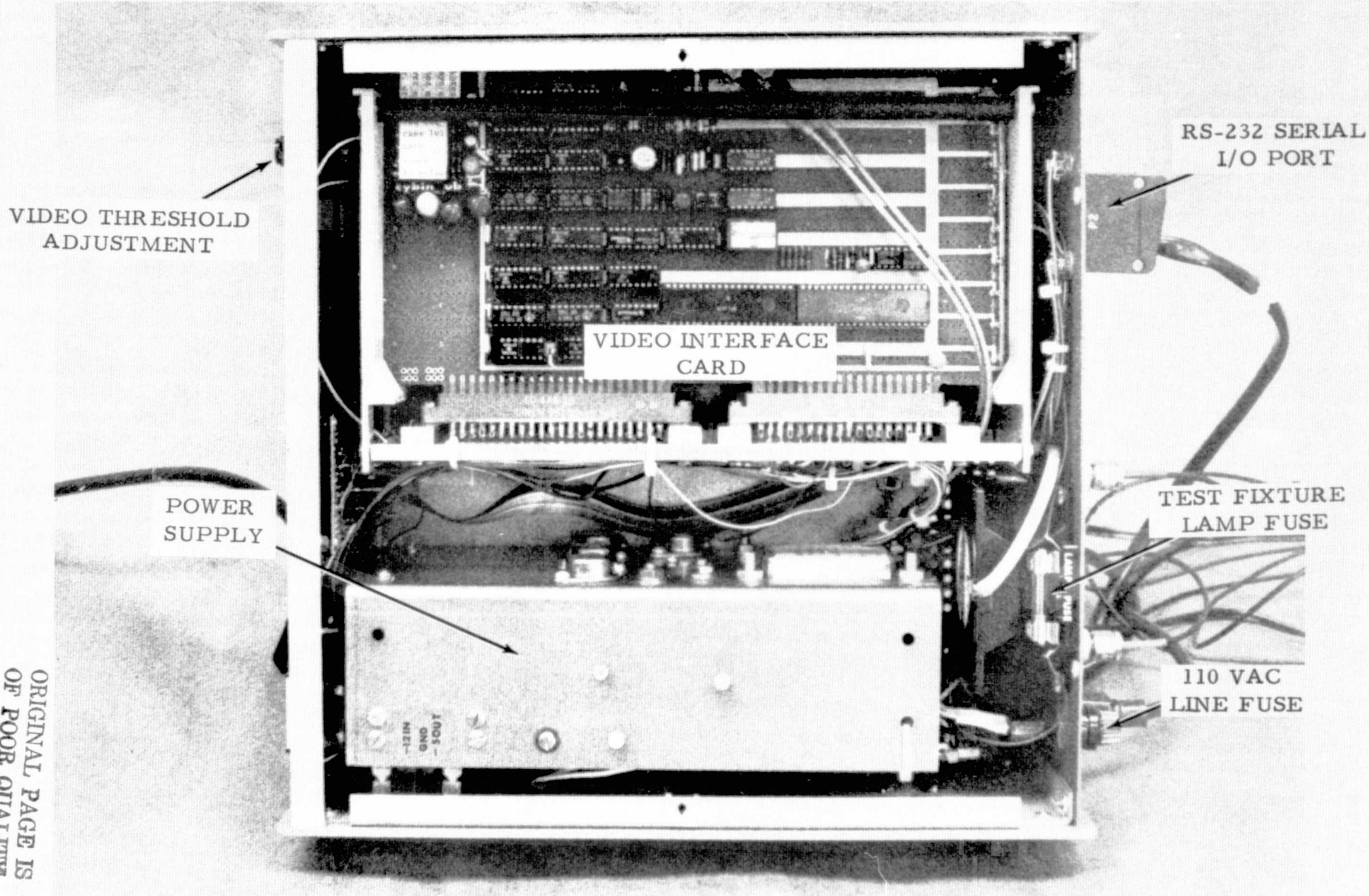

FIGURE 15. TOP VIEW OF VIDEO LINK ANGLE COMPUTER

V. SYSTEM TEST AND DEMONSTRATION

A. Subject Testing

The required testing for system demonstration involved lower arm link angle measurement for five subjects. The data taken during this performance testing is shown in Figure 16, indicating satisfactory system operation meeting all design goals.

The tests were made using a large plywood board against which the test subject placed his lower right arm. The subject was then requested to put his lower arm in the horizontal reference position for the initial reference angle measurement and then to move his lower arm to the extreme flexion angle at which point the data was automatically printed onto the data sheets.

B. Performance Testing

Additional tests were made with the system to determine absolute accuracy using the upper arm light bar test fixture attached to a Bruning drafting machine for angle reference calibration. The drafting machine was then rotated in 15° increments and the measured angle in the ANGLE window was recorded. Measurement errors found during the performance testing are shown in Table 1. Since the angle calculation mathematics of the system repeat for each 90° quadrant, errors appearing between 0° to ± 90° will be mirrored from ± 90° to 180°.

As anticipated, the total errors achieved during the testing did not exceed ± 4° at a distance of eight feet from the camera lens. Proportionally lower errors will occur with closer camera lens-to-subject spacing because of the increased video system resolution.

C. NASA On-Premises Demonstration

The completed anthropometric video link angle computer system was delivered to JSC, Houston and demonstrated to NASA as specified in the original statement of work. Attending the NASA demonstration were three representatives from NASA-JSC and two representatives from Southwest Research Institute. The demonstration consisted of a thorough explanation of the system operation and then acquisition of anthropometric data on several volunteer subjects to illustrate the simplicity of system operation.

