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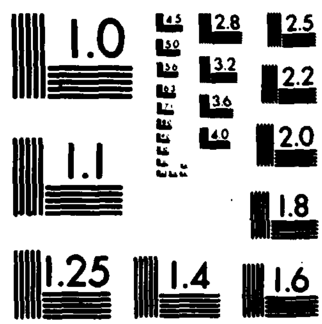

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Samuel E. Craig
Alan L. Moyer

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Final Technical Report. Sep 78 - Jul 80

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Prepared for

U.S. Army Engineer Topographic Laboratories
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Approved for public release; distribution unlimited

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This report documents the development and design of the Image and Alignment and Correlation System built for the U.S. Army Engineer Topographic Laboratories by Deft Laboratories, Inc. The purpose of the system is to provide a hardware demonstration of the applicability of DEFT (Direct Electronic Fourier Transform) technology to the problems of image

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20. ABSTRACT (cont.)

alignment and image cross-correlation measurement. These problems are related generally to the areas of topographic mapping, feature extraction and change detection, and photo-interpretation.

The system uses a highly developed image-adaptive alignment algorithm which exploits the spatial frequency analysis capability of the DEFT sensor. With high-contrast images having prominent spatial frequencies, residual alignment errors are typically 50 microns in translation and 0.1 degree in angle. The system also has the capability of displaying the spatial frequency content of an image, and of computing normalized cross-correlation coefficients based on spatial frequency data.

The major limitations of the system are its slow operating speed, which is caused by certain parts of the circuitry rather than the sensor, and its dependence on the image.

SUMMARY

This report documents the development and design of the Image and Alignment and Correlation System built for the US Army Engineer Topographic Laboratories by Deft Laboratories, Inc. The purpose of the system is to provide a hardware demonstration of the applicability of DEFT (Direct Electronic Fourier Transform) technology to the problems of image alignment and image cross-correlation measurement. These problems are related generally to the areas of topographic mapping, feature extraction and change detection, and photointerpretation.

The development of this system is a continuation of the advancement of DEFT technology and its applications. The sensor technology has received previous sponsorship at Syracuse University by ETL and by the Night Vision Laboratories. The Image Alignment and Correlation System represents a significant achievement in the application of the technology and in its interfacing and programmable control by a microprocessor. In other words, the system represents the first real "use" of DEFT sensor outputs.

The system uses a highly developed image-adaptive alignment algorithm which exploits the spatial frequency analysis capability of the DEFT sensor. With high-contrast images having prominent spatial frequencies, residual alignment errors are typically 50 microns in translation and 0.1 degree in angle. The system also has the capability of displaying the spatial frequency content of an image, and of computing normalized cross-correlation coefficients based on spatial frequency data.

The system consists of two major assemblies, which are the alignment fixture and the electronics cabinet. The alignment fixture uses translation and rotation stages driven by stepper motors to align the test image with respect to the reference image. The images are transparencies mounted on light boxes.

An x-y plotter and a graphics terminal were also furnished with the system as accessories.

The major limitations of the system are its slow operating speed, which is caused by certain parts of the circuitry rather than the sensor, and its dependence on the image.

PREFACE

This report contains all information specific to the Image Alignment and Correlation System, but it does not include background material on the principles of operation and characteristics of the DEFT sensor on which the system is based. That information can be obtained from any one of a number of previous papers and articles, the most significant of which are listed in a bibliography at the end of this document.

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I. INTRODUCTION

The Image Alignment and Correlation System was built for the U.S. Army Engineer Topographic Laboratories by Deft Laboratories, Inc. under Contract No. DAAK70-78-C-0217. Its purpose is to provide a hardware demonstration of the applicability of DEFT (Direct Electronic Fourier Transform) technology to the problems of image alignment and image cross-correlation measurement. These problems are related generally to the areas of topographic mapping, feature extraction and change detection, and photointerpretation.

The development of this system is a continuation of the advancement of DEFT technology and its applications. The sensor technology has received previous sponsorship at Syracuse University by ETL and by the Night Vision Laboratories. The Image Alignment and Correlation System represents a significant achievement in the application of the technology and in its interfacing and programmable control by a microprocessor. In other words, the system represents the first real "use" of DEFT sensor outputs.

The system performs three main functions: display, image alignment, and image correlation. There are options under each of these main functions. That of display uses as an output device either a graphics terminal which has a storage cathode-ray tube (CRT) or an x-y recorder for "hard copy." The sensor output is scanned in the spatial frequency domain under microprocessor control and displayed graphically in pseudo-three-dimensional form.

The second function aligns a test image in angle and in vertical and horizontal translation, either with respect to a reference image viewed by a second sensor, or with respect to the original position of the test image using only one sensor. Using high-contrast images which have prominent features in the spatial frequency domain, residual alignment errors are typically 50 microns in translation and 0.1 degree in angle.

The system measures image correlation by computing a normalized cross-correlation coefficient between the outputs of the two sensors over the usable range of the spatial frequency domain. The data on which the correlation coefficient is based is an approximation to the two-dimensional Fourier transform of each image's intensity pattern. Either a real coefficient using the data magnitudes or a complex coefficient using the complex data can be computed.

Because the entire system is controlled by a microprocessor, there is ample opportunity for program modification or expansion. In addition, the system can be used as a stand-alone microcomputer, either with its own terminal or with another.

The purpose of this report is to document the development and design of the system, describing both its hardware and software aspects in detail. The following sections begin with descriptions of the system hardware, the basis of the alignment algorithm, and the software which implements it and the other functions. These descriptions are followed by instructions for operating the system which are an expansion of the Condensed Operator's Manual furnished when the hardware was delivered. Then there is a review of the significant events, technical problems, and their solutions which were experienced during the contract term.

II. SYSTEM HARDWARE

A. General Description

The Image Alignment and Correlation System consists of two major assemblies and two accessories. The two major assemblies are an alignment fixture and an electronics cabinet. The two accessories are a display terminal and an x-y plotter. Some of the system functions do not require the accessories, and they can be detached and used for other purposes.

The components of the alignment fixture are mounted on an L-shaped frame made of 0.5 in. thick aluminum plate. The vertical end of the frame supports a fixed mounting for the reference image and tandem-mounted translation and rotation stages which hold the test image. Each image is a transparency, and is placed on a light box. The translation and rotation stages are driven by stepper motors which are controlled by circuitry in the electronics cabinet. At the other end of the alignment fixture is a bracket which supports a pair of modules containing the DEFT sensors.

Three cables connect the alignment fixture to the electronics cabinet. One carries signals and power to the DEFT modules, and one carries power to the three stepper motors. The remaining cable is an ac line cord for the light boxes.

The electronics cabinet contains circuits which pulse the stepper motor windings, a microprocessor which controls the entire system, some analog signal processing circuitry, and power supplies.

The three stepper motor drivers are located in the center section of the cabinet. Each driver has its own power supply for itself and for the corresponding motor. The drivers are interfaced to an input/output port for the microprocessor. During image alignment the stepper motors are controlled automatically through this interface. However, they can also be actuated manually by means of push-button controls on the front panel of the cabinet.

The top section of the cabinet front panel is a door which allows access to the microprocessor and the signal processing components. Both are assembled on plug-in circuit cards. Normal operation of the system does not require access to these cards, so the front panel door may be left closed. On the door is a 16-position keypad and a 15-position LED display. The keypad is used to select and execute the various functions which the system has been programmed to perform. The LED display shows either the positions of the translation and rotation stages or the value of the correlation coefficient, depending on the program selected. It also displays the number of the selected program and gives error warnings under certain conditions.

The bottom section of the electronics cabinet contains power supplies for the microprocessor, the analog signal processing circuits, and the DEFT sensor modules. Two power switches are located on the front panel of this section. The one on the left side is a master switch for the entire system except for the light boxes. The other switch controls the light boxes independently.

The rear panel of the cabinet is a door on which are mounted the connectors for the interfacing cable to the DEFT sensor modules, the stepper motors, and the accessory x-y plotter and display terminal. All of these connectors are different, so there is no danger of connecting the interfaces improperly. Also located on the rear panel door are the ac line fuse and two small toggle switches. These switches were used for tape cassette read/write operations when the system software was being developed. They have no effect on the presently programmed system functions.

Figure 1 shows a block diagram of the entire system. The

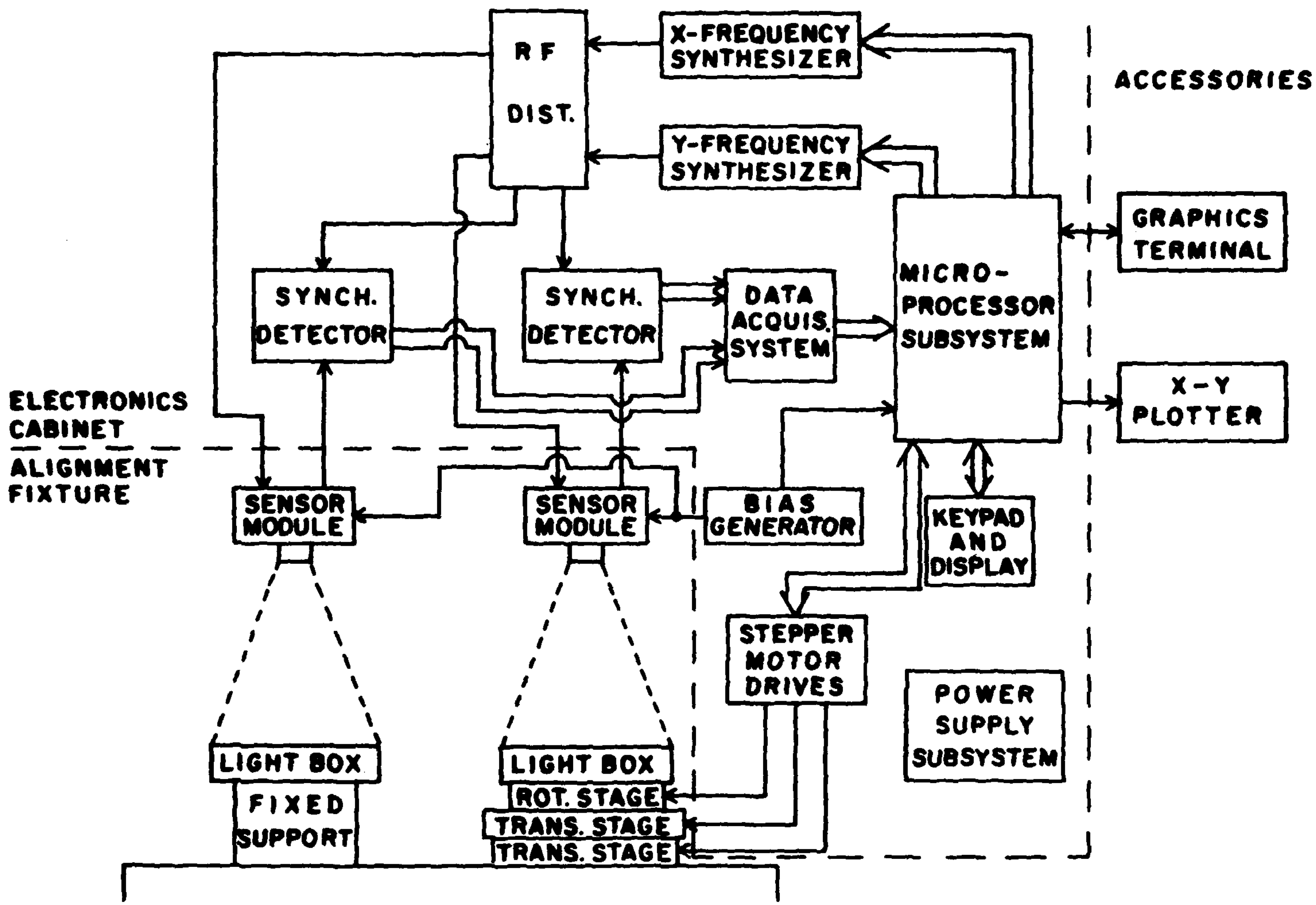


Figure 1 - Functional Block Diagram of *Image Alignment and Correlation System*

signal flow is generally from the synthesizers, which are controlled by the microprocessor, to the rf distribution circuit board, and from there to the sensor modules and synchronous detector circuit boards. Signals from the modules go to the synchronous detectors and then to the data acquisition system where they are sampled and digitized synchronously under software control. The bias generator is coupled to the microprocessor to achieve this synchronization. The microprocessor also controls the stepper motors through their drivers and the accessory x-y recorder through the analog output. It also exchanges data with the keypad and LED display and with the accessory graphics terminal. The power supply subsystem furnishes power to all parts of the system except the accessories, the stepper motors and their drivers.

B. Microprocessor Subsystem

1. General Description - The microprocessor subsystem consists of an integrated collection of modular plug-in circuit cards purchased from Wintek Corp. of Lafayette, IN. The modular approach allows the processor to be configured to meet the needs of the system at minimum cost. In addition, Wintek offers a very useful monitor in firmware called FANTOM-II, as well as an editor/assembler, which enabled the same processor to be used as a software development tool. The processor is an 8-bit machine based on the 6800, and includes a Control (CPU) Module, a ROM module with 16K capacity, a 16K dynamic RAM module, a RAM refresh module, an analog output module, and a two-port parallel I/O module. All of these cards are held in a cage behind the front door of the electronics cabinet. In addition, there is a Console I/O Module with a keypad and LED display which is mounted on the door.

All of the connections between the microprocessor and the remainder of the system, with the exception of the Data Acquisition Subsystem (DAS), are made through 6820/6821 Peripheral Interface Adapters (PIA's). The DAS is connected directly to the address and data busses through buffers located on an auxiliary card. All peripherals are memory-mapped since the 6800 has no IN or OUT instructions; that is, the peripherals are treated in the same way as memory locations by the processor. The address decoding scheme and other details can be found in the Wintek information which is included separately with the Commercial Data.

2. Control Module - This card includes the 6800 CPU, a 1K ROM which contains the FANTOM-II monitor, ½K of RAM, two PIA's, and a 6850 Asynchronous Communications Interface Adapter (ACIA). The ACIA is configured to provide transmission and reception of ASCII data through an RS-232 interface with the accessory graphics terminal. The two PIA's provide two groups each of 16 lines of parallel output data which controls the two frequency synthesizers. The interconnection is made through a 50-conductor ribbon cable.

3. Cassette Interface - This module does not plug into the card cage, but rather is mounted on the inside of the rear cabinet door. It is connected to the Control Module by a 14-conductor ribbon cable, and converts logic voltage levels to RS-232 levels and vice versa. It also can act as a modem for writing data to a cassette tape recorder and reading it back into memory later. The audio input and output lines are brought out to the connector which interfaces the system with the x-y plotter, since the plotter and the cassette recorder would not be used simultaneously. The cassette functions were used extensively while the software was being developed. They remain functional, but they are unnecessary in normal system operation. Cassette read and write procedures can be found in the Wintek documentation with the Commercial Data.

The small 7-position DIP switch on the Cassette Interface circuit board sets the baud rate for the RS-232 interface. This setting must agree with the rate set at the accessory graphics terminal. The recommended rate is the maximum accepted by the terminal in order to minimize execution times. In the case of the Tektronix 4006-1 terminal this rate is 4800 baud. To set this rate, position 6 on the DIP switch should be ON. All other positions should be OFF.

The small toggle switches on the rear panel affect only the cassette read and write operations.

4. <u>RAM and Refresh Modules</u> - the RAM module holds 16K bytes of dynamic read-write memory. Refreshing of this memory, along with some address decoding functions, is done by the RAM Refresh Module. These two cards are interconnected at their front ends as well as at the backplane.

A portion of this 16K block is unused by the existing software and is available for the temporary storage of other programs or data. In addition, the system can accommodate another 16K module without any hardware or software changes.

5. <u>ROM Module</u> - This card has the capacity for sixteen 2708-type UV-erasable programmable read-only memory (EPROM) chips. As delivered, only nine sockets are in place. Eight of them contain the 8K bytes of permanent software for the image alignment, correlation, and plotting functions. The ninth EPROM was purchased from Wintek and is programmed with a set of math routines which are used by the other software.

This module also can be expanded to its capacity of 16K bytes.

6. <u>Analog Output Module</u> - This card has two 8-bit digital-to-analog (D/A) converters which furnish the x and y input voltages for the x-y plotter. These voltages are taken to the rear panel connector through a ribbon cable which plugs into the front of the card. The D/A converters are adjusted for an output of 0.00V for a binary input of 00000000, and an output of +10.00V for an input of 11111111 (FF_H).

7. <u>Parallel I/O Module</u> - This unit has a PIA and buffers, and provides two 8-bit parallel ports, one input and one output,

for interfacing with the stepper motor drivers. These interconnections are made by means of two ribbon cables.

Although this module has the capacity for four PIA's, only one more can be added without creating a memory address conflict, because of the address decoding scheme used by Wintek.

8. <u>Console I/O Module</u> - This module is mounted on the front panel of the cabinet so that its 16-position keypad and 15-position LED display can be seen and accessed easily. Its edge connector is wired to the backplane using only those lines necessary for its operation. The system software recognizes commands entered at the keypad and uses the display to show the number of the program being (or about to be) executed. It also shows the relative position of the test image and the value of the correlation coefficient when appropriate.

This circuit generates interrupts, which are maskable, at a rate of 1200 per second. The interrupt service routine updates the display and checks the keypad for input. Further details are given in the software description and with the Commercial Data.

9. <u>Reset Generator</u> - An auxiliary circuit card, located adjacent to the left end of the microprocessor backplane, contains address and data buffers for the DAS. It also has circuitry which produces a hardware reset when the system power is turned on and when the BREAK key on the graphics terminal is pressed. A hardware reset affects all of the interface adapters and the CPU, and is necessary before the system software can configure the interface adapters for their various functions. It also causes the processor to get an address from a particular memory location and to begin execution at that address. The address is $A91C_H$, the entry point for the initialization procedure. In the case of a system malfunction which stops normal program execution, it will be necessary to reset the

system to regain control of it. Rather than remove power and reapply it, a small white button on the auxiliary card can be used. This button simply grounds the reset line.

When the front cabinet door is opened, two such buttons will be seen on adjacent cards at the left side. The reset button is the leftmost of the two. The other one grounds the non-maskable interrupt (NMI) line, and has the effect of stopping any program execution in progress and giving control to the FANTOM-II monitor. The monitor can be used only through the keyboard of a terminal connected to the RS-232 interface. This capability is useful for troubleshooting or for experimenting with new software, but it will not be needed in normal system operation. If the NMI button should be pressed accidentally, simply press the Reset button to escape from the monitor. A program listing for the monitor and instructions for using it are included with the Commercial Data.

10. Memory Allocations - The addresses for the system's memory and peripheral adapters are given in the following table. All addresses are in hexadecimal notation. Address space which is designated as "Not Available" is such because of the Wintek address decoding scheme which does not use all 16 address bits in all cases. Addresses so designated must be avoided since their use can result in the simultaneous activation of more than one peripheral, with ambiguous results. Addresses not listed in Table 1 in the range $E\emptyset\emptyset\emptyset_H$-$EFFF_H$ fall in this category, with two exceptions. Either EE∅4-EE∅7 or EF∅4-EF∅7 (but not both) may be used without any hardware modification. This space will accommodate either one additional PIA (on the Parallel I/O Module or on a separate module) or up to two additional ACIAs without conflict. See Wintek application note AN-0010 in the Commercial Data for more detail.

C. Stepper Motors and Controls

The translation and rotation stages and their controllers

TABLE 1

Memory Address Allocations

Hexadecimal Address	Function
0000 - 3FFF	RAM
4000 - 7FFF	Available for future expansion
8000 - BFFF	ROM
C000 - DEFF	Available for future expansion*
DFX0 - DFX7	Available for future expansion
DFX8 - DFXF	Data Acquisition Subsystem
E000 - EBFF	Not Available
EC00 - EDFF	RAM
EE08 - EE09	ACIA
EE10 - EE13	PIA for X Synthesizer
EE20 - EE23	PIA for Y Synthesizer
EE40 - EE43	PIA for Front-Panel Console
EE80 - EE83	PIA for Analog Output
EF00 - EF03	PIA for Stepper Motors
F000 - FBFF	Not Available
FC00 - FFFF	ROM (FANTOM-II Monitor)

*With additional address decoding hardware.

Note - See text regarding addresses starting with E.

were purchased from Aerotech, Inc. of Pittsburgh, PA. Each stage is actuated by a small stepper motor and each motor is controlled by a driver. Aerotech calls the driver a "translator," probably because it translates logic-level signals or switch closures into voltages which are applied to the motor windings in the proper sequence. Each driver is connected to one of the front-panel push-button switch assemblies by a ribbon cable. The upper switch assembly operates either the horizontal (x) or the vertical (y) translation stage, while the lower set of switches operates only the rotation stage.

Instructions and schematics pertaining to the driver (or "translator") and the switch assembly are included in the Commercial Data which is separate from this volume.

The stepper motor subsystem is interfaced to the microprocessor through two 8-bit ports on its Parallel I/O Board. One port is configured as an output and furnishes clock and direction signals to Pins 3 and 4, respectively, of J1 on each of the driver ("translator") boards. Since there are three stepper motors, only 6 of the 8 bits are used. Separate outputs which confirm the clock and direction signals are taken from J1 on the front-panel switch assemblies to the other I/O port, which is configured as an input. Again, only 6 of the 8 bits are used.

When the local/remote switch (labeled MAN/AUTO) is in the local (MAN) position, the outputs from the microprocessor are disconnected from the motor drivers. The drivers then generate their own clock pulses under the control of the STEP and SLEW switches, and the direction switch determines the motor direction. With the local/remote switch in the remote (AUTO) position, the STEP, SLEW, and direction switches have no effect and the stepper motors operate under the control of the microprocessor. The driver outputs which confirm the clock and direction signals remain connected to the processor in both modes so that it can keep track of the relative position of each stage when the system is in its calibrated state.

Each driver board has its own power supply.

D. Frequency Synthesizers

Two digital frequency synthesizers are used in the system. They ultimately provide the excitation for the orthogonal surface-acoustic wave (SAW) transducers on the DEFT sensors, and they also furnish the reference for synchronous detection of the sensor outputs.

The synthesizers are modular plug-in circuit boards made by Syntest Corp. of Marlboro, MA. They are capable of covering the range of 20.000 MHz to 159.999 MHz in 1 kHz steps, and are controlled by the parallel input of 5½ BCD digits at logic levels. In this system the most and least significant digits are always zero because they are hardwired to ground. The remaining four BCD digits for each synthesizer come from the two PIA's on the Control Module. The resulting effective frequency range is 20.00 MHz to 99.99 MHz in 10 kHz steps, and each synthesizer is controlled independently.

The two synthesizers use a common crystal-controlled 1 MHz reference which is located on one of them and cross-connected to the other. The synthesizer without the reference oscillator cannot function without the other one.

The synthesizers are located immediately to the right of the microprocessor back plane. The x-frequency is produced by the one on the left. Their outputs are carried to the rf distribution circuit board by miniature 50-ohm coaxial cables.

Specifications and other information on the synthesizers can be found with the Commercial Data.

E. RF Distribution Circuit Board

Figure 2 shows a block diagram for this unit. It is a plug-in card located immediately to the right of the synthesizers.

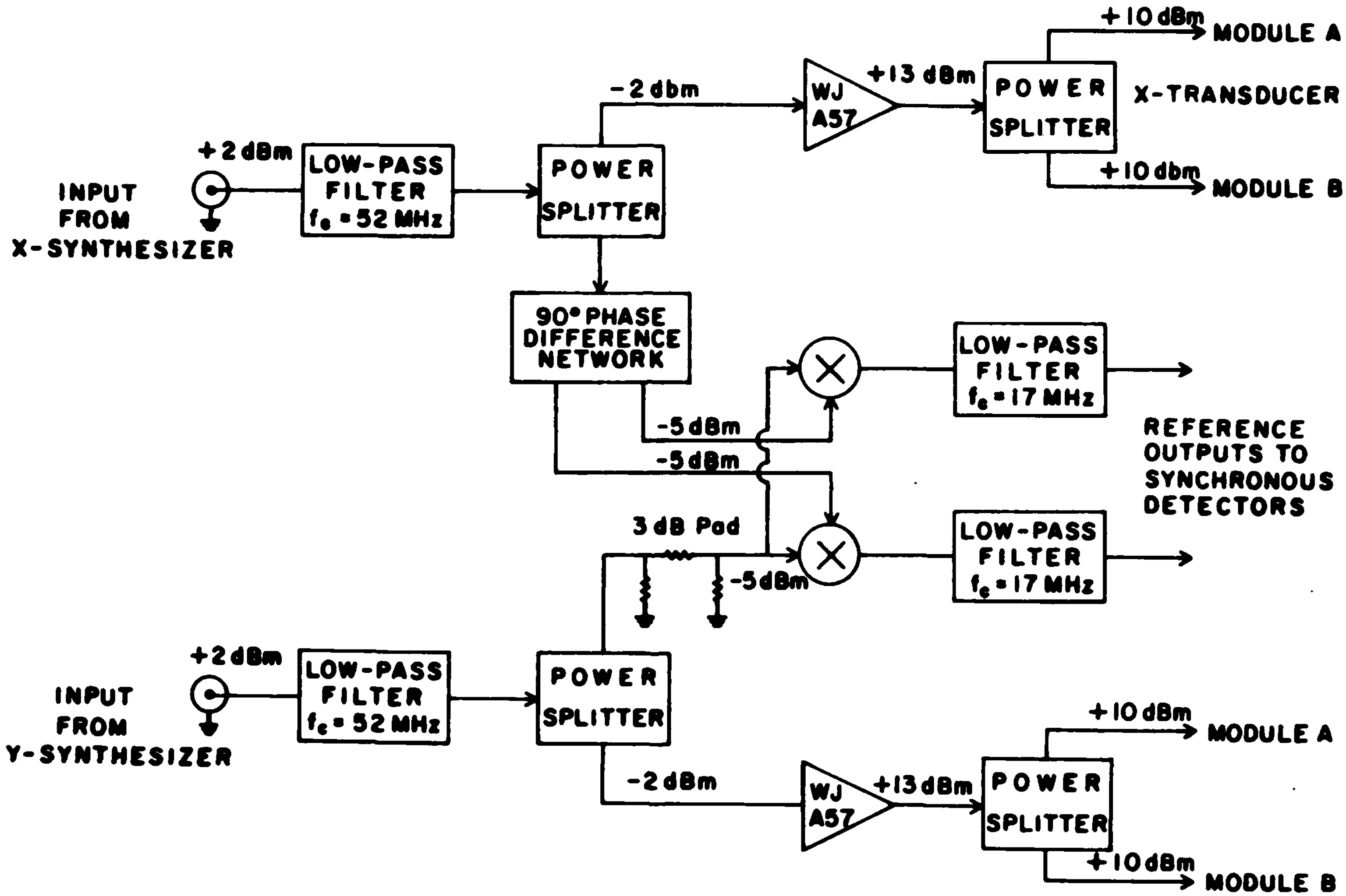


Figure 2 - Block Diagram of RF Distribution Circuit Board

Its function is to filter and amplify the synthesizer outputs and forward them to the DEFT sensor modules. In addition, the x-axis frequency is split into two orthogonal parts in a 90-degree phase difference network and each part is mixed with the y-axis frequency in a balanced modulator. The difference frequency is isolated by a low-pass filter at the output of each balanced modulator. The resulting difference-frequency signals, which are in phase quadrature, are sent on to the synchronous detector cards.

F. DEFT Sensor Modules

The two sensor modules are located on the alignment fixture. They have identical circuitry, but there are minor differences in the characteristics of the sensors themselves. The system software takes these differences into account, and for that reason the sensor modules should not be interchanged.

Figure 3 shows a block diagram for the sensor modules. The x-axis and y-axis frequencies from the rf distribution circuit board are applied to the SAW transducers on the sensor through drivers and matching networks. The purpose of the matching networks is to increase the effective acoustic bandwidth of the transducers.

Before this system was built, the practice was to apply a dc bias to the contact pattern on the sensor, and the resulting output appeared at a frequency equal to the difference between the two SAW frequencies. However, in this design, a sinusoidal ac bias is used and the output takes the form of a double-sideband suppressed carrier signal. The sidebands are displaced from the difference frequency by the bias frequency, which is 1440 Hz in this system. This scheme provides a spectral separation of the desired signal from any component at the difference frequency which might result from stray mixing of the two transducer voltages, since they are very large compared to typical signals.

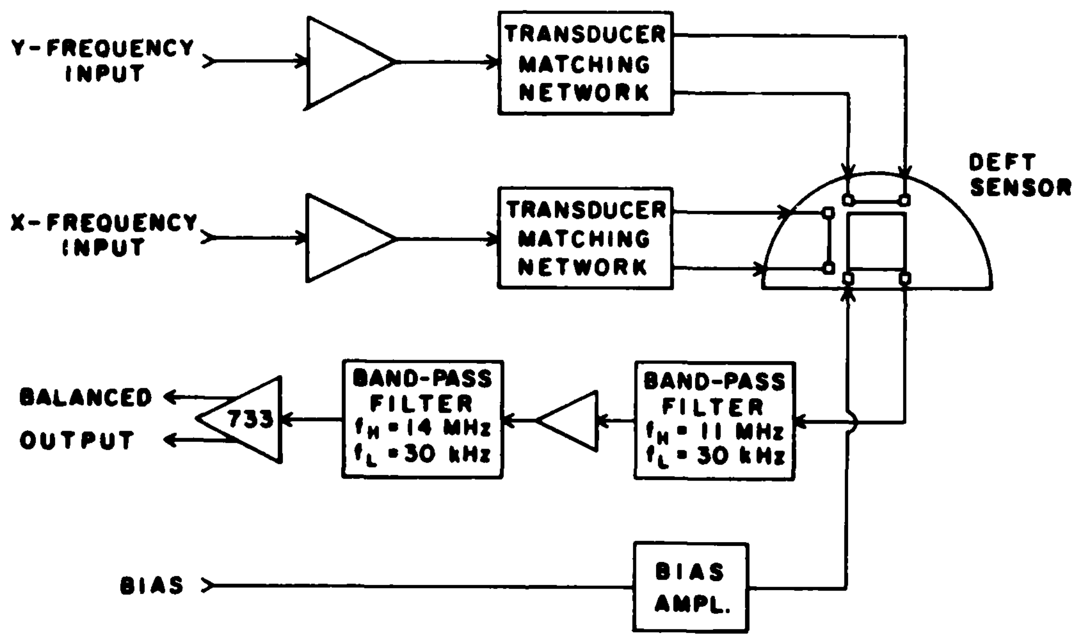


Figure 3 - Block Diagram of DEFT Sensor Module

A low-pass filter between the sensor and the signal preamplifier attenuates frequencies above the highest difference frequency, which in this case is about 10 MHz. The impedance of the sensor's contact pattern is mostly capacitive and forms an integral part of the filter circuit. Since the sensor is usually characterized as a current source as far as the signal is concerned, the preamplifier can be thought of as a current-to-voltage converter with a transimpedance of about 2.5K. Its output is again low-pass filtered and further amplified. The output of the second amplifier stage is balanced and each side is matched to the 50 Ω coaxial cables which carry the signal to the electronics cabinet.

The disc behind the lens on the module can be rotated to reveal a peep-hole on each side so that the image on the sensor can be seen. The lens is a standard one-inch format CCTV type with a "C" mounting thread (1"-32).

G. Synchronous Detector Circuit Board

The signal from each sensor module is fed to a synchronous detector card in the electronics cabinet. There are two such cards, one for each sensor module, and they are located immediately to the right of the rf distribution circuit board. They are readily identified by the 26-conductor ribbon cable which connects to the front of both of them.

Figure 4 shows a block diagram for the synchronous detector board. It consists of a pair of balanced modulators to which the signal from the sensor is fed in parallel. The reference inputs to the modulators are the difference-frequency voltages in phase quadrature which come from the rf distribution board. The balanced modulators translate the double sideband suppressed carrier signal to the bias frequency, which is constant. Low-pass filters which follow the modulators essentially remove all other frequencies from the outputs. These two bias-frequency signals are in phase, but their voltages represent two orthogonal

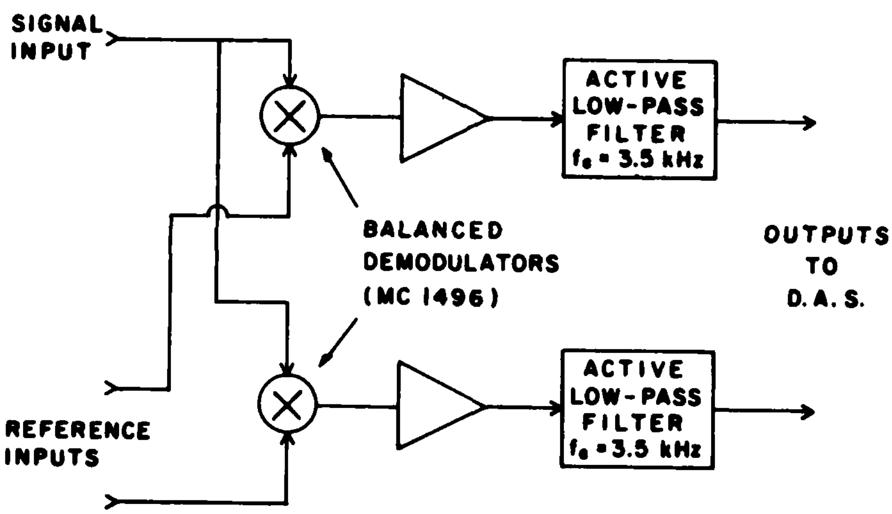


Figure 4 - Block Diagram of Synchronous Detector Circuit Board

components of the signal from the sensor. These two voltages connect to the DAS via the ribbon cable and are digitized synchronously under software control.

The synchronous detector cards have other circuitry which is not used in the present system. It was included in the original design of the card prior to the decision to implement a synchronous detector in software for the bias-frequency signal.

H. Data Acquisition System (DAS)

The DAS is in the form of a plug-in circuit card purchased from Analog Devices of Norwood, MA. Wintek offers an input version of their analog interface module but it was considered to be too slow for this application. No source was found for an analog input module compatible with the Wintek bus. The Analog Devices model RTI-1220 was selected, but buffers for the address lines and for four bits of the data bus had to be included on an auxiliary card to prevent excessive loading of the Wintek bus.

The DAS consists of an input multiplexer, a sample-and-hold circuit, a 12-bit A/D converter, and control logic. The input is configured for 16 channels of analog data with a common reference for "pseudo-differential" operation. Only four channels are used at present, and since their sources are the two side-by-side synchronous detector cards, negligible error is introduced by using a common reference. The selection of the input channel and the sampling of the analog voltage are both under software control. A conversion is initiated automatically when the sample-and-hold goes to the "hold" mode. This module is set for 2's complement binary output with an analog input range of ±5V.

A data sheet for this unit is included with the Commercial Data. More detailed information is contained in the User's Guide for the RTI-1220 and RTI-1221, which was supplied separately because of its copyright restriction.

I. Bias Generator

The bias generator furnishes the ac bias voltage for the DEFT sensors. It is the circuit card at the extreme right end of the cage. It consists of a phase-locked loop frequency synthesizer using the 60 Hz line as a reference. A miniature rotary switch at the end of the circuit card sets the output frequency, which is equal to the switch setting multiplied by 240 Hz. The switch should remain set to 6 for a bias frequency of 1440 Hz, since the timing in the software synchronous detector is matched to that frequency.

Logic-level square waves derived from the 60 Hz line and from the bias output are made available to the microprocessor through extra inputs to the PIA's on the Control Module. The synchronous detector subroutine uses these signals for timing references. The 60 Hz waveform is obtained from a small filament transformer.

The bias voltage applied to the sensors has a peak value of about 5V.

An LED below the frequency-setting switch indicates loss of phase lock. Normally it will flash when the system is turned on or if the frequency setting is changed. Otherwise it should remain off at all times.

J. Power Supplies

The power supply subsystem at the bottom of the electronics cabinet was procured from Acopian Corp. of Easton, PA. and is identified by their number 3276. The chassis wiring was modified slightly to make some of the rear terminals available for the switch which was added for the light boxes.

This subsystem consists of four separate modular supplies. One furnishes +5V and ±12V to the microprocessor system. These three outputs are overvoltage protected. The +5V also goes to the DAS. Another supply provides ±15V for the DAS, the bias generator, and all of the analog circuitry, which includes the

DEFT modules and the rf distribution and synchronous detector circuit boards. The remaining two units have outputs of +9V and +24V, respectively, for the frequency synthesizers.

The following table lists each available voltage, the rated maximum current available at that voltage at an ambient temperature of 60C, and the measured current drain with the system operating. It is evident that all of the ratings are conservative.

K. Light Boxes

Illumination for the test and reference images is provided by light boxes on which the images are held. The illuminated area is about 11 inches square, and images should be transparencies of approximately that size. They can be kept flat by squares of anti-reflective glass which were furnished with the system. The glass covering the image is retained by four spring fasteners on the light boxes.

The light source in each box is an array of six F6T5/CW fluorescent lamps, each having its own starter and ballast. Access to these parts is gained by removing the 24 screws which hold the translucent plastic cover to the box. Before removing the cover, it should be marked temporarily (with a piece of tape) so that it can be replaced with the same orientation.

A single power cord for both light boxes comes from the box which is fixed in position. This cord has a standard 3-prong grounding plug which can be mated to the receptable on the rear door of the electronics cabinet or to some other 115V 60Hz source if more convenient. The receptable on the cabinet is switched from the front panel.

The power connection between the two light boxes also has a standard 3-prong disconnect, but the female part has been modified so that the plug can be pulled out easily. This measure was taken in case the rotating stage should accidentally wrap the short cord around itself. In that event the plug and socket will disengage before tension on the cords causes any damage to the internal connections.

TABLE 2

Measured vs. Rated Power Supply Currents

Voltage	Current Rating (@ 60C), A	Measured Current, A
+5	6.0	2.26
+12	1.2	0.36
-12	1.2	0.30
+15	0.85	0.29
-15	0.85	0.61
+9	2.6	1.3
+24	0.75	.006

III. ALIGNMENT ALGORITHM

A. Overview

The function of the alignment algorithm is to align two identical or nearly identical images (e.g., stereo pairs) which are misaligned in both angle and in translation. Alignment is achieved by the following steps:

1) Selection of prominent spatial frequencies in the reference image which are then used exclusively in the subsequent processing.

2) A coarse angular alignment based on maximizing the correlation of the magnitude of the two-dimensional Fourier transforms of the reference and misaligned images sampled at the selected spatial frequencies.

3) A fine angular alignment based on maximizing the same correlation function as in 2) above. The final fine search increment is 0.1 degree.

4) A translational alignment based on a least squares estimate of Δx and Δy, the x and y-axis misalignment. Fourier transform phase data is used in this step.

5) A fine angular correction.

Steps 4) and 5) are repeated iteratively until the computed translational correction becomes less than a small threshold.

The alignment algorithm is based on the well-known Fourier transform space-shifting theorem[1]. The theorem can be stated simply as follows: Let $I(x, y)$ be the intensity function of the reference image and $I_{\Delta x, \Delta y, \Delta\Theta}(x, y)$ be the intensity function of an identical image translated by Δx, Δy and rotated by $\Delta\Theta$. Let $F(\omega_x,\omega_y)$ and $F_{\Delta x, \Delta y, \Delta\Theta}(\omega_x,\omega_y)$ be the Fourier transforms of these images respectively. Then

$$|F(\omega_x,\omega_y)| = |F_{\Delta x, \Delta y, 0}(\omega_x,\omega_y)| \tag{1}$$

and

$$\arg\{F(\omega_x,\omega_y)\} - \arg\{F_{\Delta x, \Delta y, 0}(\omega_x,\omega_y)\} = \omega_x\Delta x + \omega_y\Delta y \tag{2}$$

[1] J. W. Goodman, Introduction to Fourier Optics, McGraw-Hill 1968, chap. 2.

The first equation states that if the two images are in angular alignment (but not necessarily translational alignment) then the magnitude of their Fourier transforms would be identical. Hence, a cross-correlation of the magnitudes of the two transforms achieves its maximum when the two images are aligned in angle. This property is the basis of steps 2), 3) and 5) in the algorithm.

Once the images are in angular alignment the second equation above states that the difference between the phase of the two transforms is a bilinear function of the misalignment Δx and Δy. These offsets could, in principle, be determined using only two spatial frequencies. However, a superior approach is to increase the number of samples and estimate Δx and Δy using least squares estimation. Since a number of samples are used in computing the estimate, the effect of noise at each sample is reduced through averaging over the set of spatial frequencies. This approach is used in step 4) of the algorithm.

There is, however, an additional complication not evident in equations (1) and (2). The DEFT sensors each have a 1.27 cm x 1.27 cm square aperture onto which the images must be focused. To maximize resolution, it is desirable that I (x,y) completely fills the aperture of one sensor. Since magnification is the same for both images, $|F|$ cannot equal $|F_{\Delta x,\ \Delta y,\ \Delta\Theta}|$ unless $\Delta x = \Delta y = \Delta\Theta = 0$ since, otherwise, part of $I_{\Delta x,\ \Delta y,\ \Delta\Theta}$ will fall outside the aperture of the second sensor. Hence, equations (1) and (2) are only approximately true. The alignment algorithm has been designed to be insensitive to this approximation. This is accomplished by iterating steps 4) and 5). That is, corrections are computed assuming that equations (1) and (2) are exactly satisfied. These corrections are applied to the misaligned image to bring it into alignment with the reference. Since the equations are only partially satisfied there will be a residual error. New corrections are recomputed and applied iteratively until the magnitude of the correction falls below a threshold. At that point the two images are assumed to be aligned. If, indeed, the algorithm converges to alignment then, in the limit, equations (1) and (2) will hold exactly.

Analytic conditions for convergence are image dependent, difficult to derive and probably not useful in practice. However, in experiments using test patterns containing prominent spatial frequency components, (e.g., grid patterns), the algorithm was successful in aligning images to high accuracy. Some experimental results are presented in Table 3. The reference image in this case was a black and white checkerboard pattern with a horizontal frequency of 10 line pairs across the sensor aperture and with a vertical frequency of 5 line pairs. The reference image was placed in three orientations: 1) 10 line pairs horizontal (0 degrees), 2) 10 line pairs with a 6.5 degree tilt and 3) 10 line pairs vertical (90 degrees). The misaligned image was identical. The initial and final offsets are shown in the table. For this pattern all final errors were less than 0.1 mm in Δx, Δy with one exception and 0.2 degrees in $\Delta\theta$. (These errors are referred to the light table. Because of the 20:1 demagnification from light table to sensor, the errors Δx, Δy referred to the sensor were all less than 5 microns.)

A detailed description of the alignment algorithm is contained in Sections III B. through III E. Section III F. contains a discussion of the computational requirements of the algorithm. It is shown there that the algorithm has computational advantages over algorithms which use image intensity data as input rather than the Fourier transform.

B. Spatial Frequency Selection

For computation time and signal-to-noise considerations a small number of spatial frequencies must be automatically selected by the program from the large number of addressable spatial frequencies within the bandwidth of the DEFT sensors.

TABLE 3

Initial and Final Offsets: Typical Test Pattern

Reference Orientation (deg.)	Initial Offsets Δx (mm)	Δy (mm)	Δθ (mm)	Final Offsets Δx (mm)	Δy (mm)	Δθ (mm)
0	+5.00	+5.00	-2.0	.00	+.04	0.0
0	-5.00	+5.00	-2.0	-.02	+.05	-0.1
0	-5.00	-5.00	-2.0	-.03	-.07	-0.1
0	+5.00	-5.00	-2.0	-.01	-.13	0.0
6.5	+5.00	+5.00	-2.0	+.01	+.03	-0.1
6.5	-5.00	+5.00	-2.0	-.05	+.03	-0.2
6.5	-5.00	-5.00	-2.0	-.06	-.05	-.01
6.5	+5.00	-5.00	-2.0	-.04	-.04	-0.2
90	+5.00	+5.00	-2.0	-.02	+.05	-0.1
90	-5.00	+5.00	-2.0	-.08	+.07	-0.2
90	-5.00	-5.00	-2.0	-.06	+.03	-0.1
90	+5.00	-5.00	-2.0	+.07	+.03	0.0
Mean				-.0183	+.0033	-0.10
Standard Deviation				.0386	.0583	.0577

The method of selection of these spatial frequencies will be discussed in this section.