MUSCULOSKELETAL EXAMINATION
ANTHROPOMETRIC TEST DATA SHEET, ACTIVE ANGLES

NAME: BILL OAKEY S.S.N.: [redacted]

1. NECK, HEAD	ROTATION:	R:	1	DEG		L:		DEG
	FLEXION:			DEG	EXTENSION:			DEG
	LATERAL FLEXION:	R:	1	DEG		L:	1	DEG
2. SHOULDER	ADDUCTION	R:	3	DEG	ABDUCTION	R:		DEG
	ADDUCTION	L:	2	DEG	ABDUCTION	L:	1	DEG
ROTATION:	INT.	R:		DEG	EXT.	R:	1	DEG
	(DOWN) INT.	L:	1	DEG	(UP) EXT.	L:		DEG
FLEX/EXT:	FLEX.	R:		DEG	EXT.	R:	1	DEG
	(FORWARD) FLEX.	L:	1	DEG	(BACK) EXT.	L:	1	DEG
3. ELBOW	FLEX.	R:	73	DEG	EXT.	R:	66	DEG
	FLEX.	L:	79	DEG	EXT.	L:	78	DEG
4. FOREARM	PRON.	R:						

MUSCULOSKELETAL EXAMINATION
ANTHROPOMETRIC TEST DATA SHEET, ACTIVE ANGLES

NAME: JOHN CATER S.S.N.: [redacted]

1. NECK, HEAD	ROTATION:	R:		DEG		L:	2	DEG
	FLEXION:		4	DEG	EXTENSION:		1	DEG
	LATERAL FLEXION:	R:	1	DEG		L:		DEG
2. SHOULDER	ADDUCTION	R:	1	DEG	ABDUCTION	R:		DEG
	ADDUCTION	L:	1	DEG	ABDUCTION	L:	1	DEG
ROTATION:	INT.	R:		DEG	EXT.	R:	1	DEG
	(DOWN) INT.	L:		DEG	(UP) EXT.	L:	1	DEG
FLEX/EXT:	FLEX.	R:	2	DEG	EXT.	R:	1	DEG
	(FORWARD) FLEX.	L:		DEG	(BACK) EXT.	L:	2	DEG
3. ELBOW	FLEX.	R:	47	DEG	EXT.	R:	74	DEG
	FLEX.	L:	55	DEG	EXT.	L:	81	DEG
4. FOREARM	PRON.	R:						

FIGURE 16. TEST SUBJECT EVALUATION DATA

MUSCULOSKELETAL EXAMINATION
ANTHROPOMETRIC TEST DATA SHEET, ACTIVE ANGLES

NAME: DAYLE WINNIE S.S.N.: [redacted]

1. NECK, HEAD	ROTATION:	R:	DEG		L:		DEG
	FLEXION:		DEG	EXTENSION:			DEG
	LATERAL FLEXION:	R:	DEG		L:	1	DEG
2. SHOULDER	ADDUCTION	R:	DEG	ABDUCTION	R:		DEG
	ADDUCTION	L:	DEG	ABDUCTION	L:		DEG
ROTATION:	INT.	R:	DEG	EXT.	R:		DEG
	(DOWN) INT.	L:	DEG	(UP) EXT.	L:		DEG
FLEX/EXT:	FLEX.	R:	1 DEG	EXT.	R:		DEG
	(FORWARD) FLEX.	L:	DEG	(BACK) EXT.	L:		DEG
3. ELBOW	FLEX.	R:	88 DEG	EXT.	R:	80	DEG
	FLEX.	L:	89 DEG	EXT.	L:	91	DEG
4. FOREARM	PRON.	R:					

MUSCULOSKELETAL EXAMINATION
ANTHROPOMETRIC TEST DATA SHEET, ACTIVE ANGLES

NAME: TIM MILLINGTON S.S.N.: [redacted]

1. NECK, HEAD	ROTATION:	R:	2 DEG		L:		DEG
	FLEXION:		1 DEG	EXTENSION:		2	DEG
	LATERAL FLEXION:	R:	2 DEG		L:	1	DEG
2. SHOULDER	ADDUCTION	R:	1 DEG	ABDUCTION	R:	1	DEG
	ADDUCTION	L:	1 DEG	ABDUCTION	L:	3	DEG
ROTATION:	INT.	R:	1 DEG	EXT.	R:		DEG
	(DOWN) INT.	L:	DEG	(UP) EXT.	L:	1	DEG
FLEX/EXT:	FLEX.	R:	DEG	EXT.	R:	1	DEG
	(FORWARD) FLEX.	L:	DEG	(BACK) EXT.	L:	1	DEG
3. ELBOW	FLEX.	R:	73 DEG	EXT.	R:	73	DEG
	FLEX.	L:	88 DEG	EXT.	L:	72	DEG
4. FOREARM	PRON.	R:					

FIGURE 16. TEST SUBJECT EVALUATION DATA (CON'T)

MUSCULOSKELETAL EXAMINATION
ANTHROPOMETRIC TEST DATA SHEET, ACTIVE ANGLES

NAME: DEAN DAVIS   S.S.N.: [redacted]

1. NECK, HEAD	ROTATION:	R:	1	DEG		L:	1	DEG
	FLEXION:		2	DEG	EXTENSION:		1	DEG
	LATERAL FLEXION:	R:	1	DEG		L:	1	DEG
2. SHOULDER	ADDUCTION	R:		DEG	ABDUCTION	R:	2	DEG
	ADDUCTION	L:		DEG	ABDUCTION	L:		DEG
ROTATION:	INT.	R:	1	DEG	EXT.	R:	1	DEG
	(DOWN) INT.	L:		DEG	(UP) EXT.	L:		DEG
FLEX/EXT:	FLEX.	R:		DEG	EXT.	R:	1	DEG
	(FORWARD) FLEX.	L:	1	DEG	(BACK) EXT.	L:		DEG
3. ELBOW	FLEX.	R:	84	DEG	EXT.	R:	55	DEG
	FLEX.	L:	79	DEG	EXT.	L:	52	DEG
4. FOREARM	PRON.	R:						

FIGURE 16. TEST SUBJECT EVALUATION DATA (CON'T)

TABLE 1

PERFORMANCE DATA

Angle Measured On Bruning	Angle Measured On VLAC	Error
0 Degrees	0 Degrees	0 Degrees
-15	16	+1
-30	28	+2
-45	43	+2
-60	58	+2
-75	74	+1
-90	88	+2
0	0	0
+15	19	+4
+30	32	+2
+45	48	+3
+60	63	+3
+75	76	+1
+90	92	+2

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The demonstration of an operable anthropometric data acquisition system using video collection techniques was successful beyond the original expectations of the program. The SwRI system was demonstrated with multiple link data acquisition errors of less than ± 4 degrees at subject distances of eight to ten feet. In view of the fact that the original demonstration was to encompass only link angle data on the lower arm of a test subject, the resultant system which incorporated link angle data on all major movable limbs on the body provided system capabilities in excess of those originally anticipated.

B. Recommendations

A further expansion of the original program consisted of the large memory capability of the video link angle computer for further programming and capability expansion. Since only approximately one-half of the available memory is being used in the existing system, provision for considerable system programming expansion exists. The expansion may be accomplished by removing the resident operating software which is stored in five read-only memories and replacing them with operating software compatible with future anticipated needs.

The expansion capabilities of the existing video link angle computer range from use as a small general purpose high level language computer to complex video data acquisition using the existing peripheral equipments. Development of expansion software can be accomplished at SwRI using the software development system upon which the video link angle computer is designed.

Future developments in the video anthropometric field should include the evolutionary trend toward three-dimensional video anthropometrics, thus eliminating the single-angle single-plane problem. The use of multiple video cameras surrounding a test subject can provide three-dimensional data on anthropometric movements for design of efficient work space and cockpit areas. In addition to improving the ease of data acquisition, a new system design should be capable of being flown in space with cameras mounted permanently around a test area for observation of three-dimensional anthropometric movements.

In addition to the measurement of positional data for the construction of sweep envelopes, consideration should be given to measuring forces and velocities of body links. A machine such as the CYBEX force generator, coupled to the test subject through a gimballed pulley mechanism, could provide the basic force data. This data, digitized in real time and stored on tape with the positional data, would allow direct correlation with derived velocity and acceleration information. The end result would be a system capable of generating complete sets of anthropometric information useful in the design of man-operated controls and equipment in both earth and zero-g environments.