The alignment algorithm requires the computation of a cross-correlation at each angle increment during angular alignment. In addition, a least squares estimation is required at each iteration of the translational alignment. The computation time required is linearly proportional to the number of spatial frequency samples used. Hence, it is desirable to use as few spatial frequencies as possible. However, since each sample will contain noise due to the sensor, electronics and A/D converter it is necessary to use a set of spatial frequencies so that noise will be averaged out. Through experimentation it has been determined that about 16 spatial frequencies are adequate for the proper functioning of the algorithm.

These spatial frequencies are selected using transform data from the reference image only. A number of criteria are necessary in the selection of these points.

1). The reference transform evaluated at the spatial frequency should have a large magnitude. This increases the signal-to-noise ratio. It is especially important for least squares estimation since noisy phase data is weighted the same as phase data from significant transform components.

2). The set of spatial frequencies must not all lie along a straight line through the origin of transform space. During translational alignment a plane defined by $\omega_x \Delta x + \omega_y \Delta y$ is fitted to data consisting of transform phase differences. Since three points (which are not all on the same line) are required to define a plane, the spatial frequencies selected must not all lie along the same line. In addition, the least squares equation will be ill-conditioned if all data points are clustered along a line through the origin. If the equations are ill-conditioned then a small amount of noise at the A/D output will be magnified to a large error in the computed corrections Δx, Δy. A situation where ill-conditioning would occur would be if all the spatial frequencies selected were clustered around a single peak in the transform.

3). Spatial frequencies near the origin of spatial frequency space should not be used. The transform magnitude and phase is rather insensitive to translation and rotation for very low spatial frequencies.

4). High spatial frequencies should not be used for coarse translational alignment if Δx or Δy are so large that $|\omega_x \Delta x| + |\omega_y \Delta y| \geq \pi$. This is because true phase cannot be measured. Rather, the principal value of phase is measured. Phase differences greater than π cannot be detected. However, as translational errors are reduced Δx and Δy will be smaller, allowing the use of higher spatial frequencies for fine alignment.

A search scheme which was developed to satisfy these criteria will now be described. The area searched in spatial frequency space is shown in Figure 5. As noted above, a region of low frequencies is excluded. During the first stage of the search, this region is sampled on a grid with a spacing of 210 kHz in both dimensions. Spacing is fine enough to satisfy the Nyquist criteria but coarse enough to require sampling at only 959 points. At each point on this grid the reference transform is sampled and the magnitude of the transform computed. From these magnitudes a table is constructed. The n-th entry in this table is the number of samples for which the magnitude of the sample is greater than n x THR2 where THR2 is a small constant. (In the software, this table is constructed during calls to subroutine UPDATE.) After the transform is searched, subroutine THRSET is used to determine the number n such that the n-th table entry is less than or equal to NPT and the n-1st entry is greater than NPT. NPT is the desired number of spatial frequencies which is 16. Then the threshold THR1 is set to nxTHR2. The significance of THR1 is the following. If during the first stage of the search, a spatial frequency was accepted if and only if the magnitude of the transform at that frequency was equal to or greater

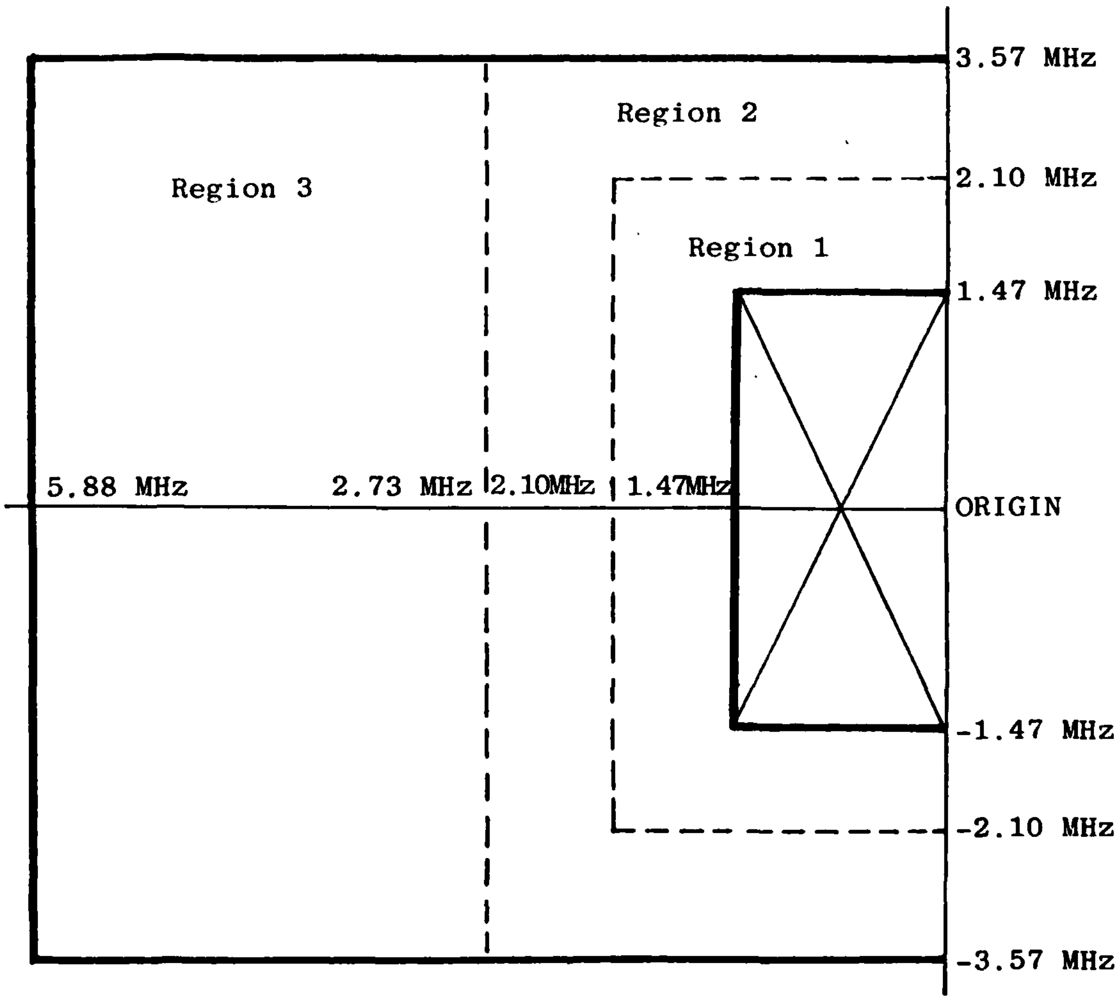


Figure 5 - Search Area in Spatial Frequency Domain

than THR1, then the number of samples accepted would be less than or equal to NPT.

Once THR1 is computed the second stage of the search is initiated. The reference transform is again searched over the coarse 210 kHz grid. However, each time the magnitude of a sample equals or exceeds THR1, a fine search is initiated in the 180 kHz x 180 kHz square centered at the sample. The fine search grid spacing is 30 kHz. (In the software, this search is carried out in subroutine GSRCH.) The spatial frequency with largest transform magnitude in this square is determined. This magnitude is compared with THR1. If it is at least as large as THR1 the spatial frequency is accepted and becomes one of the set to be used in the subsequent operations of correlation and least squares extimation. The use of the fine search results in spatial frequencies with larger magnitudes. Since a fine search is initiated only when THR1 is equalled or exceeded during the coarse search, the time spent in fine search is minimized. This procedure is continued over the entire coarse grid bounded as in Figure 5. Because of the way THR1 was chosen, the number of spatial frequencies chosen will be close to the desired NPT.

Since only one spatial frequency can be chosen in each 180 kHz x 180 kHz square, the set of spatial frequencies chosen tend to represent the prominent frequency components of the transform without clustering exclusively around a single large peak (if the transform contains one.)

To prevent a condition of phase ambiguity as outlined in criterion 4) above, the search area shown in Figure 5 is subdivided into three regions. During least squares estimation of Δx, Δy only spatial frequencies from region 1 are used until the iteration when the computed correction becomes less than a threshold DELTA (1). On the next iteration spatial frequencies in both region 1 and region 2 are used. This is the case until the iteration when the computed correction becomes less than the threshold DELTA (2). On the next and all succeeding iterations spatial frequencies from all three regions are used.

Hence, as Δx and Δy decrease higher spatial frequencies can be used to provide higher resolution since $\omega_x \Delta x + \omega_y \Delta y$ decreases with Δx, Δy.

In the alignment program the thresholds are stored in a table DELTA (L). At the beginning of least squares estimation L is set to 1. After a correction is computed, if $|\Delta x| + |\Delta y| \leq$ DELTA (L) L is incremented by 1. The parameter L also keeps track of which regions are to be used on the next iteration. DELTA (3) is the final threshold. Once the computed correction is reduced below this threshold the program assumes that the images are aligned and returns control to the supervisor. For further detail, refer to the flow diagram Figure 10.

The search scheme developed in this section has been shown to satisfy all four criteria listed above. In addition, it makes efficient use of computation time and has worked well during tests. For further detail, refer to Figure 7.

C. Angular Alignment

Angular alignment occurs at three points in the algorithm and software: 1) coarse angular alignment, 2) fine angular alignment and 3) a fine angular correction or "dithering" after each least squares estimate of Δx, Δy. In all three cases the measure used to determine alignment is the cross-correlation of the magnitudes of the Fourier transforms of the reference and misaligned image sampled at the frequencies chosen during spatial frequency selection. Let $m_{r,i}$ be the magnitude of the reference transform at spatial frequency i and let $m_{a,j}$ be the magnitude of the misaligned transform at spatial frequency j. Then the Cauchy-Schwarz inequality[2] states that

$$\left(\sum_{i=1}^{n} m_{r,i} m_{a,i}\right)^2 \leq \left(\sum_{i=1}^{n} m_{r,i}^2\right) \left(\sum_{i=1}^{n} m_{a,i}^2\right) \qquad (3)$$

with equality if and only if $m_{a,i} = m_{r,i}$ for every i. Hence,

[2] D.L.Kreider, et al., An Introduction to Linear Analysis, Addison-Wesley, 1966, chap. 7.

the measure

$$SUM = \frac{\left(\sum_{i=1}^{n} m_{r,i} m_{a,i}\right)^2}{\sum_{i=1}^{n} m_{a,i}^2} \qquad (4)$$

achieves its maximum when $m_{a,i} = m_{r,i}$ for every i. From equation (1) this condition will occur when the two images are aligned in angle. Angular alignment is achieved by trying various angles, computing SUM and picking the angle where SUM is maximum. Three different search schemes are used at the three sections in the algorithm where there is an angular alignment.

The first alignment is coarse angular alignment. The misaligned image is assumed to be misaligned in angle within some maximum displacement. (In the software this displacement is ±6 degrees and is stored in the variable CORSE.) During coarse angular alignment the light table is first rotated cw 6 degrees and SUM computed. The table is then rotated ccw in 2 degree steps over a 12 degree sector. At each step SUM is computed and compared with the previous largest value of SUM which is stored in the variable MAX. If SUM > MAX then MAX is replaced by SUM and the angular position saved in the variable STEPS. After the table has been rotated over the 12 degree sector it is rotated back to the position of maximum SUM. This ends the coarse angular alignment. For more detail, refer to the program flow diagram Fig. 8.

The next phase is fine angular alignment. At the beginning of this phase the light table is at the position of maximum SUM determined during coarse alignment. The variable MAX holds this value of SUM. The angle step size is set initially to a value stored in the variable FINE. (This value is 1.6 degrees in the program.) Current step size is stored in the variable STEPS. The light table is then rotated cw STEPS degrees and SUM is computed. If SUM >MAX a flag is set and SUM replaces MAX. The light table is then rotated ccw 2 × STEPS degrees and SUM is computed. If SUM > MAX a flag is set and SUM replaces MAX. The light table is then rotated to the position where SUM was maximum (either where it was initially or ±STEPS degrees from that position.) Then STEPS is divided by 2. The above three-position search is repeated iteratively until STEPS has been reduced below 0.1 degree. This one-dimensional search technique converges quickly to the maximum SUM to within 0.1 degrees. Since only two evaluations of SUM are required per iteration, a total of 10 evaluations are required during fine angular alignment. By comparison, a brute force search over 4 degrees in 0.1 degree steps would require 40 evaluations of SUM. Other search techniques such as Fibonacci and golden section[3] were investigated during the development of the algorithm. However, because they maximize a function of a continuous variable they were not applicable since angle increments are discrete, 0.1 degree steps in the image alignment system. Once STEPS has been reduced below 0.1 degree fine angular alignment is complete. For more detail, refer to program flow diagram Figure 9.

As discussed in the Overview, since each sensor does not see the exact same image because of misalignment, equations (1) and (2) are only approximate during alignment. The coarse and fine angular alignment must occur before estimation of Δx and Δy. This is because equation (2) requires that $\Delta\Theta = 0$. However, since $\Delta x \neq 0$, $\Delta y \neq 0$ during angle alignment, equation (1) is only approximate and very likely the position of maximum SUM will not correspond exactly with $\Delta\Theta = 0$. Hence, a residual angle error will generally exist after fine angular alignment. This residual error will prevent Δx and Δy from being estimated exactly since equation (2) will only approximately hold. However, if Δx and Δy can at least be reduced then it should be possible to further reduce $\Delta\Theta$. This will, in turn, allow better estimates of Δx, Δy. Hence, the algorithm was designed to be iterative. That is, after fine angle search a series of iterations consisting of a least squares estimation followed by a fine angle correction is carried out. This approach has worked well in practice. Depending on the test image, $\Delta\Theta$ can be as large or larger than 1.0 degree after fine angular alignment. However, as Δx and Δy are reduced $\Delta\Theta$ will

[3] D. J. Luenberger, Introduction to Linear and Nonlinear Programming, Addison-Wesley, 1973, chap. 7.

be reduced to a few tenths of a degree.

Fine angle correction is very similar to a single iteration during fine angular alignment. After Δx and Δy have been estimated and the light table moved to eliminate these estimated errors, SUM is recomputed and stored in MAX. The light table is then rotated cw 0.1 degree and SUM is computed. If SUM > MAX a flag is set and MAX is replaced with SUM. The light table is then rotated ccw 0.2 degrees and SUM is computed. If SUM > MAX a flag is set and MAX is replaced with SUM. The light table is then rotated to the position where SUM was maximum. Hence, up to ±0.1 degree of correction can be applied each iteration. For further detail refer to flow diagram Figure 10. Both fine angular alignment and fine angular correction is accomplished in software in subroutine FINSCH.

D. Least Squares Estimation of ΔX and ΔY

Estimation of Δx and Δy is based on equation (2). This equation states that if $\Delta\Theta = 0$ then the difference in phase between the reference and misaligned transform is a bilinear function of Δx and Δy. By measuring this phase difference at the previously chosen set of spatial frequencies Δx and Δy can be estimated by fitting a plane to the data. A standard means of curve fitting is least squares estimation[2].

To apply least squares estimation, the first step is to sample the transforms at the pre-selected spatial frequencies using the DEFT sensors and compute the phase from the real and imaginary parts of the transform. This rectangular-to-polar conversion is accomplished using the Cordic algorithm[4]. Both the transform magnitude and phase are computed. (In the software, this is implemented in subroutine CORDIC.) The transform phase as provided by the DEFT sensor is of the form

$$\phi_R(\omega_x,\omega_y)=\phi_{TR}(\omega_x,\omega_y)+\phi_E(\omega_x,\omega_y)+\phi_{RO} \qquad (5)$$

for the reference image and

$$\phi_A(\omega_x,\omega_y)=\phi_{TA}(\omega_x,\omega_y)+\phi_E(\omega x,\omega y)+\phi_{AO} \qquad (6)$$

for the misaligned image where ϕ_R and ϕ_A are the total phases of the reference and misaligned images, respectively. ϕ_{TA} is the phase due

[2] *op. cit.*

[4] J.E.Volder, "The Cordic Trigonometric Computing Technique," IRE Trans. Comp. Sept. 1959, pp. 330-334.

to the Fourier transform of the reference image. ϕ_{TA} is the phase due to the Fourier transform of the misaligned image. ϕ_E is phase due to the electronic detectors, filters and cables. ϕ_{RO} and ϕ_{AO} are constant phase terms associated with the reference and aligning sensor. $\phi_{RO} \neq \phi_{AO}$. This phase difference arises from the non-equal length of cables connecting the sensor modules to the computer cabinet as well as from sensor mismatch such as acoustic wave velocity differences. ϕ_E is approximately equal for both modules. Hence, if the images are perfectly aligned, $\phi_R - \phi_A = \phi_{RO} - \phi_{AO}$. Hence the term $\phi_{RO} - \phi_{AO}$ must be subtracted from the left side of equation (2) since it arises from the sensors and electronics and has nothing to do with the Fourier transform. The first step in least squares estimation then is to measure $\phi_{RO} - \phi_{AO}$. Recall that for any image which is an intensity function

$$\phi_{TR}(0,0) = \phi_{TA}(0,0) = 0 \qquad (7)$$

Hence

$$\phi_A(0,0) - \phi_A(0,0) = \phi_{RO} - \phi_{AO} \qquad (8)$$

Hence, $\phi_{RO} - \phi_{AO}$ can be measured by sampling the two transforms at zero spatial frequency, computing the phase and subtracting the respective phases. Since the transform always has maximum magnitude at zero spatial frequency, the signal-to-noise ratio for this measurement will be good. The computed phase difference $\phi_{RO} - \phi_{AO}$ must be adjusted to lie in the interval $(\pi, -\pi]$. In the software, this adjustment is made in subroutine PHASDF. Subroutine PHSSET measures the phase difference and stores the result in the variable PHASE.

Once PHASE has been computed, the left side of equation (2) can be evaluated. At each of the selected spatial frequencies ω_{xi}, ω_{yi} the two transforms are sampled and the phase computed. The difference

$$P_i = \phi_R(\omega_{xi}, \omega_{yi}) - \phi_A(\omega_{xi}, \omega_{yi}) - \text{PHASE} \qquad (9)$$

is formed and adjusted to lie in the interval $(\pi, -\pi]$. During any given iteration, only those spatial frequencies lying in the regions whose indices are less than or equal to L are evaluated. Then the following quantities are computed:

$$UU = (1/K\$G) \sum_{i=1}^{L} S1U(i) \tag{10}$$

$$VV = (1/K\$G) \sum_{i=1}^{L} S1V(i) \tag{11}$$

$$UV = (1/K\$G) \sum_{i=1}^{L} S1UV(i) \tag{12}$$

$$UP = (1/KKKK) \sum_{i=1}^{L} S1UP(i) \tag{13}$$

$$VP = (1/KKKK) \sum_{i=1}^{L} S1VP(i) \tag{14}$$

The variables UU through VP are computed in subroutine SUMPAR from partial products S1U through S1VP which are computed in subroutine MEASRE. K$G and KKKK are scale factors which scale the corrections Δx and Δy. The variables S1U through S1VP are defined as

$$S1U(i) = \sum_{j=k}^{\ell} (cf_{xj})^2 \tag{15}$$

$$S1V(i) = \sum_{j=k}^{\ell} (cf_{yj})^2 \tag{16}$$

$$S1UV(i) = \sum_{j=k}^{\ell} c^2 f_{xj} f_{yj} \tag{17}$$

$$S1UP(i) = \sum_{j=k}^{\ell} cf_{xj} P_j \tag{18}$$

$$S1VP(i) = \sum_{j=k}^{\ell} cf_{yj} P_j \tag{19}$$

where $f_{xj} = \omega_{xj}/2\pi$, $f_{yj} = \omega_{yj}/2\pi$ and c is a constant used to scale the fixed point frequency variables used by the program. The limits k and ℓ are defined by

$$k = BDRYCT(i-1) + 1 \tag{20}$$

$$\ell = BDRYCT(i) \tag{21}$$

BDRYCT is a table in software and the entry BDRYCT(i) is the number of spatial frequencies in region 1 through region i. BDRYCT(0) is defined to be zero. If $k > \ell$ then there are no points in region i and the S1 terms are defined to be zero for that i. Hence, the indices k and ℓ limit the partial products S1 to contain contributions from only those spatial frequencies within region i. The terms UU through VP contain contributions from spatial frequencies in regions 1 through region L.

With these definitions the least squares solution for Δx and Δy is given by[2]

$$\begin{bmatrix}\Delta x\\ \Delta y\end{bmatrix} = \frac{1}{K}\begin{bmatrix}UU & UV\\ UV & VV\end{bmatrix}^{-1}\begin{bmatrix}UP\\ VP\end{bmatrix} \tag{22}$$

The gain constant 1/K equals 1 during the first 12 iterations. After 12 iterations it equals 1/(i-11) on the ith iteration. Hence, after 12 iterations, the computed correction is weighted by a gain factor which decreases each succeeding iteration. This has the effect of making the final alignment insensitive to any noise in the phase differences P_i. This technique is a variation of the Robbins-Monro procedure for finding the root of a function in the presence of noise. A readable discussion of this procedure is contained in [5]. The harmonic sequence of weights {1, ½, 1/3, ¼, ... } has the property that

$$\lim_{n\to\infty} 1/n = 0 \tag{23}$$

while

$$\sum_{n=1}^{\infty} \frac{1}{n} = \infty \tag{24}$$

That is, the computed corrections will always be reduced to zero while the total corrective effort is potentially unlimited. It is shown in [5] that random experimental errors will be cancelled out using this sequence of weights. However, another important reason for using this sequence was to insure that the program will satisfy its stopping condition after a reasonable number of iterations. This stopping condition is that

$$|\Delta x| + |\Delta y| \le .04\text{mm} \tag{25}$$

It was found through experimentation that reducing the right hand side of this equation did not improve the accuracy of

[5]D.J.Wilde, Optimum Seeking Methods, Prentice-Hall Inc. 1964.

algorithm but did increase its running time.

For additional detail refer to flow diagram Fig. 10. In this figure the notation (KKKK + 2) means a variable stored in RAM two bytes after the address of the label KKKK. The corrections Δx and Δy are computed iteratively. On the first iteration L = 1. L is incremented by one,if any one of the following conditions holds:

1) $|\Delta x| + |\Delta y| \leq \text{DELTA}(1)$ (26)

2) $|\Delta x| + |\Delta y| > 2\sqrt{2}$ " (27)

3) $\text{BDRYCT}(L) < 2$ (28)

Condition 1) means that a larger region is used as soon as the correction is small enough so that there can be no phase ambiguity. DELTA (3) = .04mm and is the stopping condition since NBDRY is set to 3. Condition 2) means that the computed correction is too large. The correction is skipped and a larger region is used on the next iteration. Condition 3) means that in the present region there is at most one spatial frequency. Since at least two spatial frequencies are required for the least squares extimation of Δx and Δy, the region is enlarged in hopes of increasing the number of spatial frequencies on the next iteration.

The partial products S1U, S1V and S1UV depend only on the chosen spatial frequencies. Hence, they are only computed once during spatial frequency selection. The partial products S1UP and S1VP depend on both the spatial frequencies and the transform phase at those frequencies. Hence, they must be recomputed each iteration.

During normal operation using both sensors, fresh magnitude and phase data from both sensors is collected each iteration. In addition, the origin phase difference is re-measured each iteration. Hence, any zero mean noise in these measurements will be averaged out over a number of iterations.

E. Alignment Algorithm: Alternative Modes of Operation

To add flexibility to this experimental alignment system the basic algorithm and software implementation has been augmented with two alternative modes of operation.

In order to test the alignment capabilities of the system for test images which are misaligned in translation only, the software can function in a mode which skips all angular alignment steps. That is, coarse angular alignment, fine angular alignment and fine angular correction (or dithering) are all skipped. In the program, the flag HOW is set to zero if these functions are to be skipped and set to one if they are to be executed. Refer to flow-diagrams Figures 6 through 10 for details. Angular alignment can be skipped during both the normal two-sensor mode of operation and also during the single sensor mode which will be described next.

To this point the description of the alignment algorithm has dealt exclusively with the normal two-sensor operation. In this mode, one sensor views the fixed light table which contains the reference image. The second sensor views the movable light table which contains the misaligned image. In the single sensor mode of operation, only the sensor which views the movable light table is used. The image on this table functions as both the reference and as the misaligned image. This is accomplished as follows: During spatial frequency selection the movable image is viewed and spatial frequencies chosen from its transform. Both the magnitude and phase of the transform at these frequencies are then sampled and stored in a table. Magnitude samples are stored in table MS while phase samples are stored in table PS. <u>These samples will not be updated until a new reference alignment is initiated</u>. The alignment program then returns control to the supervisor so that the user can move the light table under manual control. If the alignment program is re-entered, it will seek to re-align the misaligned image to its position during reference alignment using the tables MS and PS as a reference.

The structure of the alignment algorithm is identical for both two-sensor and one-sensor operation with the following exceptions:

1) The flag SNFLAG = 0 for two-sensor operation and SNFLAG =1 for one-sensor operation.

2) Since the two DEFT sensors have slightly different origin frequencies, near the beginning of single sensor reference alignment the reference sensor origin frequency variables XOZERO, YOZERO are replaced with the origin frequency values contained in the aligning sensor frequency variables X1ZERO, Y1ZERO.

The subroutine RDDEFT is used to sample the DEFT sensors and average either one or sixteen samples at each spatial frequency. (Single samples are taken only during the initial search for prominent spatial frequencies.) When the flag SNFLAG = 1, RDDEFT will always sample from the sensor which views the movable table (aligning sensor). By also replacing the origin frequencies the program operates normally but only receives data from the aligning sensor.

3) Since only a single sensor is used, no sensor phase mismatch exists. Hence, when subroutine PHSSET is entered the condition SNFLAG = 1 causes an immediate return to the main alignment program and no phase difference is required.

4) During the least squares estimation iterations, new reference phase samples cannot be taken since the reference orientation no longer exists. The flag SNFLAG causes this step to be skipped. (See the flow diagram for subroutine MEASRE, Figure 11. Phase samples are normally taken during MODE = 3.)

After a sequence of one-sensor alignments, the table of variables used in the alignment program must be re-initialized by pressing F followed by E. If this is not done and a correlation is attempted, then SNFLAG = 1 and only one sensor will be used erroneously. (That is, the movable image will be correlated against itself.) If instead, a two-sensor alignment is initiated, then SNFLAG will be reset to 0. However XOZERO and YOZERO will not be restored to their proper values. This will lead to larger than desired errors in alignment.

F. Algorithm Operation Count

In this section a simplified operation count for the Fourier transform-based alignment algorithm will be developed and compared with the operation count of an algorithm which aligns two images using the image intensity functions. For this development an operation is defined to be either a multiplication or a division.

Consider first the Fourier transform-based algorithm. Let n_s be the number of spatial frequencies used in the algorithm. The cross-correlation of two sequences of length n_s requires $2n_s + 2$ ops. An additional 2ns operations are required to form the magnitude from the real and imaginary components of the transform. (The Cordic algorithm takes about as long as a multiply.) Let n_θ be the number of correlations required for an alignment. (n_θ is typically 20 - 30.) The angle correlation requires $n_\theta(4n_s+2)$ ops. One iteration of least squares estimation requires 7ns + 12 ops. This count includes Cordic, formation of UU through VP and matrix inversion.

Let $n_{\ell s}$ be the number of iterations of least squares. (Typically, $n_{\ell s}$ is less than 10.) An additional count of 2200 ops are required during the search for prominent spatial frequencies. (These are all calls to CORDIC.) The total number of operations is

$$n_\theta(4ns+2) + n_{\ell s}(7n_s+12) + 2200 \qquad (29)$$

For the typical values $n_\theta = 30$, $n_x = 16$, $n_{\ell s} = 10$ the first term contributes 1980 ops, the second term contributes 1240 ops and the total is 5420 ops.

Consider now the intensity function-based algorithm. This algorithm works as follows: A three-dimensional grid of possible Δx, Δy, and $\Delta\theta$ values is searched. At each point in the grid the misaligned image is translated and rotated to the corresponding grid positions and the two images are correlated.

It may not be necessary to correlate every pixel. Let n_p be the number of pixels used. Then a single correlation requires $2n_p + 2$ ops. Let n_x, n_x and n_θ be the number of increments of Δx, Δy and $\Delta\theta$ to be tested. Then the number of operations for alignment is

$$n_x n_y n_\theta (2n_p + 2) \text{ ops} \qquad (30)$$

Additional operation would be required to choose the n_p pixels. For simplicity these will be ignored. To arrive at a number for comparison, assume that this algorithm searches a 5 mm x 5 mm x 12 degree cube with grid spacing .05 mm in x and y and .1 degree in θ. Then, $n_x = n_y = 100$ and $n_\theta = 120$. Assume $n_p = 16$. Then 40.8×10^6 ops are required for alignment. There are a number of multidimensional search techniques which will reduce this count considerably. However, in all circumstances the Fourier transform-based algorithm is more efficient since a multidimensional search is not required.

IV. SYSTEM SOFTWARE

A. General Description

The Image Alignment and Correlation System has been programmed to perform fourteen separate functions. The control programs for these functions are stored permanently in UV-erasable read-only memories at addresses $A000_H$ - $BFFF_H$. (All address references are given here in hexadecimal notation.) The software is organized as a supervisor or main program and a master subroutine for each of the three major system functions, which are display generation, image alignment, and image cross-correlation. The master subroutines use a number of smaller subroutines, many of which are shared.

In addition to the 8K of software written in the performance of this contract, the system includes a library of mathematical functions which resides at 8000_H - $83FF_H$ and a slightly modified version of the FANTOM-II monitor, located at $FC00_H$ - $FFFF_H$. Both of these items were purchased from Wintek Corp.

The system software uses RAM at 1700_H - $1FFF_H$ and $EC00_H$ - $EDFF_H$ for temporary storage of data and parameters. The remainder of RAM is available for future expansion or software experiments.

The following sections will describe the supervisor and the three master subroutines. The smaller subroutines, except for those which are self-explanatory from their listings, are described in Appendix A. Complete program listings for all of the Deft-written software, as generated by the Wintek assembler, are found in Appendix B. The math library and the FANTOM-II monitor are documented with the Commercial Data.

B. Supervisor Program ($A91C_H$ - $AA5D_H$)

When power to the system is turned on,a delay circuit on the auxiliary card (next to the DAS card) holds the microprocessor subsystem's reset line near ground until the power supply voltages and the clock frequency have stabilized. The small button on the auxiliary card also grounds the reset line. When the reset line goes high, the processor reads the contents of memory at hex addresses $FFFE_H$ and $FFFF_H$, and loads them into the program counter. Execution begins from that point.

As supplied by Wintek the reset vector is $FE\emptyset7_H$, which is the reset entry point of the FANTOM-II monitor. For the Image Alignment and Correlation System the reset vector in the FANTOM-II EPROM was changed to $A91C_H$, and $FE\emptyset7_H$ was used instead as the vector for non-maskable interrupts (NMI) which is stored at $FFFC_H$ - $FFFD_H$. This change allows the other small button behind the door, which grounds the NMI line, to stop execution and transfer control to the FANTOM-II monitor. Except for these four bytes, the monitor in the system is identical to FANTOM-II as documented with the Commercial Data.

When execution begins at $A91C_H$ following a system reset, the first instructions set up the peripheral interfaces and initialize certain parameters in read/write, or random access memory (RAM). The supervisor then enters a wait loop at $A9B9_H$ with dashes displayed on the front-panel LED readout. The dashes indicated that the system is ready to accept commands from the keypad directly below the readout.

Pressing a key at this point will result in the display of the corresponding program number, with two exceptions. They are "A", which is reserved for ABORT, and "E", which is used for EXECUTE. After entering a valid program number, pressing "E" will cause execution of that program to begin. Any time before "E" is pressed, entering a new program number will override the preceding entry. Pressing "E" initially will have no effect. Entering "A" at any time will cause a return to the supervisor, and the execution of any program in progress will be terminated. Decoding of the "A" key and updating of the LED display is done in the interrupt service routine.

Near the end of the wait loop a test is made (at $AA\emptyset7_H$)

to see if the system is in a calibrated state for alignment. If so, another test is made to sense whether any of the stepper motors is being actuated manually. If the clock pulse which moves a motor is detected, further tests are done to identify the motor. "Error" is displayed if the motor cannot be identified, and if this should occur it would indicate a hardware failure. After the stage in motion is identified a subroutine (POSDIS) is called which updates the counters which keep track of the positions of the translation and rotation stages when the system is calibrated. This subroutine also displays these positions. On returning from the subroutine the program checks for the end of the stepper motor pulse so that one pulse is not counted as two.

The entry addresses of the master subroutines are stored in a table at $A8\emptyset\emptyset_H$. When the "E" key is pressed with a valid program number in place, the program number is used to point to the corresponding entry address, and a jump-to-subroutine (JSR) at that address is executed. Upon returning, the program number is examined and the display is either left unaltered or cleared and filled again with dashes.

C. Plotter and CRT Display Routine ($ABC\emptyset_H$ - $ADE2_H$)

Entry to this program at $AC47_H$ first initializes a number of parameters and clears a 256-byte area in RAM where the largest current vertical deflection values will be stored. It then tests the program number to determine which image is to be displayed, and sets the analog multiplexer in the DAS accordingly. A heading is written on the CRT display, showing the starting points for the frequency scan and identifying the image whose transform is being displayed.

The action of the program from this point depends on whether the x-y plotter or the CRT display is being executed, and this distinction is coded in the least-significant bit (LSB) of the program number. In the case of the plotter the pen is retraced to the lower left corner and dropped to the writing position. In the case of the CRT display, which is vector driven, a dark vector is written to the lower left corner. The synchronous detector subroutine then samples the analog outputs from the appropriate synchronous detector circuit card and converts them to a complex digital representation of the sensor output. The detector subroutine returns the sums of sixteen consecutive samples for both the real and imaginary parts.

At this point the x-axis synthesizer frequency is increased by 40 kHz to allow the subsequent processing time for frequency stabilization. An extra time delay is inserted if the synthesizer crosses the boundary of 40 MHz, but this will not occur unless the starting frequencies or increments are changed. The absolute magnitude of the complex signal value is then computed by the CORDIC subroutine and a scaling or gain adjustment is made by shifting the result to the left.

The signal magnitude then is added to the raster height and compared to the previous value at the same horizontal position. For the first line of the raster the "previous" values are all zero. If the new value exceeds the old value, the new value is stored and either the pen is moved accordingly or a vector is drawn on the CRT display. If the old value is greater, the pen is lifted, or a character denoting a dark vector is sent to the CRT display, so that raster lines behind peaks are hidden.

This sequence is repeated 192 times for each line of the raster. At the end of each line the y-axis synthesizer frequency is incremented by 120 kHz and the x-axis frequency is returned to its starting point. The position of the raster line is moved up by a count of 2 for the CRT display or 3 for the plotter. The number of the raster line becomes the initial x-coordinate to tilt the raster, and either the pen is lifted and retraced to that point or a dark vector is written to retrace the CRT display.

Sixty-four lines are drawn in this manner. At the end of the last line the pen is lifted and moved to the lower right corner if the x-y plotter is being driven, so that the paper can be removed easily. Then a bell code is sent to the terminal, followed by a return to the supervisor.

D. Alignment Program and Its Subroutine

The alignment program is written in the form of a main subroutine which is called by the supervisor program under control of the matrix key pad. Additional subroutines are called by the alignment program. The logical flow of the program is complex and is best understood by study of the assembly language listing in Appendix B. Flow diagrams are provided here which show the functional flow of the program. These diagrams can be used to relate the algorithm to its assembly language implementation.

Refer to the overall flow diagram, Figure 6. More detailed flow diagrams are shown in subsequent figures. The alignment program operation is controlled by three variables SNFLAG, HOW and CALIBR. These variables are set either before entry or upon entry to the alignment program and remain constant during each call to that program. For the various modes of operation, their values are indicated in Table 4. As shown, CALIBR indicates whether an alignment is to be a reference or a subsequent alignment. SNFLAG indicates whether one sensor or two sensors are to be used. HOW indicates whether the alignment is to include rotation.

The functional flow of the alignment program closely follows the description of the algorithm given in Section III.

The main subroutine which is called by the alignment program is MEASRE. This subroutine has a number of functions controlled by variables MODE, SNFLAG, SFLAG and ADRSW. The flow diagram of MEASRE is shown in Figure 11. When MODE = 1, MEASRE is used in spatial frequency selection. When MODE + 2 MEASRE is used in angular alignment. When MODE = 3 MEASRE is

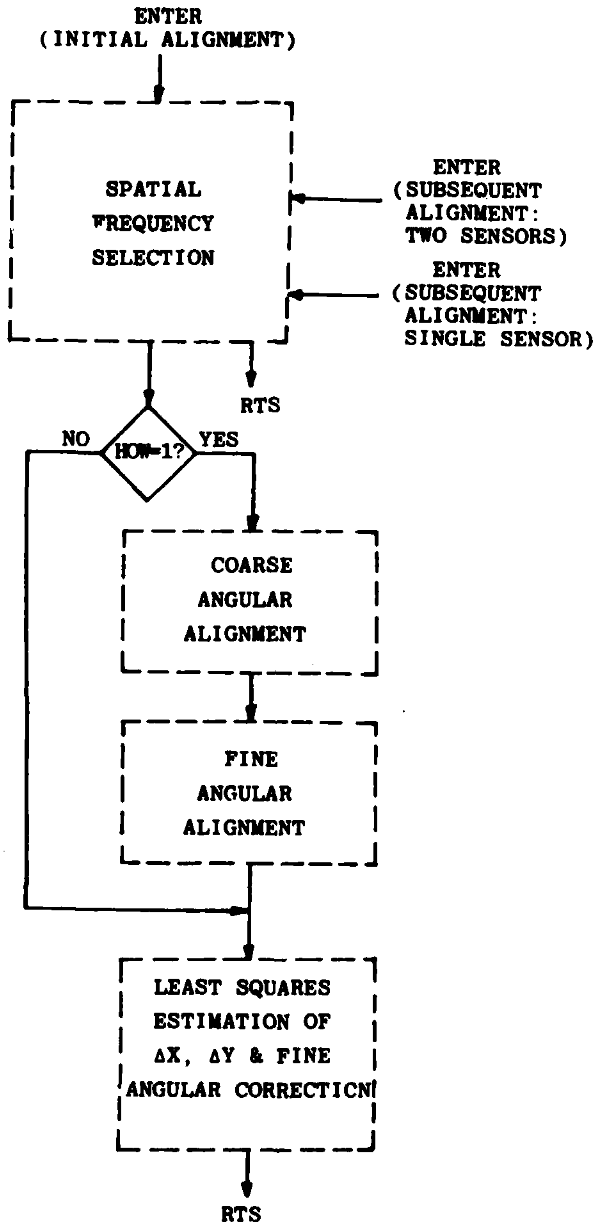


Figure 6 - Overall Flow Diagram for Alignment Program

TABLE 4

Modes of Operation	Flags		
	CALIBR	SNFLAG	HOW
Initial alignment/two sensors	0	0	1
Initial alignment/one sensor	0	1	1
Subsequent alignment/two sensors/ rotation	1	0	1
Subsequent alignment/two sensors/ no rotation	1	0	0
Subsequent alignment/one sensor/ rotation	1	1	1
Subsequent alignment/one sensor/ no rotation	1	1	0

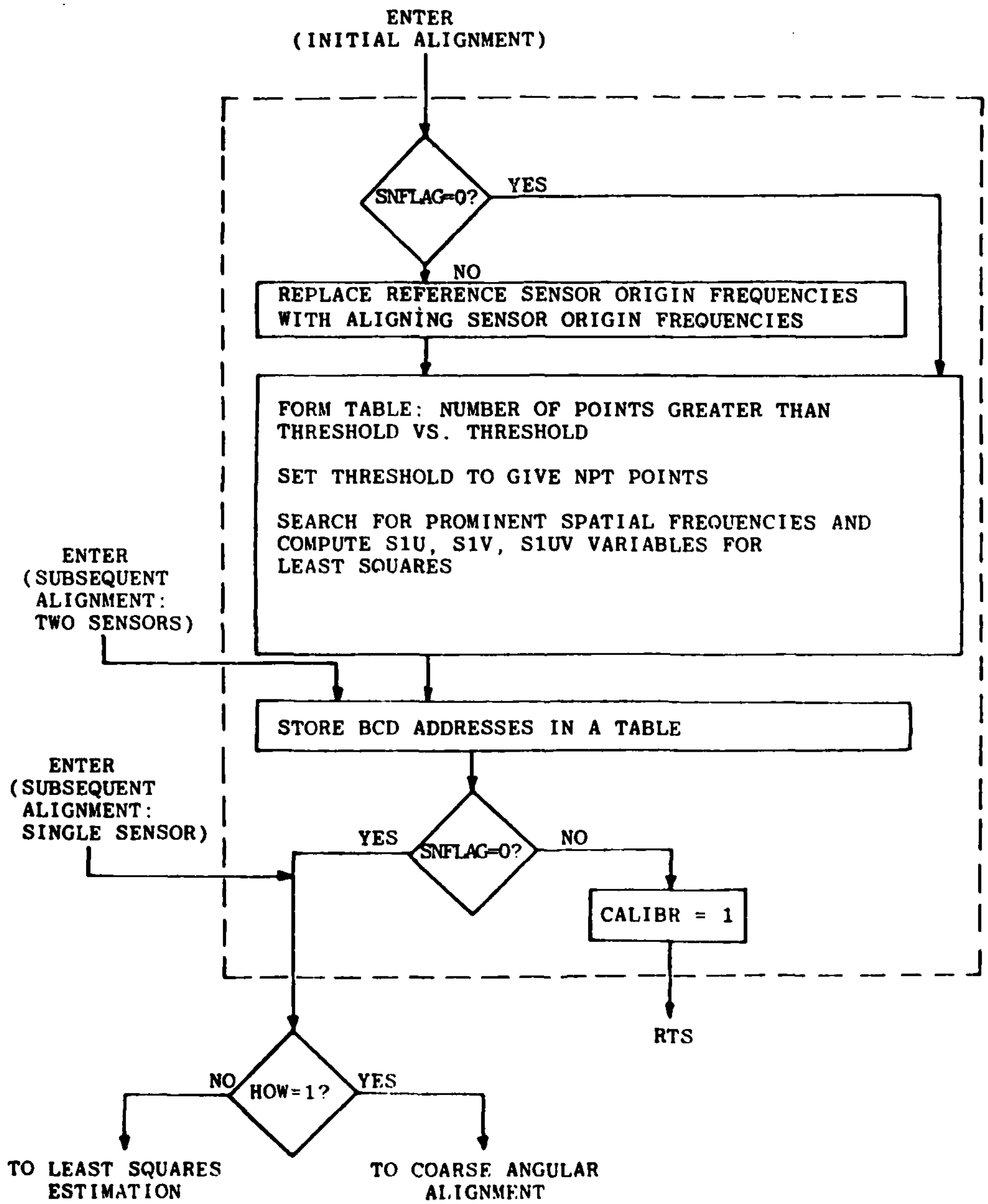


Figure 7 - Flow Diagram for Spatial Frequency Selection

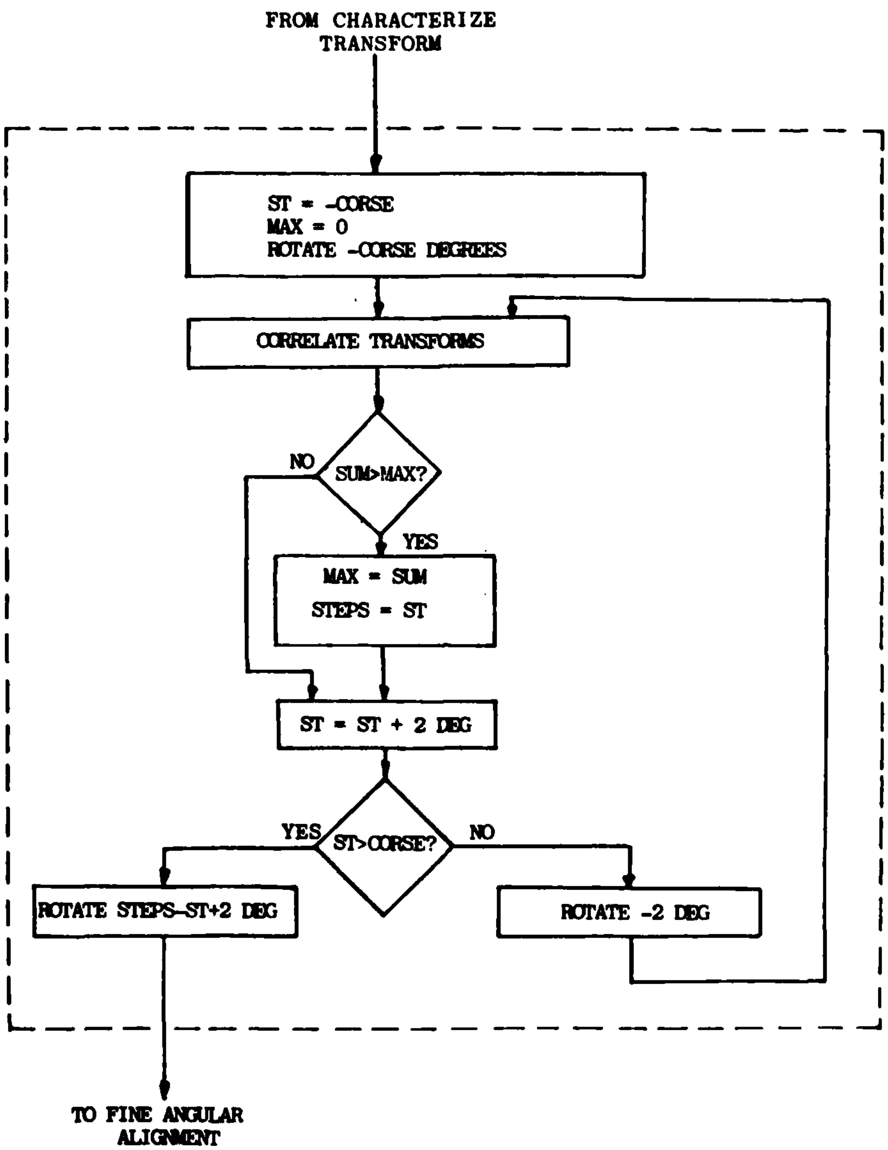
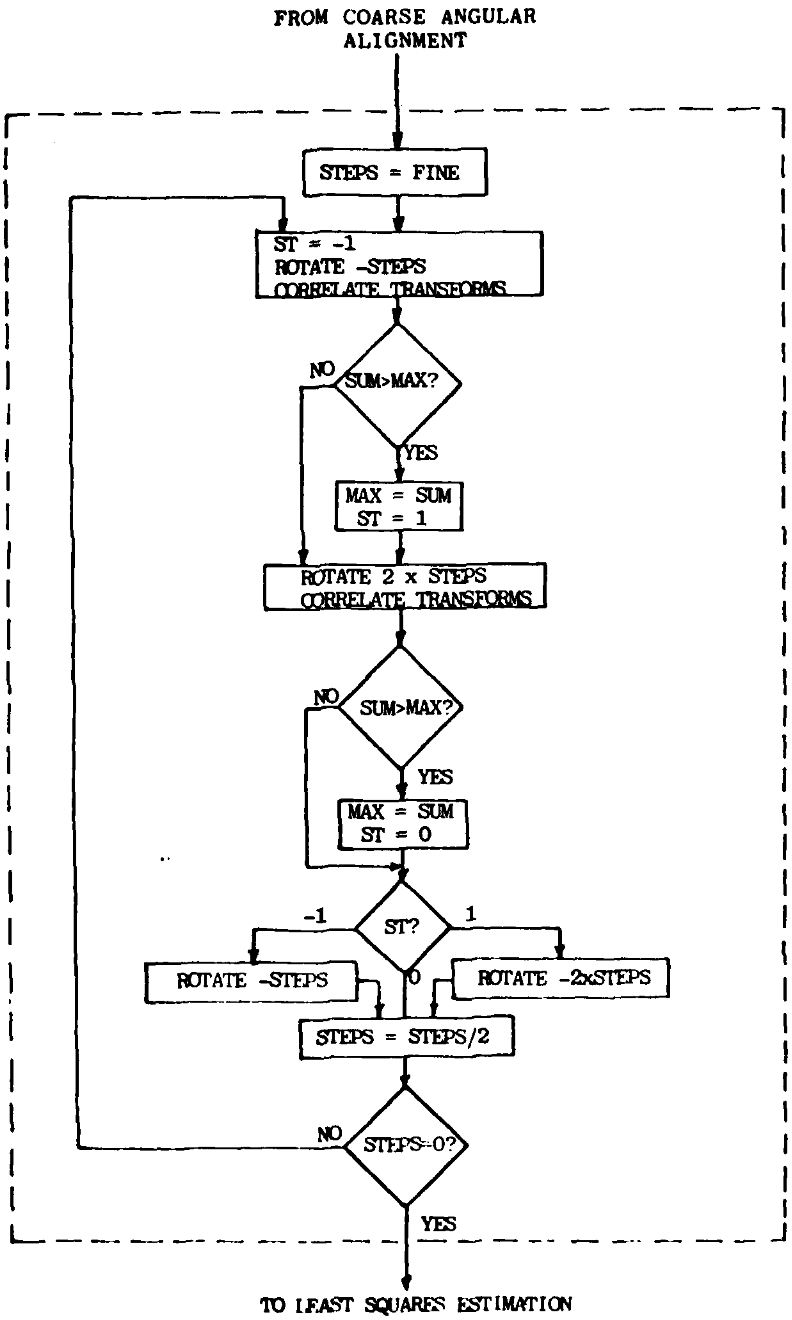


Figure 8 - Flow Diagram for Coarse Angular Alignment



<u>Figure 9</u> - Flow Diagram for Fine Angular Alignment

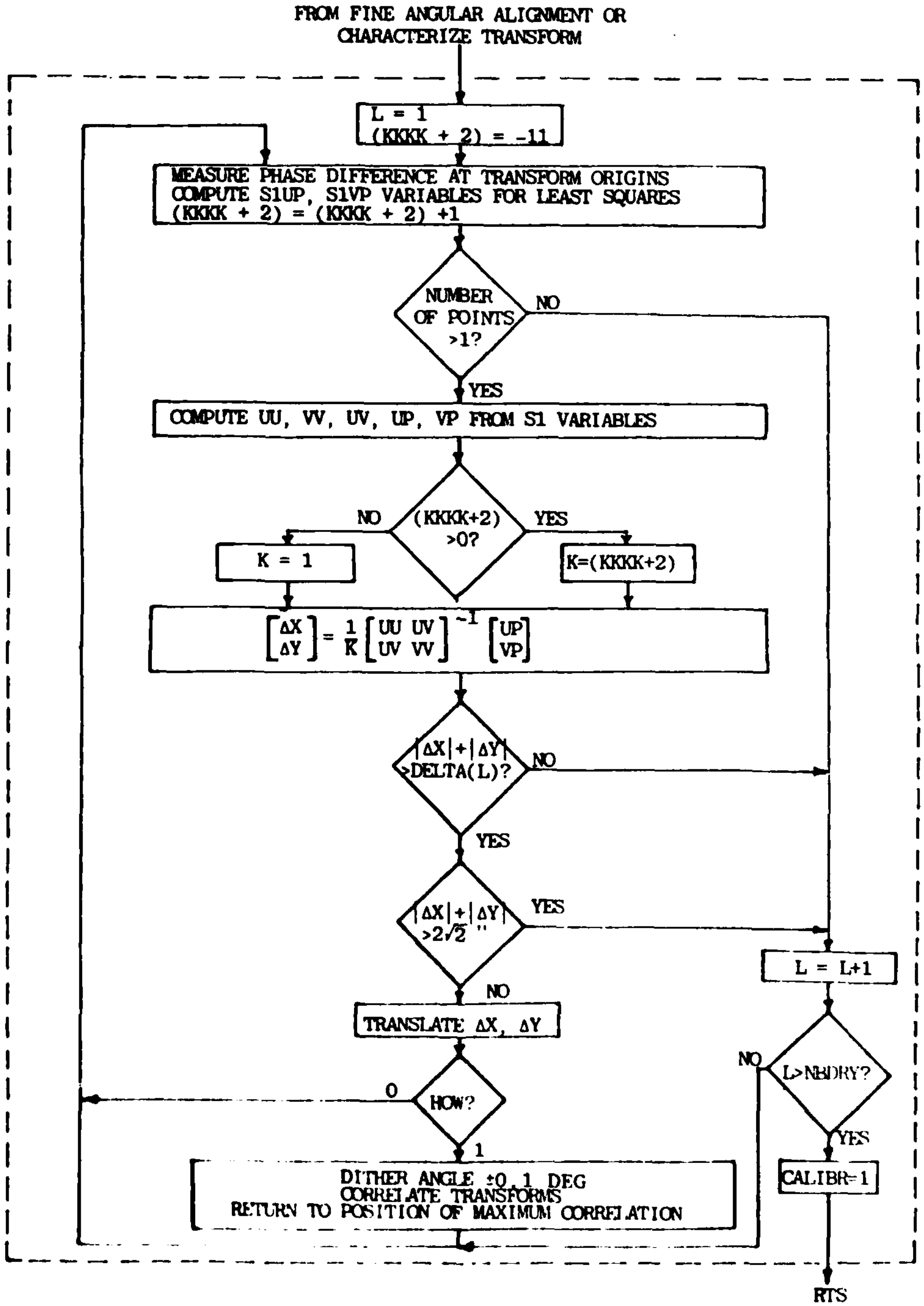


Figure 10 - Flow Diagram for Least Squares Estimation of ΔX, ΔY and Fine Angular Correction

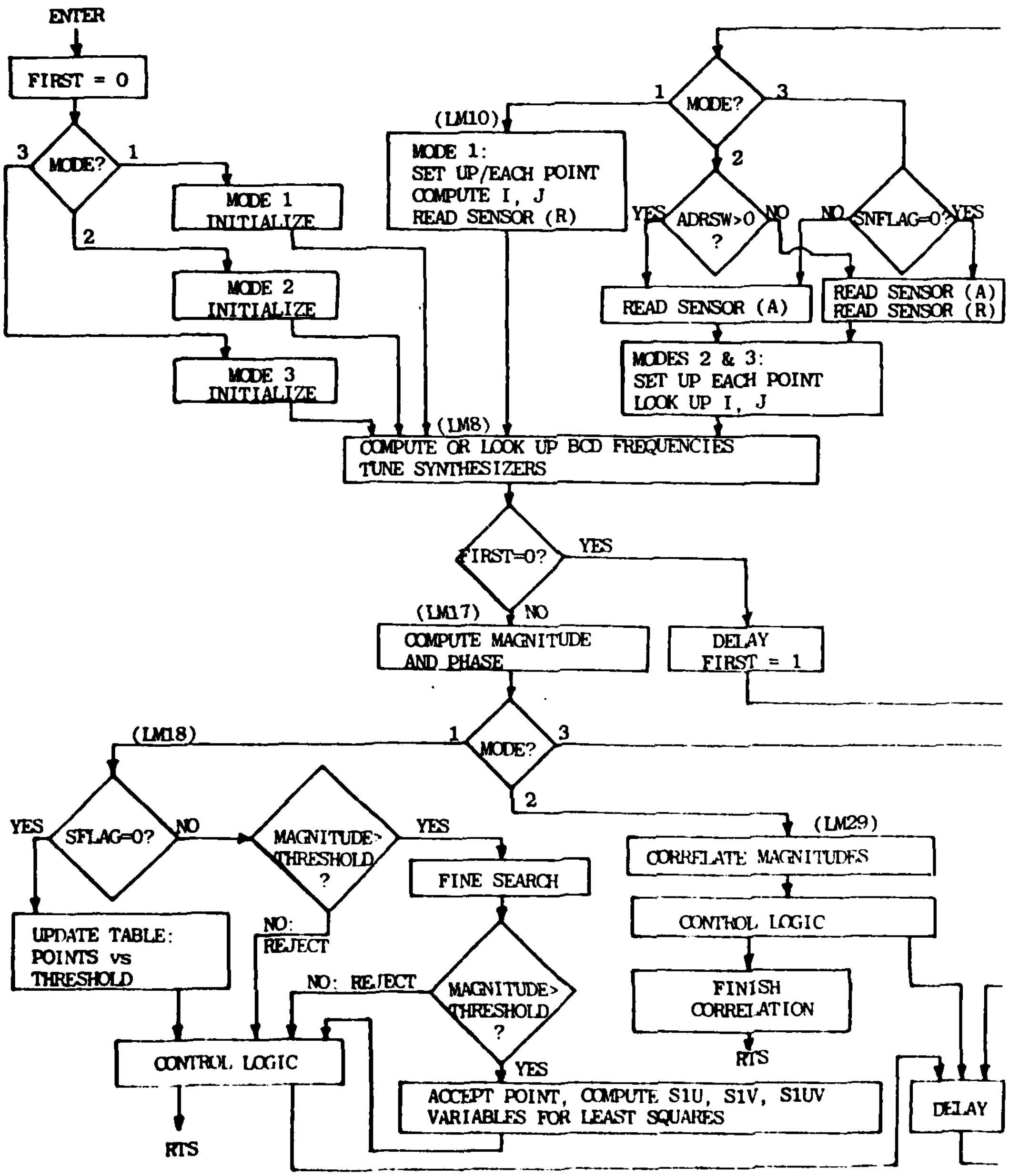
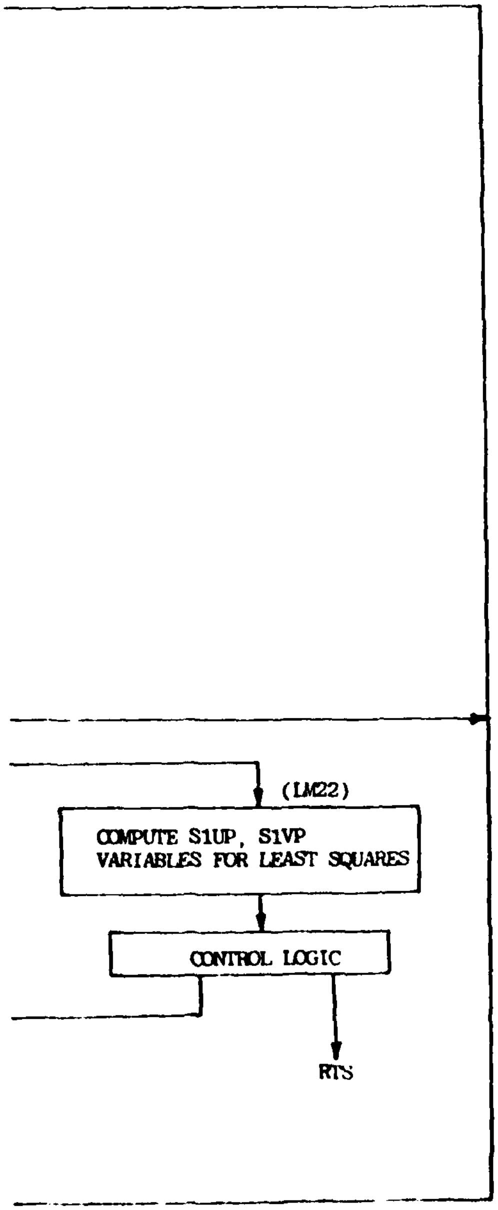


Figure 11 - Flow Diagram for Subroutine MEASRE


(LM22)
COMPUTE S1UP, S1VP
VARIABLES FOR LEAST SQUARES
CONTROL LOGIC
RTS

is used in least squares estimation.

Consider first MODE = 1 operation. MEASRE is called twice. During the first call SFLAG = 0. The transform is searched and a table characterizing the transform is set up using subroutine UPDATE. (See section on alignment algorithm for a discussion.) During the second Call SFLAG = 1. The transform is again searched and the prominent spatial frequencies are selected. In addition, during this second call the variables S1U(i), S1V(i) and S1UV(i) are computed and stored since their values depend only on the spatial frequencies and do not change until there is another initial alignment.

Consider now MODE = 2 operation. During the first call to MEASRE, ADRSW = -1 . This causes the frequency addresses of the prominent spatial frequencies to be computed and stored in Table BCDAR. In addition, the magnitudes of the reference transform at these frequencies are stored in Table MS.

Subsequent calls to MEASRE are used to compute SUM as defined by equation 4. Hence, MEASRE computes the function "correlate transforms" shown in Figures 8, 9 and 10. In all cases ADRSW = 1 so that fresh data from the misaligned sensor will be taken and correlated against reference data which has been stored in the Table MS.

Finally consider MODE = 3 operation. The variables S1UP(i) and S1VP(i) are computed for least squares estimation. If SNFLAG = o then fresh data from both sensors is used to compute these variables. If, instead, SNFLAG = 1 then fresh data from the misaligned sensor is used along with stored phase data from Table PS to compute these variables.

The remainder of this section consists of a brief description of the major subroutines and variables used by the alignment program. The notation (VAR1, VAR2) is used to indicate a two-byte variable consisting of the one-byte word VAR1 which is followed in memory immediately by the one-byte word VAR2.

Subroutine FINSCH is called during fine angular alignment and fine angular correction (dither angle). It computes SUM at the present position and at ±FINE degrees from it. It then moves the light table to the position of maximum correlation.

Subroutine SUMPAR computes UU, UV, VV, UP and VP from the partial products S1U, S1V, S1UV, S1UP and S1VP. The variable L is used to set the summation limits in the defining equations (10) through (14).

Subroutine CORDIC computes the Cordic algorithm with 16 iterations. The algorithm has two functions. First, if variables COR9 = COR10 = 0 upon entry then the two byte rectangular coordinates (COR1, COR2), (COR3, COR4) will be converted to polar form with (COR1, COR2) = .41169 x magnitude and (COR9, COR10) = phase (radians/π). If the two-byte variable (COR9, COR10) $\neq$ 0 then the rectangular coordinates (COR1, COR2), (COR3, COR4) are rotated through the angle (COR9, COR10) and suffer a gain change of .41169.

Subroutines ADDRES computes the BCD frequency variables UI1, UI2, VJ1, VJ2 from the binary frequency variables I, J. In addition, under control of variable ADRSW the BCD variables can be either stored in Table BCDAR after computation or read from that table in lieu of computation.

Subroutine READ is used to read data from the reference sensor and store the magnitude and phase in MP and PS respectively.

Subroutine BI$BCD computes a BCD number from a binary number.

The PUSH and PULL subroutines are used to push or pull four-byte numbers on or off the stack for use with the MATH chip.

The MATH chip contains software which implements fixed point and floating point arithmetic operations. The use of this software is described in the manual from Wintek Corp. supplied in the Commercial Data.

Subroutine RDDEFT takes a number of samples from one of the Deft sensors, averages them and returns the average value in (real) (COR1, COR2) and (imag.) (COR3, COR4). If SENSOR = -1 then NS samples of the reference transform are averaged. If SENSOR = 0 then one sample of the reference transform is taken. If SENSOR = 1 then NS samples of the misaligned transform are averaged.

Subroutine INDEX1 computes the next coarse grid point from the previous grid point during transform search.

Subroutine GSRCH performs a fine grid search around a coarse grid point. The fine grid increment is 30 kHz and an area of 180 x 180 kHz is searched.

Subroutine UPDATE updates a table during the initial transform search during spatial frequency selection. When completed, the n-th entry in this table is the number of samples for which the magnitude of the sample is greater than n x THR2 where THR2 is a small constant.

Using the table constructed by UPDATE, subroutine THRSET sets the threshold THR1 so that THR1 = n x THR2 where the n-th entry in the table is less than or equal to NPT and the n-1st entry is greater than NPT. NPT is the desired number of spatial frequencies.

Subroutine PHASDF computes the difference of two phase samples and adjusts the difference to lie in the interval $(\pi, -\pi]$.

Subroutine PHSSET measures the phase difference at the dc peak of the two sensors and stores the result in variable PHASE. If alignment is with one sensor only then there is no phase difference. In that case, (SNFLAG = 1), the subroutine immediately returns to the calling program.

Subroutine INIZE is used to initialize a table in RAM with program constants which are stored in ROM. The area in RAM consists of the block from 1808_H to $1FFF_H$ and the block 1812_H

to 1891_H. Most of the memory in the first block is simply cleared to zero. These memory blocks are reinitialized whenever the key pad key F is pressed. It is then possible to modify any parameter in RAM prior to alignment by using the monitor program. To enter the monitor, open the front panel and press the right-most button. An asterisk should appear on the CRT terminal. To modify RAM, refer to the monitor reference manual supplied in the Commercial Data. After memory has been modified, press together the control key and P on the terminal. Then enter A99B and carriage return. Follow this by G, carriage return. There should now be dashes on the LED display and control has been returned to the supervisor. Caution: Memory modification should only be attempted if the user has intimate knowledge of the alignment program, assembly language and hexidecimal notation. The program has been designed so that memory modification is not necessary during normal operation. In particular, the software adjusts automatically to the test image presented to it. That is, the program automatically characterizes the transform and determines which spatial frequencies it will use.

The remaining subroutines used in alignment are adequately explained in the assembly language listing. The remainder of this section consists of a description of the important variables used in the alignment program. Memory locations 1800_H - 1809_H hold temporary variables which will not be discussed.

PHASE holds the difference in the phase of the two transforms provided by the two Deft sensors measured at the dc peaks.

XØZERO and YØZERO are the coordinates of the dc peak of the reference sensor. X1ZERO and Y1ZERO are the coordinates of the dc peak of the aligning sensor. (MHz/10)

COR1, COR2, COR3, COR4, COR9, COR10 are used to store the two-byte variables input to and output from the CORDIC subroutine. (See description of CORDIC.)

I and J hold binary numbers which address spatial frequencies. I = J = 0 addresses the dc peak of either sensor. In general, to convert from these normalized addresses to the actual electrical frequencies use the formulas:

$$f_x = 30 \text{ kHz} \times I + \text{dc peak x-coordinate} \quad (37)$$

$$f_y = 30 \text{ kHz} \times J + \text{dc peak y-coordinate} \quad (38)$$

ID and JD are the normalized frequencies of the previous grid point.

UI1 and VJi are the x and y frequencies of the reference sensor expressed as BCD numbers. UI2 and VJ2 are the same for the aligning sensor. They are all computed from I and J using subroutine ADDRES.

MODE controls the function of subroutine MEASRE. (See description of MEASRE.)

DTIME is a parameter which controls the delay provided by subroutine DELAY1.

JSTART is the initial value of J during the search of the transform. It is set large enough to avoid the low-frequency region of the transforms.

BDRY indicates which region of the transform the variables I and J presently address. BDRYD is the same for ID and JD.

NBDRY gives the total number of regions that the transform is divided into. This number is 3.

BDRYPT is a pointer used to index the S1 variables.

FIRST is a flag used in subroutine MEASRE to tell whether the current point is the first point.

SENSOR tells whether the reference or aligning sensor is to be used.

NSAMP is the number of samples to be averaged in subroutine RDDEFT. LOGS = $\log_2$NSAMP.

BCDPTR is a pointer used to index array BCDAR.

L is the present, outermost region. It is used during least squares estimation.

LIMIT is the largest allowable value of I which limits the search area to the sensor bandwidths.

X is the number of spatial frequencies chosen by the program.

Y is used to index data stored in MS and PS.

ZERO is not used.

X1INC and Y1INC are the fine grid increments scaled by 10. Their value is 30 kHz/10.

NPT is the desired number of spatial frequencies (16).

STACK1, STACK2, PUSHST are temporary variables used by the PUSH and PULL subroutines.

(THR11, THR12) is the magnitude threshold set by the program to pass approximately NPT points.

(THR21, THR22) = 8 is a small constant used to quantize the available range of magnitude values.

HOW is a flag indicating rotation or no rotation during alignment.

IJPTR and IJPTR1 are pointers which index array IJ.

ADRSW is a flag which controls the operation of subroutine ADDRES.

SETUP is not used.

FINE = 16 is the initial fine angle increment.

K$G is a gain constant used to scale UU, VV, and UV.

KKKK is a gain constant used to scale UP and VP.

CORSE = 60 is the angle which the light table moves prior to the coarse angular alignment.

ST is a variable used to keep track of angular position.

SAVESP is not used.

MAX is the largest correlation to date during angle alignment.

SUM is the current correlation value.

XTRAN and YTRAN hold the x and y translations for the stepper motor subroutine.

DELX and DELY are four-byte variables which are the computed translations for the stepper motor. The lower two bytes are then stored in XTRAN and YTRAN.

VP, UP, UV, and UU are the computed least squares variables which are defined in Section III.

STEPS holds the angle where maximum correlation occurred.

ANGLE holds the angle used by the stepper motor subroutine.

SMAG holds the denominator of equation (4).

SAVEZ, SAVEY, DIRECT, DTHR11, DTHR12, DTHR21 and DTHR22 are not used.

MPLX stores the current multiplexer address.

SIGNI and SIGNQ are used to hold sign bits to sign-extend the real and imaginary sample respectively.

SFLAG is a flag which indicates first or second pass through MEASRE when MODE = 1.

SNFLAG is a flag which indicates two-sensor or single-sensor alignment.

CFLAG is a flag which indicates real or complex correlation in the correlation program.

CCFLAG is a flag which indicates whether or not the scan of the transforms is complete in the correlation program.

Some of the above variables are also occasionally used for temporary storage. The alignment program also uses a block of memory for table or array storage. These tables are listed below.

DELTA is a table holding threshold values used to determine if L should be incremented or the alignment considered complete.

BCDAR is an array which is filled with the BCD values of the spatial frequencies chosen by the program.

BDRYLF is a table which holds the boundary values of J used to determine which region of the transform a grid point is in.

BDRYCT is an array which is filled during the second call to MEASRE, MODE = 1. The i-th entry in this table is the value of the index y for the last spatial frequency chosen in region i.

S1YP, S1UP, S1UV, S1U and S1V are arrays which hold the partial products used in least squares extimation. The notation S1VP1M means that the table points to the first word in the table and the MSB of the word.

IJ is an array which holds the normalized frequency variables I and J for each spatial frequency chosen.

PS and MS are arrays which hold the phase and magnitude of the reference transform at the chosen spatial frequencies.

ARRAY is an array used in the correlation program to hold the partial products during scanning of the transforms.

E. Calculation of Image Transform Cross-Correlation Function

To compute a cross-correlation in the spatial frequency domain, first that domain is restricted to the bandwidth of the Deft sensors. The area used is a square extending from the location of the dc peak along the f_x-axis 6 MHz and along the f_y-axis ±3 MHz. This area is quantized to a grid with spacing 100 kHz in both f_x and f_y. Let r_i be the aligning Deft sensor transform component evaluated at grid point i. Let a_i be the aligning Deft sensor transform component evaluated at grid point i. In general r_i and a_i are complex numbers. The standard formula for cross-correlation of these samples is

$$r = \frac{\sum_{i=1}^{n} (r_i - m_r)\ (a_i - m_a)^*}{\sqrt{\sum_{i=1}^{n} (r_i - m_r)\ (r_i - m_r)^*}\sqrt{\sum_{i=1}^{n} (a_i - m_a)\ (a_i - m_a)^*}} \tag{31}$$

where

$$m_r = \frac{1}{n}\sum_{i=1}^{n} r_i \tag{32}$$

$$m_a = \frac{1}{n}\sum_{i=1}^{n} a_i \tag{33}$$

The symbol (*) means complex conjugate. Equation (31) can be found in the references defined in the context of random variables[6] or the Cauchy-Schwarz inequality[7].

This formula is evaluated by the correlation routine and the result displayed on the LED display and on the computer display terminal if it is connected. In general, r will be a complex number. It is displayed in polar form.

In some cases it is more desirable to compute the cross-correlation between the magnitude of the transforms. The corresponding formula is

$$r = \frac{\sum_{i=1}^{n} (|r_i| - m_{|r|})(|a_i| - m_{|a|})}{\sqrt{\sum_{i=1}^{n} (|r_i| - m_{|r|})^2}\ \sqrt{\sum_{i=1}^{n} (|a_i| - m_{|a|})^2}} \tag{34}$$

where (| |) means absolute value and

$$m_{|r|} = \frac{1}{n}\sum_{i=1}^{n} |r_i| \tag{35}$$

$$m_{|a|} = \frac{1}{n}\sum_{i=1}^{n} |a_i| \tag{36}$$

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[6] A.Papoulis, Probability, Random Variables and Stochastic Processes, McGraw-Hill, 1965, chap. 7.

[7] D.G.Luenberger, Optimization by Vector Space Methods, John Wiley & Sons, 1969, chap. 2.

This cross-correlation can also be computed by the routine. This is accomplished by finding the magnitude of each r_i and a_i sample using CORDIC. Then the real part of r_i or a_i is replaced by the corresponding magnitude and the imaginary part is set to zero. The subsequent computations are identical for both real and complex cross-correlation. However, for real correlation the computed phase should be zero or near zero and only represents roundoff errors in the calculations. Hence, it is to be ignored.

For additional details refer to the flow diagram Figure 12. Most of the time required for correlation is spent in the loop which samples the sensors, increments frequencies and computes partial products for r. Since the origin frequencies of the two sensors are slightly different, it is necessary to retune the synthesizers between sampling r_i and a_i for the same grid point i. Once the loop is exited the remaining computation requires only about one second.

F. Major Shared Subroutines

1. <u>Subroutine to Move Stepper Motors</u> ($A82\emptyset_H$-$A8DD_H$) - This subroutine moves each stepper motor by a specific amount which depends on the contents of three 2-byte memory locations labeled XTRAN,YTRAN, and ANGLE. Before the subroutine is called these locations are filled with 2's complement numbers. In the cases of XTRAN and YTRAN they are equal to the desired displacements of the x- and y-translation stages, respectively, in hundredths of a millimeter. In the case of ANGLE the number specifies the desired rotation in tenths of a degree.

The subroutine always operates the three motors one at a time in the order given above. Upon entry certain parameters are set up which are peculiar to the motor being operated. Then the program number is checked because Program D, whose function is to update the position display without moving the motors, has the same entry point. Next the desired number of steps is changed from 2's complement to sign-magnitude form. If the

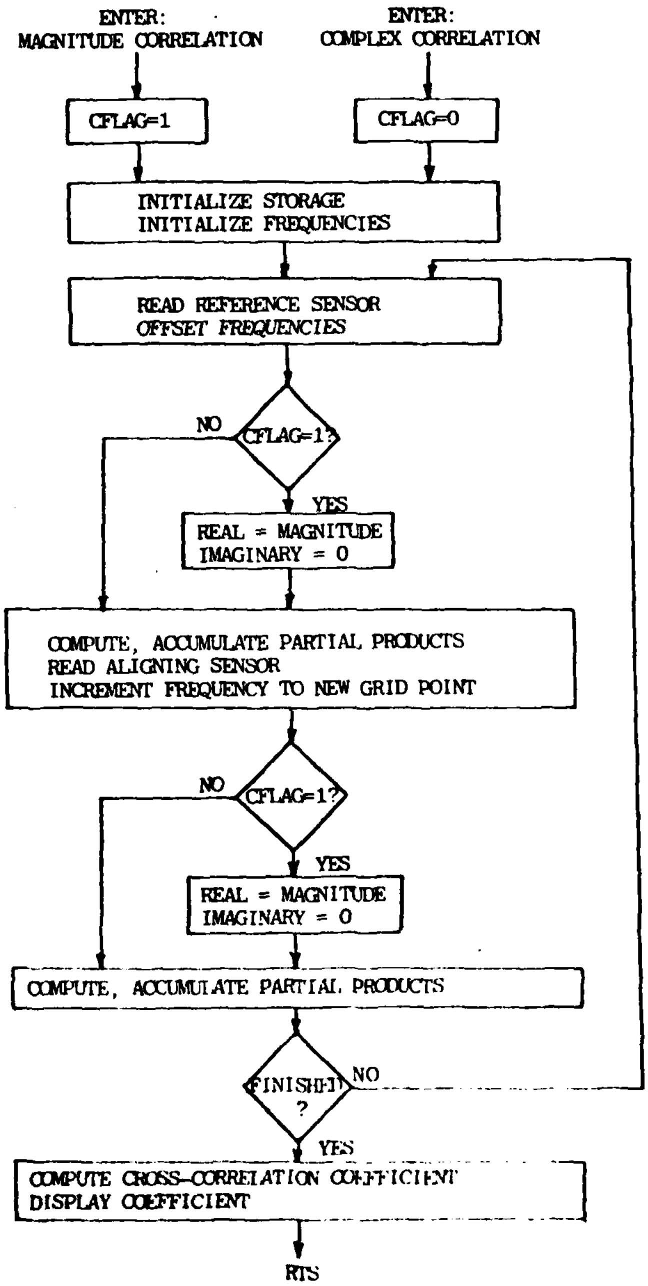

Figure 12 - Flow Diagram for Correlation Coefficient Subroutine

number is equal to zero the program goes directly on to the next motor.

Before the motor is operated a bit is either set or cleared in the PIA which establishes the direction of motion. The program operates by applying a given number (contained in Accumulator B) of clock pulses to the motor control and then decrementing the desired number of steps. Since the translation tables have a step size of .002 mm, the number of pulses is 5 for horizontal and vertical motion. For rotation it is 3 since the step size for the rotating stage is 1/30 degree. After each pulse which steps the motor the position display is updated, but only if the system is in a calibrated state.

When the desired number of increments has been counted down to zero, the subroutine returns to take care of the next motor. The last return is to the calling program.

2. Position Display Subroutine ($AADE_H$-$AB93_H$) - This part of the code is responsible for keeping track of the motion of the translation and rotation stages and updating the front-panel LED display accordingly. It is called by the stepper motor subroutine in the case of automated operation, or by the supervisor if the stepper motors are actuated manually. Entry is made with Accumulator A containing a mask which identifies the clock bit in the stepper motor control interface. The next bit to the left is the motor direction. In order to make up, right, and clockwise be the positive directions it was necessary to invert the direction bit for horizontal or rotational motion.

A total of five bytes is reserved in RAM for the position of each stage. Three bytes keep the step count in BCD form for the display, and two bytes keep it in 2's complement binary form. In the case of translation, the least significant BCD byte is incremented or decremented by 20 for each clock pulse, since the program step size is 5 times as great as the step size of the stage. For rotation the increment or decrement is

33. To prevent roundoff error from accumulating, 99 is rounded up to 100 and 1 is rounded down to zero.

The two most significant BCD bytes are changed from 9's complement to sign-magnitude form, converted to the 7-segment display code, and stored in the appropriate part of the display buffer. The display is refreshed by the interrupt service routine, located at $AAA5_H$.

This subroutine has another entry point at $AB3D_H$ which is used by the image correlation routine to display the result of the computation. Entry here is made with a two-byte 9's complement BCD number in the A and B accumulators. This number is changed to sign-magnitude form and displayed.

3. Synchronous Sampler Subroutine ($AE2A_H$-$AEBD_H$) - This part of the program operates the DAS to sample the signals from the detector circuit boards in synchronism with the bias frequency and the 60 Hz line frequency. Single-bit inputs on the PIA's which control the synthesizers are configured to set flags internal to the PIA's when the 60 Hz line and the bias signal undergo positive- or negative-going zero-crossings. These functions are independent from the synthesizer control functions even though the same PIA's are used.

After clearing the memory locations where the signal values will be accumulated, the subroutine sets the interrupt mask so the time required for interrupt service will not disturb the synchronism of the sampling. It then waits for a transition of the 60 Hz line, which marks the beginning of a group of 16 consecutive signal samples taken at the positive and negative peaks of the signal. At the bias frequency of 1440 Hz, the positive and negative peaks are separated by 347 μs, so the 16 consecutive samples take 5.5 ms, which is somewhat less than a half-cycle at 60 Hz. After the next 60 Hz transition another 16 samples are taken. This method distributes the samples evenly over a full cycle of the line frequency so that cyclic variations of the image brightness do not affect the data. The interrupt mask is cleared between groups of samples so the interrupt service routine can refresh the front-panel LED display.

A software time delay between the bias reference transitions and the sample commands was adjusted experimentally to make the samples coincide with the signal peaks. The pair of signals which represent the output from each sensor are in phase, although their voltages represent two orthogonal vectors which describe the signal's phase as well as its amplitude. Two samples are taken from one of the signal pair at positive and negative peaks, followed by two samples from the other one of the pair, and so on. Alternate sampling of the two orthogonal signal components minimizes phase errors caused by short-term signal fluctuations. Sampling positive and negative peak values and accumulating their difference eliminates any dc offset associated with the signal and provides some additional narrowband filtering around the bias frequency.

Exit from the subroutine occurs with the two orthogonal signal vectors accumulated separately in four consecutive memory locations pointed to by the x register. The accumulation scales the 12-bit signal voltage samples up by a factor of 16 so that they each fill two bytes.

V. OPERATING INSTRUCTIONS

A. Operating Functions

The Image Alignment and Correlation System has been programmed to perform fourteen separate functions. The control programs for these functions are stored permanently in UV-erasable read-only memories in the microprocessor subsystem. The software is organized as a supervisor or main program and a master subroutine for each system function.

When power is first turned on, the supervisor enters a wait loop with dashes displayed on the front-panel LED readout. The dashes indicate that the system is ready to accept commands from the keypad directly below the readout.

Pressing a key at this point will result in the display of the corresponding program number, with two exceptions. They are "A", which is reserved for ABORT, and "E", which is used for EXECUTE. After entering a valid program number, pressing "E" will cause execution of that program to begin. Any time before "E" is pressed, entering a new program number will override the preceding entry. Pressing "E" initially will have no effect. Entering "A" at any time will cause a return to the supervisor, and the execution of any program in progress will be terminated.

Next is a tabulation of the fourteen program functions, followed by a description and instructions for each one.

TABLE 5

Pre-programmed System Functions

Identifier	Description
0	Graphic x-y plot (hard copy) of spatial frequency content of test image (i.e., the image to be aligned).
1	Graphic CRT display of spatial frequency content of test image.
2	Graphic x-y plot of spatial frequency content of reference (fixed) image.
3	Graphic CRT display of spatial frequency content of reference image.
4	Initial alignment and calibration using both sensors.
5	Calibration for re-alignment using test image only (single sensor).
6	Alignment after calibration using both sensors, including rotation.
7	Alignment after calibration using both sensors, without rotation.
8	Alignment after calibration using test image only, including rotation.
9	Alignment after calibration using test image only, without rotation.
A	Abort execution and return to supervisor.
B	Compute real image correlation coefficient using magnitude of spatial frequency data.
C	Compute complex correlation coefficient using complex spatial frequency data.
D	Display position of test image on LED readout (only after calibration).
E	Execute displayed program number.
F	Re-initialize parameters.

O - X-Y Plot from Test Image - This program operates the accessory x-y plotter, making it draw on paper a pseudo three-dimensional graphic representation of the spatial frequency content of the test image. (The test image is the one on the left, viewed from the sensor modules.) Before executing this program for the first time, the instruction manual for the plotter (Hewlett-Packard model 8015B) should be read and understood. In addition, the following steps must be taken prior to execution:

a. Connect the power cord on the x-y plotter to the 115V ac supply.
b. Connect the interfacing cable from the x-y plotter to the system's electronics cabinet.
c. Position a clean sheet of paper on the plotter. The use of paper furnished by the plotter manufacturer is recommended.
d. Set up the plotter controls as follows:

Line - On
V/In - 1 for both x and y
Cal/Vernier - Cal for x; vernier for y
Chart - Hold after paper is in place
Servo - On (Note: Pen may move quickly.)
Pen - Lift
Reset/Sweep - Reset
X Inputs/X Time Base - X Inputs

e. Place a pen of the desired color in the holder.
f. Depress Zero Check for the y axis and adjust Zero so that the pen is directly over the lowest line on the chart grid. Repeat for the X Asix, placing the pen over the left-hand end of the grid. (Note: The pen may move quickly to the zero locations when the Zero Check button is pressed. Be sure its movement is not obstructed.)
g. Last, remove the cap on the pen and lower the pen holder.

The program may now be executed. A complete plot takes about 14 minutes.

Replacing the pen cap after each plot will prevent drying of the felt tip and will prolong pen life. It is also a good idea to keep the plastic cover on the plotter when it is not in use. However, be sure the power to the plotter is off before replacing the cover.

Periodically the recorder's y-axis vernier gain adjustment should be checked, although it affects only the vertical size of the graph. The procedure is as follows:

1. Perform steps a. through f. above.
2. Turn on the graphics terminal.
3. Open the door of the electronics cabinet and press the right-hand one of the two small white buttons. An asterisk will appear on the CRT.
4. Using the terminal's keyboard, enter MEE8Ø and press the RETURN key. The terminal will respond by printing EE8Ø followed by a space and two hexadecimal digits.
5. Now enter FF and RETURN. The pen on the recorder should move quickly to the top of the paper.
6. Do not disturb the Zero knob, but adjust the Vernier knob to position the pen directly over the top line on the paper.
7. While holding the CTRL and SHIFT keys down together, enter K. The terminal will respond with an asterisk.
8. Either press the BREAK key on the terminal or the small white button on the left inside the door of the cabinet. The pen should move quickly to the bottom line of the paper and dashes should return to the front panel LED display. This completes the adjustment.

<u>1 - Graphic CRT Display from Test Image</u> - This program produces the same display as Program 0, but it appears on the accessory graphics terminal instead of the plotter. In this case, be sure that the interfacing cable from the terminal is connected

to the electronics cabinet, and that power is applied to the terminal. The terminal's ac power switch is located at the rear, on the right side as viewed from the front. Also check that both the transmit and receive baud rate switches on the rear of the terminal are set to 4800. Execution can then be started.

When program execution begins, the display, which is a storage CRT, will be erased. The program then labels the top of the display to show the x and y transducer frequencies at the starting point, which is the lower left-hand corner. The label also identifies the image being examined. The display covers a span of 7.6 MHz along each axis. A complete plot takes about 9 minutes. The terminal will sound an audible "beep" when the display is completed.

Except for the PAGE and BREAK keys, entries at the keyboard have no effect on this program. Pressing the PAGE key will erase the display. Execution will continue, but the terminal will print characters instead of drawing vectors. The only recourse is to abort execution and restart it.

Depressing the BREAK key causes a hardware reset which terminates any execution in progress and re-initializes the entire system. This applies to all of the fourteen available program functions as long as the terminal is connected and turned on.

The terminal should be turned on for a warm-up of several minutes before use. After prolonged periods of inactivity, the manufacturer recommends a 20-minute warm-up.

<u>2 - X-Y Plot from Reference Image</u> - All of the comments under Program 0 apply, except that the data is taken from the module which examines the reference image.

<u>3 - Graphic CRT Display from Reference Image</u> - All of the comments under Program 1 apply, except that the data is from the reference image.

4- Initial Alignment and Calibration, Both Sensors - In demonstrating alignment of the Test Image with the Reference Image, it is first necessary for the system to align the Test Image to a position which is defined as zero error. Program 4 performs this function. It begins by searching the spatial frequency domain of the reference image to select a set of up to 16 points which are associated with prominent components of the image's spatial frequency spectrum. The system retains the locations of these points in the spatial frequency domain, and uses them first to achieve a preliminary alignment in angle. It searches over a range of ±6 degrees from the original orientation of the Test Image, and computes a cross-correlation coefficient based on the magnitudes of these sample points. After finding the angle where the correlation is greatest, the system uses the phase information from the same data points to align the Test Image laterally and vertically. It then alternately performs fine angular and translational adjustments, until the next computed translational correction falls below a preset threshold. At that point the system sets an internal flag which designates the calibrated state, and control returns to the supervisor.