APPENDIX

```
TIM
.R  2CD2 B9 BB B9 3B B9
.:  3206 00 00 00 00 FF
.G
INPUT START ADDRESS:2800
2800-    A2 08        LDX    #$08
2802-    A9 34        LDA    #$34
2804-    8D 01 80     STA    $8001
2807-    20 38 28     JSR    $2838
280A-    AD 00 80     LDA    $8000
280D-    9D FF 07     STA    $07FF,X
2810-    AD 02 80     LDA    $8002
2813-    9D 07 08     STA    $0807,X
2816-    A9 04        LDA    #$04
2818-    8D 01 80     STA    $8001
281B-    A9 34        LDA    #$34
281D-    8D 03 80     STA    $8003
2820-    20 38 28     JSR    $2838
2823-    AD 00 80     LDA    $8000
2826-    9D 0F 08     STA    $080F,X
2829-    AD 02 80     LDA    $8002
282C-    9D 17 08     STA    $0817,X
282F-    A9 04        LDA    #$04
2831-    8D 03 80     STA    $8003
2834-    CA           DEX
2835-    D0 CB        BNE    $2802
2837-    60           RTS
2838-    A9 60        LDA    #$60
283A-    8D 07 6E     STA    $6E07
283D-    AD 07 6E     LDA    $6E07
2840-    F0 FB        BEQ    $283D
2842-    60           RTS
2843-    A2 00        LDX    #$00
2845-    A0 00        LDY    #$00
2847-    86 AA        STX    $AA
2849-    8A           TXA
284A-    0A           ASL
284B-    0A           ASL
284C-    0A           ASL
284D-    AA           TAX
284E-    BD 00 08     LDA    $0800,X
2851-    99 A0 00     STA    $00A0,Y
2854-    E8           INX
2855-    C8           INY
2856-    C0 08        CPY    #$08
2858-    30 F4        BMI    $284E
285A-    EA           NOP
285B-    A2 18        LDX    #$18
285D-    A9 00        LDA    #$00
285F-    CA           DEX
2860-    9D 20 08     STA    $0820,X
2863-    D0 FA        BNE    $285F
2865-    A2 07        LDX    #$07
2867-    A0 07        LDY    #$07
2869-    BD A0 00     LDA    $00A0,X
286C-    85 C0        STA    $C0
286E-    B9 A0 00     LDA    $00A0,Y
2871-    85 C1        STA    $C1
2873-    20 39 29     JSR    $2939
2876-    A5 C2        LDA    $C2
2878-    85 C0        STA    $C0
287A-    A5 A8        LDA    $A8
287C-    85 C1        STA    $C1
287E-    20 39 29     JSR    $2939
2881-    A5 C3        LDA    $C3
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2881-   A5 C3       LDA   $C3
2883-   F0 02       BEQ   $2887
2885-   D0 04       BNE   $288B
2887-   A5 C2       LDA   $C2
2889-   D0 03       BNE   $288E
288B-   FE 20 08    INC   $0820,X
288E-   88          DEY
288F-   10 D8       BPL   $2869
2891-   A0 07       LDY   #$07
2893-   CA          DEX
2894-   10 D3       BPL   $2869
2896-   A2 07       LDX   #$07
2898-   8E 38 08    STX   $0838
289B-   BD 20 08    LDA   $0820,X
289E-   CA          DEX
289F-   30 0E       BMI   $28AF
28A1-   DD 20 08    CMP   $0820,X
28A4-   10 F8       BPL   $289E
28A6-   8E 38 08    STX   $0838
28A9-   BD 20 08    LDA   $0820,X
28AC-   18          CLC
28AD-   90 EF       BCC   $289E
28AF-   AE 38 08    LDX   $0838
28B2-   BD 20 08    LDA   $0820,X
28B5-   A6 AA       LDX   $AA
28B7-   9D B0 00    STA   $00B0,X
28BA-   AC 38 08    LDY   $0838
28BD-   B9 A0 00    LDA   $00A0,Y
28C0-   9D B8 00    STA   $00B8,X
28C3-   E6 AA       INC   $AA
28C5-   A5 AA       LDA   $AA
28C7-   C9 04       CMP   #$04
28C9-   10 05       BPL   $28D0
28CB-   A6 AA       LDX   $AA
28CD-   4C 45 28    JMP   $2845
28D0-   EA          NOP
28D1-   A9 00       LDA   #$00
28D3-   85 AB       STA   $AB
28D5-   A2 03       LDX   #$03
28D7-   A9 04       LDA   #$04
28D9-   DD B0 00    CMP   $00B0,X
28DC-   10 06       BPL   $28E4
28DE-   CA          DEX
28DF-   10 F8       BPL   $28D9
28E1-   18          CLC
28E2-   90 04       BCC   $28E8
28E4-   A9 F0       LDA   #$F0
28E6-   85 AB       STA   $AB
28E8-   A2 01       LDX   #$01
28EA-   BD B8 00    LDA   $00B8,X
28ED-   85 C0       STA   $C0
28EF-   BD BA 00    LDA   $00BA,X
28F2-   85 C1       STA   $C1
28F4-   20 39 29    JSR   $2939
28F7-   A5 C3       LDA   $C3
28F9-   9D B4 00    STA   $00B4,X
28FC-   A5 C2       LDA   $C2
28FE-   9D BC 00    STA   $00BC,X
2901-   85 C0       STA   $C0
2903-   A5 A8       LDA   $A8
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2903-   A5 A8      LDA   $A8
2905-   85 C1      STA   $C1
2907-   20 39 29   JSR   $2939
290A-   A5 C2      LDA   $C2
290C-   F0 15      BEQ   $2923
290E-   A5 C3      LDA   $C3
2910-   D0 11      BNE   $2923