Neither the CRT terminal or the x-y plotter are required for this program. The light boxes must be turned on with suitable patterns in place before execution is started. In addition, the two push-button switches on the electronics cabinet marked MAN/AUTO must be in the AUTO position. Best alignment performance is obtained after a period of at least 30 minutes to allow for thermal stabilization of the sensors. One of the plotter programs should be executed after the system is first turned on, to initiate the stabilization.

It is good practice to execute Program F immediately before starting this function, to insure proper initialization.

5 - Calibration for Re-alignment, Single Sensor - This program is similar to the preceding one, except that only the Test Image

is involved. The system may be calibrated with the Test Image in any position, and subsequent alignments will return it to that position. The selection of a set of data points in the spatial frequency domain proceeds as in Program 4, but in this case the magnitude and phase values at these points are simply stored in memory, and no rotation or translation of the image takes place.

The last two paragraphs under Program 4 above apply here also. However, the single-sensor mode of operation is more sensitive to thermal drift, so calibration should be done immediately prior to subsequent re-alignments using Programs 8 or 9.

<u>6 - Alignment with Both Sensors, Including Rotation</u> - Before executing this program the system must be aligned for calibration using Program 4. Any attempt to run either Program 6 or 7 before calibration, or immediately after a system reset, will cause a return to the supervisor with the word "Error" shown on the front-panel LED display.

After the system has been aligned for calibration using Program 4, the Test Image can be displaced and rotated manually before this program is run to demonstrate re-alignment. Manual control of the stepper motors is effected with the two front-panel buttons labeled MAN/AUTO in the "out" (MAN) position. The step, direction, and slew buttons, and the x/y button in the case of rotation, can then be used to move the Test Image to the desired starting point. The position on each axis will be shown on the LED display as each stepper motor is activated. The angular misalignment should not be made more than 6 degrees, so as not to exceed the search range of the alignment program. The allowable translational misalignment depends on the image, but displacements up to ±5 mm have worked well in our tests.

As with any of the alignment programs (4, 6, 7, 8, or 9), the MAN/AUTO switches must be returned to AUTO before this program is executed. Failure to do so will result in a program halt with "Error" displayed. The program may be restarted by pressing the "E" key after resetting the stepper motor controls to AUTO.

While the program is running, the LED display will show the position of the Test Image. When no further correction is indicated, execution will stop and dashes will return to the display. The final errors may be examined by pressing "D" followed by "E" on the front-panel keypad. (See section on "D.")

If the accessory CRT terminal is connected and turned on in advance, it will show a graphic display of the translation of the Test Image as alignment progresses. Initially the display will have the x and y axes with a very small square at their intersection. This square represents translational error bounds of 0.1 mm (100 μ). The display encompasses an area in xy-space of about 24 mm by 18 mm. When the translational errors have been reduced to less than 1 mm in x and 0.5 mm in y, the display will be erased and replaced by a new one which is magnified 16x. The display does not give any information as to the angular position of the image.

<u>7- Alignment with Both Sensors, Without Rotation</u> - This program is similar to the preceding one except that the Test Image is re-aligned only in translation. Omitting the angular correction decreases the running time, and this mode also can be used to study the effects of constant angular errors on the translational corrections.

Except for those which refer specifically to rotation, all of the comments under Program 6 apply here also. The most accurate translational re-alignment will take place when no angular offset is introduced after calibration.

<u>8 - Alignment with Single Sensor, Including Rotation</u> - This function is again similar to Program 6, except that only the Test Image is used. Program 5 must be run before this program is executed. Otherwise, the "Error" message will be displayed

and control will return to the supervisor. The most accurate results will be obtained when re-alignment immediately follows calibration.

Except for the difference in program numbers, the discussion under Program 6 applies here also.

9 - Alignment with Single Sensor, Without Rotation - This program is the only remaining permutation of the alignment functions. It must be preceded by Program 5 for calibration. Except for the lack of rotation, it is the same as Program 8.

A - Abort - Pressing this key at any time will stop the execution of any program which is in progress. The front-panel LED display will fill with dashes, showing that control has returned to the supervisor. In general, it is good practice to run Program F following an abort.

B - Correlation of Magnitudes - This program computes a normalized cross-correlation coefficient from the magnitudes of a large set of samples in the spatial frequency domain of both sensors. The samples are taken on a square grid at intervals of 100 kHz, over an area 6 MHz square in the transducer frequency domain. The corresponding area in the spatial frequency domain is 20 cycles square, and is somewhat smaller than the area covered by the plotter programs.

Mathematically, the correlation coefficient can be expressed as Equation 34 (page 63).

In order for the correlation program to give the correct result, the most recent calibration program executed must have been Program 4 (i.e., the one involving both sensors). Normally this would be done anyway, to insure that the degree of correlation is being measured between two images which are properly aligned. If the effect of misalignment is to be studied, the Test Image can be displaced manually after the initial alignment has been completed.

This program takes about 14 minutes to execute. At its completion the correlation coefficient will appear on the LED display, and on the CRT terminal if it is connected. The terminal will also sound a "beep" to alert the user. The first number displayed is the result. The second number, labeled "Phase" on the CRT, should be very small and has no meaning in this case since a real number is computed.

C - Complex Correlation - In this case a complex normalized cross-correlation coefficient is calculated, using the same data grid as in Program B. Here the expression is the same as Equation 31 (page 63). The result is in polar form, with the phase given in degrees.

Running time is about 14 minutes, and a "beep" will sound from the terminal upon completion.

Both of the correlation computations reflect the response of the sensors as well as the content of the images. The complex computation takes the phase of the samples into account, and the sensors are not matched as well in phase as they are in magnitude. Therefore, the complex correlation value tends to be smaller than the value computed from the magnitudes alone, for a given pair of images.

D - Position Display - This function uses the LED readout to display the position of the Test Image relative to its calibrated position. The first two numbers are the lateral and vertical translations in millimeters, respectively, and the third number is the angular position in degrees.

The displayed positions will always be zero upon initial turn-on of the system. In addition, Programs 4, 5, or F will clear the position counters, returning the displayed values to zero. When the system is in an uncalibrated state (i.e., neither 4 nor 5 has been run after initialization) manual operation of the stepper motors will not affect the position counters or the display. In the calibrated state, the position counters and the display will track any manual or programmed movement of the Test Image.

E - Execute - Any time a program number shows at the left-hand end of the LED display, pressing the "E" key will start execution of that program. Pressing "E" when the dashes are displayed has no effect.

<u>F - Re-Initialize Parameters</u> - When the system is first powered up, a hardware reset vectors the processor to a sequence of instructions which, among other things, sets a number of program parameters in read-write memory. An example is the counters which keep track of the translation and rotation stages. These counters are set to zero initially, but can be changed during operation of the system.

Program F returns all of these parameters to their initial values. It was included to allow for the possibility that parameter values could be changed selectively by using the processor's internal monitor through the CRT display keyboard. Such changes are not recommended unless the user understands both the software which implements the alignment algorithm and the processor's internal FANTOM-II monitor. The monitor is documented in the Commercial Data, and the software listings appear in Appendix B.

Although the system has received many hours of testing, the possibility still exists that the software has some "bugs" that have not been identified. For this reason it is a good practice to use Program F immediately prior to the execution of any other program except those which follow a calibration. In other words, do not precede Programs 6 through 9 by Program F.

VI. REVIEW OF THE SYSTEM'S DEVELOPMENT

Our technical proposal, on which this contract award was based, reveals that the final form of the system as it was delivered to ETL is remarkable similar to that originally envisioned, in spite of a number of significant technical problems which were encountered subsequently. The block diagram in the proposal is nearly identical to the current one in Section II. It was clear at the outset that the system should have microprocessor control. An image alignment algorithm which used the magnitude of the Fourier transform to achieve angular alignment was also seen as very probable, since the magnitude of the transform theoretically is insensitive to image translation. We knew that the phase of transform components would be the key to translational alignment, but the relationships involved turned out to be less clear than anticipated.

The first work undertaken on this program was the selection of a suitable microprocessor subsystem. Originally it had been planned to concentrate first on the DEFT sensors and their surrounding circuitry. However, at that time a design for a new, higher=resolution DEFT sensor operating near 100 MHz was about to be tried, and we wanted to use it in this system if it could be proven in time. Therefore, the sensor work was exchanged in the schedule for work with the microprocessor. This effort involved the circuit design of interfaces between the processor and the stepper motors, the frequency synthesizers, the data acquisition system, the x-y plotter, the CRT display, and the front-panel LED display and keypad along with programming to support each of these interfaces. All of this was accomplished with relative ease.

Over a period of time, one of the frequency synthesizers malfunctioned intermittently, and the cause was traced to defective plated-through holes on its circuit board. It was finally replaced by the manufacturer. Unfortunately, we know of no other source for a similar product. However, the problem has not recurred.

Two major factors which were not well established until later in the program were the format of the images and their means of illumination. The original discussions on this matter ranged from back-lighted 35 mm transparencies to opaque photographic prints.

When it was decided to use front-lighted opaque images in the system, the design of the alignment fixture could be finalized, and it was fabricated. At about the same time it became clear that the 100 MHz sensor could not be perfected in time for inclusion in the system, so sensor modules were built with the 35 MHz sensor with which we had accumulated a fair amount of experience. In the meantime, the first version of the alignment algorithm had been programmed, so it became possible to try the image alignment function of the system. These first tests were encouraging, but they did not show the degree of alignment accuracy we were seeking.

As program debugging and system testing proceeded we became aware of a number of previously unknown factors which bore on the performance of the alignment algorithm. For example, the phase of the sensor output is approximately a linear function of the difference between the two SAW frequencies, with a proportionality constant of about 1 degree per kHz. This phase function is in addition to the phase which the image imparts to the transform. A phase change of 1 degree at a point 3 MHz away from the origin in the frequency domain corresponds to an image displacement of only 3.5 μ at the sensor, or 70 μ at the image with 20× demagnification. Therefore, much greater significance became attached to the relatively small differences in the SAW frequencies which identify the spatial frequency origins of the two sensors. It became necessary to measure these frequencies accurately so the alignment program could use them to measure the phase of each sensor at its transform origin. These phases were then applied as corrections to the phases measured at other points in the spatial frequency domain, since theoretically the phase of the transform at the origin should be zero for any real image.

Even after these refinements were incorporated into the software, the alignment accuracy was not satisfying. Errors in translation were typically 0.2 mm and rotational errors were typically 0.3 degree. Although the delivery date specified in the contract was very close, we felt that better performance could and should be obtained. Therefore we decided to ask for a 90-day extension to the contract at no additional cost to the government.

In this request for an extension we proposed changes in the wording of the work statement so that the required alignment accuracy would be quantified. In addition, we suggested that image correlation be computed from the respective transforms rather than presented subjectively by means of the plotter or graphics display. The contract extension and the changes in wording were granted subsequently.

In the intervening time several changes were made in order to increase the signal-to-noise ratio from the sensors and to reduce or eliminate any suspected source of error. One factor which had been disturbing was the lack of contrast obtained with front-lighted opaque images. Several methods of making image patterns were tried, and even the most seemingly non-reflective surface tended to scatter back enough light to result in signals that were less than satisfactory. Therefore we decided to modify the alignment fixture to include light boxes so that transparencies could be used.

In order to get the highest brightness consistent with reasonable power and heat dissipation levels, fluorescent lamps were used in the light boxes. Unfortunately, the light output of a fluroescent lamp varies considerably over the power line cycle, and this variation modulates the sensor output. This modulation would have introduced a significant source of error in the data. In order to avoid this error it became necessary to phase-lock the sensor bias voltage to the power line frequency and to synchronize the sampling of the signals with the line frequency also. This procedure averages a number of samples over a complete cycle of the power line frequency so that each data point is sampled with the same apparent light level.

As additional steps to increase the available signal-to-noise ratio, the f/1.4 lenses originally used on the sensor modules were replaced by f/0.85 lenses, and the sensor bias voltage was increased by a factor of 5. Typical signal-to-noise ratios at that point were of the order of 55 dB for prominent spatial frequencies.

Further improvements included a re-design of the layout of the rf distribution circuit board for better isolation and shielding, and a change in the synchronous sampling subroutine to interleave the "real" and "imaginary" samples. Both of these steps improved the accuracy of the data, particularly in regard to its phase.

With these improvements the alignment accuracy of the system exceeded the specification in the contract as modified, and it was delivered to ETL on schedule.

In order to compensate in some way for the extra time required to complete the system, a feature was added to the graphics display which portrays the motion of the test image as alignment progresses.

There is little to present in the way of study results on this contract since most of the work has dealt with hardware design and its practical problems. The exception to this is the development of the alignment algorithm, which is presented in Section III.

VII. CONCLUSIONS

The Image Alignment and Correlation System has demonstrated the application of DEFT technology to the problem of aligning two identical images in translation and rotation. The system uses a highly developed image-adaptive algorithm which exploits the spatial frequency analysis capability of the DEFT sensor. The alignment accuracy of the system is image dependent, but with high contrast images having prominent spatial frequency features, the accuracy approaches the resolution of the translation and rotation stages. The accuracy is limited by the signal-to-noise ratio of the image's spatial frequency components and by mismatch between the two sensors. However, the alignment algorithm makes corrections for these differences wherever possible.

In the course of developing this system, new information has been obtained regarding the use of an ac bias with the DEFT sensor, and on circuitry for processing the sensor's output signal coherently. This information has advanced the state of the art in DEFT applications, and will be of value to any related future development.

The alignment algorithm, its implementation in software, and particularly its refinement to suit the characteristics of the sensor, also represent a significant achievement in the application of DEFT technology. Especially noteworthy are the image-adaptive properties of that part of the program which selects the most useful spatial frequency data from the image.

The use of the method of least squares to provide translation offset estimates is sufficiently general so that alignment of rather arbitrary images should be possible when more sensitive DEFT sensors become available.

This system has shown that the spatial frequency information provided by the DEFT sensor can be used to actually perform a function, as well as being made available for interpretation and analysis.

VIII. RECOMMENDATIONS

The Image Alignment and Correlation System is most in need of improvement in the areas of operating speed and image dependence. Speed of execution was not a primary consideration in the design of the system, and it would have been impossible to assess this factor accurately prior to the development of the alignment algorithm. However, now that the system is complete and some experience has been gained with it, a reduction in execution times clearly would be a desirable improvement.

Speed of execution is limited primarily by the phase-locked loop frequency synthesizers in the system, which require about 30 ms for settling after a frequency change in commanded. Modifying the synthesizers to reduce their settling time by a factor of 10 would make a significant improvement in the operating speed of the system. There are probably areas of software which could be improved in regard to execution times. However, in the absense of a dc-powered light source, the need for data sampling which is synchronous with the ac line frequency puts a lower limit of about 16 ms on the time required for each signal sample. This factor alone accounts for 13% of the execution time for the image correlation function, for example.

The dependence of the system on particular types of images is based on the sensitivity of the DEFT sensors. Higher sensor output would allow operation with images having lower contrast or less prominent spatial frequency features. When improved sensors become available, they could be considered for retrofit into the system, and modifications to reduce execution times could be made concurrently.

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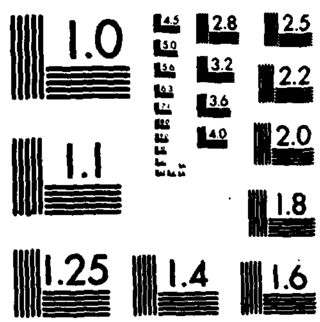
IMAGE ALIGNMENT AND CORRELATION SYSTEM.(U)
JUL 80 S E CRAIG, A L MOYER DAAK70-78-C-0217
UNCLASSIFIED 0101-A002 ETL-0237 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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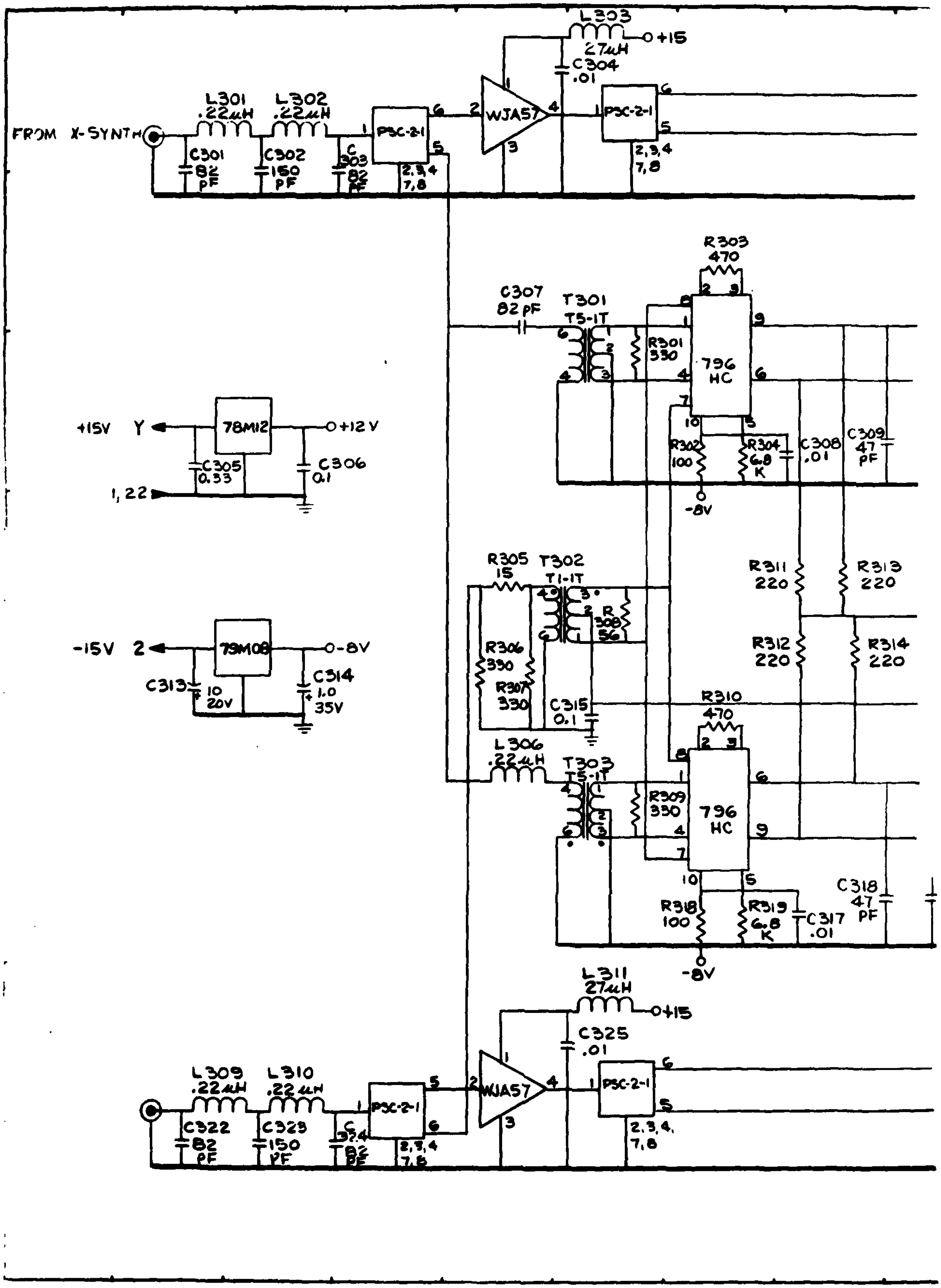
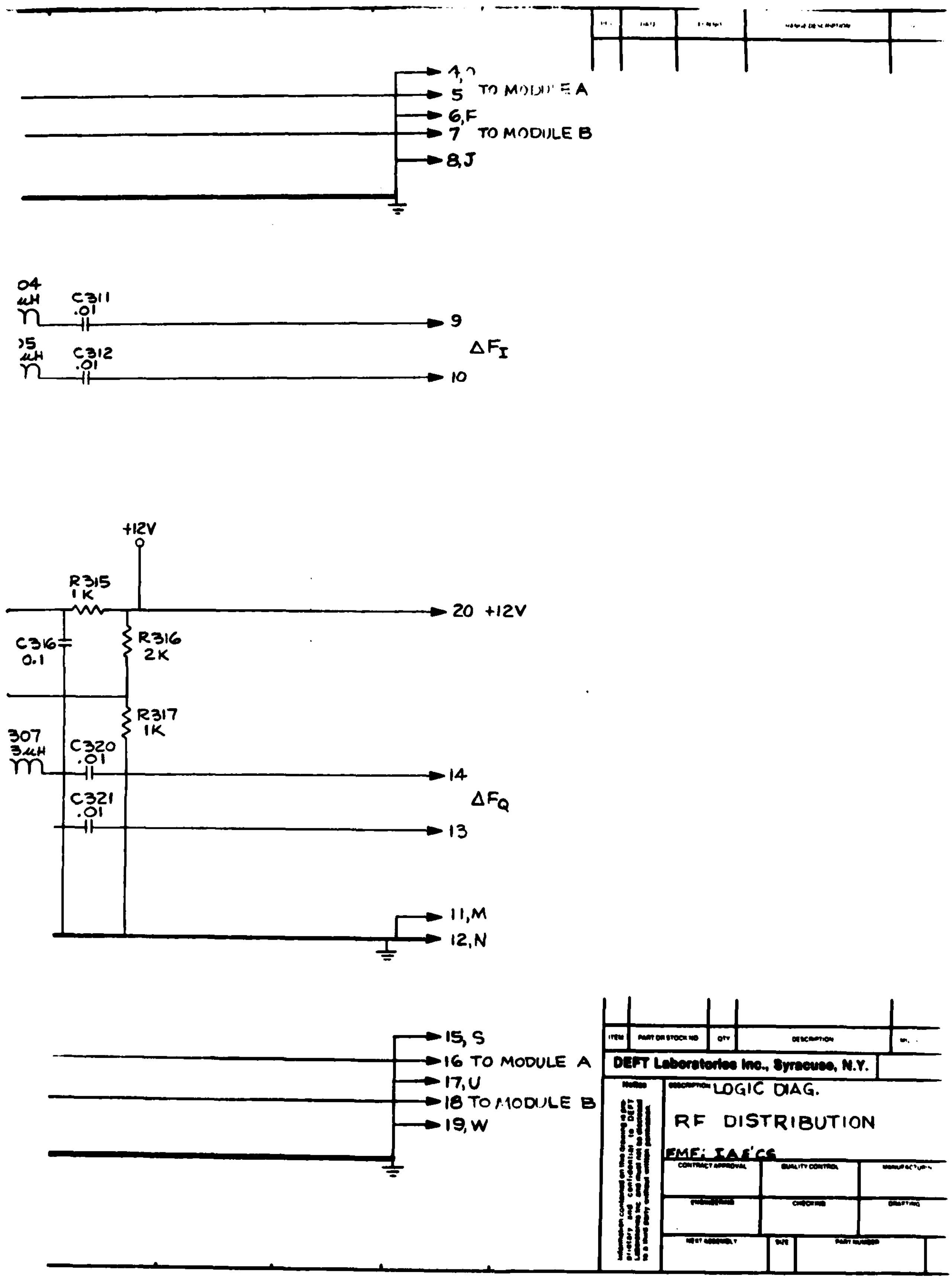
3. Kornreich, P.G. et al, "DEFT: Direct Electronic Fourier Transforms of Optical Images", Proc. IEEE, Vol. 62, August 1974, pp. 1072-1087.

APPENDIX A

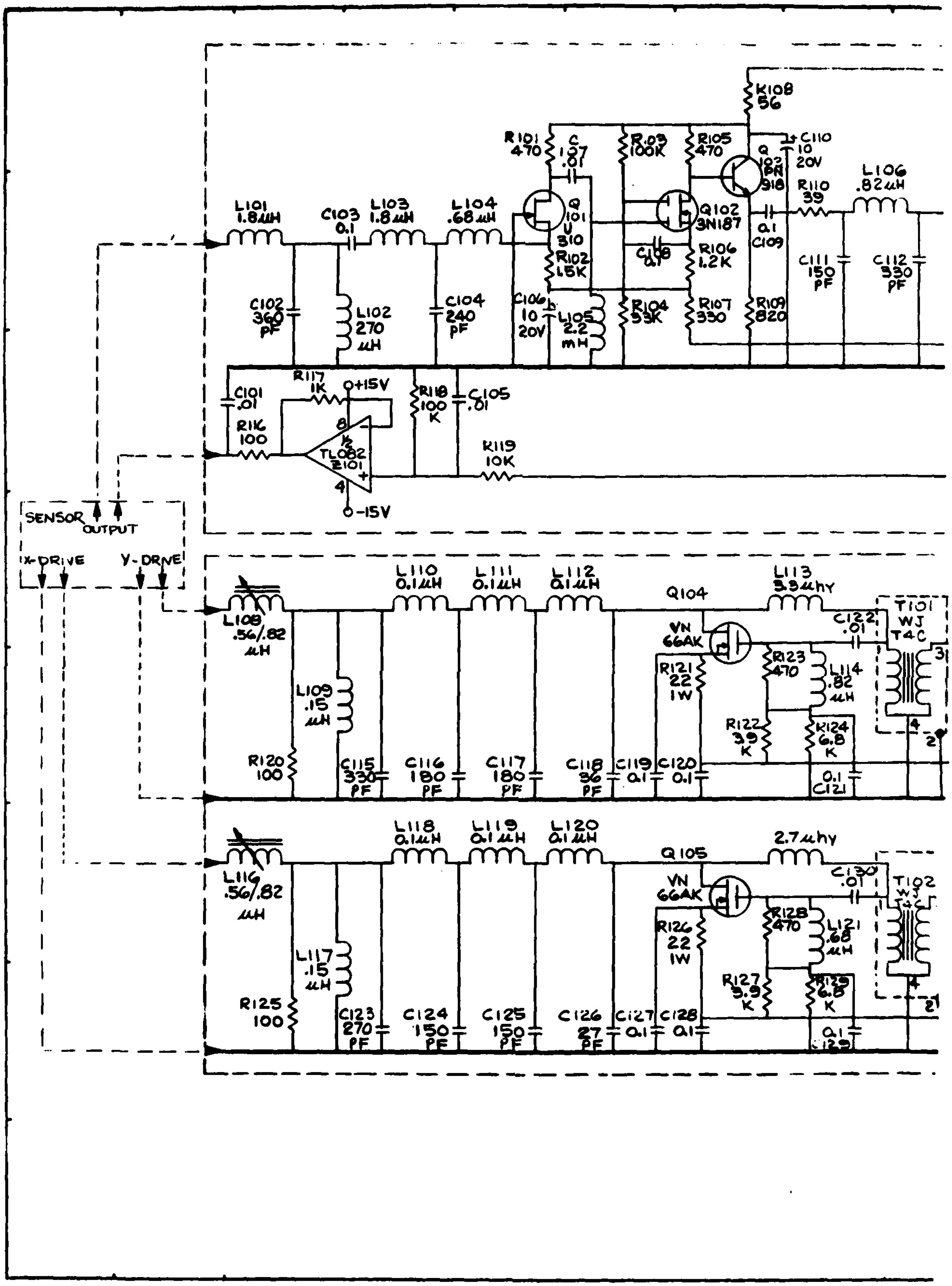
This section shows schematic diagrams for the various units described in Section II.

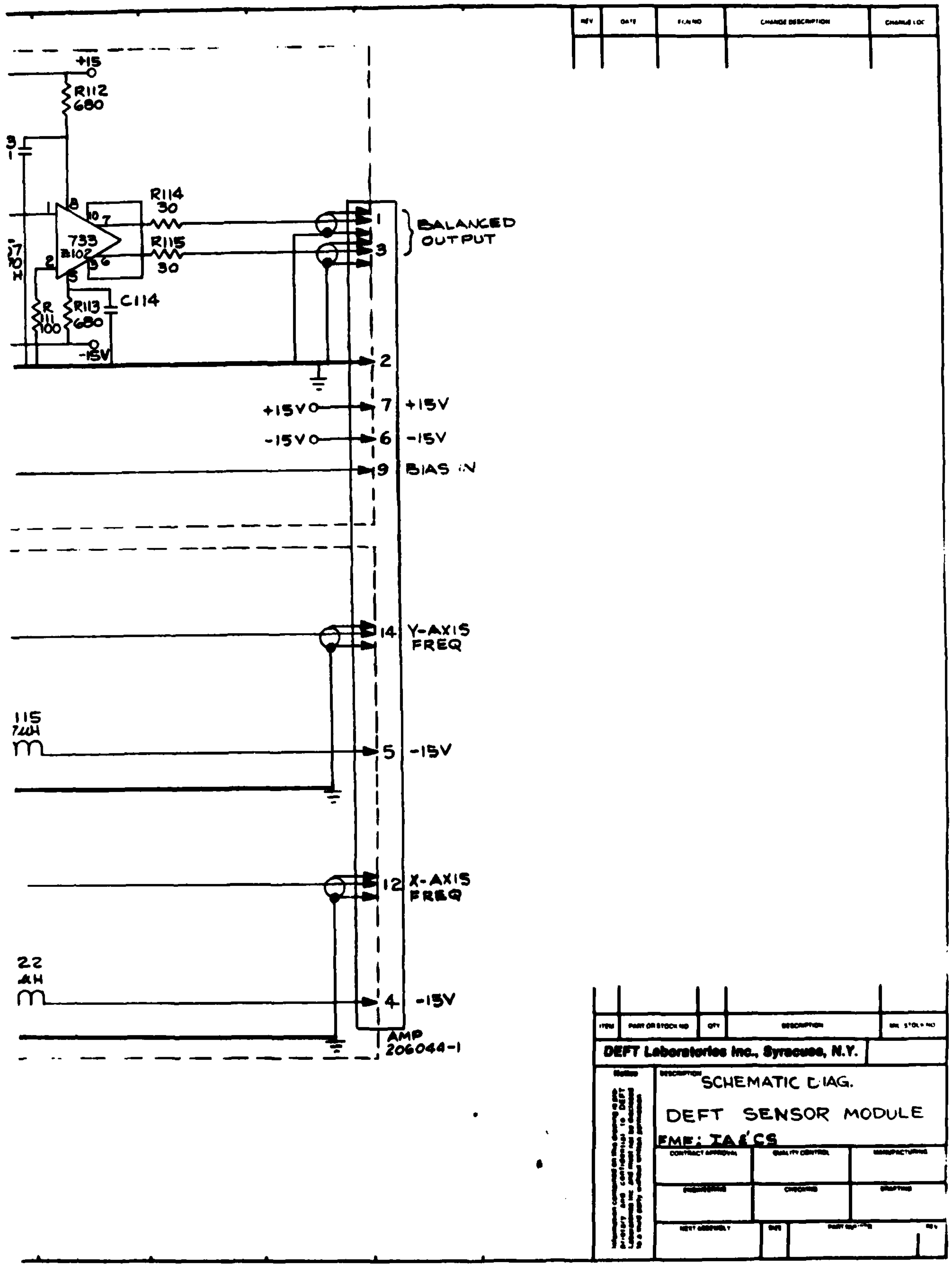


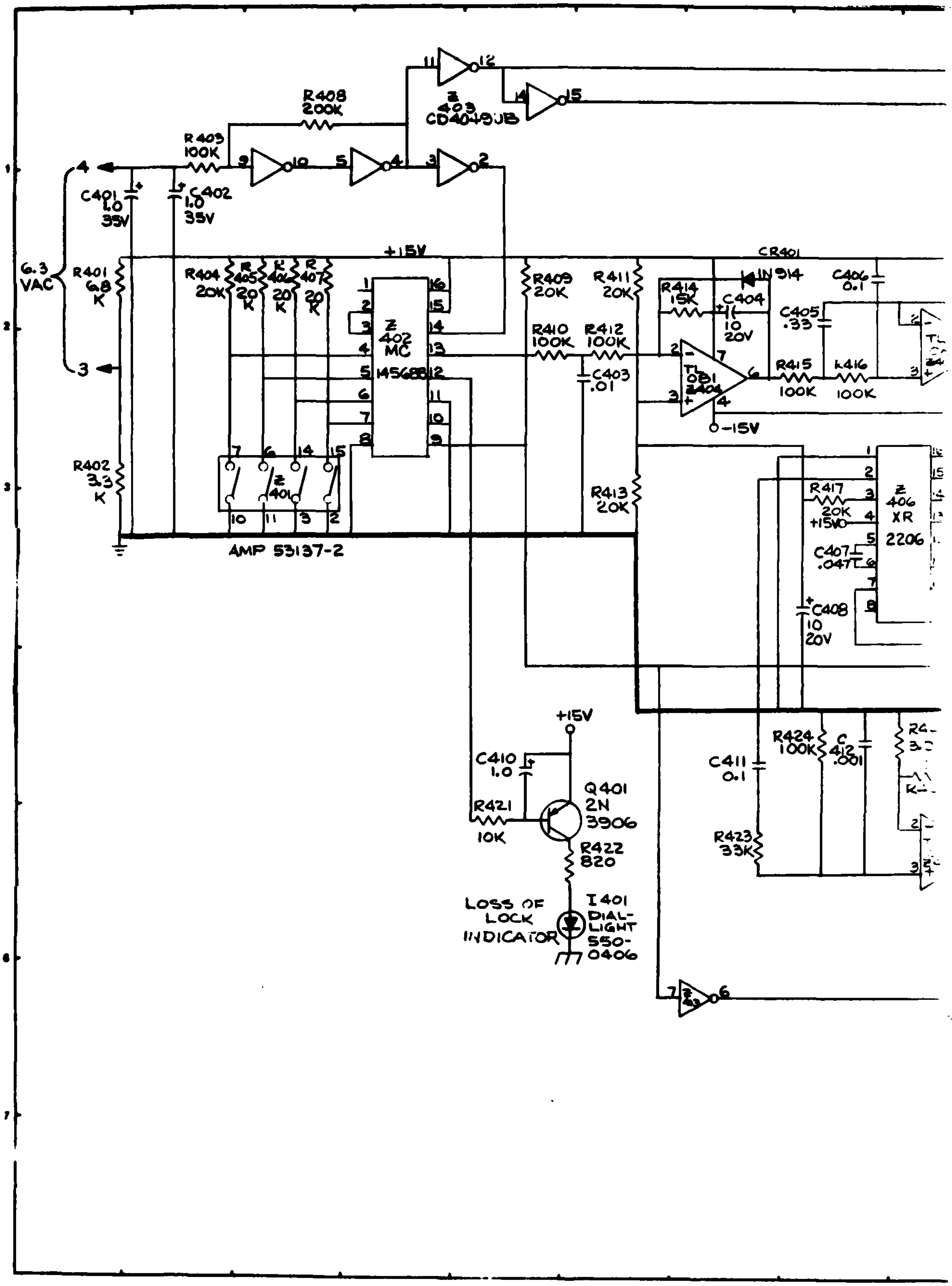
FROM X-SYNTH
L301
.22uH
L302
.22uH
C301
82
PF
C302
150
PF
C
303
82
PF
PSC-2-1
2,3,4
7,8
WJA57
L303
27uH
+15
C304
.01
PSC-2-1
2,3,4
7,8
R303
470
C307
82 pF
T301
T5-1T
R301
330
796
HC
R302
100
R304
6.8
K
C308
.01
C309
47
PF
-8V
+15V
Y
78M12
+12 V
C305
0.33
C306
0.1
1, 22
-15V
2
79M08
-8V
C313
10
20V
C314
1.0
35V
R305
15
T302
T1-1T
R
308
56
R306
330
R307
330
C315
0.1
R311
220
R312
220
R313
220
R314
220
R310
470
L306
.22uH
T303
T5-1T
R309
330
796
HC
R318
100
R319
6.8
K
C317
.01
C318
47
PF
-8V
L311
27uH
+15
C325
.01
L309
.22uH
L310
.22uH
C322
82
PF
C323
150
PF
C
324
82
PF
PSC-2-1
2,3,4
7,8
WJA57
PSC-2-1
2,3,4,
7,8

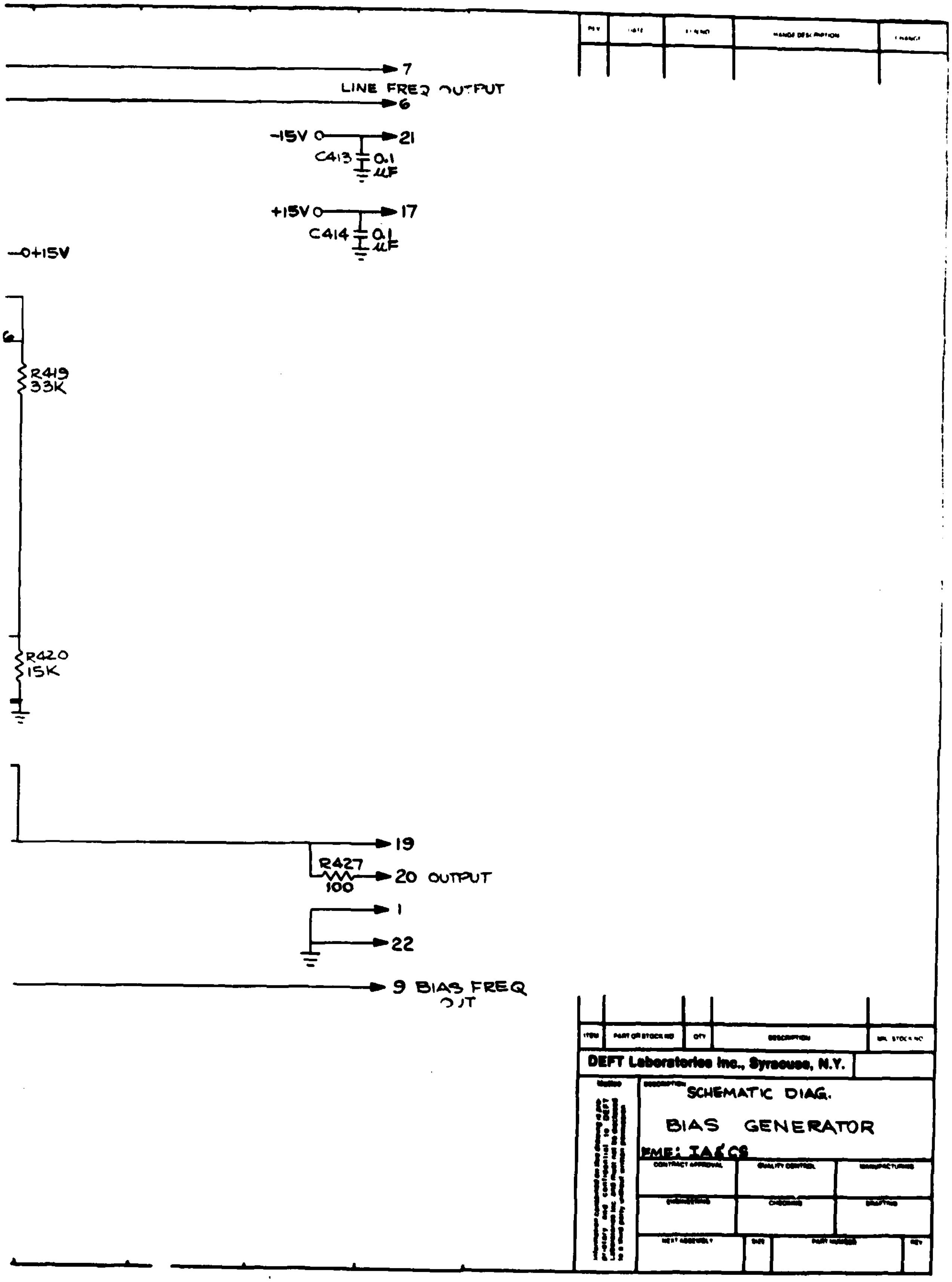


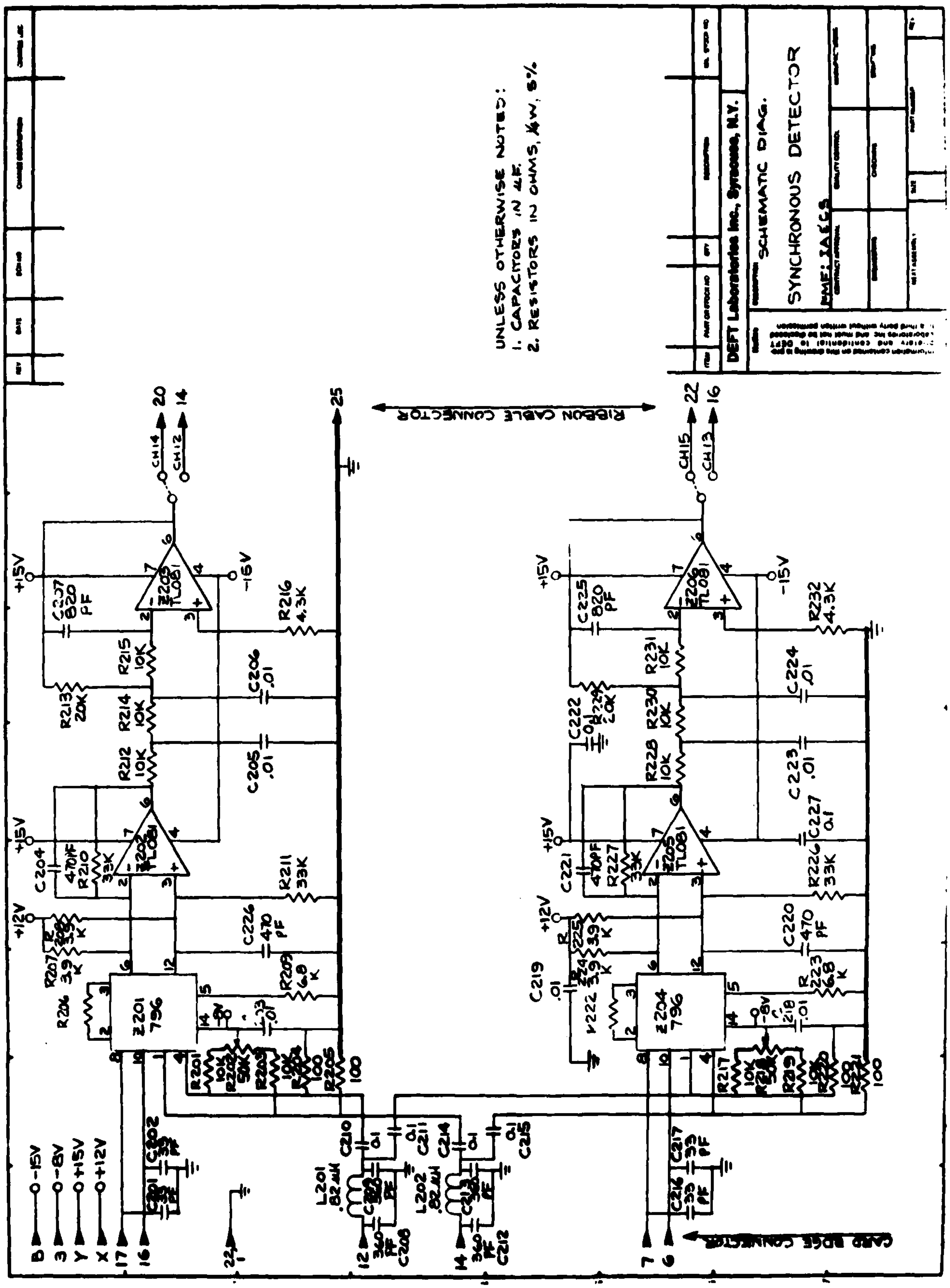
5
6,F
7 TO MODULE B
8,J
C311
.01
9
ΔF_I
C312
.01
10
+12V
R315
1K
20 +12V
C316
0.1
R316
2K
R317
1K
307
3μH
C320
.01
14
ΔF_Q
C321
.01
13
11,M
12,N
15, S
16 TO MODULE A
17,U
18 TO MODULE B
19, W
DEFT Laboratories Inc., Syracuse, N.Y.
LOGIC DIAG.
RF DISTRIBUTION

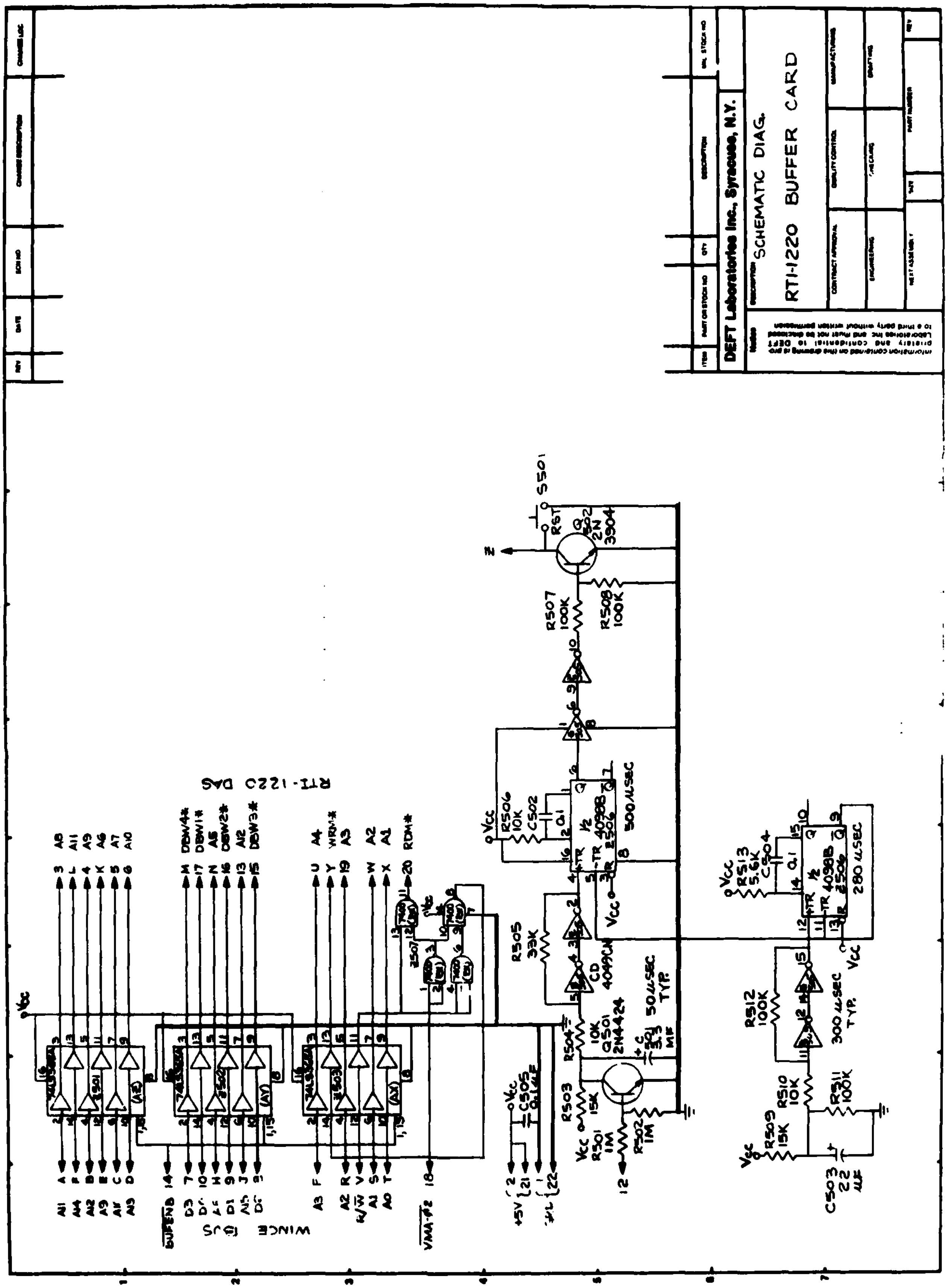

SENSOR OUTPUT
X-DRIVE
Y-DRIVE
L101 1.8µH
C102 360 pF
L102 270 µH
C103 0.1
L103 1.8µH
L104 .68µH
C104 240 pF
R101 470
C107 .01
Q101 U310
R102 1.5K
C106 10 20V
L105 2.2 mH
R103 100K
C108 0.1
R104 33K
R105 470
R106 1.2K
R107 330
Q102 3N187
R108 56
Q103 PN918
C110 10 20V
R109 820
C109 0.1
R110 39
C111 150 pF
L106 .82µH
C112 330 pF
C101 .01
R116 100
R117 1K
+15V
-15V
1/2 TL082 Z101
R118 100 K
C105 .01
R119 10K
L108 .56/.82 µH
L109 .15 µH
R120 100
C115 330 PF
L110 0.1µH
C116 180 PF
L111 0.1µH
C117 180 PF
L112 0.1µH
C118 36 PF
C119 0.1
C120 0.1
Q104 VN66AK
R121 22 1W
R123 470
R122 3.9 K
L113 3.3µhy
L114 .82 µH
R124 6.8 K
C121 0.1
C122 .01
T101 WJ T4C
L116 .56/.82 µH
L117 .15 µH
R125 100
C123 270 PF
L118 0.1µH
C124 150 PF
L119 0.1µH
C125 150 PF
L120 0.1µH
C126 27 PF
C127 0.1
C128 0.1
Q105 VN66AK
R126 22 1W
R128 470
R127 3.9 K
2.7µhy
L121 .68 µH
R129 6.8 K
C129 0.1
C130 .01
T102 WJ T4C

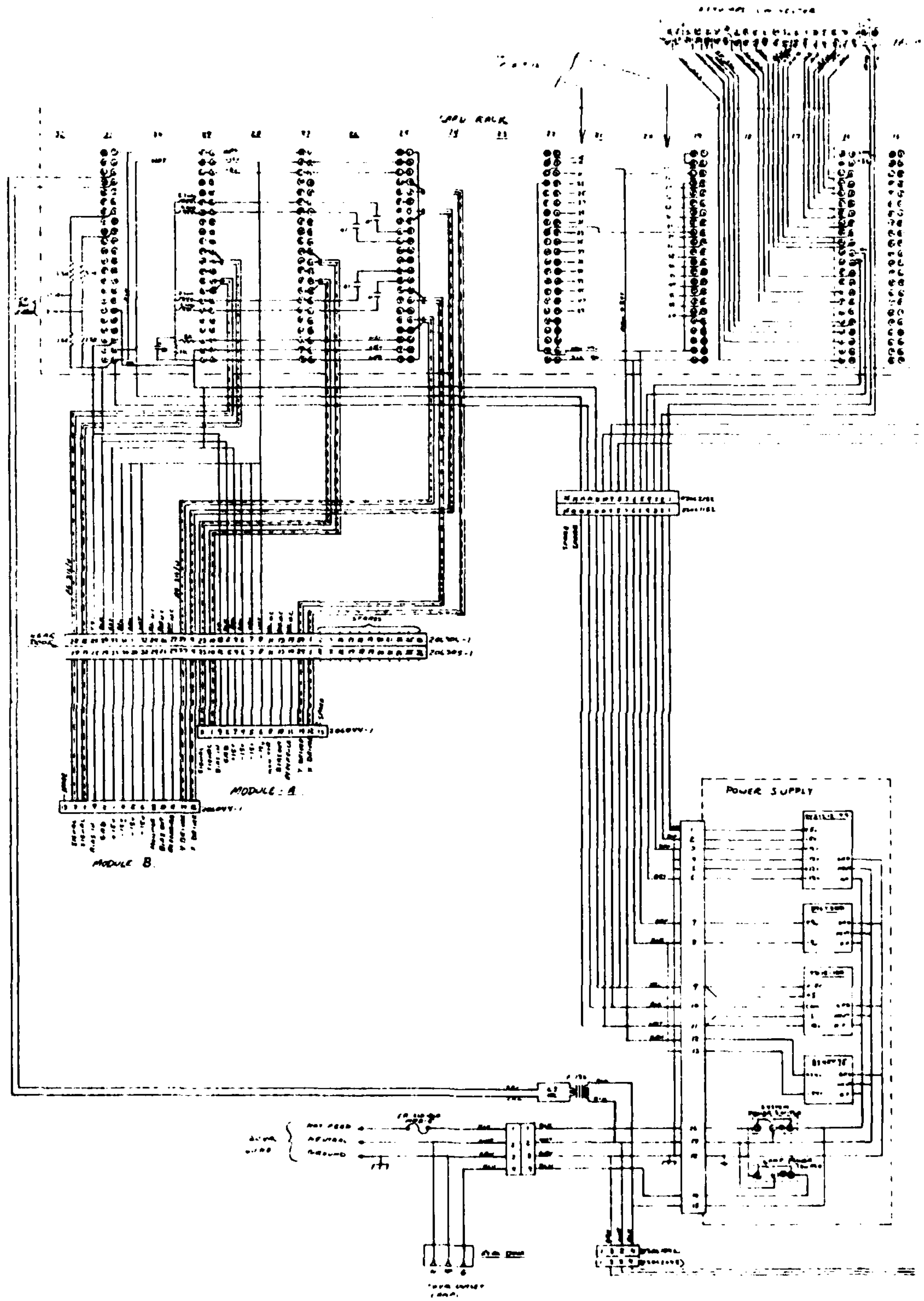

+15
R112
680
R114
30
733
B102
R115
30
R113
680
C114
R
111
100
-15V
BALANCED
OUTPUT
+15V
-15V
+15V
-15V
BIAS IN
Y-AXIS
FREQ
115
-15V
X-AXIS
FREQ
22
-15V
AMP
206044-1
DEFT Laboratories Inc., Syracuse, N.Y.
SCHEMATIC DIAG.
DEFT SENSOR MODULE

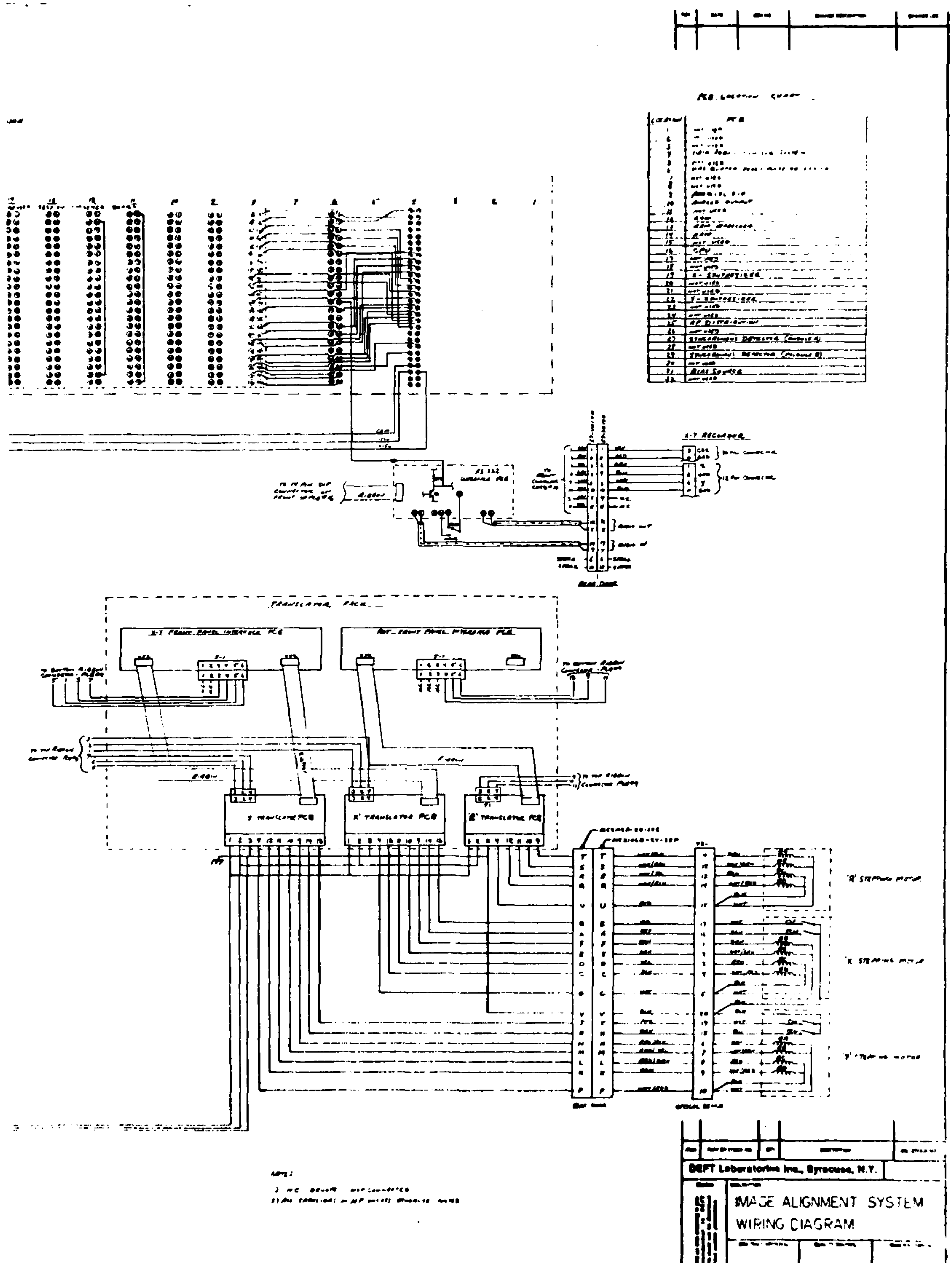

R408
200K
Z
403
CD4049UB
R403
100K
C401
1.0
35V
C402
1.0
35V
6.3
VAC
R401
6.8
K
+15V
CR401
1N914
C406
0.1
R404
20K
R405
20K
R406
20K
R407
20K
Z
402
MC
14568B
R409
20K
R411
20K
R414
15K
C404
10
20V
C405
.33
R410
100K
R412
100K
C403
.01
TL
081
R415
100K
R416
100K
-15V
R402
3.3
K
Z
401
R413
20K
R417
20K
+15V
Z
406
XR
2206
C407
.047
C408
10
20V
AMP 53137-2
+15V
C410
1.0
Q401
2N
3906
R421
10K
R422
820
C411
0.1
R424
100K
C
412
.001
R423
33K
LOSS OF
LOCK
INDICATOR
I401
DIAL-
LIGHT
550-
0406


7
LINE FREQ OUTPUT
6
-15V
21
C413
0.1 uF
+15V
17
C414
0.1 uF
+15V
R419
33K
R420
15K
19
R427
100
20 OUTPUT
1
22
9 BIAS FREQ OUT
DEFT Laboratories Inc., Syracuse, N.Y.
SCHEMATIC DIAG.
BIAS GENERATOR
FME: IA&CS


UNLESS OTHERWISE NOTED:
1. CAPACITORS IN µF.
2. RESISTORS IN OHMS, 1/4W, 5%
DEFT Laboratories Inc., Syracuse, N.Y.
SCHEMATIC DIAG.
SYNCHRONOUS DETECTOR
RIBBON CABLE CONNECTOR
CARD EDGE CONNECTOR


DEFT Laboratories Inc., Syracuse, N.Y.
SCHEMATIC DIAG.
RTI-1220 BUFFER CARD
RTI-1220 DAS
WINCE BUS
Information contained on this drawing is proprietary and confidential to DEFT Laboratories Inc. and must not be disclosed to a third party without written permission
S501
RST
Q502 2N 3904
R507 100K
R508 100K
R506 10K
C502 0.1
1/2 4098B Z506
500 μSEC
R505 33K
CD 4049CN
50 μSEC TYP.
R504 10K
Q501 2N4424
C501 3.3 MF
R503 15K
R501 1M
R502 1M
C505 0.1 μF
R513 5.6K
C504 0.1
280 μSEC
R512 100K
300 μSEC TYP.
R509 15K
R510 10K
R511 100K
C503 22 μF
74LS365A
Z501
Z502
Z503
Z507
Vcc
+5V
BUFENB
VMA·Φ2
RDM*
DBW4*
DBW1*
DBW2*
DBW3*
WRM*


CARD RACK
MODULE : B
MODULE B.
POWER SUPPLY


DEFT Laboratories Inc., Syracuse, N.Y.
IMAGE ALIGNMENT SYSTEM
WIRING DIAGRAM

APPENDIX B

This section contains listings of all of the software furnished with the Image Alignment and Correlation System except for that purchased from Wintek Corp. All addresses and opcodes are hexadecimal. In the operand column of the statements, the following symbols are used:

$	Hexadecimal Prefix
%	Binary Prefix
H	Hexadecimal Postfix
D	Decimal Postfix
B	Binary Postfix
#	Denotes Immediate Addressing Mode

```
                        *       SUBROUTINE CORRELATION COEFFICIENT
                        *       SCANS TRANSFORMS AND COMPUTES THEIR
                        *       COMPLEX CORRELATION COEFFICIENT
    1800                        ORG     $1800
    1800                TEMP1   RMB     1
    1801                TEMP2   RMB     1
    1802                TEMP3   RMB     1
    1803                TEMP4   RMB     1
    1804                TEMP5   RMB     1
    1805                TEMP6   RMB     1
    1806                BCD1    RMB     1
    1807                BCD2    RMB     1
    1808                CTR     RMB     1
    1809                CTR1    RMB     1
    1824                        ORG     $1824
    1824                COR1    RMB     1
    1825                COR2    RMB     1
    1826                COR3    RMB     1               IMAG
    1827                COR4    RMB     3
    182A                COR9    RMB     1               THETA
    182B                COR10   RMB     1
    182C                I       RMB     1
    182D                J       RMB     1
    182E                ID      RMB     1
    182F                JD      RMB     1
    1830                UI1     RMB     1
    1831                UI2     RMB     1
    1832                VJ1     RMB     1
    1833                VJ2     RMB     1
    1834                MODE    RMB     1
    1835                DTIME   RMB     1
    1836                JSTART  RMB     1
    1837                BDRY    RMB     1
    1838                BDRYD   RMB     1
    1839                NBDRY   RMB     1
    183A                BDRYPT  RMB     1
    183B                FIRST   RMB     1
    183C                SENSOR  RMB     1
    183D                NSAMP   RMB     1
    183E                LOGS    RMB     1
    187A                        ORG     $187A
    187A                VP      RMB     4
    187E                UP      RMB     4
    1882                UV      RMB     4
    1886                VV      RMB     4
    188A                UU      RMB     4
    1856                CFLAG   EQU     $1856
    1857                CCFLAG  EQU     $1857
    1E40                ARRAY   EQU     $1E40
    BB68                PULL4   EQU     $BB68
    BB8E                PUSH44  EQU     $BB8E
    BBB4                PUSH41  EQU     $BBB4
    BBD1                PUSH42  EQU     $BBD1
    B9A0                DELAY1  EQU     $B9A0
    BB17                BI$BCD  EQU     $BB17
    BBF4                TUNE    EQU     $BBF4
    BC0D                RDDEFT  EQU     $BC0D
```

```
8000                MATH    EQU    $8000
BDD6                CORDIC  EQU    $BDD6
ED00                LEDBFR  EQU    $ED00
ED2F                DISPTR  EQU    $ED2F
AB66                FIXSGN  EQU    $AB66
AEF7                CORCRT  EQU    $AEF7
                    *
A000                        ORG    $A000
A000  86 01         CORMAG  LDAA   #1          MAGNITUDE CORRELATION
A002  B7 18 56              STAA   CFLAG
A005  20 03                 BRA    CR1
A007  7F 18 56      CORCOM  CLR    CFLAG       COMPLEX CORRELATION
A00A  CE 00 00      CR1     LDX    #0
A00D  BF 18 00              STS    TEMP1
A010  8E 1E 6F              LDS    #ARRAY+47D
A013  4F                    CLRA
A014  36            CR2     PSHA
A015  08                    INX
A016  8C 00 30              CPX    #48D
A019  26 F9                 BNE    CR2
A01B  BE 18 00              LDS    TEMP1
A01E  7F 18 57              CLR    CCFLAG
A021  CE 39 26              LDX    #$3926
A024  FF 18 30              STX    UI1
A027  CE 30 52              LDX    #$3052
A02A  FF 18 32              STX    VJ1
A02D  BD BB F4              JSR    TUNE
A030  CE 01 00              LDX    #$0100
A033  FF 18 3D              STX    NSAMP
A036  86 0A                 LDAA   #$A
A038  B7 18 35              STAA   DTIME
A03B  BD B9 A0              JSR    DELAY1
A03E  86 FF         CR3     LDAA   #$FF
A040  B7 18 3C              STAA   SENSOR
A043  BD BC 0D              JSR    RDDEFT      REF
A046  FE 18 24              LDX    COR1
A049  FF 18 8A              STX    UU
A04C  FE 18 26              LDX    COR3
A04F  FF 18 8C              STX    UU+2
A052  BD BC 0D              JSR    RDDEFT      REF AGAIN
A055  CE 18 30              LDX    #UI1
A058  A6 01                 LDAA   1,X         OFFSET FREQ
A05A  8B 91                 ADDA   #$91
A05C  19                    DAA
A05D  A7 01                 STAA   1,X
A05F  A6 00                 LDAA   0,X
A061  89 99                 ADCA   #$99
A063  19                    DAA
A064  A7 00                 STAA   0,X
A066  A6 03                 LDAA   3,X
A068  8B 95                 ADDA   #$95
A06A  19                    DAA
A06B  A7 03                 STAA   3,X
A06D  A6 02                 LDAA   2,X
A06F  89 99                 ADCA   #$99
```

CORRELATION COEFFICIENT

```
A071  19               DAA
A072  A7 02            STAA    2,X
A074  BD BB F4         JSR     TUNE
A077  7D 18 56         TST     CFLAG
A07A  27 03            BEQ     CR4
A07C  BD A5 6E         JSR     CRDIC
A07F  FE 18 24   CR4   LDX     COR1
A082  FF 18 86         STX     VV
A085  FE 18 26         LDX     COR3
A088  FF 18 88         STX     VV+2
A08B  5F               CLRB
A08C  4F               CLRA
A08D  F0 18 27         SUBB    COR4
A090  B2 18 26         SBCA    COR3
A093  B7 18 26         STAA    COR3
A096  F7 18 27         STAB    COR4
A099  BD A4 2D         JSR     CMULT
A09C  CE 18 24         LDX     #COR1
A09F  7F 18 00         CLR     TEMP1
A0A2  BD A3 F6         JSR     ACCUM           REF
A0A5  CE 18 86         LDX     #VV
A0A8  86 20            LDAA    #32D
A0AA  B7 18 00         STAA    TEMP1
A0AD  BD A5 3A         JSR     ACCUM1          REF MEAN
A0B0  86 01            LDAA    #1
A0B2  B7 18 3C         STAA    SENSOR
A0B5  86 04            LDAA    #4
A0B7  B7 18 35         STAA    DTIME
A0BA  BD B9 A0         JSR     DELAY1
A0BD  BD BC 0D         JSR     RDDEFT          ALIGN
A0C0  FE 18 24         LDX     COR1
A0C3  FF 18 8A         STX     UU
A0C6  FE 18 26         LDX     COR3
A0C9  FF 18 8C         STX     UU+2
A0CC  BD BC 0D         JSR     RDDEFT          ALIGN MEAN
A0CF  BD A4 D6         JSR     INDEX2          NEW FREQ
A0D2  BD BB F4         JSR     TUNE
A0D5  7D 18 56         TST     CFLAG
A0D8  27 03            BEQ     CR5
A0DA  BD A5 6E         JSR     CRDIC
A0DD  FE 18 24   CR5   LDX     COR1
A0E0  FF 18 82         STX     UV
A0E3  5F               CLRB
A0E4  4F               CLRA
A0E5  F0 18 27         SUBB    COR4
A0E8  B2 18 26         SBCA    COR3
A0EB  B7 18 26         STAA    COR3
A0EE  F7 18 27         STAB    COR4
A0F1  B7 18 84         STAA    UV+2
A0F4  F7 18 85         STAB    UV+3
A0F7  BD A4 2D         JSR     CMULT
A0FA  CE 18 24         LDX     #COR1
A0FD  86 08            LDAA    #8
A0FF  B7 18 00         STAA    TEMP1
A102  BD A3 F6         JSR     ACCUM           ALIGN
A105  CE 18 82         LDX     #UV
A108  86 28            LDAA    #40D
```

```
A10A  B7 18 00         STAA   TEMP1
A10D  BD A5 3A         JSR    ACCUM1         ALIGN AGAIN
A110  FE 18 82         LDX    UV
A113  FF 18 24         STX    COR1
A116  FE 18 84         LDX    UV+2
A119  FF 18 26         STX    COR3
A11C  FE 18 86         LDX    VV
A11F  FF 18 8A         STX    UU
A122  FE 18 88         LDX    VV+2
A125  FF 18 8C         STX    UU+2
A128  BD A4 2D         JSR    CMULT
A12B  CE 18 24         LDX    #COR1
A12E  86 10            LDAA   #16D
A130  B7 18 00         STAA   TEMP1
A133  BD A3 F6         JSR    ACCUM          CROSS: REAL
A136  CE 18 8A         LDX    #UU
A139  86 18            LDAA   #24D
A13B  B7 18 00         STAA   TEMP1
A13E  BD A3 F6         JSR    ACCUM          CROSS: IMAG
A141  7D 18 57         TST    CCFLAG
A144  26 03            BNE    CR6
A146  7E A0 3E         JMP    CR3
A149  CE 1E 44   CR6   LDX    #ARRAY+4       FINISHED SCANNING
A14C  4F               CLRA
A14D  BD BB 8E         JSR    PUSH44
A150  86 05            LDAA   #5
A152  B7 18 35         STAA   DTIME
A155  CE 10 04         LDX    #$1004
A158  FF 18 3D         STX    NSAMP
A15B  CE 1E 40         LDX    #ARRAY
A15E  4F               CLRA
A15F  BD BB 8E         JSR    PUSH44
A162  7F 18 00         CLR    TEMP1
A165  BD A5 9C         JSR    MEAN
A168  CE 1E 4C         LDX    #ARRAY+12D
A16B  4F               CLRA
A16C  BD BB 8E         JSR    PUSH44
A16F  CE 1E 48         LDX    #ARRAY+8
A172  4F               CLRA
A173  BD BB 8E         JSR    PUSH44
A176  86 08            LDAA   #8
A178  B7 18 00         STAA   TEMP1
A17B  BD A5 9C         JSR    MEAN
A17E  86 01            LDAA   #1
A180  BD 80 00         JSR    MATH           DENOMINATOR SQUARED
A183  CE 18 7A         LDX    #VP            FIND SQUARE ROOT
A186  4F               CLRA
A187  BD BB 68         JSR    PULL4
A18A  CE 18 7E         LDX    #UP
A18D  4F               CLRA
A18E  BD BB 68         JSR    PULL4          VP,UP=DEN SQ
A191  FE 18 7A         LDX    VP             COPY
A194  FF 18 82         STX    UV
A197  FE 18 7C         LDX    VP+2
A19A  FF 18 84         STX    UV+2
A19D  FE 18 7E         LDX    UP
A1A0  FF 18 86         STX    VV
```

```
A1A3  FE 18 80          LDX    UP+2
A1A6  FF 18 88          STX    VV+2
A1A9  B6 18 89          LDAA   VV+3         EXP
A1AC  47                ASRA
A1AD  B7 18 89   CR7    STAA   VV+3         UV,VV=INITIAL ITERATE
A1B0  86 0A             LDAA   #10D
A1B2  B7 18 00          STAA   TEMP1
A1B5  CE 18 7E   CR8    LDX    #UP          ITERATE
A1B8  4F                CLRA
A1B9  BD BB 8E          JSR    PUSH44
A1BC  CE 18 7A          LDX    #VP
A1BF  4F                CLRA
A1C0  BD BB 8E          JSR    PUSH44
A1C3  CE 18 86          LDX    #VV
A1C6  4F                CLRA
A1C7  BD BB 8E          JSR    PUSH44
A1CA  CE 18 82          LDX    #UV
A1CD  4F                CLRA
A1CE  BD BB 8E          JSR    PUSH44
A1D1  86 02             LDAA   #2
A1D3  BD 80 00          JSR    MATH         X=(DEN SQ)/ITERATE
A1D6  CE 18 86          LDX    #VV
A1D9  4F                CLRA
A1DA  BD BB 8E          JSR    PUSH44
A1DD  CE 18 82          LDX    #UV
A1E0  4F                CLRA
A1E1  BD BB 8E          JSR    PUSH44
A1E4  86 06             LDAA   #6
A1E6  BD 80 00          JSR    MATH         X=X+ITERATE
A1E9  30                TSX
A1EA  6A 07             DEC    7,X          X=0.5X
A1EC  CE 18 82          LDX    #UV
A1EF  4F                CLRA
A1F0  BD BB 68          JSR    PULL4
A1F3  CE 18 86          LDX    #VV
A1F6  4F                CLRA
A1F7  BD BB 68          JSR    PULL4        UV,VV=NEW ITERATE
A1FA  7A 18 00          DEC    TEMP1
A1FD  26 B6             BNE    CR8
A1FF  CE 1E 54          LDX    #ARRAY+20D   SQUARE ROOT DONE
A202  4F                CLRA
A203  BD BB 8E          JSR    PUSH44
A206  CE 1E 50          LDX    #ARRAY+16D
A209  4F                CLRA
A20A  BD BB 8E          JSR    PUSH44       CROSS: REAL
A20D  4F                CLRA
A20E  BD BB B4          JSR    PUSH41
A211  CE 1E 60          LDX    #ARRAY+32D
A214  4F                CLRA
A215  BD BB 8E          JSR    PUSH44       A
A218  86 07             LDAA   #7
A21A  BD 80 00          JSR    MATH
A21D  4F                CLRA
A21E  BD BB B4          JSR    PUSH41
A221  CE 1E 68          LDX    #ARRAY+40D
A224  4F                CLRA
A225  BD BB 8E          JSR    PUSH44       C
```

```
A228  86 07       LDAA  #7
A22A  BD 80 00    JSR   MATH
A22D  86 01       LDAA  #1
A22F  BD 80 00    JSR   MATH          AC
A232  4F          CLRA
A233  BD BB B4    JSR   PUSH41
A236  CE 1E 64    LDX   #ARRAY+36D
A239  4F          CLRA
A23A  BD BB 8E    JSR   PUSH44        B
A23D  86 07       LDAA  #7
A23F  BD 80 00    JSR   MATH
A242  4F          CLRA
A243  BD BB B4    JSR   PUSH41
A246  CE 1E 6C    LDX   #ARRAY+44D
A249  4F          CLRA
A24A  BD BB 8E    JSR   PUSH44        D
A24D  86 07       LDAA  #7
A24F  BD 80 00    JSR   MATH
A252  86 01       LDAA  #1
A254  BD 80 00    JSR   MATH          BD
A257  86 05       LDAA  #5
A259  BD 80 00    JSR   MATH          AC-BD
A25C  86 05       LDAA  #5
A25E  BD 80 00    JSR   MATH
A261  CE 18 86    LDX   #VV
A264  4F          CLRA
A265  BD BB 8E    JSR   PUSH44
A268  CE 18 82    LDX   #UV
A26B  4F          CLRA
A26C  BD BB 8E    JSR   PUSH44
A26F  86 02       LDAA  #2
A271  BD 80 00    JSR   MATH          REAL/DEN
A274  CE 18 7A    LDX   #VP
A277  4F          CLRA
A278  BD BB 68    JSR   PULL4
A27B  CE 18 7E    LDX   #UP
A27E  4F          CLRA
A27F  BD BB 68    JSR   PULL4         VP,UP=REAL FPN
A282  CE 1E 5C    LDX   #ARRAY+28D
A285  4F          CLRA
A286  BD BB 8E    JSR   PUSH44
A289  CE 1E 58    LDX   #ARRAY+24D
A28C  4F          CLRA
A28D  BD BB 8E    JSR   PUSH44        CROSS: IMAG
A290  4F          CLRA
A291  BD BB B4    JSR   PUSH41
A294  CE 1E 60    LDX   #ARRAY+32D
A297  4F          CLRA
A298  BD BB 8E    JSR   PUSH44        A
A29B  86 07       LDAA  #7
A29D  BD 80 00    JSR   MATH
A2A0  4F          CLRA
A2A1  BD BB B4    JSR   PUSH41
A2A4  CE 1E 6C    LDX   #ARRAY+44D
A2A7  4F          CLRA
A2A8  BD BB 8E    JSR   PUSH44        D
A2AB  86 07       LDAA  #7
```

```
A2AD  BD 80 00          JSR    MATH
A2B0  86 01             LDAA   #1
A2B2  BD 80 00          JSR    MATH              AD
A2B5  4F                CLRA
A2B6  BD BB B4          JSR    PUSH41
A2B9  CE 1E 64          LDX    #ARRAY+36D
A2BC  4F                CLRA
A2BD  BD BB 8E          JSR    PUSH44            B
A2C0  86 07             LDAA   #7
A2C2  BD 80 00          JSR    MATH
A2C5  4F                CLRA
A2C6  BD BB B4          JSR    PUSH41
A2C9  CE 1E 68          LDX    #ARRAY+40D
A2CC  4F                CLRA
A2CD  BD BB 8E          JSR    PUSH44            C
A2D0  86 07             LDAA   #7
A2D2  BD 80 00          JSR    MATH
A2D5  86 01             LDAA   #1
A2D7  BD 80 00          JSR    MATH              BC
A2DA  86 06             LDAA   #6
A2DC  BD 80 00          JSR    MATH              AD+BC
A2DF  86 05             LDAA   #5
A2E1  BD 80 00          JSR    MATH
A2E4  CE 18 86          LDX    #VV
A2E7  4F                CLRA
A2E8  BD BB 8E          JSR    PUSH44
A2EB  CE 18 82          LDX    #UV
A2EE  4F                CLRA
A2EF  BD BB 8E          JSR    PUSH44
A2F2  86 02             LDAA   #2
A2F4  BD 80 00          JSR    MATH              IMAG/DEN
A2F7  CE 18 82          LDX    #UV
A2FA  4F                CLRA
A2FB  BD BB 68          JSR    PULL4
A2FE  CE 18 86          LDX    #VV
A301  4F                CLRA
A302  BD BB 68          JSR    PULL4             UV,VV=IMAG FPN
A305  F6 18 81          LDAB   UP+3              FLOAT TO FIX REAL
A308  50                NEGB
A309  CE 18 7A          LDX    #VP
A30C  5D          CR9   TSTB
A30D  27 0D             BEQ    CR10
A30F  A6 00             LDAA   0,X
A311  47                ASRA
A312  A7 00             STAA   0,X
A314  A6 01             LDAA   1,X
A316  46                RORA
A317  A7 01             STAA   1,X
A319  5A                DECB
A31A  20 F0             BRA    CR9
A31C  F6 18 89    CR10  LDAB   VV+3              FLOAT TO FIX IMAG
A31F  50                NEGB
A320  CE 18 82          LDX    #UV
A323  5D          CR11  TSTB
A324  27 0D             BEQ    CR12
A326  A6 00             LDAA   0,X
A328  47                ASRA
```

```
A329  A7 00            STAA   0,X
A32B  A6 01            LDAA   1,X
A32D  46               RORA
A32E  A7 01            STAA   1,X
A330  5A               DECB
A331  20 F0            BRA    CR11
A333  FE 18 7A  CR12   LDX    VP
A336  FF 18 24         STX    COR1
A339  FE 18 82         LDX    UV
A33C  FF 18 26         STX    COR3
A33F  7F 18 2A         CLR    COR9
A342  7F 18 2B         CLR    COR10
A345  BD BD D6         JSR    CORDIC
A348  FE 18 24         LDX    COR1
A34B  FF 18 00         STX    TEMP1
A34E  7F 18 02         CLR    TEMP3
A351  7F 18 03         CLR    TEMP4
A354  CE 18 00         LDX    #TEMP1
A357  4F               CLRA
A358  BD BB 8E         JSR    PUSH44
A35B  86 5A            LDAA   #$5A
A35D  36               PSHA
A35E  86 59            LDAA   #$59
A360  36               PSHA
A361  86 01            LDAA   #1
A363  36               PSHA
A364  4A               DECA
A365  36               PSHA                 SF=.41169*65536*32768/10000
A366  86 09            LDAA   #9
A368  BD 80 00         JSR    MATH          SCALE MAG
A36B  CE 18 00         LDX    #TEMP1
A36E  4F               CLRA
A36F  BD BB 68         JSR    PULL4
A372  BD BB 17         JSR    BI$BCD
A375  FE 18 06         LDX    BCD1
A378  FF 18 24         STX    COR1          MAG IN BCD
A37B  FE 18 2A         LDX    COR9
A37E  FF 18 00         STX    TEMP1
A381  7F 18 02         CLR    TEMP3
A384  7F 18 03         CLR    TEMP4
A387  CE 18 00         LDX    #TEMP1
A38A  4F               CLRA
A38B  BD BB 8E         JSR    PUSH44
A38E  86 56            LDAA   #$56
A390  36               PSHA
A391  86 34            LDAA   #$34
A393  36               PSHA
A394  86 12            LDAA   #$12
A396  36               PSHA
A397  4F               CLRA
A398  36               PSHA                 SF=32768*65536/1800
A399  86 09            LDAA   #9
A39B  BD 80 00         JSR    MATH          SCALE PHASE
A39E  CE 18 00         LDX    #TEMP1
A3A1  4F               CLRA
A3A2  BD BB 68         JSR    PULL4
A3A5  B6 18 00         LDAA   TEMP1
```

```
A3A8  B7 18 2A          STAA   COR9
A3AB  2A 0E             BPL    CR13
A3AD  4F                CLRA
A3AE  5F                CLRB
A3AF  F0 18 03          SUBB   TEMP4
A3B2  B2 18 02          SBCA   TEMP3
A3B5  B7 18 02          STAA   TEMP3
A3B8  F7 18 03          STAB   TEMP4
A3BB  BD BB 17  CR13    JSR    BI$BCD
A3BE  FE 18 06          LDX    BCD1
A3C1  FF 18 26          STX    COR3           PHASE IN BCD (DEG)
A3C4  7D 18 2A          TST    COR9
A3C7  2A 01             BPL    CORDSP
A3C9  0D                SEC
A3CA  07        CORDSP  TPA
A3CB  36                PSHA                  SAVE SIGN
A3CC  86 0A             LDAA   #10
A3CE  B7 ED 30          STAA   DISPTR+1
A3D1  CE 18 26          LDX    #COR1+2
A3D4  86 10             LDAA   #$10
A3D6  8D 16             BSR    CORDS1         FOR ANGLE
A3D8  86 03             LDAA   #3
A3DA  B7 ED 30          STAA   DISPTR+1
A3DD  CE 18 24          LDX    #COR1
A3E0  86 FF             LDAA   #$FF
A3E2  8D 0A             BSR    CORDS1         FOR MAGNITUDE
A3E4  86 01             LDAA   #1             TO MAKE '0.'
A3E6  B7 ED 03          STAA   LEDBFR+3
A3E9  32                PULA
A3EA  06                TAP
A3EB  7E AE F7          JMP    CORCRT         WRITE TO CRT
A3EE  36        CORDS1  PSHA
A3EF  A6 00             LDAA   0,X
A3F1  E6 01             LDAB   1,X
A3F3  7E AB 66  G1      JMP    FIXSGN
                *
                *
                *       SUBROUTINE ACCUM
                *       ACCUMULATES PARTIAL PRODUCTS
A3F6  4F        ACCUM   CLRA
A3F7  BD BB B4          JSR    PUSH41
A3FA  4F                CLRA
A3FB  BD BB 8E          JSR    PUSH44
A3FE  86 07             LDAA   #7
A400  BD 80 00          JSR    MATH           NFPN
A403  CE 1E 44          LDX    #ARRAY+4
A406  B6 18 00          LDAA   TEMP1
A409  BD BB 8E          JSR    PUSH44
A40C  CE 1E 40          LDX    #ARRAY
A40F  B6 18 00          LDAA   TEMP1
A412  BD BB 8E          JSR    PUSH44
A415  86 06             LDAA   #6
A417  BD 80 00          JSR    MATH           ADD
A41A  CE 1E 40          LDX    #ARRAY
A41D  B6 18 00          LDAA   TEMP1
A420  BD BB 68          JSR    PULL4
A423  CE 1E 44          LDX    #ARRAY+4
```

```
A426  B6 18 00          LDAA   TEMP1
A429  BD BB 68          JSR    PULL4
A42C  39                RTS
                 *
                 *
                 *      SUBROUTINE CMULT
                 *      DOES COMPLEX MULTIPLY
                 *      (COR1,COR2+JCOR3,COR4)*(UU,UU+1+JUU+2,UU+3)
                 *      RETURNS REAL IN COR1 TO COR4; IMAG IN UU TO UU+3
A42D  F6 18 25   CMULT  LDAB   COR2
A430  B6 18 24          LDAA   COR1           A
A433  BD BB D1          JSR    PUSH42
A436  F6 18 27          LDAB   COR4
A439  B6 18 26          LDAA   COR3           B
A43C  BD BB D1          JSR    PUSH42
A43F  86 0C             LDAA   #12D
A441  BD 80 00          JSR    MATH           A-B
A444  F6 18 8B          LDAB   UU+1
A447  B6 18 8A          LDAA   UU             C
A44A  BD BB D1          JSR    PUSH42
A44D  F6 18 8D          LDAB   UU+3
A450  B6 18 8C          LDAA   UU+2           D
A453  BD BB D1          JSR    PUSH42
A456  86 0B             LDAA   #11D
A458  BD 80 00          JSR    MATH           C+D
A45B  86 0A             LDAA   #10D
A45D  BD 80 00          JSR    MATH           (A-B)*(C+D)
A460  F6 18 25          LDAB   COR2
A463  B6 18 24          LDAA   COR1
A466  BD BB D1          JSR    PUSH42
A469  F6 18 8D          LDAB   UU+3
A46C  B6 18 8C          LDAA   UU+2
A46F  BD BB D1          JSR    PUSH42
A472  86 0A             LDAA   #10D
A474  BD 80 00          JSR    MATH           AD
A477  CE 18 7A          LDX    #VP
A47A  4F                CLRA
A47B  BD BB 68          JSR    PULL4
A47E  F6 18 27          LDAB   COR4
A481  B6 18 26          LDAA   COR3
A484  BD BB D1          JSR    PUSH42
A487  F6 18 8B          LDAB   UU+1
A48A  B6 18 8A          LDAA   UU
A48D  BD BB D1          JSR    PUSH42
A490  86 0A             LDAA   #10D
A492  BD 80 00          JSR    MATH           BC
A495  CE 18 7E          LDX    #UP
A498  4F                CLRA
A499  BD BB 68          JSR    PULL4
A49C  CE 18 7E          LDX    #UP
A49F  4F                CLRA
A4A0  BD BB 8E          JSR    PUSH44
A4A3  CE 18 7A          LDX    #VP
A4A6  4F                CLRA
A4A7  BD BB 8E          JSR    PUSH44
A4AA  86 0B             LDAA   #11D
A4AC  BD 80 00          JSR    MATH           IMAG=AD+BC
```

```
A4AF  CE 18 8A           LDX     #UU
A4B2  4F                 CLRA
A4B3  BD BB 68           JSR     PULL4
A4B6  CE 18 7E           LDX     #UP
A4B9  4F                 CLRA
A4BA  BD BB 8E           JSR     PUSH44
A4BD  CE 18 7A           LDX     #VP
A4C0  4F                 CLRA
A4C1  BD BB 8E           JSR     PUSH44
A4C4  86 0C              LDAA    #12D
A4C6  BD 80 00           JSR     MATH             BC-AD
A4C9  86 0B              LDAA    #11D
A4CB  BD 80 00           JSR     MATH             REAL=(A-B)*(C+D)+(BC-AD)
A4CE  CE 18 24           LDX     #COR1
A4D1  4F                 CLRA
A4D2  BD BB 68           JSR     PULL4
A4D5  39                 RTS
                   *
                   *
                   *     SUBROUTINE INDEX2
                   *     INCREMENTS FREQUENCIES
A4D6  CE 18 30   INDEX2  LDX     #UI1             OFFSET FREQ
A4D9  A6 01              LDAA    1,X
A4DB  8B 09              ADDA    #9
A4DD  19                 DAA
A4DE  A7 01              STAA    1,X
A4E0  A6 00              LDAA    0,X
A4E2  89 00              ADCA    #0
A4E4  19                 DAA
A4E5  A7 00              STAA    0,X
A4E7  A6 03              LDAA    3,X
A4E9  8B 05              ADDA    #5
A4EB  19                 DAA
A4EC  A7 03              STAA    3,X
A4EE  A6 02              LDAA    2,X
A4F0  89 00              ADCA    #0
A4F2  19                 DAA
A4F3  A7 02              STAA    2,X
A4F5  A6 01              LDAA    1,X              INC UI 100 KH
A4F7  8B 90              ADDA    #$90
A4F9  19                 DAA
A4FA  A7 01              STAA    1,X
A4FC  A6 00              LDAA    0,X
A4FE  89 99              ADCA    #$99
A500  19                 DAA
A501  A7 00              STAA    0,X
A503  A6 01              LDAA    1,X
A505  8B 74              ADDA    #$74
A507  19                 DAA
A508  A6 00              LDAA    0,X
A50A  89 66              ADCA    #$66
A50C  19                 DAA
A50D  81 99              CMPA    #$99
A50F  27 01              BEQ     IEX1
A511  39                 RTS
A512  CE 39 26   IEX1    LDX     #$3926           RESTORE UI
A515  FF 18 30           STX     UI1
```

```
A518  CE 18 30         LDX    #UI1
A51B  A6 03            LDAA   3,X            INC VJ 100 KHZ
A51D  8B 10            ADDA   #$10
A51F  19               DAA
A520  A7 03            STAA   3,X
A522  A6 02            LDAA   2,X
A524  89 00            ADCA   #0
A526  19               DAA
A527  A7 02            STAA   2,X
A529  A6 03            LDAA   3,X
A52B  8B 38            ADDA   #$38
A52D  19               DAA
A52E  A6 02            LDAA   2,X
A530  89 63            ADCA   #$63
A532  19               DAA
A533  27 01            BEQ    IEX2
A535  39               RTS
A536  7C 18 57  IEX2   INC    CCFLAG
A539  39               RTS
                *
                *
A53A  FF 18 01  ACCUM1 STX    TEMP2
A53D  8D 10            BSR    ACCUM2
A53F  B6 18 00         LDAA   TEMP1
A542  8B 04            ADDA   #4
A544  B7 18 00         STAA   TEMP1
A547  FE 18 01         LDX    TEMP2
A54A  08               INX
A54B  08               INX
A54C  8D 01            BSR    ACCUM2
A54E  39               RTS
                *
A54F  E6 01     ACCUM2 LDAB   1,X
A551  A6 00            LDAA   0,X
A553  BD BB D1         JSR    PUSH42
A556  CE 1E 40         LDX    #ARRAY
A559  B6 18 00         LDAA   TEMP1
A55C  BD BB 8E         JSR    PUSH44
A55F  86 0B            LDAA   #11D
A561  BD 80 00         JSR    MATH           ACCUM
A564  CE 1E 40         LDX    #ARRAY
A567  B6 18 00         LDAA   TEMP1
A56A  BD BB 68         JSR    PULL4
A56D  39               RTS
                *
                *
A56E  7F 18 2A  CRDIC  CLR    COR9
A571  7F 18 2B         CLR    COR10
A574  BD BD D6         JSR    CORDIC
A577  FE 18 8C         LDX    UU+2
A57A  FF 18 26         STX    COR3
A57D  FE 18 24         LDX    COR1
A580  FF 18 00         STX    TEMP1
A583  FE 18 8A         LDX    UU
A586  FF 18 24         STX    COR1
A589  FE 18 00         LDX    TEMP1
A58C  FF 18 8A         STX    UU
```