2912-   CA         DEX
2913-   10 D5      BPL   $28EA
2915-   A5 AB      LDA   $AB
2917-   30 04      BMI   $291D
2919-   49 0F      EOR   #$0F
291B-   D0 05      BNE   $2922
291D-   A9 07      LDA   #$07
291F-   20 C6 72   JSR   $72C6
2922-   60         RTS
2923-   8A         TXA
2924-   F0 09      BEQ   $292F
2926-   A5 AB      LDA   $AB
2928-   09 0C      ORA   #$0C
292A-   85 AB      STA   $AB
292C-   18         CLC
292D-   90 E3      BCC   $2912
292F-   A5 AB      LDA   $AB
2931-   09 03      ORA   #$03
2933-   85 AB      STA   $AB
2935-   18         CLC
2936-   90 DA      BCC   $2912
2938-   00         BRK
2939-   A9 00      LDA   #$00
293B-   85 C3      STA   $C3
293D-   85 C4      STA   $C4
293F-   A5 C0      LDA   $C0
2941-   30 34      BMI   $2977
2943-   A5 C1      LDA   $C1
2945-   30 1A      BMI   $2961
2947-   A5 C0      LDA   $C0
2949-   38         SEC
294A-   E5 C1      SBC   $C1
294C-   10 07      BPL   $2955
294E-   49 FF      EOR   #$FF
2950-   18         CLC
2951-   69 01      ADC   #$01
2953-   E6 C3      INC   $C3
2955-   85 C2      STA   $C2
2957-   A5 C3      LDA   $C3
2959-   F0 05      BEQ   $2960
295B-   E6 C4      INC   $C4
295D-   18         CLC
295E-   90 03      BCC   $2963
2960-   60         RTS
2961-   E6 C3      INC   $C3
2963-   A5 C0      LDA   $C0
2965-   85 C5      STA   $C5
2967-   A5 C1      LDA   $C1
2969-   85 C0      STA   $C0
296B-   A5 C5      LDA   $C5
296D-   85 C1      STA   $C1
296F-   A5 C4      LDA   $C4
2971-   F0 01      BEQ   $2974
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```
2971-    F0 01       BEQ   $2974
2973-    60          RTS
2974-    18          CLC
2975-    90 04       BCC   $297B
2977-    A5 C1       LDA   $C1
2979-    30 CC       BMI   $2947
297B-    A5 C0       LDA   $C0
297D-    38          SEC
297E-    E5 C1       SBC   $C1
2980-    85 C2       STA   $C2
2982-    60          RTS
2983-    00          BRK
2984-    A0 00       LDY   #$00
2986-    A9 00       LDA   #$00
2988-    E0 00       CPX   #$00
298A-    F0 0A       BEQ   $2996
298C-    F8          SED
298D-    18          CLC
298E-    69 01       ADC   #$01
2990-    90 01       BCC   $2993
2992-    C8          INY
2993-    CA          DEX
2994-    D0 F7       BNE   $298D
2996-    D8          CLD
2997-    60          RTS
2998-    00          BRK
2999-    A9 00       LDA   #$00
299B-    85 C1       STA   $C1
299D-    A2 02       LDX   #$02
299F-    A5 BC       LDA   $BC
29A1-    18          CLC
29A2-    65 BC       ADC   $BC
29A4-    90 02       BCC   $29A8
29A6-    E6 C1       INC   $C1
29A8-    CA          DEX
29A9-    D0 F6       BNE   $29A1
29AB-    85 C0       STA   $C0
29AD-    46 C1       LSR   $C1
29AF-    66          ???
29B0-    C0 A5       CPY   #$A5
29B2-    C1 F0       CMP   ($F0,X)
29B4-    06 46       ASL   $46
29B6-    C1 66       CMP   ($66,X)
29B8-    C0 46       CPY   #$46
29BA-    BD A5 C0    LDA   $C0A5,X
29BD-    85 BC       STA   $BC
29BF-    EA          NOP
29C0-    EA          NOP
29C1-    85 C0       STA   $C0
29C3-    A5 BD       LDA   $BD
29C5-    85 C1       STA   $C1
29C7-    20 39 29    JSR   $2939
29CA-    A5 C3       LDA   $C3
29CC-    85 C6       STA   $C6
29CE-    A5 C2       LDA   $C2
29D0-    D0 06       BNE   $29D8
29D2-    A9 FF       LDA   #$FF
29D4-    85 CB       STA   $CB
29D6-    30 49       BMI   $2A21
29D8-    A9 00       LDA   #$00
```

```
29D8-   A9 00       LDA  #$00
29DA-   A2 06       LDX  #$06
29DC-   9D C6 00    STA  $00C6,X
29DF-   CA          DEX
29E0-   D0 FA       BNE  $29DC
29E2-   A5 C1       LDA  $C1
29E4-   85 C9       STA  $C9
29E6-   A5 C0       LDA  $C0
29E8-   4A          LSR
29E9-   85 CE       STA  $CE
29EB-   A9 00       LDA  #$00
29ED-   90 02       BCC  $29F1
29EF-   09 80       ORA  #$80
29F1-   85 CD       STA  $CD
29F3-   A5 C7       LDA  $C7
29F5-   38          SEC
29F6-   E5 CD       SBC  $CD
29F8-   85 C7       STA  $C7
29FA-   A5 C8       LDA  $C8
29FC-   E5 CE       SBC  $CE
29FE-   85 C8       STA  $C8
2A00-   A5 C9       LDA  $C9
2A02-   E9 00       SBC  #$00
2A04-   85 C9       STA  $C9
2A06-   A5 CA       LDA  $CA
2A08-   E9 00       SBC  #$00
2A0A-   85 CA       STA  $CA
2A0C-   EA          NOP
2A0D-   90 0E       BCC  $2A1D
2A0F-   A5 CB       LDA  $CB