CORRELATION COEFFICIENT

```
      A58F   CE 00 00          LDX     #0
      A592   FF 18 8C          STX     UU+2
      A595   FF 18 2A          STX     COR9
      A598   BD BD D6          JSR     CORDIC
      A59B   39                RTS
                         *
                         *
      A59C   86 01       MEAN  LDAA    #1
      A59E   B7 18 04          STAA    TEMP5
      A5A1   32                PULA
      A5A2   B7 18 02          STAA    TEMP3
      A5A5   32                PULA
      A5A6   B7 18 03          STAA    TEMP4
      A5A9   4F          M1    CLRA
      A5AA   BD BB B4          JSR     PUSH41
      A5AD   CE 1E 60          LDX     #ARRAY+32D
      A5B0   B6 18 00          LDAA    TEMP1
      A5B3   BD BB 8E          JSR     PUSH44
      A5B6   86 07             LDAA    #7
      A5B8   BD 80 00          JSR     MATH
      A5BB   7A 18 04          DEC     TEMP5
      A5BE   2A E9             BPL     M1
      A5C0   86 01             LDAA    #1
      A5C2   B7 18 04          STAA    TEMP5
      A5C5   BD 80 00          JSR     MATH            REAL SQ
      A5C8   4F          M2    CLRA
      A5C9   BD BB B4          JSR     PUSH41
      A5CC   CE 1E 64          LDX     #ARRAY+36D
      A5CF   B6 18 00          LDAA    TEMP1
      A5D2   BD BB 8E          JSR     PUSH44
      A5D5   86 07             LDAA    #7
      A5D7   BD 80 00          JSR     MATH
      A5DA   7A 18 04          DEC     TEMP5
      A5DD   2A E9             BPL     M2
      A5DF   86 01             LDAA    #1
      A5E1   BD 80 00          JSR     MATH            IMAG SQ
      A5E4   86 06             LDAA    #6
      A5E6   BD 80 00          JSR     MATH            REAL SQ + IM SQ
      A5E9   86 05             LDAA    #5
      A5EB   BD 80 00          JSR     MATH
      A5EE   B6 18 03          LDAA    TEMP4
      A5F1   36                PSHA
      A5F2   B6 18 02          LDAA    TEMP3
      A5F5   36                PSHA
      A5F6   39                RTS
      A5F7                     END
```

STATEMENTS =731

FREE BYTES =489

NO ERRORS DETECTED

MORE MEASURE SUBROUTINES

```
1800                ORG     $1800
1800      TEMP1     RMB     1
1801      TEMP2     RMB     1
1802      TEMP3     RMB     1
1803      TEMP4     RMB     1
1804      TEMP5     RMB     1
1805      TEMP6     RMB     1
1806      BCD1      RMB     1
1807      BCD2      RMB     1
1808      CTR       RMB     1
1809      CTR1      RMB     1
1812                ORG     $1812
1812      PHASE     RMB     2
1814      XOZERO    RMB     4
1818      YOZERO    RMB     4
181C      X1ZERO    RMB     4
1820      Y1ZERO    RMB     4
1824      COR1      RMB     1            REAL
1825      COR2      RMB     1
1826      COR3      RMB     1            IMAG
1827      COR4      RMB     3
182A      COR9      RMB     1            THETA
182B      COR10     RMB     1
182C      I         RMB     1
182D      J         RMB     1
182E      ID        RMB     1
182F      JD        RMB     1
1830      UI1       RMB     1
1831      UI2       RMB     1
1832      VJ1       RMB     1
1833      VJ2       RMB     1
1834      MODE      RMB     1
1835      DTIME     RMB     1
1836      JSTART    RMB     1
1837      BDRY      RMB     1
1838      BDRYD     RMB     1
1839      NBDRY     RMB     1
183A      BDRYPT    RMB     1
183B      FIRST     RMB     1
183C      SENSOR    RMB     1
183D      NSAMP     RMB     1
183E      LOGNS     RMB     1
183F      BCDPTR    RMB     2
1841      L         RMB     1
1842      LIMIT     RMB     1
1843      X         RMB     1
1844      Y         RMB     1
1845      ZERO      RMB     4
1849      X1INC     RMB     2
184B      Y1INC     RMB     2
184D      NPT       RMB     1
184E      STACK1    RMB     1
184F      STACK2    RMB     1
1850      PUSHST    RMB     1
1851      THR11     RMB     1
1852      THR12     RMB     1
1853      THR21     RMB     1
```

MORE MEASURE SUBROUTINES

```
1854    THR22   RMB   1
1855    HOW     RMB   1
1856    IJPTR   RMB   1
1857    IJPTR1  RMB   1
1858    ADRSW   RMB   1
1859    SETUP   RMB   1
185A    FINE    RMB   1
185B    K$G     RMB   1
185C    KKKK    RMB   4
1860    CORSE   RMB   2
1862    ST      RMB   2
1864    SAVESP  RMB   2
1866    MAX     RMB   4
186A    SUM     RMB   4
186E    XTRAN   RMB   2
1870    YTRAN   RMB   2
1872    DELX    RMB   4
1876    DELY    RMB   4
187A    VP      RMB   4
187E    UP      RMB   4
1882    UV      RMB   4
1886    VV      RMB   4
188A    UU      RMB   4
188E    STEPS   RMB   2
1890    ANGLE   RMB   2
1892    SMAG    RMB   4
1896    SAVEX   RMB   2
1898    SAVEY   RMB   2
189A    DIRECT  RMB   1
189B    DTHR11  RMB   1
189C    DTHR12  RMB   1
189D    DTHR21  RMB   1
189E    DTHR22  RMB   1
189F    MPLX    RMB   2
18A1    SIGNI   RMB   1
18A2    SIGNQ   RMB   1
18A3    SFLAG   RMB   1
18A4    SNFLAG  RMB   1
18D8            ORG   $18D8
18D8    DELTA   RMB   10D
18E2    BCDAR   RMB   512D
1AE2    BDRYLF  RMB   5
1AE7    BDRYCT  RMB   5
1AEC    S1VP1M  RMB   20D
1B00    S1UP1M  RMB   20D
1B14    S1UV1M  RMB   20D
1B28    S1V1M   RMB   20D
1B3C    S1U1M   RMB   20D
1B50    IJ      RMB   400D
1CE0    PS1MS   RMB   400D
1E70    MS1MS   RMB   400D
B000    MATH    EQU   $B000
BDD6    CORDIC  EQU   $BDD6
AE2A    SYNDET  EQU   $AE2A
BBD1    PUSH42  EQU   $BBD1
BB68    PULL4   EQU   $BB68
BCCF    INDEX   EQU   $BCCF
```

MORE MEASURE SUBROUTINES

```
B9B6                ADDRES  EQU     $B9B6
BBF4                TUNE    EQU     $BBF4
B9A0                DELAY1  EQU     $B9A0
BC0D                RDDEFT  EQU     $BC0D
A5F7                        ORG     $A5F7
                    *
A5F7  BD BD D6      CORD    JSR     CORDIC
A5FA  FE 18 2A              LDX     COR9
A5FD  FF 18 00              STX     TEMP1
A600  FE 18 12              LDX     PHASE
A603  FF 18 02              STX     TEMP3
A606  CE 18 00              LDX     #TEMP1
A609  BD A7 4C              JSR     PHASDF
A60C  EE 00                 LDX     0,X
A60E  FF 18 2A              STX     COR9
A611  39                    RTS
                    *
A612  08            IXST    INX
A613  08                    INX
A614  08                    INX
A615  FF 18 3F              STX     BCDPTR
A618  39                    RTS
                    *
A619  B6 18 9F      CALSDI  LDAA    MPLX
A61C  B7 DF F9              STAA    $DFF9
A61F  CE 18 00              LDX     #TEMP1
A622  BD AE 2A              JSR     SYNDET
A625  7D 18 00              TST     TEMP1
A628  8D 0C                 BSR     SGNSET
A62A  B7 18 A1              STAA    SIGNI
A62D  7D 18 02              TST     TEMP3
A630  8D 04                 BSR     SGNSET
A632  B7 18 A2              STAA    SIGNQ
A635  39                    RTS
                    *
A636  2A 03         SGNSET  BPL     SETPOS
A638  86 FF                 LDAA    #$FF
A63A  39                    RTS
A63B  4F            SETPOS  CLRA
A63C  39                    RTS
                    *       SUBROUTINE IDEX
                    *       INDEXES ARRAYS
A63D  FF 18 00      IDEX    STX     TEMP1
A640  B7 18 02              STAA    TEMP3
A643  F7 18 03              STAB    TEMP4
A646  B6 18 00              LDAA    TEMP1
A649  F6 18 01              LDAB    TEMP2
A64C  FB 18 03              ADDB    TEMP4
A64F  B9 18 02              ADCA    TEMP3
A652  B7 18 00              STAA    TEMP1
A655  F7 18 01              STAB    TEMP2
A658  FE 18 00              LDX     TEMP1
A65B  39                    RTS
                    *       SUBROUTINE INDEX1
                    *       EXTENDS SEARCH OUT WX-AXIS
A65C  BD BC CF      INDEX1  JSR     INDEX
A65F  B6 18 2D              LDAA    J
```

```
A662  81 77              CMPA    #119D
A664  2E 06              BGT     IND1
A666  40                 NEGA
A667  81 77              CMPA    #119D
A669  2E 0C              BGT     IND2
A66B  39                 RTS
A66C  86 77     IND1     LDAA    #119D
A66E  B7 18 2D           STAA    J
A671  8B 07              ADDA    #7
A673  B7 18 2C           STAA    I
A676  39                 RTS
A677  86 77     IND2     LDAA    #119D
A679  B7 18 2D           STAA    J
A67C  B6 18 2C           LDAA    I
A67F  8B 07              ADDA    #7
A681  B7 18 2C           STAA    I
A684  39                 RTS
                *        SUBROUTINE UPDATE
                *
A685  CE 00 00  UPDATE   LDX     #0
A688  FF 18 51           STX     THR11
A68B  FF 18 43           STX     X
A68E  F6 18 25  UP1      LDAB    COR2
A691  B6 18 24           LDAA    COR1
A694  F0 18 52           SUBB    THR12
A697  B2 18 51           SBCA    THR11
A69A  2D 34              BLT     UP2
A69C  CE 1B 50           LDX     #IJ                 MAG>THR(X)
A69F  F6 18 44           LDAB    Y
A6A2  B6 18 43           LDAA    X
A6A5  BD A6 3D           JSR     IDEX
A6A8  E6 00              LDAB    0,X
A6AA  A6 01              LDAA    1,X
A6AC  CB 01              ADDB    #1
A6AE  89 00              ADCA    #0
A6B0  E7 00              STAB    0,X
A6B2  A7 01              STAA    1,X
A6B4  F6 18 52           LDAB    THR12
A6B7  B6 18 51           LDAA    THR11
A6BA  FB 18 54           ADDB    THR22
A6BD  B9 18 53           ADCA    THR21
A6C0  F7 18 52           STAB    THR12
A6C3  B7 18 51           STAA    THR11
A6C6  FE 18 43           LDX     X
A6C9  08                 INX
A6CA  08                 INX
A6CB  FF 18 43           STX     X
A6CE  20 BE              BRA     UP1
A6D0  39        UP2      RTS     THR>MAG
                *        SUBROUTINE THRSET
                *        SETS THRESHOLD
A6D1  7F 18 43  THRSET   CLR     X
A6D4  7F 18 44           CLR     Y
A6D7  CE 7F FF           LDX     #$7FFF
A6DA  FF 18 66           STX     MAX
A6DD  CE 1B 50  TH1      LDX     #IJ
A6E0  F6 18 44           LDAB    Y
```

```
A6E3  B6 18 43            LDAA   X
A6E6  BD A6 3D            JSR    IDEX
A6E9  E6 00               LDAB   0,X                N(X)
A6EB  A6 01               LDAA   1,X
A6ED  5D                  TSTB
A6EE  26 03               BNE    TH2
A6F0  4D                  TSTA
A6F1  27 32               BEQ    TH6
A6F3  F0 18 4D   TH2      SUBB   NPT                N>0
A6F6  82 00               SBCA   #0
A6F8  2C 07               BGE    TH4
A6FA  50                  NEGB
A6FB  25 03               BCS    TH3
A6FD  40                  NEGA
A6FE  20 01               BRA    TH4
A700  43         TH3      COMA
A701  F7 18 69   TH4      STAB   MAX+3              ABS(N-NPT)
A704  B7 18 68            STAA   MAX+2
A707  F0 18 67            SUBB   MAX+1
A70A  B2 18 66            SBCA   MAX
A70D  2C 0C               BGE    TH5
A70F  FE 18 68            LDX    MAX+2
A712  FF 18 66            STX    MAX
A715  FE 18 43            LDX    X
A718  FF 18 8A            STX    UU
A71B  FE 18 43   TH5      LDX    X
A71E  08                  INX
A71F  08                  INX
A720  FF 18 43            STX    X
A723  20 B8               BRA    TH1
A725  F6 18 8B   TH6      LDAB   UU+1               N=0
A728  B6 18 8A            LDAA   UU
A72B  47                  ASRA
A72C  56                  RORB
A72D  BD BB D1            JSR    PUSH42
A730  F6 18 54            LDAB   THR22
A733  B6 18 53            LDAA   THR21
A736  BD BB D1            JSR    PUSH42
A739  86 0A               LDAA   #10D
A73B  BD 80 00            JSR    MATH               X*THR2
A73E  CE 18 8A            LDX    #UU
A741  4F                  CLRA
A742  BD BB 68            JSR    PULL4
A745  FE 18 8C            LDX    UU+2
A748  FF 18 51            STX    THR11              THRESHOLD SET
A74B  39                  RTS
                 *        SUBROUTINE PHASDF
                 *        COMPUTES PHASE1-PHASE2
                 *        ENTER WITH PHASE1,PHASE2 IN ADJACENT MEMORY
                 *        X POINTS TO PHASE1
                 *        PHASE DIFF RETURNED IN PLACE OF PHASE1
A74C  A6 00      PHASDF   LDAA   0,X
A74E  E6 01               LDAB   1,X
A750  E0 03               SUBB   3,X                P1-P2
A752  A2 02               SBCA   2,X
A754  28 24               BVC    PDF2
A756  A6 00               LDAA   0,X                OVERFLOW
```

```
A758  E6 01                LDAB    1,X
A75A  CB FF                ADDB    #$FF            P1+PHI
A75C  89 7F                ADCA    #$7F
A75E  29 0A                BVS     PDF1
A760  E0 03                SUBB    3,X
A762  A2 02                SBCA    2,X
A764  CB FF                ADDB    #$FF            PD=(P1+PHI)-(P2-PHI)
A766  89 7F                ADCA    #$7F
A768  20 10                BRA     PDF2
A76A  A6 00       PDF1     LDAA    0,X             P1+PHI>PHI
A76C  E6 01                LDAB    1,X
A76E  C0 FF                SUBB    #$FF
A770  82 7F                SBCA    #$7F
A772  E0 03                SUBB    3,X
A774  A2 02                SBCA    2,X
A776  C0 FF                SUBB    #$FF            PD=(P1-PHI)-(P2+PHI)
A778  82 7F                SBCA    #$7F
A77A  A7 00       PDF2     STAA    0,X             PD
A77C  E7 01                STAB    1,X
A77E  39                   RTS
                  *        SUBROUTINE PHSSET
                  *        MEASURES PHASE DIFF AT ORIGINS AND STORES IN PHASE
A77F  7D 18 A4    PHSSET   TST     SNFLAG
A782  2E 65                BGT     PSS
A784  7F 18 58             CLR     ADRSW
A787  7F 18 2C             CLR     I
A78A  7F 18 2D             CLR     J
A78D  7F 18 3C             CLR     SENSOR
A790  BD B9 B6             JSR     ADDRES
A793  BD BB F4             JSR     TUNE
A796  7A 18 58             DEC     ADRSW
A799  7A 18 3C             DEC     SENSOR
A79C  BD B9 A0             JSR     DELAY1
A79F  BD BC 0D             JSR     RDDEFT
A7A2  7F 18 2A             CLR     COR9
A7A5  7F 18 2B             CLR     COR10
A7A8  BD BD D6             JSR     CORDIC
A7AB  FE 18 2A             LDX     COR9
A7AE  FF 18 12             STX     PHASE
A7B1  7C 18 3C             INC     SENSOR
A7B4  7C 18 3C             INC     SENSOR
A7B7  CE 1C D6             LDX     #PS1MS-10D
A7BA  FF 18 3F             STX     BCDPTR
A7BD  BD B9 B6             JSR     ADDRES
A7C0  BD BB F4             JSR     TUNE
A7C3  BD B9 A0             JSR     DELAY1
A7C6  BD BC 0D             JSR     RDDEFT
A7C9  7F 18 2A             CLR     COR9
A7CC  7F 18 2B             CLR     COR10
A7CF  BD BD D6             JSR     CORDIC
A7D2  FE 18 12             LDX     PHASE
A7D5  FF 18 00             STX     TEMP1
A7D8  FE 18 2A             LDX     COR9
A7DB  FF 18 02             STX     TEMP3
A7DE  CE 18 00             LDX     #TEMP1
A7E1  BD A7 4C             JSR     PHASDF          PS(REF)-PS(ALIGN)
A7E4  EE 00                LDX     0,X
```

MORE MEASURE SUBROUTINES

```
A7E6  FF 18 12          STX     PHASE
A7E9  39          PSS   RTS
A7EA                    END
```

STATEMENTS =346

FREE BYTES =4319

NO ERRORS DETECTED

```
                        **      SUBROUTINE TO MOVE STEPPER MOTORS
                        *       USES ALL REGISTERS

                        *       HARDWARE DEFINITION
EF02                    TABLE   EQU     $EF02

                        *       EXTERNAL REFERENCE
AF88                    GRAPH2  EQU     $AF88

                        *       RAM DECLARATIONS
186E                    XTRAN   EQU     $186E
1870                    YTRAN   EQU     $1870
1890                    ANGLE   EQU     $1890
ED1E                            ORG     $ED1E
ED1E                    XCOUNT  RMB     5
ED23                    YCOUNT  RMB     5
ED28                    RCOUNT  RMB     5
ED2D                    CTRPTR  RMB     2
ED2F                    DISPTR  RMB     2
ED31                    STEPNR  RMB     1
ED32                    TEMP1   RMB     2

                        *       PARAMETERS
0002                    XMASK   EQU     %00000010
0005                    XCYCLE  EQU     5
0008                    YMASK   EQU     %00001000
0005                    YCYCLE  EQU     5
0020                    RMASK   EQU     %00100000
0003                    RCYCLE  EQU     3

A820                            ORG     $A820
A820  86 20             XSTEP   LDA A   #$20
A822  B7 ED 16                  STA A   INCRMT
A825  CE ED 1E                  LDX     #XCOUNT
A828  FF ED 2D                  STX     CTRPTR
A82B  7F ED 30                  CLR     DISPTR+1
A82E  CE 18 6E                  LDX     #XTRAN
A831  86 02                     LDA A   #XMASK
A833  C6 05                     LDA B   #XCYCLE
A835  8D 35                     BSR     MV$RST
A837  CE ED 23          YSTEP   LDX     #YCOUNT
A83A  FF ED 2D                  STX     CTRPTR
A83D  86 05                     LDA A   #5
A83F  B7 ED 30                  STA A   DISPTR+1
A842  CE 18 70                  LDX     #YTRAN
A845  86 08                     LDA A   #YMASK
A847  C6 05                     LDA B   #YCYCLE
A849  8D 21                     BSR     MV$RST
A84B  86 33             ROTATE  LDA A   #$33
A84D  B7 ED 16                  STA A   INCRMT
A850  CE ED 28                  LDX     #RCOUNT
A853  FF ED 2D                  STX     CTRPTR
A856  86 0A                     LDA A   #10
A858  B7 ED 30                  STA A   DISPTR+1
A85B  CE 18 90                  LDX     #ANGLE
A85E  86 20                     LDA A   #RMASK
A860  C6 03                     LDA B   #RCYCLE
```

SUBROUTINE TO MOVE STEPPER MOTORS

```
A862  8D 08              BSR    MV$RST
A864  7D ED 15           TST    CALIBR
A867  27 74              BEQ    RETRN3
A869  7E AF 88           JMP    GRAPH2
A86C  37        MV$RST   PSH B
A86D  F6 ED 17           LDA B  PROGNR
A870  C1 0D              CMP B  #$D         DISPLAY ONLY?
A872  33                 PUL B
A873  26 0C              BNE    MOVE
A875  44                 LSR A              MAKE IT CLOCK MASK
A876  36                 PSH A
A877  FE ED 2D           LDX    CTRPTR
A87A  A6 00              LDA A  0,X
A87C  E6 01              LDA B  1,X
A87E  7E AB 3D           JMP    SNMG10      TO RESTORE DISPLAY
A881  F7 ED 31  MOVE     STA B  STEPNR
A884  36                 PSH A
A885  E6 01              LDA B  1,X         GET NUMBER OF STEPS
A887  A6 00              LDA A  0,X
A889  8D 53              BSR    SINMAG
A88B  37                 PSH B              PUT BACK IN X
A88C  36                 PSH A
A88D  30                 TSX
A88E  EE 00              LDX    0,X
A890  31                 INS
A891  31                 INS
A892  32                 PUL A
A893  27 48              BEQ    RETRN3      NO MOTION REQUIRED
A895  16                 TAB                DIRECTION MASK
A896  25 06              BCS    REVERS
A898  53        FORWRD   COM B
A899  F4 EF 02           AND B  TABLE       MAKE IT ZERO
A89C  20 03              BRA    DIRECT
A89E  FA EF 02  REVERS   ORA B  TABLE       MAKE IT 1
A8A1  F7 EF 02  DIRECT   STA B  TABLE
A8A4  44                 LSR A              CHANGE MASK TO CLOCK
A8A5  F6 ED 31  CYCLE    LDA B  STEPNR
A8A8  FF ED 32           STX    TEMP1
A8AB  37        CYCLE1   PSH B
A8AC  CE EF 02           LDX    #TABLE
A8AF  16                 TAB                CLOCK MASK TO (B)
A8B0  53                 COM B
A8B1  E4 00              AND B  0,X
A8B3  E7 00              STA B  0,X         PULSE MOTOR
A8B5  16                 TAB
A8B6  E4 01              AND B  1,X         CONFIRM PULSE
A8B8  36                 PSH A
A8B9  AA 00              ORA A  0,X
A8BB  A7 00              STA A  0,X         REMOVE PULSE
A8BD  32                 PUL A
A8BE  5D                 TST B
A8BF  26 28              BNE    LIMIT       NO CONFIRMATION
A8C1  C6 F0              LDA B  #$F0
A8C3  7D ED 15           TST    CALIBR
A8C6  27 08              BEQ    SPEED
A8C8  FE ED 2D           LDX    CTRPTR
A8CB  BD AA DE           JSR    POSDIS      TO UPDATE DISPLAY
```

SUBROUTINE TO MOVE STEPPER MOTORS

```
A8CE   C6 C0               LDA B   #$C0           EQUALIZE DELAY
A8D0   BD AA 75   SPEED    JSR     DELAY1         SET STEPPING RATE
A8D3   33                  PUL B
A8D4   5A                  DEC B
A8D5   26 D4               BNE     CYCLE1
A8D7   FE ED 32            LDX     TEMP1
A8DA   09                  DEX
A8DB   26 C8               BNE     CYCLE
A8DD   39         RETRN3   RTS

A8DE   0C         SINMAG   CLC
A8DF   2A 07               BPL     PLUS
A8E1   43                  COM A
A8E2   53                  COM B
A8E3   CB 01               ADD B   #1             FOR 2'S COMP.
A8E5   89 00               ADC A   #0
A8E7   0D                  SEC
A8E8   39         PLUS     RTS

A8E9   8E EC FF   LIMIT    LDS     #USRSTK
A8EC   7E AA 3A            JMP     ERROR2

                  **       CALLING ROUTINE FOR INITIAL ALIGNMENT

B470              INALGN   EQU     $B470

A8EF   CE A9 9B   ALIGN    LDX     #SUPRVR
A8F2   FF ED 1C            STX     ABTVEC
A8F5   7F ED 15            CLR     CALIBR
A8F8   BD B4 70            JSR     INALGN
A8FB   7C ED 15            INC     CALIBR         SO IT'S NON-ZERO
A8FE   20 10               BRA     CLEAR
```

```
                    **      SETS UP PIA'S FOR SYNTHESIZERS & PLOTTER
                    *       FOLLOWS HARDWARE RESET

                    *       HARDWARE DEFINITIONS

EE00                PIA     EQU     $EE00
EE40                CONSOLE EQU     $EE40
EE40                KEYPAD  EQU     $EE40

                    *       MONITOR REFERENCES

ECFF                USRSTK  EQU     $ECFF
EDF7                UIRQ    EQU     $EDF7

                    *       OTHER REFERENCES

A000                CORMAG  EQU     $A000
A007                CORCOM  EQU     $A007
AC47                KSPLOT  EQU     $AC47
B47E                DOUBLE  EQU     $B47E
B487                SINGLE  EQU     $B487
B88C                INIZE   EQU     $B88C

                    *       RAM DECLARATIONS

ED00                        ORG     $ED00
ED00                LEDBFR  RMB     15
ED0F                BUFEND  EQU     *
ED0F                BUFPNT  RMB     2
ED11                KEYVAL  RMB     2
ED13                LEDPTR  RMB     2
ED15                CALIBR  RMB     1
ED16                INCRMT  RMB     1
ED17                PROGNR  RMB     1
ED18                PRGJMP  RMB     2
ED1A                TEMP    RMB     2
ED1C                ABTVEC  RMB     2
ED48                GAIN    EQU     $ED48
ED49                A$GAIN  EQU     $ED49
ED4A                R$GAIN  EQU     $ED4A
ED4B                SETDEL  EQU     $ED4B

                    *       PROGRAM TABLE

A800                        ORG     $A800

                    *          ENTRY ADDRESS         PROGRAM NUMBER AND FUNCTION
A800  AC 47         PRGTBL  FDB        KSPLOT        0, X-Y PLOT FROM TEST IMAGE
A802  AC 47                 FDB        KSPLOT        1, CRT DISPLAY FROM TEST IMA
A804  AC 47                 FDB        KSPLOT        2, X-Y PLOT FROM REF. IMAGE
A806  AC 47                 FDB        KSPLOT        3, CRT DISPLAY FROM REF. IMA
A808  A8 EF                 FDB        ALIGN         4, INITIAL ALIGNMENT, 2 SENS
A80A  A8 EF                 FDB        ALIGN         5, INITIAL ALIGNMENT, 1 SENS
A80C  B4 7E                 FDB        DOUBLE        6, TEST ALIGNMENT, 2 SENSORS
A80E  B4 7E                 FDB        DOUBLE        7, TEST ALIGNMENT, 2 SENS.,
A810  B4 87                 FDB        SINGLE        8, TEST ALIGNMENT, 1 SENSOR
```

```
A812  B4 87             FDB     SINGLE          9, TEST ALIGNMENT, 1 SENSOR,
A814                    RMB     2                 RESERVED FOR ABORT
A816  A0 00             FDB     CORMAG          B, MAGNITUDE CORRELATION
A818  A0 07             FDB     CORCOM          C, COMPLEX CORRELATION
A81A  A8 20             FDB     XSTEP           D, DISPLAY TABLE POSITION
A81C                    RMB     2                 RESERVED FOR EXECUTE
A81E  A9 6A             FDB     INITLZ          F, RE-INITIALIZE PARAMETERS

                  *     SEGMENT TABLE

A900                    ORG     $A900
A900  81 CF 92  LEDTBL  FCB     $81,$CF,$92,$86,$CC,$A4,$A0,$8F
A908  80 8C 88          FCB     $80,$8C,$88,$E0,$B1,$C2,$B0,$B8

                  **    SETS POSITION COUNTERS TO ZERO

A910  CE ED 1E  CLEAR   LDX     #XCOUNT
A913  6F 00     CLEAR1  CLR     0,X
A915  08                INX
A916  8C ED 2D          CPX     #XCOUNT+15
A919  26 F8             BNE     CLEAR1
A91B  39                RTS

                  **    HARDWARE RESET VECTORS HERE

A91C  01        ARESET  NOP
A91D  CE EE 07          LDX     #PIA+7
A920  EF 00             STX     0,X
A922  09        ARSET1  DEX
A923  26 FD             BNE     ARSET1
A925  CE EE 00          LDX     #PIA
A928  35                TXS
A929  86 41             LDA A   #$41            7+E+2,1/16,RTS FALSE
A92B  A7 08             STA A   8,X
A92D  86 FF             LDA A   #$FF
A92F  A7 10             STA A   $10,X           ALL OUTPUTS
A931  A7 11             STA A   $11,X
A933  A7 20             STA A   $20,X
A935  A7 21             STA A   $21,X
A937  A7 41             STA A   $41,X
A939  A7 80             STA A   $80,X
A93B  A7 81             STA A   $81,X
A93D  86 36             LDA A   #%00110110      TO SENSE POSITIVE BIAS TRANS
A93F  A7 12             STA A   $12,X              THRU CA1
A941  A7 13             STA A   $13,X           LINE TRANSITION THRU CB1
A943  86 04             LDA A   #%00000100      TO SENSE NEG. TRANSITION
A945  A7 22             STA A   $22,X
A947  A7 82             STA A   $82,X
A949  86 34             LDA A   #%00110100      CB2 AS LOW OUTPUT
A94B  A7 23             STA A   $23,X
A94D  A7 83             STA A   $83,X
A94F  A7 42             STA A   $42,X           CA2 HERE
A951  86 2D             LDA A   #%00101101
A953  A7 43             STA A   $43,X           PULSE MODE, INTERRUPTS ON
A955  CE EF 00          LDX     #PIA+$100
A958  86 CF             LDA A   #$FF-$30
A95A  A7 00             STA A   0,X             TURN AROUND LS245'S
```

```
A95C  6F 02               CLR     2,X           AND THEN PIA DDR
A95E  86 CB               LDA A   #$FF-$34
A960  A7 00               STA A   0,X
A962  86 C3               LDA A   #$FF-$3C
A964  A7 01               STA A   1,X           A-SIDE REMAINS INPUTS
A966  86 FF               LDA A   #$FF          B-SIDE OUTPUTS LOW
A968  A7 02               STA A   2,X
A96A  86 ED      INITLZ   LDA A   #LEDBFR/256
A96C  B7 ED 2F            STA A   DISPTR
A96F  86 A9               LDA A   #LEDTBL/256
A971  B7 ED 13            STA A   LEDPTR
A974  86 7E               LDA A   #$7E          JMP INSTRUCTION
A976  B7 ED F7            STA A   UIRQ
A979  CE AA A5            LDX     #INTSRV       SET INTERRUPT VECTOR
A97C  FF ED F8            STX     UIRQ+1
A97F  8D 8F               BSR     CLEAR
A981  86 A8               LDA A   #PRGTBL/256
A983  B7 ED 18            STA A   PRGJMP
A986  7F ED 15            CLR     CALIBR
A989  CE 00 01            LDX     #1
A98C  FF ED 4B            STX     SETDEL
A98F  86 03               LDA A   #3
A991  B7 ED 49            STA A   A$GAIN
A994  4A                  DEC A
A995  B7 ED 4A            STA A   R$GAIN
A998  BD B8 8C            JSR     INIZE
A99B  CE ED 00   SUPRVR   LDX     #LEDBFR
A99E  FF ED 0F            STX     BUFFNT
A9A1  86 FE               LDA A   #$FE
A9A3  A7 00      DASH     STA A   0,X           DISPLAY DASHES
A9A5  08                  INX
A9A6  8C ED 0F            CPX     #BUFEND
A9A9  26 F8               BNE     DASH
A9AB  86 FF               LDA A   #$FF
A9AD  B7 ED 17            STA A   PROGNR
A9B0  8E EC FF            LDS     #USRSTK
A9B3  CE A9 9B            LDX     #SUPRVR
A9B6  FF ED 1C            STX     ABTVEC

                 *        WAIT FOR KEYPAD INPUT & PROCESS COMMAND

A9B9  01         WAITLP   NOP
A9BA  0E                  CLI
A9BB  01                  NOP
A9BC  B6 EE 40            LDA A   KEYPAD
A9BF  43                  COM A
A9C0  27 45               BEQ     MANDSP        NO KEY PRESSED
A9C2  CE ED 11            LDX     #KEYVAL
A9C5  BD AA 7B            JSR     KEYIN
A9C8  E6 00               LDA B   0,X
A9CA  2B 3B               BMI     MANDSP        INVALID KEY VALUE
A9CC  C1 0A               CMP B   #$A           ABORT KEY?
A9CE  27 37               BEQ     MANDSP
A9D0  C1 0E               CMP B   #$E           EXECUTE?
A9D2  26 19               BNE     PRGDSP
A9D4  B6 ED 17            LDA A   PROGNR
A9D7  2B E0               BMI     WAITLP        NO PROGRAM NUMBER
```

```
A9D9   48                      ASL A                  DOUBLE IT
A9DA   B7 ED 19                STA A    PRGJMP+1
A9DD   FE ED 18                LDX      PRGJMP
A9E0   EE 00                   LDX      0,X           PROGRAM VECTOR
A9E2   AD 00                   JSR      0,X           TO EXECUTE
A9E4   B6 ED 17                LDA A    PROGNR
A9E7   81 0B                   CMP A    #$B
A9E9   24 CE                   BCC      WAITLP
A9EB   20 AE                   BRA      SUPRVR
A9ED   F7 ED 14      PRGDSP    STA B    LEDPTR+1      DISPLAY PROGRAM NUMBER
A9F0   FE ED 13                LDX      LEDPTR
A9F3   A6 00                   LDA A    0,X
A9F5   CE ED 00                LDX      #LEDBFR
A9F8   A7 00                   STA A    0,X
A9FA   F7 ED 17                STA B    PROGNR
A9FD   86 FF                   LDA A    #$FF
A9FF   08            CLEAR2    INX
AA00   A7 00                   STA A    0,X
AA02   8C ED 0E                CPX      #BUFEND-1
AA05   26 F8                   BNE      CLEAR2
AA07   7D ED 15      MANDSP    TST      CALIBR        INITIAL ALIGNMENT DONE?
AA0A   27 AD                   BEQ      WAITLP
AA0C   86 15                   LDA A    #%00010101    MASK FOR ANY CLOCK
AA0E   B4 EF 03                AND A    TABLE+1
AA11   88 15                   EOR A    #%00010101
AA13   27 A4                   BEQ      WAITLP        NO PULSE
AA15   C6 05                   LDA B    #5
AA17   8D 5E                   BSR      DELAY2
AA19   16                      TAB
AA1A   F4 EF 03                AND B    TABLE+1       CONFIRM IT
AA1D   26 9A                   BNE      WAITLP
AA1F   36                      PSH A
AA20   C6 03                   LDA B    #3
AA22   CE ED 1E                LDX      #XCOUNT
AA25   44            IDENT     LSR A                  FIND OUT WHICH AXIS
AA26   25 28                   BCS      INCSET
AA28   44                      LSR A
AA29   08                      INX
AA2A   08                      INX
AA2B   08                      INX
AA2C   08                      INX
AA2D   08                      INX
AA2E   5A                      DEC B
AA2F   26 F4                   BNE      IDENT
AA31   C6 02         ERROR     LDA B    #2
AA33   F7 ED 30                STA B    DISPTR+1
AA36   20 02                   BRA      ERROR2
AA38   8D 24         ERROR1    BSR      SETUP
AA3A   FE ED 2F      ERROR2    LDX      DISPTR
AA3D   C6 B0                   LDA B    #$B0          'E'
AA3F   E7 00                   STA B    0,X
AA41   C6 FA                   LDA B    #$FA          LOWER CASE 'R'
AA43   E7 01                   STA B    1,X
AA45   E7 02                   STA B    2,X
AA47   E7 04                   STA B    4,X
AA49   C6 E2                   LDA B    #$E2          'O'
AA4B   E7 03                   STA B    3,X
```

```
AA4D  7E A9 B9  WAITEX  JMP    WAITLP
AA50  8D 0C     INCSET  BSR    SETUP
AA52  32                PUL A                 RETRIEVE CLOCK MASK
AA53  BD AA DE          JSR    POSDIS
AA56  16        CLKLOW  TAB
AA57  F4 EF 03          AND B  TABLE+1        WAIT FOR END OF PULSE
AA5A  27 FA             BEQ    CLKLOW
AA5C  20 EF             BRA    WAITEX

AA5E  50        SETUP   NEG B
AA5F  CB 03             ADD B  #3
AA61  86 20             LDA A  #$20           5 STEPS/COUNT FOR X OR Y
AA63  C1 02             CMP B  #2
AA65  2B 02             BMI    STEPST
AA67  86 33             LDA A  #$33           3 STEPS/COUNT FOR R
AA69  B7 ED 16  STEPST  STA A  INCRMT
AA6C  17                TBA                   MULTIPLY BY 5
AA6D  48                ASL A
AA6E  48                ASL A
AA6F  1B                ABA
AA70  B7 ED 30          STA A  DISPTR+1       LED BUFFER OFFSET
AA73  39                RTS

                **      DELAY SUBROUTINES

AA74  5F        DELAY0  CLR B
AA75  8D 00     DELAY1  BSR    DELAY2
AA77  5A        DELAY2  DEC B
AA78  26 FD             BNE    DELAY2
AA7A  39                RTS

                **      DEBOUNCE/DECODE ROUTINE

AA7B  86 FF     KEYIN   LDA A  #$FF
AA7D  A7 00             STA A  0,X            DEFAULT VALUE
AA7F  B8 EE 40          EOR A  KEYPAD         TO INVERT
AA82  27 20             BEQ    RETURN         NO KEY PRESSED
AA84  8D EE             BSR    DELAY0         FOR DEBOUNCE
AA86  B6 EE 40          LDA A  KEYPAD
AA89  8D E9             BSR    DELAY0
AA8B  16                TAB
AA8C  F8 EE 40          EOR B  KEYPAD         SAME KEY?
AA8F  26 13             BNE    RETURN         READ ERROR
AA91  36                PSH A
AA92  C6 04             LDA B  #4
AA94  5A        COLUMN  DEC B
AA95  48                ASL A
AA96  25 FC             BCS    COLUMN
AA98  32                PUL A
AA99  47        ROW     ASR A
AA9A  24 06             BCC    DONE
AA9C  CB 04             ADD B  #4
AA9E  25 04             BCS    RETURN         DECODE ERROR
AAA0  20 F7             BRA    ROW
AAA2  E7 00     DONE    STA B  0,X
AAA4  39        RETURN  RTS
```

```
                        **        INTERRUPT SERVICE ROUTINE

    AAA5  FE ED OF  INTSRV  LDX      BUFFNT
    AAA8  8C ED OF          CPX      #BUFEND
    AAAB  26 OD             BNE      CHAN1            NOT PAST LAST DIGIT
    AAAD  CE ED 00          LDX      #LEDBFR
    AAB0  86 3C             LDA A    #%00111100       RESET DISPLAY COUNT
    AAB2  B7 EE 42          STA A    CONSOLE+2
    AAB5  86 34             LDA A    #%00110100
    AAB7  B7 EE 42          STA A    CONSOLE+2
    AABA  A6 00     CHAN1   LDA A    0,X
    AABC  B7 EE 41          STA A    CONSOLE+1        OUTPUT NEW DIGIT
    AABF  08                INX
    AAC0  FF ED OF          STX      BUFFNT           STORE NEW POINTER
    AAC3  7D EE 41          TST      CONSOLE+1        CLEAR INTERRUPT REQUEST
    AAC6  B6 EE 40          LDA A    KEYPAD
    AAC9  81 BB             CMP A    #$BB             IS 'A' PRESSED?
    AACB  26 10             BNE      RETRN1           NO
    AACD  CE ED 12          LDX      #KEYVAL+1
    AAD0  8D A9             BSR      KEYIN            BE SURE IT'S 'A'
    AAD2  A6 00             LDA A    0,X
    AAD4  81 0A             CMP A    #$A
    AAD6  26 05             BNE      RETRN1           FALSE ALARM
    AAD8  FE ED 1C          LDX      ABTVEC           GET ABORT VECTOR
    AADB  6E 00             JMP      0,X
    AADD  3B        RETRN1  RTI
    AADE            POSDIS  EQU      *
    AB3D            SNMG10  EQU      *+$5F
    AADE                    END


STATEMENTS =466

FREE BYTES =1263

NO ERRORS DETECTED
--


^+1,$ASSEMBLE
```

STEPPER MOTOR POSITION DISPLAY
FOR IMAGE ALIGNMENT SYSTEM

```
                          *       EXTERNAL REFERENCES

 EF02                     TABLE   EQU      $EF02
 ED13                     LEDPTR  EQU      $ED13
 ED16                     INCRMT  EQU      $ED16
 ED1A                     TEMP    EQU      $ED1A
 ED2F                     DISPTR  EQU      $ED2F

 AADE                             ORG      $AADE
 AADE  36                 POSDIS  PSH A                     STORE CLOCK MASK
 AADF  48                         ASL A
 AAE0  16                         TAB
 AAE1  B4 EF 03                   AND A    TABLE+1          WHICH DIRECTION?
 AAE4  C5 08                      BIT B    #%00001000
 AAE6  26 06                      BNE      Y
 AAE8  F7 ED 1A                   STA B    TEMP
 AAEB  B8 ED 1A                   EOR A    TEMP             SO DISPLAY AGREES WITH DIREC
 AAEE  4D                 Y       TST A
 AAEF  27 0C                      BEQ      INCR1
 AAF1  86 FF              DECR    LDA A    #$FF             REVERSE
 AAF3  36                         PSH A
 AAF4  36                         PSH A
 AAF5  86 99                      LDA A    #$99             FOR BCD UPDATE
 AAF7  B0 ED 16                   SUB A    INCRMT
 AAFA  0D                         SEC
 AAFB  20 09                      BRA      ADD1
 AAFD  4F                 INCR1   CLR A                     FORWARD
 AAFE  36                         PSH A
 AAFF  86 01                      LDA A    #1
 AB01  36                         PSH A
 AB02  B6 ED 16                   LDA A    INCRMT
 AB05  5F                         CLR B
 AB06  A9 02              ADD1    ADC A    2,X              BCD UPDATE
 AB08  19                         DAA
 AB09  25 0A                      BCS      TEST1            TAKE CARE OF ROUNDOFF ERROR
 AB0B  81 99                      CMP A    #$99
 AB0D  0C                         CLC
 AB0E  26 0B                      BNE      STORE
 AB10  8B 01                      ADD A    #1               ROUND UP TO 100
 AB12  19                         DAA
 AB13  20 06                      BRA      STORE
 AB15  81 01              TEST1   CMP A    #1
 AB17  26 01                      BNE      SETCRY
 AB19  4F                         CLR A                     ROUND DOWN TO 0
 AB1A  0D                 SETCRY  SEC
 AB1B  A7 02              STORE   STA A    2,X
 AB1D  86 00                      LDA A    #0               ASSUME FORWARD
 AB1F  C4 FF                      AND B    #$FF
 AB21  27 02                      BEQ      ADD2
 AB23  86 99                      LDA A    #$99             NO, REVERSE
 AB25  16                 ADD2    TAB
 AB26  A9 01                      ADC A    1,X
 AB28  19                         DAA
 AB29  A7 01                      STA A    1,X
 AB2B  17                         TBA
 AB2C  A9 00                      ADC A    0,X
 AB2E  19                         DAA
```

```
AB2F  A7 00              STA A   0,X
AB31  33                 PUL B                    UPDATE BINARY COUNT
AB32  EB 04              ADD B   4,X
AB34  E7 04              STA B   4,X
AB36  33                 PUL B
AB37  E9 03              ADC B   3,X
AB39  E7 03              STA B   3,X
AB3B  E6 01              LDA B   1,X              BCD COUNT NOW IN (AB)
AB3D  FF ED 1A  SNMG10   STX     TEMP             CONVERT TO SIGN/MAGNITUDE
AB40  EE 00              LDX     0,X
AB42  8C 50 00           CPX     #$5000
AB45  0C                 CLC
AB46  2B 1E              BMI     FIXSGN           IT'S POSITIVE
AB48  FE ED 1A  MINUS1   LDX     TEMP             IT'S NEGATIVE
AB4B  86 99              LDA A   #$99
AB4D  16                 TAB
AB4E  E0 01              SUB B   1,X
AB50  F7 ED 1B           STA B   TEMP+1
AB53  A0 00              SUB A   0,X
AB55  B7 ED 1A           STA A   TEMP
AB58  4F                 CLR A
AB59  0D                 SEC
AB5A  B9 ED 1B           ADC A   TEMP+1
AB5D  19                 DAA
AB5E  16                 TAB
AB5F  86 00              LDA A   #0
AB61  B9 ED 1A           ADC A   TEMP
AB64  19                 DAA
AB65  0D                 SEC                      TO MARK SIGN
AB66  36        FIXSGN   PSH A                    FIX SIGN ON DISPLAY
AB67  86 00              LDA A   #0
AB69  49                 ROL A                    GET CARRY BIT
AB6A  43                 COM A                    CARRY SET MAKES MINUS
AB6B  FE ED 2F           LDX     DISPTR           LEFTMOST DIGIT
AB6E  A7 00              STA A   0,X
AB70  32                 PUL A                    M. S. DIGITS
AB71  37                 PSH B
AB72  8D 20              BSR     LOOKUP
AB74  FE ED 2F           LDX     DISPTR
AB77  08                 INX
AB78  8D 32              BSR     DISPLA
AB7A  32                 PUL A                    L. S. DIGITS
AB7B  8D 17              BSR     LOOKUP
AB7D  FE ED 2F           LDX     DISPTR
AB80  08                 INX
AB81  08                 INX
AB82  08                 INX
AB83  8D 27              BSR     DISPLA
AB85  32                 PUL A
AB86  81 10              CMP A   #%00010000       IS IT ANGLE?
AB88  27 03              BEQ     ANGLPT
AB8A  22 07              BHI     RETRN2           IT'S CORRELATION COEFFICIENT
AB8C  09                 DEX                      POSITION D. P.
AB8D  E6 00     ANGLPT   LDA B   0,X
AB8F  C4 7F              AND B   #$7F             TO ADD D. P.
AB91  E7 00              STA B   0,X
AB93  39        RETRN2   RTS
```

STEPPER MOTOR POSITION DISPLAY
FOR IMAGE ALIGNMENT SYSTEM

```
AB94  16          LOOKUP  TAB
AB95  44                  LSR A
AB96  44                  LSR A
AB97  44                  LSR A
AB98  44                  LSR A
AB99  B7 ED 14            STA A   LEDPTR+1        FIRST DIGIT
AB9C  FE ED 13            LDX     LEDPTR
AB9F  A6 00               LDA A   0,X             GET SEGMENT CODE
ABA1  C4 0F               AND B   #$0F            SECOND DIGIT
ABA3  F7 ED 14            STA B   LEDPTR+1
ABA6  FE ED 13            LDX     LEDPTR
ABA9  E6 00               LDA B   0,X
ABAB  39                  RTS

ABAC  48          DISPLA  ASL A
ABAD  68 00               ASL     0,X             SAVE D. P. IN 'C'
ABAF  A7 00               STA A   0,X
ABB1  66 00               ROR     0,X             RESTORE D. P.
ABB3  58                  ASL B
ABB4  68 01               ASL     1,X
ABB6  E7 01               STA B   1,X
ABB8  66 01               ROR     1,X
ABBA  39                  RTS

ABBB                      END
```

STATEMENTS =142

FREE BYTES =7297

NO ERRORS DETECTED

^+1,$ASSEMBLE

```
                    **      SUPERVISOR REFERENCES

    ED1A            TEMP    EQU     $ED1A
    ED17            PROGNR  EQU     $ED17
    ED1C            ABTVEC  EQU     $ED1C
    A99B            SUPRVR  EQU     $A99B

    BDD6            CORDIC  EQU     $BDD6

                    **      RAM DECLARATIONS

    1700                    ORG     $1700
    1700            VMAX    RMB     256
    1824            COR1    EQU     $1824
    ED34                    ORG     $ED34
    ED34            VMXPTR  RMB     1
    ED35            XCOORD  RMB     2
    ED37            YCOORD  RMB     2
    ED39            SLOW    RMB     2
    ED3B            XNMBR   RMB     1
    ED3C            YNMBR   RMB     1
    ED3D            YPOSN   RMB     1
    ED3E            XMSG    RMB     4
    ED42            CTR     RMB     1
    ED43            FREQ    RMB     4
    ED47            SIGN    RMB     1
    ED48            GAIN    RMB     1
    ED49            A$GAIN  RMB     1
    ED4A            R$GAIN  RMB     1
    ED4B            SETDEL  RMB     2

                    **      HARDWARE DEFINITIONS

    DFF0            DAS     EQU     $DFF0
    EE08            ACIASR  EQU     $EE08
    EE00            PIA     EQU     $EE00
    EE80            VERT    EQU     PIA+$80
    EE81            HORIZ   EQU     VERT+1
    EE10            XFREQ   EQU     PIA+$10
    EE20            YFREQ   EQU     PIA+$20

                    **      FANTOM-II REFERENCES

    FD7A            OUT4HS  EQU     $FD7A
    FD7E            OUTSP   EQU     $FD7E
    FD80            OUTCH   EQU     $FD80
    FDFF            OUTSTR  EQU     $FDFF
    FDA9            CRLF1   EQU     $FDA9
    FD8F            THB     EQU     $FD8F
    FD9C            THB1    EQU     $FD9C

                    **      ASCII MESSAGE DATA

    ABC0                    ORG     $ABC0
    ABC0  20 53 54  STMSG   FCC     ' STARTING FREQ''','S'+$80
    ABD0  20 4D 48  MHZMSG  FCC     ' MHz',' '+$80
```

X-Y PLOTTER/CRT DISPLAY PROGRAM
FOR IMAGE ALIGNMENT SYSTEM

```
ABD5  0D 0A 1B  ESC$FF  FCC    $0D,$0A,$1B,$0C+$80
ABD9  54 45 53  TSTMSG  FCC    'TEST IMAG','E'+$80
ABE3  52 45 46  REFMSG  FCC    'REFERENCE IMAG','E'+$80
ABF2  1F 87     SIGNAL  FCC    $1F,7+$80


ABF4  CE AB D5  PAGE    LDX    #ESC$FF        SEND CR, LF, AND ESC/FF
ABF7  BD FD FF          JSR    OUTSTR
ABFA  CE 00 00          LDX    #0
ABFD  BD AD 7A          JSR    DELAY          1 SECOND TO ERASE CRT
AC00  7E AD 7A          JMP    DELAY          RETURNS VIA RTS IN DELAY

AC03  8D EF     OUTFRQ  BSR    PAGE
AC05  CE AB C0          LDX    #STMSG
AC08  BD FD FF          JSR    OUTSTR
AC0B  86 3A             LDA A  #':'
AC0D  BD FD 80          JSR    OUTCH
AC10  CE 20 46          LDX    #' F'
AC13  FF ED 3E          STX    XMSG
AC16  CE 78 BD          LDX    #'x='+$80
AC19  FF ED 40          STX    XMSG+2
AC1C  B6 ED 46          LDA A  FREQ+3
AC1F  8D 1A             BSR    SHUFL
AC21  08                INX
AC22  08                INX
AC23  8D 08             BSR    OUTFR1
AC25  7C ED 40          INC    XMSG+2         CHANGE TO Y
AC28  B6 ED 44          LDA A  FREQ+1
AC2B  8D 0E             BSR    SHUFL
AC2D  86 2E     OUTFR1  LDA A  #'.'
AC2F  BD FD 80          JSR    OUTCH
AC32  BD FD 8F          JSR    THB
AC35  CE AB D0          LDX    #MHZMSG
AC38  7E FD FF          JMP    OUTSTR

AC3B  B7 ED 42  SHUFL   STA A  XMSG+4         (USE 'CTR' TEMPORARILY)
AC3E  CE ED 3E          LDX    #XMSG
AC41  BD FD FF          JSR    OUTSTR
AC44  7E FD 8F          JMP    THB


                **      MAIN PROGRAM


AC47  CE AD 01  KSPLOT  LDX    #PABORT        LOAD ABORT VECTOR
AC4A  FF ED 1C          STX    ABTVEC
AC4D  CE 58 29          LDX    #$5829         LOAD STARTING FREQ'S.
AC50  FF ED 43          STX    FREQ
AC53  CE 26 32          LDX    #$2632
AC56  FF ED 45          STX    FREQ+2
AC59  FE ED 43          LDX    FREQ
AC5C  FF EE 20          STX    YFREQ
AC5F  FE ED 45          LDX    FREQ+2
AC62  FF EE 10          STX    XFREQ
AC65  8D 9C             BSR    OUTFRQ
AC67  CE 17 00          LDX    #VMAX
AC6A  FF ED 34          STX    VMXPTR
```

X-Y PLOTTER/CRT DISPLAY PROGRAM
FOR IMAGE ALIGNMENT SYSTEM

```
AC6D  6F 00     ZERO    CLR     0,X
AC6F  08                INX
AC70  8C 18 00          CPX     #VMAX+256
AC73  26 F8             BNE     ZERO
AC75  CE ED 35          LDX     #XCOORD
AC78  6F 00     ZERO1   CLR     0,X
AC7A  08                INX
AC7B  8C ED 3E          CPX     #XMSG
AC7E  26 F8             BNE     ZERO1
AC80  7F EE 80          CLR     VERT
AC83  CE AB D9          LDX     #TSTMSG
AC86  B6 ED 49          LDA A   A$GAIN
AC89  B7 ED 48          STA A   GAIN
AC8C  B6 ED 17          LDA A   PROGNR
AC8F  84 02             AND A   #%00000010
AC91  B7 DF F9          STA A   DAS+9           SELECT DAS INPUT
AC94  27 09             BEQ     IDENT
AC96  CE AB E3          LDX     #REFMSG
AC99  B6 ED 4A          LDA A   R$GAIN
AC9C  B7 ED 48          STA A   GAIN
AC9F  C6 0C     IDENT   LDA B   #12
ACA1  BD AF 3A          JSR     SPSTR1
ACA4  4F                CLR A
ACA5  B7 ED 35  RETRCE  STA A   XCOORD
ACA8  BD AD 60          JSR     PROGTST
ACAB  27 6E             BEQ     HPOSN
ACAD  BD AE 25          JSR     DARK
ACB0  CE 20 00          LDX     #$2000
ACB3  BD AD 7A          JSR     DELAY
ACB6  20 6F             BRA     CONVRT
ACB8  7C ED 3B  XCHECK  INC     XNMBR
ACBB  F6 ED 3B          LDA B   XNMBR
ACBE  C1 C0             CMP B   #192            END OF LINE?
ACC0  26 65             BNE     CONVRT
ACC2  FE ED 45          LDX     FREQ+2
ACC5  FF EE 10          STX     XFREQ
ACC8  7F ED 3B          CLR     XNMBR
ACCB  CE EE 20          LDX     #YFREQ
ACCE  86 12             LDA A   #$12
ACD0  8D 34             BSR     DECADD
ACD2  7C ED 3C          INC     YNMBR
ACD5  BD AD 66          JSR     LFTPEN
ACD8  B6 ED 3D          LDA A   YPOSN
ACDB  8B 02             ADD A   #2
ACDD  BD AD 60          JSR     PROGTST
ACE0  26 02             BNE     YCMPR
ACE2  8B 01             ADD A   #1
ACE4  B7 ED 3D  YCMPR   STA A   YPOSN
ACE7  B7 EE 80          STA A   VERT
ACEA  B6 ED 3C          LDA A   YNMBR
ACED  81 40             CMP A   #64
ACEF  26 B4             BNE     RETRCE
ACF1  8D 73     DONE    BSR     LFTPEN
ACF3  7F EE 80          CLR     VERT
ACF6  86 FF             LDA A   #$FF
ACF8  B7 EE 81          STA A   HORIZ
ACFB  CE AB F2          LDX     #SIGNAL
```

X-Y PLOTTER/CRT DISPLAY PROGRAM
FOR IMAGE ALIGNMENT SYSTEM

```
ACFE  7E FD FF            JMP     OUTSTR           RETURNS VIA RTS
AD01  8D EE      PABORT   BSR     DONE
AD03  7E A9 9B            JMP     SUPRVR

AD06  AB 00      DECADD   ADD A   0,X
AD08  19                  DAA
AD09  A7 00               STA A   0,X
AD0B  A6 01               LDA A   1,X
AD0D  89 00               ADC A   #0
AD0F  19                  DAA
AD10  A7 01               STA A   1,X
AD12  39                  RTS

AD13  7A EE 81   PLOTRT   DEC     HORIZ
AD16  CE 02 92            LDX     #$292
AD19  8D 5F               BSR     DELAY
AD1B  B1 EE 81   HPOSN    CMP A   HORIZ
AD1E  26 F3               BNE     PLOTRT
AD20  CE 80 00            LDX     #$8000
AD23  8D 55               BSR     DELAY
AD25  8D 4B               BSR     DROPEN
AD27  CE 18 24   CONVRT   LDX     #COR1
AD2A  BD AE 2A            JSR     SYNDET
AD2D  CE EE 10            LDX     #XFREQ
AD30  86 04               LDA A   #$04
AD32  E6 01               LDA B   1,X
AD34  C0 30               SUB B   #$30
AD36  8D CE               BSR     DECADD
AD38  EA 01               ORA B   1,X
AD3A  C4 30               AND B   #$30             CHECK X FREQ CHANGE
AD3C  26 05               BNE     DISPL1
AD3E  CE FF FF            LDX     #$FFFF           39 TO 40 OR 79 TO 80
AD41  8D 37               BSR     DELAY
AD43  FE ED 4B   DISPL1   LDX     SETDEL           OPTIONAL DELAY
AD46  8D 32               BSR     DELAY            FOR SYNTH. SETTLING
AD48  CE 18 24            LDX     #COR1
AD4B  6F 06               CLR     6,X
AD4D  6F 07               CLR     7,X
AD4F  BD BD D6            JSR     CORDIC
AD52  F6 ED 48            LDA B   GAIN
AD55  78 18 25   BOOST    ASL     COR1+1
AD58  79 18 24            ROL     COR1
AD5B  5A                  DEC B
AD5C  26 F7               BNE     BOOST
AD5E  20 1E               BRA     MASK

AD60  F6 ED 17   PROGTST  LDA B   PROGNR
AD63  C5 01               BIT B   #1
AD65  39                  RTS

AD66  CE 80 00   LFTPEN   LDX     #$8000
AD69  8D 0F               BSR     DELAY
AD6B  86 34               LDA A   #$34
AD6D  B7 EE 83            STA A   VERT+3           LIFT PEN
AD70  20 05               BRA     DELAY1
AD72  C6 3C      DROPEN   LDA B   #$3C
AD74  F7 EE 83            STA B   VERT+3
```

X-Y PLOTTER/CRT DISPLAY PROGRAM
FOR IMAGE ALIGNMENT SYSTEM

```
AD77  CE 10 00  DELAY1  LDX     #$1000
AD7A  09        DELAY   DEX
AD7B  26 FD             BNE     DELAY
AD7D  39                RTS

AD7E  B6 18 24  MASK    LDA A   COR1
AD81  F6 18 25          LDA B   COR1+1
AD84  F7 ED 38          STA B   YCOORD+1         VERTICAL CHANGE
AD87  BB ED 3D          ADD A   YPOSN
AD8A  24 02             BCC     NOTSAT
AD8C  86 FF             LDA A   #$FF
AD8E  FE ED 34  NOTSAT  LDX     VMXPTR           VMXPTR+1=XCOORD
AD91  E6 00             LDA B   0,X
AD93  11                CBA
AD94  24 11             BCC     BIGR             NEW IS HIGHER
AD96  37                PSH B
AD97  8D C7             BSR     PROGTST
AD99  26 48             BNE     BLANK
AD9B  86 08             LDA A   #%00001000       CHECK PEN
AD9D  B5 EE 83          BIT A   VERT+3
ADA0  27 02             BEQ     KEEPB            UP ALREADY
ADA2  8D C2             BSR     LFTPEN
ADA4  32        KEEPB   PUL A
ADA5  20 12             BRA     SMALR            KEEP OLD ELEV.
ADA7  8D B7     BIGR    BSR     PROGTST
ADA9  26 09             BNE     CNTNUE
ADAB  C6 08             LDA B   #%00001000       CHECK PEN
ADAD  F5 EE 83          BIT B   VERT+3
ADB0  26 02             BNE     CNTNUE           DOWN ALREADY
ADB2  8D BE             BSR     DROPEN
ADB4  FE ED 34  CNTNUE  LDX     VMXPTR
ADB7  A7 00             STA A   0,X
ADB9  B7 ED 37  SMALR   STA A   YCOORD
ADBC  7C ED 35          INC     XCOORD
ADBF  8D 9F             BSR     PROGTST
ADC1  26 1C             BNE     WRITE
ADC3  16        SLWADJ  TAB                      GET VERT CHANGE
ADC4  F0 EE 80          SUB B   VERT
ADC7  24 01             BCC     POS
ADC9  50                NEG B
ADCA  58        POS     ASL B                    MULTIPLY BY 4
ADCB  58                ASL B
ADCC  CB 08             ADD B   #8               MINIMUM PLOT DELAY
ADCE  F7 ED 39          STA B   SLOW
ADD1  FE ED 39          LDX     SLOW
ADD4  8D A4             BSR     DELAY
ADD6  B7 EE 80          STA A   VERT
ADD9  7C EE 81          INC     HORIZ
ADDC  7E AC B8  XCHJMP  JMP     XCHECK
ADDF  8D 11     WRITE   BSR     VECTOR
ADE1  20 F9             BRA     XCHJMP
```

X-Y PLOTTER/CRT DISPLAY PROGRAM
FOR IMAGE ALIGNMENT SYSTEM

```
                        **      FORMAT DATA FOR OUTPUT TO TEK 4006-1

    ADE3  31            BLANK   INS
    ADE4  A6 00                 LDA A   0,X
    ADE6  B7 ED 37              STA A   YCOORD
    ADE9  7C ED 35              INC     XCOORD
    ADEC  8D 02                 BSR     DRKVCT
    ADEE  20 EC                 BRA     XCHJMP

    ADF0  8D 33         DRKVCT  BSR     DARK
    ADF2  CE ED 35      VECTOR  LDX     #XCOORD
    ADF5  8D 1B                 BSR     LOBYTE
    ADF7  8B C0                 ADD A   #$40+$80          MARK END OF STRING
    ADF9  36                    PSH A                     LAST WORD OUT
    ADFA  8D 21                 BSR     HIBYTE
    ADFC  36                    PSH A
    ADFD  CE ED 37      LOY     LDX     #YCOORD
    AE00  8D 10                 BSR     LOBYTE
    AE02  8B 60                 ADD A   #$60              ADD TAG
    AE04  36                    PSH A
    AE05  8D 16                 BSR     HIBYTE
    AE07  4C                    INC A                     MOVE RASTER UP 32 LINES
    AE08  36                    PSH A                     FIRST WORD OUT
    AE09  30                    TSX
    AE0A  BD FD FF              JSR     OUTSTR            SEND VECTORS TO DISPLAY
    AE0D  31                    INS                       RESTORE S.P.
    AE0E  31                    INS
    AE0F  31                    INS
    AE10  31                    INS
    AE11  39                    RTS

    AE12  A6 00         LOBYTE  LDA A   0,X
    AE14  E6 01                 LDA B   1,X
    AE16  58                    ASL B
    AE17  49                    ROL A
    AE18  58                    ASL B
    AE19  49                    ROL A
    AE1A  84 1F                 AND A   #%00011111
    AE1C  39                    RTS

    AE1D  A6 00         HIBYTE  LDA A   0,X
    AE1F  44                    LSR A
    AE20  44                    LSR A
    AE21  44                    LSR A
    AE22  8B 20                 ADD A   #$20              ADD TAG
    AE24  39                    RTS

    AE25  86 1D         DARK    LDA A   #$1D
    AE27  7E FD 80              JMP     OUTCH
```

SYNCHRONOUS DETECTOR
FOR IMAGE ALIGNER/PLOTTER

```
                       **      THIS VERSION INTERLEAVES I & Q SAMPLES
                       *       ENTRY:  MUX ADDRESS ($DFF9) SET TO DESIRED MODULE
                       *       EXIT:   VALUES FROM EVEN MUX ADDRESS IN [(0,X)(1,X)]
                       *               VALUE FROM ODD MUX ADDRESS IN [(2,X)(3,X)]

EE12                   POSTRAN EQU     PIA+$12
EE22                   NEGTRAN EQU     PIA+$22

AE2A  6F 00            SYNDET  CLR     0,X
AE2C  6F 01                    CLR     1,X
AE2E  6F 02                    CLR     2,X
AE30  6F 03                    CLR     3,X
AE32  C6 02                    LDA B   #2
AE34  37               LOOP60  PSH B
AE35  7D EE 11                 TST     POSTRAN-1       CLEAR CRB-7
AE38  7D EE 21                 TST     NEGTRAN-1
AE3B  0F                       SEI
AE3C  B6 EE 13         SYNDT1  LDA A   POSTRAN+1
AE3F  BA EE 23                 ORA A   NEGTRAN+1
AE42  2A F8                    BPL     SYNDT1          WAIT FOR 60HZ CYCLE
AE44  C6 04                    LDA B   #4
AE46  37               SYNDT2  PSH B
AE47  C6 02            BIGLOOP LDA B   #2
AE49  37               SIGNTST PSH B
AE4A  7D EE 10                 TST     POSTRAN-2
AE4D  7D EE 20                 TST     NEGTRAN-2
AE50  7D ED 47                 TST     SIGN            TAKE OTHER HALF CYCLE
AE53  27 0A                    BEQ     NEGTST
AE55  B6 EE 12         POSTST  LDA A   POSTRAN
AE58  2A FB                    BPL     POSTST
AE5A  7F ED 47                 CLR     SIGN
AE5D  20 0A                    BRA     SAMPLE
AE5F  B6 EE 22         NEGTST  LDA A   NEGTRAN
AE62  2A FB                    BPL     NEGTST
AE64  86 FF                    LDA A   #$FF
AE66  B7 ED 47                 STA A   SIGN
AE69  C6 14            SAMPLE  LDA B   #20
AE6B  5A               DELAY2  DEC B
AE6C  26 FD                    BNE     DELAY2          SIGNAL PHASE COMPENSATION
AE6E  B7 DF FA                 STA A   DAS+$A          CONVERT COMMAND
AE71  B6 DF FB         WAIT    LDA A   DAS+$B          FOR EOC
AE74  2A FB                    BPL     WAIT
AE76  B6 DF FD                 LDA A   DAS+$D          GET HI BYTE
AE79  F6 DF FC                 LDA B   DAS+$C          GET LO BYTE
AE7C  7D ED 47                 TST     SIGN
AE7F  26 05                    BNE     SUBTR
AE81  43                       COM A                   RE-INVERT
AE82  53                       COM B
AE83  0C                       CLC
AE84  20 01                    BRA     ADDATA
AE86  0D               SUBTR   SEC                     DATA IS ALREADY INVERTED
AE87  E9 01            ADDATA  ADC B   1,X
AE89  A9 00                    ADC A   0,X
AE8B  28 0D                    BVC     STORE           NO OVERFLOW
AE8D  2A 08                    BPL     MINUS           FILL FILTER WITH MAX. VALUE
AE8F  C6 FF                    LDA B   #$FF
AE91  86 7F                    LDA A   #$7F
```