2A11-   18          CLC
2A12-   69 01       ADC  #$01
2A14-   85 CB       STA  $CB
2A16-   90 02       BCC  $2A1A
2A18-   E6 CC       INC  $CC
2A1A-   18          CLC
2A1B-   90 D6       BCC  $29F3
2A1D-   46 CC       LSR  $CC
2A1F-   66          ???
2A20-   CB          ???
2A21-   A2 00       LDX  #$00
2A23-   A5 CB       LDA  $CB
2A25-   85 C0       STA  $C0
2A27-   BD 55 2A    LDA  $2A55,X
2A2A-   85 C1       STA  $C1
2A2C-   20 39 29    JSR  $2939
2A2F-   A5 C2       LDA  $C2
2A31-   F0 08       BEQ  $2A3B
2A33-   A5 C3       LDA  $C3
2A35-   D0 04       BNE  $2A3B
2A37-   E8          INX
2A38-   D0 ED       BNE  $2A27
2A3A-   00          BRK
2A3B-   EA          NOP
2A3C-   86 C7       STX  $C7
2A3E-   A5 C6       LDA  $C6
2A40-   F0 07       BEQ  $2A49
2A42-   A9 5A       LDA  #$5A
2A44-   38          SEC
2A45-   E5 C7       SBC  $C7
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2A45-   E5 C7      SBC  $C7
2A47-   85 C7      STA  $C7
2A49-   A5 C7      LDA  $C7
2A4B-   AA         TAX
2A4C-   20 84 29   JSR  $2984
2A4F-   84 C8      STY  $C8
2A51-   85 C9      STA  $C9
2A53-   60         RTS
2A54-   00         BRK
2A55-   00         BRK
2A56-   04         ???
2A57-   09 0D      ORA  #$0D
2A59-   09 16      ORA  #$16
2A5B-   1B         ???
2A5C-   1F         ???
2A5D-   24 28      BIT  $28
2A5F-   2D 32 36   AND  $3632
2A62-   3B         ???
2A63-   40         RTI
2A64-   44         ???
2A65-   49 4E      EOR  #$4E
2A67-   53         ???
2A68-   58         CMS
2A69-   5D 62 67   EOR  $6762,X
2A6C-   6C 71 77   JMP  ($7771)
2A6F-   7C         ???
2A70-   82         ???
2A71-   88         DEY
2A72-   8D 94 99   STA  $9994
2A75-   9F         ???
2A76-   A6 AC      LDX  $AC
2A78-   B3         ???
2A79-   B9 C0 C7   LDA  $C7C0,Y
2A7C-   CE D6 DE   DEC  $DED6
2A7F-   E6 EE      INC  $EE
2A81-   F6 FF      INC  $FF,X
2A83-   00         BRK
2A84-   A0 50      LDY  #$50
2A86-   A9 5F      LDA  #$5F
2A88-   20 C6 72   JSR  $72C6
2A8B-   88         DEY
2A8C-   D0 F8      BNE  $2A86
2A8E-   84 E0      STY  $E0
2A90-   20 94 2A   JSR  $2A94
2A93-   60         RTS
2A94-   20 8A 72   JSR  $728A
2A97-   20 8A 72   JSR  $728A
2A9A-   20 8A 72   JSR  $728A
2A9D-   20 8A 72   JSR  $728A
2AA0-   20 8A 72   JSR  $728A
2AA3-   60         RTS
2AA4-   A9 00      LDA  #$00
2AA6-   85 EE      STA  $EE
2AA8-   AA         TAX
2AA9-   A9 18      LDA  #$18
2AAB-   85 EF      STA  $EF
2AAD-   A1 EE      LDA  ($EE,X)
2AAF-   C9 FF      CMP  #$FF
2AB1-   D0 01      BNE  $2AB4
2AB3-   60         RTS
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2AB3-   60         RTS
2AB4-   20 C6 72   JSR   $72C6
2AB7-   20 97 73   JSR   $7397
2ABA-   4C AD 2A   JMP   $2AAD
2ABD-   A9 FF      LDA   #$FF
2ABF-   8D 04 80   STA   $8004
2AC2-   8D 06 80   STA   $8006
2AC5-   A9 04      LDA   #$04
2AC7-   8D 07 80   STA   $8007
2ACA-   A9 34      LDA   #$34
2ACC-   8D 05 80   STA   $8005
2ACF-   A9 FF      LDA   #$FF
2AD1-   85 74      STA   $74
2AD3-   85 75      STA   $75
2AD5-   20 B4 2B   JSR   $2BB4
2AD8-   20 E9 72   JSR   $72E9
2ADB-   C9 45      CMP   #$45
2ADD-   F0 3E      BEQ   $2B1D
2ADF-   C9 50      CMP   #$50
2AE1-   F0 5E      BEQ   $2B41
2AE3-   C9 52      CMP   #$52
2AE5-   F0 0D      BEQ   $2AF4
2AE7-   C9 43      CMP   #$43
2AE9-   D0 ED      BNE   $2AD8
2AEB-   20 62 2B   JSR   $2B62
2AEE-   20 B4 2B   JSR   $2BB4
2AF1-   18         CLC
2AF2-   90 E4      BCC   $2AD8
2AF4-   20 00 28   JSR   $2800
2AF7-   A9 04      LDA   #$04
2AF9-   8D 05 80   STA   $8005
2AFC-   20 43 28   JSR   $2843
2AFF-   A9 34      LDA   #$34
2B01-   8D 05 80   STA   $8005
2B04-   20 59 2C   JSR   $2C59
2B07-   90 08      BCC   $2B11
2B09-   A9 00      LDA   #$00
2B0B-   85 72      STA   $72
2B0D-   85 73      STA   $73
2B0F-   F0 C7      BEQ   $2AD8
2B11-   20 99 29   JSR   $2999
2B14-   20 03 2C   JSR   $2C03
2B17-   20 59 2B   JSR   $2B59
2B1A-   18         CLC
2B1B-   90 BB      BCC   $2AD8
2B1D-   20 00 28   JSR   $2800
2B20-   A9 04      LDA   #$04
2B22-   8D 05 80   STA   $8005
2B25-   20 43 28   JSR   $2843
2B28-   A9 34      LDA   #$34
2B2A-   8D 05 80   STA   $8005
2B2D-   20 59 2C   JSR   $2C59
2B30-   B0 A6      BCS   $2AD8
2B32-   20 99 29   JSR   $2999
2B35-   20 03 2C   JSR   $2C03
2B38-   20 72 2B   JSR   $2B72
2B3B-   20 B4 2B   JSR   $2BB4
2B3E-   18         CLC
2B3F-   90 97      BCC   $2AD8
2B41-   A5 74      LDA   $74
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2B41-   A5 74       LDA   $74
2B43-   C9 FF       CMP   #$FF
2B45-   F0 91       BEQ   $2AD8
2B47-   A9 04       LDA   #$04
2B49-   8D 05 80    STA   $8005
2B4C-   20 D4 2B    JSR   $2BD4
2B4F-   A9 FF       LDA   #$FF
2B51-   85 74       STA   $74
2B53-   85 75       STA   $75
2B55-   20 B4 2B    JSR   $2BB4
2B58-   60          RTS
2B59-   A5 70       LDA   $70
2B5B-   85 72       STA   $72
2B5D-   A5 71       LDA   $71
2B5F-   85 73       STA   $73
2B61-   60          RTS
2B62-   F8          SED
2B63-   38          SEC
2B64-   A9 60       LDA   #$60
2B66-   E5 75       SBC   $75
2B68-   85 75       STA   $75
2B6A-   A9 03       LDA   #$03
2B6C-   E5 74       SBC   $74
2B6E-   85 74       STA   $74
2B70-   D8          CLD
2B71-   60          RTS
2B72-   A5 70       LDA   $70
2B74-   C5 72       CMP   $72
2B76-   90 18       BCC   $2B90
2B78-   D0 06       BNE   $2B80
2B7A-   A5 71       LDA   $71
2B7C-   C5 73       CMP   $73
2B7E-   90 10       BCC   $2B90
2B80-   A6 70       LDX   $70
2B82-   A4 72       LDY   $72
2B84-   86 72       STX   $72
2B86-   84 70       STY   $70
2B88-   A6 71       LDX   $71
2B8A-   A4 73       LDY   $73
2B8C-   86 73       STX   $73
2B8E-   84 71       STY   $71
2B90-   F8          SED
2B91-   38          SEC
2B92-   A5 73       LDA   $73
2B94-   E5 71       SBC   $71
2B96-   85 75       STA   $75
2B98-   A5 72       LDA   $72
2B9A-   E5 70       SBC   $70
2B9C-   85 74       STA   $74
2B9E-   0A          ASL
2B9F-   85 78       STA   $78
2BA1-   A5 75       LDA   $75
2BA3-   29 80       AND   #$80
2BA5-   2A          ROL
2BA6-   2A          ROL
2BA7-   05 78       ORA   $78
2BA9-   C9 03       CMP   #$03
2BAB-   B0 02       BCS   $2BAF
2BAD-   90 03       BCC   $2BB2
2BAF-   20 62 2B    JSR   $2B62
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2BAF-   20 62 2B    JSR   $2B62
2BB2-   D8          CLD
2BB3-   60          RTS
2BB4-   A5 74       LDA   $74
2BB6-   D0 07       BNE   $2BBF
2BB8-   A9 FF       LDA   #$FF
2BBA-   8D 06 80    STA   $8006
2BBD-   D0 05       BNE   $2BC4
2BBF-   8D 06 80    STA   $8006
2BC2-   D0 0A       BNE   $2BCE
2BC4-   A9 F0       LDA   #$F0
2BC6-   24 75       BIT   $75
2BC8-   D0 04       BNE   $2BCE
2BCA-   05 75       ORA   $75
2BCC-   D0 02       BNE   $2BD0
2BCE-   A5 75       LDA   $75
2BD0-   8D 04 80    STA   $8004
2BD3-   60          RTS
2BD4-   A0 00       LDY   #$00
2BD6-   84 80       STY   $80
2BD8-   C8          INY
2BD9-   A5 74       LDA   $74
2BDB-   48          PHA
2BDC-   4A          LSR
2BDD-   4A          LSR
2BDE-   4A          LSR
2BDF-   4A          LSR
2BE0-   20 EF 2B    JSR   $2BEF
2BE3-   68          PLA
2BE4-   29 0F       AND   #$0F
2BE6-   20 EF 2B    JSR   $2BEF
2BE9-   A5 75       LDA   $75
2BEB-   88          DEY
2BEC-   F0 ED       BEQ   $2BDB
2BEE-   60          RTS
2BEF-   A6 80       LDX   $80
2BF1-   D0 0A       BNE   $2BFD
2BF3-   C9 00       CMP   #$00
2BF5-   D0 04       BNE   $2BFB
2BF7-   A9 20       LDA   #$20
2BF9-   D0 04       BNE   $2BFF
2BFB-   85 80       STA   $80
2BFD-   09 30       ORA   #$30
2BFF-   20 C6 72    JSR   $72C6
2C02-   60          RTS
2C03-   F8          SED
2C04-   A5 B4       LDA   $B4
2C06-   F0 2D       BEQ   $2C35
2C08-   A5 B5       LDA   $B5
2C0A-   D0 0A       BNE   $2C16
2C0C-   A5 C8       LDA   $C8
2C0E-   85 70       STA   $70
2C10-   A5 C9       LDA   $C9
2C12-   85 71       STA   $71
2C14-   D8          CLD
2C15-   60          RTS
2C16-   38          SEC
2C17-   A9 60       LDA   #$60
2C19-   E5 C9       SBC   $C9
2C1B-   85 71       STA   $71
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2C1B-   85 71     STA   $71
2C1D-   A9 03     LDA   #$03
2C1F-   E5 C8     SBC   $C8
2C21-   85 70     STA   $70
2C23-   C9 03     CMP   #$03
2C25-   D0 ED     BNE   $2C14
2C27-   A5 71     LDA   $71
2C29-   C9 60     CMP   #$60
2C2B-   D0 E7     BNE   $2C14
2C2D-   A9 00     LDA   #$00
2C2F-   85 70     STA   $70
2C31-   85 71     STA   $71
2C33-   F0 DF     BEQ   $2C14
2C35-   A5 B5     LDA   $B5
2C37-   F0 10     BEQ   $2C49
2C39-   18        CLC
2C3A-   A5 C9     LDA   $C9
2C3C-   69 80     ADC   #$80
2C3E-   85 71     STA   $71
2C40-   A9 01     LDA   #$01
2C42-   65 C8     ADC   $C8
2C44-   85 70     STA   $70
2C46-   18        CLC
2C47-   90 CB     BCC   $2C14
2C49-   38        SEC
2C4A-   A9 80     LDA   #$80
2C4C-   E5 C9     SBC   $C9
2C4E-   85 71     STA   $71
2C50-   A9 01     LDA   #$01
2C52-   E5 C8     SBC   $C8
2C54-   85 70     STA   $70
2C56-   18        CLC
2C57-   90 BB     BCC   $2C14
2C59-   A5 AB     LDA   $AB
2C5B-   48        PHA
2C5C-   29 F0     AND   #$F0
2C5E-   C9 F0     CMP   #$F0
2C60-   D0 03     BNE   $2C65
2C62-   68        PLA
2C63-   38        SEC
2C64-   60        RTS
2C65-   68        PLA
2C66-   29 0F     AND   #$0F
2C68-   C9 0F     CMP   #$0F
2C6A-   18        CLC
2C6B-   D0 F7     BNE   $2C64
2C6D-   F0 F4     BEQ   $2C63
2C6F-   FF        ???
2C70-   FF        ???
2C71-   FF        ???
2C72-   FF        ???
2C73-   FF        ???
2C74-   FF        ???
2C75-   FF        ???
2C76-   FF        ???
2C77-   FF        ???
2C78-   FF        ???
2C79-   FF        ???
2C7A-   FF        ???
2C7B-   FF        ???
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2C7B-   FF          ???
2C7C-   FF          ???
2C7D-   FF          ???
2C7E-   FF          ???
2C7F-   FF          ???
2C80-   A9 16       LDA   #$16
2C82-   8D 03 6E    STA   $6E03
2C85-   A2 FF       LDX   #$FF
2C87-   9A          TXS
2C88-   E8          INX
2C89-   A9 01       LDA   #$01
2C8B-   85 E3       STA   $E3
2C8D-   D8          CLD
2C8E-   A9 06       LDA   #$06
2C90-   85 EA       STA   $EA
2C92-   A9 33       LDA   #$33
2C94-   85 EB       STA   $EB
2C96-   86 E7       STX   $E7
2C98-   A9 34       LDA   #$34
2C9A-   8D 05 80    STA   $8005
2C9D-   20 E9 72    JSR   $72E9
2CA0-   A9 00       LDA   #$00
2CA2-   8D 05 80    STA   $8005
2CA5-   A9 02       LDA   #$02
2CA7-   85 A8       STA   $A8
2CA9-   20 8A 72    JSR   $728A
2CAC-   20 84 2A    JSR   $2A84
2CAF-   20 A4 2A    JSR   $2AA4
2CB2-   20 E9 72    JSR   $72E9
2CB5-   C9 54       CMP   #$54
2CB7-   D0 19       BNE   $2CD2
2CB9-   20 E9 72    JSR   $72E9
2CBC-   C9 49       CMP   #$49
2CBE-   D0 12       BNE   $2CD2
2CC0-   20 E9 72    JSR   $72E9
2CC3-   C9 4D       CMP   #$4D
2CC5-   D0 0B       BNE   $2CD2
2CC7-   A9 D2       LDA   #$D2
2CC9-   85 F6       STA   $F6
2CCB-   A9 2C       LDA   #$2C
2CCD-   85 F7       STA   $F7
2CCF-   4C 86 70    JMP   $7086
2CD2-   A9 00       LDA   #$00
2CD4-   8D 05 80    STA   $8005
2CD7-   20 8A 72    JSR   $728A
2CDA-   D8          CLD
2CDB-   A2 FF       LDX   #$FF
2CDD-   9A          TXS
2CDE-   E8          INX
2CDF-   8A          TXA
2CE0-   85 EE       STA   $EE
2CE2-   A9 0C       LDA   #$0C
2CE4-   85 EF       STA   $EF
2CE6-   20 84 2A    JSR   $2A84
2CE9-   20 F8 2C    JSR   $2CF8
2CEC-   20 94 2A    JSR   $2A94
2CEF-   20 94 2A    JSR   $2A94
2CF2-   20 94 2A    JSR   $2A94
2CF5-   4C D5 2C    JMP   $2CD5
2CF8-   A2 00       LDX   #$00
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2CF8-    A2 00       LDX   #$00
2CFA-    A1 EE       LDA   ($EE,X)
2CFC-    D0 01       BNE   $2CFF
2CFE-    60          RTS
2CFF-    C9 80       CMP   #$80
2D01-    B0 09       BCS   $2D0C
2D03-    20 C6 72    JSR   $72C6
2D06-    20 97 73    JSR   $7397
2D09-    4C F8 2C    JMP   $2CF8
2D0C-    D0 1B       BNE   $2D29
2D0E-    A9 34       LDA   #$34
2D10-    8D 05 80    STA   $8005
2D13-    20 E9 72    JSR   $72E9
2D16-    C9 1B       CMP   #$1B
2D18-    90 F4       BCC   $2D0E
2D1A-    A2 00       LDX   #$00
2D1C-    8E 05 80    STX   $8005
2D1F-    C9 1B       CMP   #$1B
2D21-    F0 21       BEQ   $2D44
2D23-    20 C6 72    JSR   $72C6
2D26-    4C 0E 2D    JMP   $2D0E
2D29-    C9 81       CMP   #$81
2D2B-    D0 06       BNE   $2D33
2D2D-    20 BD 2A    JSR   $2ABD
2D30-    4C 44 2D    JMP   $2D44
2D33-    48          PHA
2D34-    29 1F       AND   #$1F
2D36-    AA          TAX
2D37-    68          PLA
2D38-    29 E0       AND   #$E0
2D3A-    C9 E0       CMP   #$E0
2D3C-    D0 06       BNE   $2D44
2D3E-    20 77 73    JSR   $7377
2D41-    CA          DEX
2D42-    D0 FA       BNE   $2D3E
2D44-    20 97 73    JSR   $7397
2D47-    4C F8 2C    JMP   $2CF8
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