SYNCHRONOUS DETECTOR
FOR IMAGE ALIGNER/PLOTTER

```
AE93  20 05              BRA    STORE
AE95  20 9D     LOOP61   BRA    LOOP60         BRANCH EXTENSION
AE97  5F        MINUS    CLR B
AE98  86 80              LDA A  #$80
AE9A  E7 01     STORE    STA B  1,X
AE9C  A7 00              STA A  0,X
AE9E  33                 PUL B
AE9F  5A                 DEC B
AEA0  26 A7              BNE    SIGNTST        NEXT HALF-CYCLE
AEA2  B6 DF F9           LDA A  DAS+9
AEA5  44                 LSR A
AEA6  25 07              BCS    ODD
AEA8  7C DF F9           INC    DAS+9          OTHER CHANNEL
AEAB  08                 INX
AEAC  08                 INX
AEAD  20 98              BRA    BIGLOOP
AEAF  7A DF F9  ODD      DEC    DAS+9          FIRST CHANNEL
AEB2  09                 DEX
AEB3  09                 DEX
AEB4  33                 PUL B
AEB5  5A                 DEC B
AEB6  26 8E              BNE    SYNDT2         TAKE ANOTHER CYCLE
AEB8  33                 PUL B
AEB9  0E                 CLI
AEBA  5A                 DEC B
AEBB  26 D8              BNE    LOOP61
AEBD  39                 RTS
```

```
                    *       WRITES CORRELATION COEFFICIENT ON CRT

                    *       TEXT FOR HEADINGS

AEBE  43 4F 52  HEADG1  FCC     'CORRELATION COEF'
AECE  46 49 43          FCC     'FICIENT',$D,$A,$A,$A+$80
AED9  4D 41 47  HEADG2  FCC     'MAGNITUDE   PHAS'
AEE9  45 20 28          FCC     'E (Deg)',$D,$A,$A,7+$80
AEF4  20 30 AE  DATA    FCC     ' 0','.'+$80

AEF7  07        CORCRT  TPA
AEF8  36                PSH A
AEF9  BD AB F4          JSR     PAGE
AEFC  C6 0F             LDA B   #15
AEFE  BD FD A9  LINE    JSR     CRLF1
AF01  5A                DEC B
AF02  26 FA             BNE     LINE            MOVE DOWN 15 LINES
AF04  CE AE BE          LDX     #HEADG1
AF07  8D 2F             BSR     SPSTR           1ST LINE OF TEXT
AF09  8D 2D             BSR     SPSTR           2ND LINE
AF0B  8D 2B             BSR     SPSTR           3RD LINE
AF0D  CE 18 24          LDX     #COR1
AF10  BD FD 7A          JSR     OUT4HS          PRINT MAGNITUDE
AF13  C6 05             LDA B   #5
AF15  8D 28             BSR     SPACE
AF17  32                PUL A                   GET SIGN OF ANGLE
AF18  84 01             AND A   #1
AF1A  48                ASL A
AF1B  8B 2B             ADD A   #$2B
AF1D  BD FD 80          JSR     OUTCH
AF20  BD FD 8F          JSR     THB
AF23  A6 00     CRT1    LDA A   0,X
AF25  36                PSH A
AF26  44                LSR A
AF27  44                LSR A
AF28  44                LSR A
AF29  44                LSR A
AF2A  BD FD 9C          JSR     THB1
AF2D  86 2E             LDA A   #'.'            ANGLE HAS FORM XXX.X
AF2F  BD FD 80          JSR     OUTCH
AF32  32                PUL A
AF33  84 0F             AND A   #$F
AF35  7E FD 9C          JMP     THB1            RETURNS VIA RTS

AF38  C6 17     SPSTR   LDA B   #23
AF3A  8D 03     SPSTR1  BSR     SPACE           TO CENTER TEXT ON CRT
AF3C  7E FD FF          JMP     OUTSTR

AF3F  BD FD 7E  SPACE   JSR     OUTSP           SPACE (B) TIMES
AF42  5A                DEC B
AF43  26 FA             BNE     SPACE
AF45  39                RTS
```

```
                        *       EXTERNAL REFERENCES

ED15                    CALIBR  EQU     $ED15
ED1E                    XCOUNT  EQU     $ED1E
ED23                    YCOUNT  EQU     $ED23
A820                    XSTEP   EQU     $A820
ED4D                    MAG     EQU     $ED4D
ED4E                    MAG1    EQU     $ED4E

                        *       VECTORS FOR TEK 4006-1

AF46  1D 2C 66  AXES    FCB     $1D,',f @','f?_',$1D,' `O@','81','@'+$80
AF56  1D 2C 63  SMALSQ  FCB     $1D,',c/]','i]','iOC',/cC','c/]',$1D+$80
AF66  1D 2A 74  MAGSQ   FCB     $1D,'*t.N','-xN','x1R','*tR'
AF74  74 2E 4E          FCB     't.N',$1D+$80

AF78  BD AB F4  CROSS   JSR     PAGE
AF7B  CE AF 46          LDX     #AXES
AF7E  7E FD FF  SQUARE  JMP     OUTSTR

AF81  7F ED 4E  GRAPH1  CLR     MAG1
AF84  8D F2             BSR     CROSS           PAINT TARGET
AF86  8D F6             BSR     SQUARE
AF88  B6 ED 17  GRAPH2  LDA A   PROGNR
AF8B  81 0D             CMP A   #$D
AF8D  26 01             BNE     GO
AF8F  39                RTS                     SPURIOUS ENTRY FROM 'D' COM
AF90  7F ED 4D  GO      CLR     MAG
AF93  FE ED 21          LDX     XCOUNT+3
AF96  8C 20 00          CPX     #512*16         10 BITS MAX. FOR CRT
AF99  2B 03             BMI     TEST2
AF9B  CE 20 00          LDX     #512*16
AF9E  8C E0 00  TEST2   CPX     #-8192
AFA1  2A 03             BPL     STORE1
AFA3  CE E0 00          LDX     #-8192
AFA6  FF ED 35  STORE1  STX     XCOORD
AFA9  8C 02 00          CPX     #512            TOO BIG AFTER 16X MAG?
AFAC  2A 08             BPL     Y
AFAE  8C FE 00          CPX     #-512
AFB1  2B 03             BMI     Y
AFB3  7C ED 4D          INC     MAG             O.K. SO FAR
AFB6  FE ED 26  Y       LDX     YCOUNT+3
AFB9  8C 1E 00          CPX     #512*16-512     CRT VERTICAL IS SMALLER
AFBC  2B 03             BMI     TEST3
AFBE  CE 1E 00          LDX     #512*16-512
AFC1  8C DF 00  TEST3   CPX     #-8192-256
AFC4  2A 03             BPL     STORE2
AFC6  CE DF 00          LDX     #-8192-256
AFC9  FF ED 37  STORE2  STX     YCOORD
AFCC  7D ED 4E          TST     MAG1
AFCF  26 2B             BNE     CENTER          HAVE MAGNIFIED TARGET ALREA
AFD1  8C 01 00          CPX     #256
AFD4  2A 16             BPL     SCALE
AFD6  8C FF 00          CPX     #-256
AFD9  2B 11             BMI     SCALE
AFDB  7D ED 4D          TST     MAG             WAS X O.K.?
```

```
    AFDE   27 0C                BEQ     SCALE
    AFE0   8D 96      MAG16X    BSR     CROSS            PAINT MAGNIFIED TARGET
    AFE2   CE AF 66             LDX     #MAGSQ
    AFE5   8D 97                BSR     SQUARE
    AFE7   7C ED 4E             INC     MAG1
    AFEA   20 10                BRA     CENTER
    AFEC   CE ED 35   SCALE     LDX     #XCOORD          REDUCE COORDINATES TO 1/16
    AFEF   C6 04                LDA B   #4
    AFF1   67 00      LOOP      ASR     0,X
    AFF3   66 01                ROR     1,X
    AFF5   67 02                ASR     2,X
    AFF7   66 03                ROR     3,X
    AFF9   5A                   DEC B
    AFFA   26 F5                BNE     LOOP
    AFFC   CE ED 35   CENTER    LDX     #XCOORD
    AFFF   A6 00                LDA A   0,X
    B001   8B 02                ADD A   #512/256         SHIFT TO HORIZ. CENTER
    B003   E6 01                LDA B   1,X
    B005   8D 0F                BSR     EXCHNG
    B007   08                   INX
    B008   08                   INX
    B009   E6 01                LDA B   1,X
    B00B   A6 00                LDA A   0,X
    B00D   CB 66                ADD B   #390-32-256      SHIFT TO VERTICAL CENTER
    B00F   89 01                ADC A   #390-32/256      "VECTOR" ADDS BACK 32
    B011   8D 03                BSR     EXCHNG
    B013   7E AD F2             JMP     VECTOR

    B016   47         EXCHNG    ASR A
    B017   56                   ROR B
    B018   46                   ROR A
    B019   56                   ROR B
    B01A   46                   ROR A
    B01B   A7 01                STA A   1,X              (A) NOW HAS L.S. 2 OF 10 BIT
    B01D   E7 00                STA B   0,X              (B) HAS M.S. 8 OF 10 BITS
    B01F   39         RETRN4    RTS

    B020                        END



STATEMENTS =574

FREE BYTES =19

NO ERRORS DETECTED
```

```
                  *       SUBROUTINE                MEASURE
                  *       MEASURES DEFT DEVICE OUTPUTS AND COMPUTES
                  *       VARIABLES FOR CORRELATION AND LEAST SQUARES ESTIMATI
                  *       MODE=1 FOR REFERENCE
                  *       MODE=2 FOR CORRELATE
                  *       MODE=3 FOR LEAST SQUARES
                  *       1>=L>=NBDRY SETS FREQUENCY PLANE BOUNDARY FOR
                  *       LEAST SQUARES
   1800                   ORG     $1800
   1800           TEMP1   RMB     1
   1801           TEMP2   RMB     1
   1802           TEMP3   RMB     1
   1803           TEMP4   RMB     1
   1804           TEMP5   RMB     1
   1805           TEMP6   RMB     1
   1806           BCD1    RMB     1
   1807           BCD2    RMB     1
   1808           CTR     RMB     1
   1809           CTR1    RMB     1
   1814                   ORG     $1814
   1814           XOZERO  RMB     4
   1818           YOZERO  RMB     4
   181C           X1ZERO  RMB     4
   1820           Y1ZERO  RMB     4
   1824           COR1    RMB     1                 REAL
   1825           COR2    RMB     1
   1826           COR3    RMB     1                 IMAG
   1827           COR4    RMB     3
   182A           COR9    RMB     1                 THETA
   182B           COR10   RMB     1
   182C           I       RMB     1
   182D           J       RMB     1
   182E           ID      RMB     1
   182F           JD      RMB     1
   1830           UI1     RMB     1
   1831           UI2     RMB     1
   1832           VJ1     RMB     1
   1833           VJ2     RMB     1
   1834           MODE    RMB     1
   1835           DTIME   RMB     1
   1836           JSTART  RMB     1
   1837           BDRY    RMB     1
   1838           BDRYD   RMB     1
   1839           NBDRY   RMB     1
   183A           BDRYPT  RMB     1
   183B           FIRST   RMB     1
   183C           SENSOR  RMB     1
   183D           NSAMP   RMB     1
   183E           LOGNS   RMB     1
   183F           BCDPTR  RMB     2
   1841           L       RMB     1
   1842           LIMIT   RMB     1
   1843           X       RMB     1
   1844           Y       RMB     1
   1845           ZERO    RMB     4
   1849           X1INC   RMB     2
   184B           Y1INC   RMB     2
```

```
184D   NPT      RMB   1
184E   STACK1   RMB   1
184F   STACK2   RMB   1
1850   PUSHST   RMB   1
1851   THR11    RMB   1
1852   THR12    RMB   1
1853   THR21    RMB   1
1854   THR22    RMB   1
1855   HOW      RMB   1
1856   IJPTR    RMB   1
1857   IJPTR1   RMB   1
1858   ADRSW    RMB   1
1859   SETUP    RMB   1
185A   FINE     RMB   1
185B   K$G      RMB   1
185C   KKKK     RMB   4
1860   CORSE    RMB   2
1862   ST       RMB   2
1864   SAVESP   RMB   2
1866   MAX      RMB   4
186A   SUM      RMB   4
186E   XTRAN    RMB   2
1870   YTRAN    RMB   2
1872   DELX     RMB   4
1876   DELY     RMB   4
187A   VP       RMB   4
187E   UP       RMB   4
1882   UV       RMB   4
1886   VV       RMB   4
188A   UU       RMB   4
188E   STEPS    RMB   2
1890   ANGLE    RMB   2
1892   SMAG     RMB   4
1896   SAVEX    RMB   2
1898   SAVEY    RMB   2
189A   DIRECT   RMB   1
189B   DTHR11   RMB   1
189C   DTHR12   RMB   1
189D   DTHR21   RMB   1
189E   DTHR22   RMB   1
189F   MPLX     RMB   2
18A1   SIGNI    RMB   1
18A2   SIGNQ    RMB   1
18A3   SFLAG    RMB   1
18A4   SNFLAG   RMB   1
18D8            ORG   $18D8
18D8   DELTA    RMB   10D
18E2   BCDAR    RMB   512D
1AE2   BDRYLF   RMB   5
1AE7   BDRYCT   RMB   5
1AEC   S1VP1M   RMB   20D
1B00   S1UP1M   RMB   20D
1B14   S1UV1M   RMB   20D
1B28   S1V1M    RMB   20D
1B3C   S1U1M    RMB   20D
1B50   IJ       RMB   400D
1CE0   PS1MS    RMB   400D
```

```
1E70                MS1MS   RMB    400D
BB68                FULL4   EQU    $BB68
BB8E                PUSH44  EQU    $BB8E
BBB4                PUSH41  EQU    $BBB4
BBD1                PUSH42  EQU    $BBD1
B9A0                DELAY1  EQU    $B9A0
BB17                BI$BCD  EQU    $BB17
BBF4                TUNE    EQU    $BBF4
BA92                READ    EQU    $BA92
BC0D                RDDEFT  EQU    $BC0D
B9B6                ADDRES  EQU    $B9B6
8000                MATH    EQU    $8000
BDD6                CORDIC  EQU    $BDD6
BD28                GSRCH   EQU    $BD28
A65C                INDEX1  EQU    $A65C
A685                UPDATE  EQU    $A685
A63D                IDEX    EQU    $A63D
A74C                PHASDF  EQU    $A74C
                    *
B040                        ORG    $B040
B040  7F 18 3B      MEASRE  CLR    FIRST
B043  B6 18 34              LDAA   MODE        WHICH MODE?
B046  4A                    DECA
B047  27 05                 BEQ    LM1
B049  4A                    DECA
B04A  27 2D                 BEQ    LM4
B04C  20 3C                 BRA    LM5
B04E  7F 18 2C      LM1     CLR    I           MODE 1: INITIALIZE
B051  86 01                 LDAA   #01
B053  B7 18 43              STAA   X
B056  B7 18 37              STAA   BDRY
B059  B6 18 36              LDAA   JSTART
B05C  B7 18 2D              STAA   J
B05F  CE 00 00              LDX    #0
B062  BF 18 00              STS    TEMP1
B065  8E 1B 4F              LDS    #IJ-1       S1U(5) LS
B068  4F                    CLRA
B069  36            LM2     PSHA               CLEAR S1 VARIABLES
B06A  08                    INX
B06B  8C 00 3C              CPX    #60D
B06E  26 F9                 BNE    LM2
B070  BE 18 00      LM3     LDS    TEMP1
B073  7F 18 3C              CLR    SENSOR      0=REFERENCE SENSOR
B076  7E B1 28              JMP    LM8         TO ADDRES
B079  CE 00 00      LM4     LDX    #0          MODE 2: INITIALIZE
B07C  FF 18 6A              STX    SUM
B07F  FF 18 6C              STX    SUM+2
B082  FF 18 92              STX    SMAG
B085  FF 18 94              STX    SMAG+2
B088  20 11                 BRA    LM7
B08A  86 01         LM5     LDAA   #1          MODE 3: INITIALIZE
B08C  B7 18 37              STAA   BDRY
B08F  CE 1A EC              LDX    #S1VP1M
B092  4F                    CLRA
B093  A7 00         LM6     STAA   0,X         CLEAR S1UP AND S1VP
B095  08                    INX
B096  8C 1B 14              CPX    #S1UV1M
```

```
B099  26 F8              BNE   LM6
B09B  86 01      LM7     LDAA  #1           MODES 2 AND 3: INITIALIZE
B09D  B7 18 44           STAA  Y
B0A0  CE 18 DE           LDX   #BCDAR-4
B0A3  FF 18 3F           STX   BCDPTR
B0A6  CE 1B 50           LDX   #IJ
B0A9  FF 18 56           STX   IJPTR
B0AC  A6 00              LDAA  0,X
B0AE  B7 18 2D           STAA  J            PASS IU(1),JV(1) TO ADDRES
B0B1  CE 1C 18           LDX   #IJ+200D
B0B4  A6 00              LDAA  0,X
B0B6  B7 18 2C           STAA  I
B0B9  86 01              LDAA  #1
B0BB  B7 18 3C           STAA  SENSOR       1=ALIGNING SENSOR
B0BE  7E B1 28           JMP   LM8          TO TUNE
B0C1  FE 18 2C   LM9     LDX   I            SAVE OLD VALUES
B0C4  FF 18 2E           STX   ID
B0C7  B6 18 34           LDAA  MODE         WHICH MODE?
B0CA  4A                 DECA
B0CB  27 0A              BEQ   LM10
B0CD  4A                 DECA
B0CE  27 34              BEQ   LM131
B0D0  7D 18 A4           TST   SNFLAG
B0D3  27 34              BEQ   LM14
B0D5  20 28              BRA   LM130
B0D7  B6 18 37   LM10    LDAA  BDRY         MODE 1: SET UP
B0DA  B7 18 38           STAA  BDRYD
B0DD  BD A6 5C           JSR   INDEX1
B0E0  7D 18 2C           TST   I
B0E3  26 18              BNE   LM13
B0E5  B6 18 2D           LDAA  J
B0E8  CE 1A E2           LDX   #BDRYLF      TABLE OF NORMALIZED BOUNDARI
B0EB  5F                 CLRB
B0EC  A1 00      LM11    CMPA  0,X
B0EE  27 09              BEQ   LM12
B0F0  5C                 INCB
B0F1  08                 INX
B0F2  F1 18 39           CMPB  NBDRY
B0F5  27 06              BEQ   LM13         IF ZERO, IN OLD REGION
B0F7  20 F3              BRA   LM11
B0F9  5C         LM12    INCB               IN NEW REGION
B0FA  F7 18 37           STAB  BDRY
B0FD  20 26      LM13    BRA   LM15
B0FF  BD BC 0D   LM130   JSR   RDDEFT
B102  20 08              BRA   LM141
B104  7D 18 58   LM131   TST   ADRSW
B107  2E F6              BGT   LM130
B109  BD BA 92   LM14    JSR   READ         MODE 2 AND 3: SET UP
B10C  FE 18 56   LM141   LDX   IJPTR
B10F  08                 INX
B110  FF 18 56           STX   IJPTR
B113  A6 00              LDAA  0,X
B115  B7 18 2D           STAA  J            J=IJ(IJPTR)
B118  4F                 CLRA
B119  C6 C8              LDAB  #200D
B11B  BD A6 3D           JSR   IDEX
B11E  A6 00              LDAA  0,X
```

```
B120  B7 18 2C          STAA   I             I=IJ(IJPTR+200)
B123  20 03             BRA    LM8
B125  BD BC 0D  LM15    JSR    RDDEFT
B128  BD B9 B6  LM8     JSR    ADDRES        ALL MODES
B12B  BD BB F4  LM16    JSR    TUNE
B12E  7D 18 3B          TST    FIRST
B131  26 09             BNE    LM17
B133  BD B9 A0          JSR    DELAY1        FIRST ITERATION
B136  7C 18 3B          INC    FIRST
B139  7E B0 C1          JMP    LM9
B13C  7F 18 2A  LM17    CLR    COR9          CORDIC VECTOR MODE
B13F  7F 18 2B          CLR    COR10
B142  BD BD D6          JSR    CORDIC        CORDIC
B145  B6 18 34          LDAA   MODE
B148  4A                DECA
B149  27 09             BEQ    LM18          MODE 1
B14B  4A                DECA
B14C  27 03             BEQ    LM171         MODE 2
B14E  7E B3 1A          JMP    LM22          MODE 3
B151  7E B2 12  LM171   JMP    LM29
B154  7D 18 A3  LM18    TST    SFLAG         MODE 1: SEARCH TRANSFORM
B157  2E 06             BGT    LM180
B159  BD A6 85          JSR    UPDATE        SFLAG=0
B15C  7E B2 94          JMP    LM20
B15F  B6 18 24  LM180   LDAA   COR1          SFLAG=1
B162  F6 18 25          LDAB   COR2
B165  F0 18 52          SUBB   THR12
B168  B2 18 51          SBCA   THR11
B16B  2C 03             BGE    LM19
B16D  7E B2 94          JMP    LM20          REJECT:  INSIGNIFICANT MAG
B170  B6 18 2C  LM19    LDAA   I
B173  B7 18 8B          STAA   UU+1
B176  B6 18 2D          LDAA   J
B179  B7 18 87          STAA   VV+1
B17C  7F 18 66          CLR    MAX
B17F  7F 18 67          CLR    MAX+1
B182  86 02             LDAA   #2
B184  B7 18 62          STAA   ST
B187  BD BD 28          JSR    GSRCH
B18A  7A 18 62          DEC    ST
B18D  BD BD 28          JSR    GSRCH
B190  B6 18 8B          LDAA   UU+1
B193  B7 18 2C          STAA   I
B196  B6 18 87          LDAA   VV+1
B199  B7 18 2D          STAA   J
B19C  BD B9 B6          JSR    ADDRES
B19F  BD BB F4          JSR    TUNE
B1A2  B6 18 66          LDAA   MAX
B1A5  F6 18 67          LDAB   MAX+1
B1A8  F0 18 52          SUBB   THR12
B1AB  B2 18 51          SBCA   THR11
B1AE  2C 03             BGE    LM190
B1B0  7E B2 94          JMP    LM20          REJECT
B1B3  FE 18 66  LM190   LDX    MAX
B1B6  FF 18 24          STX    COR1
B1B9  FE 18 68          LDX    MAX+2
B1BC  FF 18 2A          STX    COR9
```

```
B1BF  CE 1C 17          LDX   #MS1MS-601D
B1C2  FF 18 00          STX   TEMP1
B1C5  B6 18 00          LDAA  TEMP1
B1C8  F6 18 01          LDAB  TEMP2
B1CB  FB 18 43          ADDB  X
B1CE  89 00             ADCA  #0
B1D0  B7 18 00          STAA  TEMP1
B1D3  F7 18 01          STAB  TEMP2
B1D6  FE 18 00          LDX   TEMP1
B1D9  B6 18 2E          LDAA  ID
B1DC  A7 00             STAA  0,X            IJ(X+200)=ID
B1DE  B6 18 00          LDAA  TEMP1
B1E1  C0 C8             SUBB  #200D
B1E3  82 00             SBCA  #0
B1E5  B7 18 00          STAA  TEMP1
B1E8  F7 18 01          STAB  TEMP2
B1EB  FE 18 00          LDX   TEMP1
B1EE  B6 18 2F          LDAA  JD
B1F1  A7 00             STAA  0,X            IJ(X)=JD
B1F3  F6 18 38          LDAB  BDRYD          UPDATE S1 VARIABLES
B1F6  58                ASLB
B1F7  58                ASLB
B1F8  C0 03             SUBB  #3
B1FA  F7 18 3A          STAB  BDRYPT         POINTS TO MS BYTE
B1FD  F6 18 2E          LDAB  ID             S1U(BDRYD)=S1U(BDRYD)+ID*ID
B200  4F                CLRA
B201  BD BB D1          JSR   PUSH42
B204  F6 18 2E          LDAB  ID
B207  4F                CLRA
B208  BD BB D1          JSR   PUSH42
B20B  86 0A             LDAA  #10D
B20D  BD 80 00          JSR   MATH
B210  20 03             BRA   LM28
B212  7E B2 A6    LM29  JMP   LM21
B215  CE 1B 3B    LM28  LDX   #S1U1M-1
B218  B6 18 3A          LDAA  BDRYPT
B21B  BD BB 8E          JSR   PUSH44
B21E  86 0B             LDAA  #11D
B220  BD 80 00          JSR   MATH
B223  CE 1B 3B          LDX   #S1U1M-1
B226  B6 18 3A          LDAA  BDRYPT
B229  BD BB 68          JSR   PULL4
B22C  B6 18 2F          LDAA  JD             S1V(BDRYD)=S1V(BDRYD)+JD*JD
B22F  BD BB B4          JSR   PUSH41
B232  B6 18 2F          LDAA  JD
B235  BD BB B4          JSR   PUSH41
B238  86 0A             LDAA  #10D
B23A  BD 80 00          JSR   MATH
B23D  CE 1B 27          LDX   #S1V1M-1
B240  B6 18 3A          LDAA  BDRYPT
B243  BD BB 8E          JSR   PUSH44
B246  86 0B             LDAA  #11D
B248  BD 80 00          JSR   MATH
B24B  CE 1B 27          LDX   #S1V1M-1
B24E  B6 18 3A          LDAA  BDRYPT
B251  BD BB 68          JSR   PULL4
B254  F6 18 2E          LDAB  ID             S1UV(BDRYD)=S1UV(BDRYD)+ID*J
```

```
B257  4F                    CLRA
B258  BD BB D1              JSR     PUSH42
B25B  B6 18 2F              LDAA    JD
B25E  BD BB B4              JSR     PUSH41
B261  86 0A                 LDAA    #10D
B263  BD 80 00              JSR     MATH
B266  CE 1B 13              LDX     #S1UV1M-1
B269  B6 18 3A              LDAA    BDRYPT
B26C  BD BB 8E              JSR     PUSH44
B26F  86 0B                 LDAA    #11D
B271  BD 80 00              JSR     MATH
B274  CE 1B 13              LDX     #S1UV1M-1
B277  B6 18 3A              LDAA    BDRYPT
B27A  BD BB 68              JSR     PULL4
B27D  CE 1A E6              LDX     #BDRYCT-1       BDRYCT(BDRYD)=X
B280  F6 18 38              LDAB    BDRYD
B283  4F                    CLRA
B284  BD A6 3D              JSR     IDEX
B287  B6 18 43              LDAA    X
B28A  A7 00                 STAA    0,X
B28C  B0 18 4D              SUBA    NPT
B28F  2C 14                 BGE     LM201           GOT NPT SIGNIFICANT POINTS
B291  7C 18 43              INC     X               X=X+1
B294  F6 18 2C    LM20      LDAB    I
B297  4F                    CLRA
B298  F0 18 42              SUBB    LIMIT
B29B  82 00                 SBCA    #0
B29D  2C 03                 BGE     LM202
B29F  7E B3 CF              JMP     LM26            DO ANOTHER POINT
B2A2  7A 18 43    LM202     DEC     X
B2A5  39          LM201     RTS
B2A6  CE 1E 6E    LM21      LDX     #MS1MS-2        MODE 2: CORRELATION
B2A9  FF 18 00              STX     TEMP1
B2AC  B6 18 00              LDAA    TEMP1
B2AF  F6 18 01              LDAB    TEMP2
B2B2  FB 18 44              ADDB    Y
B2B5  89 00                 ADCA    #0
B2B7  FB 18 44              ADDB    Y
B2BA  89 00                 ADCA    #0
B2BC  B7 18 00              STAA    TEMP1
B2BF  F7 18 01              STAB    TEMP2
B2C2  FE 18 00              LDX     TEMP1
B2C5  A6 00                 LDAA    0,X             GET MS(Y)
B2C7  E6 01                 LDAB    1,X
B2C9  BD BB D1              JSR     PUSH42
B2CC  B6 18 24              LDAA    COR1
B2CF  F6 18 25              LDAB    COR2
B2D2  BD BB D1              JSR     PUSH42
B2D5  86 0A                 LDAA    #10D
B2D7  BD 80 00              JSR     MATH            MS(Y)*MAG
B2DA  CE 18 6A              LDX     #SUM
B2DD  4F                    CLRA
B2DE  BD BB 8E              JSR     PUSH44
B2E1  86 0B                 LDAA    #11D
B2E3  BD 80 00              JSR     MATH            SUM=SUM+MAG*MS(Y)
B2E6  CE 18 6A              LDX     #SUM
B2E9  4F                    CLRA
```

```
B2EA  BD BB 68             JSR    PULL4
B2ED  B6 18 24             LDAA   COR1
B2F0  F6 18 25             LDAB   COR2
B2F3  BD BB D1             JSR    PUSH42
B2F6  B6 18 24             LDAA   COR1
B2F9  F6 18 25             LDAB   COR2
B2FC  BD BB D1             JSR    PUSH42
B2FF  86 0A                LDAA   #10D
B301  BD 80 00             JSR    MATH              MAG*MAG
B304  CE 18 92             LDX    #SMAG
B307  4F                   CLRA
B308  BD BB 8E             JSR    PUSH44
B30B  86 0B                LDAA   #11D
B30D  BD 80 00             JSR    MATH              SMAG=SMAG+MAG*MAG
B310  CE 18 92             LDX    #SMAG
B313  4F                   CLRA
B314  BD BB 68             JSR    PULL4
B317  7E B3 D6             JMP    LM30
B31A  CE 1A E6   LM22      LDX    #BDRYCT-1         MODE 3: LEAST SQUARE
B31D  F6 18 37             LDAB   BDRY
B320  4F                   CLRA
B321  BD A6 3D             JSR    IDEX
B324  A6 00                LDAA   0,X
B326  B0 18 44             SUBA   Y
B329  2C 05                BGE    LM23
B32B  7C 18 37             INC    BDRY
B32E  20 EA                BRA    LM22
B330  B6 18 37   LM23      LDAA   BDRY
B333  B0 18 41             SUBA   L
B336  2F 04                BLE    LM24
B338  7A 18 44             DEC    Y
B33B  39                   RTS                      BDRY>L
B33C  F6 18 37   LM24      LDAB   BDRY
B33F  58                   ASLB
B340  58                   ASLB
B341  C0 03                SUBB   #3
B343  F7 18 3A             STAB   BDRYPT
B346  CE 1C DE             LDX    #PS1MS-2
B349  F6 18 44             LDAB   Y
B34C  4F                   CLRA
B34D  58                   ASLB
B34E  49                   ROLA
B34F  BD A6 3D             JSR    IDEX
B352  20 03                BRA    LM243
B354  7E B3 C4   LM240     JMP    LM25
B357  EE 00      LM243     LDX    0,X
B359  FF 18 02             STX    TEMP3
B35C  FE 18 2A             LDX    COR9
B35F  FF 18 00             STX    TEMP1
B362  CE 18 00             LDX    #TEMP1
B365  BD A7 4C             JSR    PHASDF
B368  EE 00                LDX    0,X
B36A  FF 18 2A             STX    COR9
B36D  F6 18 2E             LDAB   ID                S1UP(BDRY)=S1UP(BDRY)+ID*PD
B370  4F                   CLRA
B371  BD BB D1             JSR    PUSH42
B374  B6 18 2A             LDAA   COR9
```

```
B377  F6 18 2B          LDAB    COR10
B37A  BD BB D1          JSR     PUSH42
B37D  86 0A             LDAA    #10D
B37F  BD 80 00          JSR     MATH
B382  CE 1A FF          LDX     #S1UP1M-1
B385  B6 18 3A          LDAA    BDRYPT
B388  BD BB 8E          JSR     PUSH44
B38B  86 0B             LDAA    #11D
B38D  BD 80 00          JSR     MATH
B390  CE 1A FF          LDX     #S1UP1M-1
B393  B6 18 3A          LDAA    BDRYPT
B396  BD BB 68          JSR     PULL4
B399  B6 18 2F          LDAA    JD            S1VP(BDRY)=S1VP(BDRY)+JD*PD
B39C  BD BB B4          JSR     PUSH41
B39F  B6 18 2A          LDAA    COR9
B3A2  F6 18 2B          LDAB    COR10
B3A5  BD BB D1          JSR     PUSH42
B3A8  86 0A             LDAA    #10D
B3AA  BD 80 00          JSR     MATH
B3AD  CE 1A EB          LDX     #S1VP1M-1
B3B0  B6 18 3A          LDAA    BDRYPT
B3B3  BD BB 8E          JSR     PUSH44
B3B6  86 0B             LDAA    #11D
B3B8  BD 80 00          JSR     MATH
B3BB  CE 1A EB          LDX     #S1VP1M-1
B3BE  B6 18 3A          LDAA    BDRYPT
B3C1  BD BB 68          JSR     PULL4
B3C4  7C 18 44    LM25  INC     Y             MODES 2 AND 3
B3C7  B6 18 43          LDAA    X
B3CA  B0 18 44          SUBA    Y
B3CD  2D 06             BLT     LM27          NO MORE SIGNIFICANT POINTS
B3CF  BD B9 A0    LM26  JSR     DELAY1
B3D2  7E B0 C1          JMP     LM9           NEXT POINT
B3D5  39          LM27  RTS                   TO MAIN ALIGNMENT PROGRAM
B3D6  7C 18 44    LM30  INC     Y             MODE 2
B3D9  B6 18 43          LDAA    X
B3DC  B0 18 44          SUBA    Y
B3DF  2C EE             BGE     LM26
B3E1  CE 18 7E    LM31  LDX     #VP+4
B3E4  4F                CLRA
B3E5  BD BB 8E          JSR     PUSH44
B3E8  CE 18 7A          LDX     #VP
B3EB  4F                CLRA
B3EC  BD BB 8E          JSR     PUSH44        MAX NFPN
B3EF  4F                CLRA
B3F0  BD BB B4          JSR     PUSH41
B3F3  CE 18 6A          LDX     #SUM
B3F6  4F                CLRA
B3F7  BD BB 8E          JSR     PUSH44
B3FA  86 07             LDAA    #7
B3FC  BD 80 00          JSR     MATH          SUM NFPN
B3FF  4F                CLRA
B400  BD BB B4          JSR     PUSH41
B403  CE 18 6A          LDX     #SUM
B406  4F                CLRA
B407  BD BB 8E          JSR     PUSH44
B40A  86 07             LDAA    #7
```

```
B40C  BD 80 00        JSR    MATH        SUM NFPN
B40F  86 01           LDAA   #1
B411  BD 80 00        JSR    MATH        SUM*SUM (FP)
B414  4F              CLRA
B415  BD BB B4        JSR    PUSH41
B418  CE 18 92        LDX    #SMAG
B41B  4F              CLRA
B41C  BD BB 8E        JSR    PUSH44
B41F  86 07           LDAA   #7
B421  BD 80 00        JSR    MATH        SMAG NFPN
B424  86 02           LDAA   #2
B426  BD 80 00        JSR    MATH        SUM=SUM*SUM/SMAG
B429  CE 18 82        LDX    #UV
B42C  4F              CLRA
B42D  BD BB 68        JSR    PULL4
B430  CE 18 86        LDX    #UV+4
B433  4F              CLRA
B434  BD BB 68        JSR    PULL4       UV=SUM
B437  CE 18 86        LDX    #UV+4
B43A  4F              CLRA
B43B  BD BB 8E        JSR    PUSH44
B43E  CE 18 82        LDX    #UV
B441  4F              CLRA
B442  BD BB 8E        JSR    PUSH44
B445  86 02           LDAA   #2
B447  BD 80 00        JSR    MATH        MAX/SUM
B44A  CE 18 6A        LDX    #SUM
B44D  4F              CLRA
B44E  BD BB 68        JSR    PULL4
B451  CE 18 6A        LDX    #SUM
B454  4F              CLRA
B455  BD BB 68        JSR    PULL4       IF SUM+3<0 THEN SUM>MAX
B458  39              RTS
B459                  END
```

STATEMENTS =548

FREE BYTES =1023

NO ERRORS DETECTED

```
1800                    ORG     $1800
1800            TEMP1   RMB     1
1801            TEMP2   RMB     1
1802            TEMP3   RMB     1
1803            TEMP4   RMB     1
1804            TEMP5   RMB     1
1805            TEMP6   RMB     1
1806            BCD1    RMB     1
1807            BCD2    RMB     1
1808            CTR     RMB     1
1809            CTR1    RMB     1
1812                    ORG     $1812
1812            PHASE   RMB     2
1814            XOZERO  RMB     4
1818            YOZERO  RMB     4
181C            X1ZERO  RMB     4
1820            Y1ZERO  RMB     4
1824            COR1    RMB     1               REAL
1825            COR2    RMB     1
1826            COR3    RMB     1               IMAG
1827            COR4    RMB     3
182A            COR9    RMB     1               THETA
182B            COR10   RMB     1
182C            I       RMB     1
182D            J       RMB     1
182E            ID      RMB     1
182F            JD      RMB     1
1830            UI1     RMB     1
1831            UI2     RMB     1
1832            VJ1     RMB     1
1833            VJ2     RMB     1
1834            MODE    RMB     1
1835            DTIME   RMB     1
1836            JSTART  RMB     1
1837            BDRY    RMB     1
1838            BDRYD   RMB     1
1839            NBDRY   RMB     1
183A            BDRYPT  RMB     1
183B            FIRST   RMB     1
183C            SENSOR  RMB     1
183D            NSAMP   RMB     1
183E            LOGS    RMB     1
183F            BCDPTR  RMB     2
1841            L       RMB     1
1842            LIMIT   RMB     1
1843            X       RMB     1
1844            Y       RMB     1
1845            ZERO    RMB     4
1849            X1INC   RMB     2
184B            Y1INC   RMB     2
184D            NPT     RMB     1
184E            STACK1  RMB     1
184F            STACK2  RMB     1
1850            PUSHST  RMB     1
1851            THR11   RMB     1
1852            THR12   RMB     1
1853            THR21   RMB     1
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1854    THR22   RMB   1
1855    HOW     RMB   1
1856    IJPTR   RMB   1
1857    IJPTR1  RMB   1
1858    ADRSW   RMB   1
1859    SETUP   RMB   1
185A    FINE    RMB   1
185B    K$G     RMB   1
185C    KKKK    RMB   4
1860    CORSE   RMB   2
1862    ST      RMB   2
1864    SAVESP  RMB   2
1866    MAX     RMB   4
186A    SUM     RMB   4
186E    XTRAN   RMB   2
1870    YTRAN   RMB   2
1872    DELX    RMB   4
1876    DELY    RMB   4
187A    VP      RMB   4
187E    UP      RMB   4
1882    UV      RMB   4
1886    VV      RMB   4
188A    UU      RMB   4
188E    STEPS   RMB   2
1890    ANGLE   RMB   2
1892    SMAG    RMB   4
1896    SAVEX   RMB   2
1898    SAVEY   RMB   2
189A    DIRECT  RMB   1
189B    DTHR11  RMB   1
189C    DTHR12  RMB   1
189D    DTHR21  RMB   1
189E    DTHR22  RMB   1
189F    MPLX    RMB   2
18A1    SIGNI   RMB   1
18A2    SIGNQ   RMB   1
18A3    SFLAG   RMB   1
18A4    SNFLAG  RMB   1
18D8            ORG   $18D8
18D8    DELTA   RMB   10D
18E2    BCDAR   RMB   512D
1AE2    BDRYLF  RMB   5
1AE7    BDRYCT  RMB   5
1AEC    S1VP1M  RMB   20D
1B00    S1UP1M  RMB   20D
1B14    S1UV1M  RMB   20D
1B28    S1V1M   RMB   20D
1B3C    S1U1M   RMB   20D
1B50    IJ      RMB   400D
1CE0    PS1MS   RMB   400D
1E70    MS1MS   RMB   400D
BB68    PULL4   EQU   $BB68
BB8E    PUSH44  EQU   $BB8E
BBB4    PUSH41  EQU   $BBB4
BBD1    PUSH42  EQU   $BBD1
A6D1    THRSET  EQU   $A6D1
A9A1    SUPRVR  EQU   $A9A1
```

```
8000                    MATH    EQU     $8000
B040                    MEASRE  EQU     $B040
A77F                    PHSSET  EQU     $A77F
FE2D                    FANTOM  EQU     $FE2D
A820                    STPMTR  EQU     $A820
ED15                    CALIBR  EQU     $ED15
AA31                    ERROR   EQU     $AA31
AF81                    GRAPH1  EQU     $AF81
ED17                    PROGNR  EQU     $ED17
                        *       SUBROUTINE              ALIGN
                        *       MAIN ALIGNMENT PROGRAM
B470                            ORG     $B470
B470  7F 18 A4          INALGN  CLR     SNFLAG
B473  B6 ED 17                  LDAA    PROGNR
B476  46                        RORA
B477  24 33                     BCC     LA2
B479  7C 18 A4                  INC     SNFLAG
B47C  20 2E                     BRA     LA2
B47E  7D 18 A4          DOUBLE  TST     SNFLAG
B481  2E 20                     BGT     H3
B483  8D 0B                     BSR     HOWSET
B485  20 5C                     BRA     LA21
B487  7D 18 A4          SINGLE  TST     SNFLAG
B48A  27 17                     BEQ     H3
B48C  8D 02                     BSR     HOWSET
B48E  20 69                     BRA     LA23
B490  7F 18 55          HOWSET  CLR     HOW
B493  B6 ED 17                  LDAA    PROGNR
B496  46                        RORA
B497  25 03                     BCS     H1
B499  7C 18 55                  INC     HOW
B49C  7D ED 15          H1      TST     CALIBR
B49F  26 07                     BNE     H2
B4A1  31                        INS
B4A2  31                        INS
B4A3  31                H3      INS
B4A4  31                        INS
B4A5  7E AA 31                  JMP     ERROR
B4A8  BD AF 81          H2      JSR     GRAPH1
B4AB  39                        RTS
B4AC  86 01             LA2     LDAA    #1              INITIAL ALIGNMENT
B4AE  B7 18 34                  STAA    MODE
B4B1  B7 18 55                  STAA    HOW
B4B4  7F 18 58                  CLR     ADRSW
B4B7  7F 18 A3                  CLR     SFLAG
B4BA  7D 18 A4                  TST     SNFLAG
B4BD  27 18                     BEQ     LA20
B4BF  FE 18 1C                  LDX     X1ZERO
B4C2  FF 18 14                  STX     X0ZERO
B4C5  FE 18 1E                  LDX     X1ZERO+2
B4C8  FF 18 16                  STX     X0ZERO+2
B4CB  FE 18 20                  LDX     Y1ZERO
B4CE  FF 18 18                  STX     Y0ZERO
B4D1  FE 18 22                  LDX     Y1ZERO+2
B4D4  FF 18 1A                  STX     Y0ZERO+2
B4D7  BD B0 40          LA20    JSR     MEASRE          CHARACTERIZE TRANSFORM
B4DA  BD A6 D1                  JSR     THRSET          SET THRESHOLD
```

```
B4DD  7C 18 A3           INC    SFLAG
B4E0  BD B0 40           JSR    MEASRE       REFERENCE
B4E3  86 02       LA21   LDAA   #2           ENTER TO READ SAME REF
B4E5  B7 18 34           STAA   MODE
B4E8  86 FF              LDAA   #$FF
B4EA  B7 18 58           STAA   ADRSW
B4ED  BD B0 40           JSR    MEASRE       STORE BCD ADDRESSES
B4F0  7D 18 A4           TST    SNFLAG
B4F3  27 04              BEQ    LA23
B4F5  7C ED 15           INC    CALIBR
B4F8  39                 RTS
B4F9  7D 18 55    LA23   TST    HOW
B4FC  2E 03              BGT    LA24
B4FE  7E B5 9F           JMP    LA85
B501  CE 00 00    LA24   LDX    #0           ENTER TO SKIP REF
B504  FF 18 6E           STX    XTRAN
B507  FF 18 70           STX    YTRAN
B50A  FF 18 7A           STX    VP
B50D  FF 18 7C           STX    VP+2
B510  FF 18 7E           STX    VP+4
B513  CE 00 80           LDX    #$0080
B516  FF 18 80           STX    VP+6         FP ZERO
B519  4F                 CLRA
B51A  5F                 CLRB
B51B  F0 18 61           SUBB   CORSE+1
B51E  B2 18 60           SBCA   CORSE
B521  F7 18 91           STAB   ANGLE+1
B524  B7 18 90           STAA   ANGLE
B527  F7 18 63           STAB   ST+1
B52A  B7 18 62           STAA   ST
B52D  BD A8 20           JSR    STPMTR       -CORSE
B530  86 01              LDAA   #1
B532  B7 18 58           STAA   ADRSW
B535  86 02              LDAA   #2
B537  B7 18 34           STAA   MODE
B53A  BD B0 40    LA3    JSR    MEASRE       CORRELATE: CORSE LOOP
B53D  7D 18 6D           TST    SUM+3
B540  2E 09              BGT    LA4
B542  BD B8 1D    LA32   JSR    MAXSUM       SUM>MAX
B545  FE 18 62           LDX    ST
B548  FF 18 8E           STX    STEPS        STEPS=ST
B54B  F6 18 63    LA4    LDAB   ST+1         ST=ST+2 DEG
B54E  CB 14              ADDB   #$14
B550  F7 18 63           STAB   ST+1
B553  B6 18 62           LDAA   ST
B556  89 00              ADCA   #0
B558  B7 18 62           STAA   ST
B55B  F0 18 61           SUBB   CORSE+1      ST-CORSE-0.1 DEG
B55E  B2 18 60           SBCA   CORSE
B561  C0 01              SUBB   #1
B563  82 00              SBCA   #0
B565  2C 0E              BGE    LA5
B567  86 14              LDAA   #$14
B569  B7 18 91           STAA   ANGLE+1
B56C  7F 18 90           CLR    ANGLE        ANGLE=2 DEG
B56F  BD A8 20           JSR    STPMTR
B572  7E B5 3A           JMP    LA3          TO MEASRE
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B575  B6 18 8E  LA5    LDAA   STEPS        ST>CORSE
B578  F6 18 8F         LDAB   STEPS+1
B57B  F0 18 63         SUBB   ST+1
B57E  B2 18 62         SBCA   ST
B581  CB 14            ADDB   #$14
B583  89 00            ADCA   #0
B585  B7 18 90         STAA   ANGLE        ANGLE=STEPS-ST+2 DEG
B588  F7 18 91         STAB   ANGLE+1
B58B  BD A8 20         JSR    STPMTR       ROTATE BACK
B58E  B6 18 5A         LDAA   FINE
B591  B7 18 8F         STAA   STEPS+1
B594  7F 18 8E         CLR    STEPS
B597  BD B7 B2  LA6    JSR    FINSCH
B59A  77 18 8F         ASR    STEPS+1
B59D  26 F8            BNE    LA6
B59F  86 03     LA85   LDAA   #3           ENTER TO SKIP REF, ROTATION
B5A1  B7 18 34         STAA   MODE
B5A4  86 01            LDAA   #1
B5A6  B7 18 41         STAA   L
B5A9  B7 18 58         STAA   ADRSW
B5AC  B7 18 8F         STAA   STEPS+1
B5AF  7F 18 8E         CLR    STEPS
B5B2  86 F5            LDAA   #$F5
B5B4  B7 18 5E         STAA   KKKK+2
B5B7  BD A7 7F  LA9    JSR    PHSSET       MEASURE PHASE DIFF
B5BA  86 01            LDAA   #1
B5BC  B7 18 58         STAA   ADRSW
B5BF  BD B0 40         JSR    MEASRE       LEAST SQUARES
B5C2  7C 18 5E         INC    KKKK+2
B5C5  B6 18 44         LDAA   Y
B5C8  4A               DECA
B5C9  2E 03            BGT    LA90
B5CB  7E B7 9E         JMP    LA12
B5CE  B6 18 5F  LA90   LDAA   KKKK+3
B5D1  B7 18 5C         STAA   KKKK
B5D4  CE 1A EB         LDX    #S1VP1M-1
B5D7  FF 18 00         STX    TEMP1
B5DA  CE 18 7A         LDX    #VP
B5DD  FF 18 02         STX    TEMP3
B5E0  BD B8 49         JSR    SUMPAR
B5E3  CE 1A FF         LDX    #S1UP1M-1
B5E6  FF 18 00         STX    TEMP1
B5E9  CE 18 7E         LDX    #UP
B5EC  FF 18 02         STX    TEMP3
B5EF  BD B8 49         JSR    SUMPAR
B5F2  B6 18 5B         LDAA   K$G
B5F5  B7 18 5C         STAA   KKKK
B5F8  CE 1B 13         LDX    #S1UV1M-1
B5FB  FF 18 00         STX    TEMP1
B5FE  CE 18 82         LDX    #UV
B601  FF 18 02         STX    TEMP3
B604  BD B8 49         JSR    SUMPAR
B607  CE 1B 27         LDX    #S1V1M-1
B60A  FF 18 00         STX    TEMP1
B60D  CE 18 86         LDX    #VV
B610  FF 18 02         STX    TEMP3
B613  BD B8 49         JSR    SUMPAR
```

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B616  CE 18 3B          LDX    #S1U1M-1
B619  FF 18 00          STX    TEMP1
B61C  CE 18 8A          LDX    #UU
B61F  FF 18 02          STX    TEMP3
B622  BD B8 49          JSR    SUMPAR
B625  CE 18 86          LDX    #VV
B628  4F                CLRA
B629  BD BB 8E          JSR    PUSH44
B62C  CE 18 8A          LDX    #UU
B62F  4F                CLRA
B630  BD BB 8E          JSR    PUSH44
B633  86 0A             LDAA   #10D
B635  BD 80 00          JSR    MATH          UU*VV
B638  CE 18 82          LDX    #UV
B63B  4F                CLRA
B63C  BD BB 8E          JSR    PUSH44
B63F  CE 18 82          LDX    #UV
B642  4F                CLRA
B643  BD BB 8E          JSR    PUSH44
B646  86 0A             LDAA   #10D
B648  BD 80 00          JSR    MATH          UV*UV
B64B  86 0C             LDAA   #12D
B64D  BD 80 00          JSR    MATH          DET=UU*VV-UV*UV
B650  7D 18 5E          TST    KKKK+2
B653  2F 0B             BLE    LA92
B655  B6 18 5E          LDAA   KKKK+2
B658  BD BB B4          JSR    PUSH41
B65B  86 0A             LDAA   #10D
B65D  BD 80 00          JSR    MATH          DET=DET*(KKKK+2)
B660  CE 18 00    LA92  LDX    #TEMP1
B663  4F                CLRA
B664  BD BB 68          JSR    PULL4
B667  CE 18 7A          LDX    #VP
B66A  4F                CLRA
B66B  BD BB 8E          JSR    PUSH44
B66E  CE 18 82          LDX    #UV
B671  4F                CLRA
B672  BD BB 8E          JSR    PUSH44
B675  86 0A             LDAA   #10D
B677  BD 80 00          JSR    MATH          UV*VP
B67A  CE 18 86          LDX    #VV
B67D  4F                CLRA
B67E  BD BB 8E          JSR    PUSH44
B681  CE 18 7E          LDX    #UP
B684  4F                CLRA
B685  BD BB 8E          JSR    PUSH44
B688  86 0A             LDAA   #10D
B68A  BD 80 00          JSR    MATH          VV*UP
B68D  86 0C             LDAA   #12D
B68F  BD 80 00          JSR    MATH          UV*VP-VV*UP
B692  CE 18 00          LDX    #TEMP1
B695  4F                CLRA
B696  BD BB 8E          JSR    PUSH44
B699  86 09             LDAA   #9
B69B  BD 80 00          JSR    MATH          DELX=(UV*VP-VV*UP)/DET
B69E  24 03             BCC    LA91
B6A0  7E B7 9E          JMP    LA12
```

```
B6A3  CE 18 72  LA91   LDX    #DELX
B6A6  4F               CLRA
B6A7  BD BB 68         JSR    PULL4
B6AA  CE 18 8A         LDX    #UU
B6AD  4F               CLRA
B6AE  BD BB 8E         JSR    PUSH44
B6B1  CE 18 7A         LDX    #VP
B6B4  4F               CLRA
B6B5  BD BB 8E         JSR    PUSH44
B6B8  86 0A            LDAA   #10D
B6BA  BD 80 00         JSR    MATH         UU*VP
B6BD  CE 18 82         LDX    #UV
B6C0  4F               CLRA
B6C1  BD BB 8E         JSR    PUSH44
B6C4  CE 18 7E         LDX    #UP
B6C7  4F               CLRA
B6C8  BD BB 8E         JSR    PUSH44
B6CB  86 0A            LDAA   #10D
B6CD  BD 80 00         JSR    MATH         UV*UP
B6D0  86 0C            LDAA   #12D
B6D2  BD 80 00         JSR    MATH         UU*VP-UV*UP
B6D5  CE 18 00         LDX    #TEMP1
B6D8  4F               CLRA
B6D9  BD BB 8E         JSR    PUSH44
B6DC  86 09            LDAA   #9
B6DE  BD 80 00         JSR    MATH         DELY=(UU*VP-UV*UP)/DET
B6E1  CE 18 76         LDX    #DELY
B6E4  4F               CLRA
B6E5  BD BB 68         JSR    PULL4
B6E8  FE 18 74         LDX    DELX+2
B6EB  FF 18 6E         STX    XTRAN
B6EE  FE 18 78         LDX    DELY+2
B6F1  FF 18 70         STX    YTRAN
B6F4  7F 18 90         CLR    ANGLE
B6F7  7F 18 91         CLR    ANGLE+1
B6FA  7D 18 72         TST    DELX
B6FD  2C 06            BGE    LA10
B6FF  CE 18 72         LDX    #DELX
B702  BD B8 36         JSR    COMP
B705  7D 18 76  LA10   TST    DELY
B708  2C 06            BGE    LA11
B70A  CE 18 76         LDX    #DELY
B70D  BD B8 36         JSR    COMP
B710  CE 18 72  LA11   LDX    #DELX
B713  4F               CLRA
B714  BD BB 8E         JSR    PUSH44
B717  CE 18 76         LDX    #DELY
B71A  4F               CLRA
B71B  BD BB 8E         JSR    PUSH44
B71E  86 0B            LDAA   #11D
B720  BD 80 00         JSR    MATH         A(DELX)+A(DELY)
B723  CE 18 72         LDX    #DELX
B726  4F               CLRA
B727  BD BB 68         JSR    PULL4
B72A  CE 18 72         LDX    #DELX
B72D  4F               CLRA
B72E  BD BB 8E         JSR    PUSH44
```

```
B731   CE 18 D6            LDX     #DELTA-2
B734   FF 18 00            STX     TEMP1
B737   B6 18 00            LDAA    TEMP1
B73A   F6 18 01            LDAB    TEMP2
B73D   FB 18 41            ADDB    L
B740   89 00               ADCA    #0
B742   FB 18 41            ADDB    L
B745   89 00               ADCA    #0
B747   B7 18 00            STAA    TEMP1
B74A   F7 18 01            STAB    TEMP2
B74D   FE 18 00            LDX     TEMP1
B750   A6 00               LDAA    0,X
B752   E6 01               LDAB    1,X
B754   BD BB D1            JSR     PUSH42
B757   86 0C               LDAA    #12D
B759   BD 80 00            JSR     MATH        A(DELX)+A(DELY)-DELTA
B75C   CE 18 76            LDX     #DELY
B75F   4F                  CLRA
B760   BD BB 68            JSR     PULL4
B763   7D 18 76            TST     DELY
B766   2B 36               BMI     LA12
B768   CE 18 72            LDX     #DELX
B76B   4F                  CLRA
B76C   BD BB 8E            JSR     PUSH44
B76F   86 1C               LDAA    #$1C
B771   C6 10               LDAB    #$10
B773   BD BB D1            JSR     PUSH42
B776   86 0C               LDAA    #12D
B778   BD 80 00            JSR     MATH        A(DELX)+A(DELY)-7184D
B77B   CE 18 76            LDX     #DELY
B77E   4F                  CLRA
B77F   BD BB 68            JSR     PULL4
B782   7D 18 76            TST     DELY
B785   2A 17               BPL     LA12
B787   BD A8 20            JSR     STPMTR      TRANSLATE DELX,DELY
B78A   7D 18 55            TST     HOW
B78D   27 0C               BEQ     LA14
B78F   7A 18 34            DEC     MODE
B792   7F 18 3B            CLR     FIRST
B795   BD B7 B2            JSR     FINSCH      DITHER ANGLE
B798   7C 18 34            INC     MODE
B79B   7E B5 B7   LA14     JMP     LA9         TO MEASRE: SAME REGION
B79E   7C 18 41   LA12     INC     L
B7A1   B6 18 39            LDAA    NBDRY
B7A4   B0 18 41            SUBA    L
B7A7   2D 03               BLT     LA13
B7A9   7E B5 B7            JMP     LA9         TO MEASRE: NEW REGION
B7AC   86 01      LA13     LDAA    #1
B7AE   B7 ED 15            STAA    CALIBR
B7B1   39                  RTS
                  *        SUBROUTINE FINSCH
                  *        FINE ANGLE SEARCH
B7B2   CE FF 01   FINSCH   LDX     #$FF01
B7B5   FF 18 62            STX     ST
B7B8   CE 00 00            LDX     #0
B7BB   FF 18 6E            STX     XTRAN
B7BE   FF 18 70            STX     YTRAN
```

```
B7C1  7D 18 3B          TST    FIRST
B7C4  2E 06             BGT    FS1
B7C6  BD B0 40          JSR    MEASRE
B7C9  BD B8 1D          JSR    MAXSUM
B7CC  FE 18 8E   FS1    LDX    STEPS
B7CF  FF 18 90          STX    ANGLE
B7D2  70 18 91          NEG    ANGLE+1
B7D5  73 18 90          COM    ANGLE
B7D8  BD A8 20          JSR    STPMTR       -STEPS
B7DB  BD B0 40   FS2    JSR    MEASRE
B7DE  7D 18 6D          TST    SUM+3
B7E1  2E 09             BGT    FS3
B7E3  BD B8 1D          JSR    MAXSUM
B7E6  B6 18 63          LDAA   ST+1
B7E9  B7 18 62          STAA   ST
B7EC  7A 18 63   FS3    DEC    ST+1
B7EF  2B 0E             BMI    FS4
B7F1  FE 18 8E          LDX    STEPS
B7F4  FF 18 90          STX    ANGLE
B7F7  78 18 91          ASL    ANGLE+1
B7FA  BD A8 20          JSR    STPMTR       2*STEPS
B7FD  20 DC             BRA    FS2
B7FF  FE 18 8E   FS4    LDX    STEPS
B802  FF 18 90          STX    ANGLE
B805  70 18 91          NEG    ANGLE+1
B808  73 18 90          COM    ANGLE        -STEPS
B80B  7D 18 62          TST    ST
B80E  2E 03             BGT    FS5
B810  2B 07             BMI    FS6
B812  39                RTS
B813  78 18 91   FS5    ASL    ANGLE+1
B816  79 18 90          ROL    ANGLE        -2*STEPS
B819  BD A8 20   FS6    JSR    STPMTR
B81C  39                RTS
                 *      SUBROUTINE MAXSUM
                 *      MAX=SUM
B81D  FE 18 82   MAXSUM LDX    UV
B820  FF 18 7A          STX    VP
B823  FE 18 84          LDX    UV+2
B826  FF 18 7C          STX    VP+2
B829  FE 18 86          LDX    UV+4
B82C  FF 18 7E          STX    VP+4
B82F  FE 18 88          LDX    UV+6
B832  FF 18 80          STX    VP+6
B835  39                RTS
                 *      SUBROUTINE COMP
                 *      COMPS 4 BYTE NUMBER
B836  60 03      COMP   NEG    3,X
B838  86 03             LDAA   #3
B83A  25 04      C1     BCS    C2
B83C  60 02             NEG    2,X
B83E  20 02             BRA    C3
B840  63 02      C2     COM    2,X
B842  4A         C3     DECA
B843  27 03             BEQ    C4
B845  09                DEX
B846  20 F2             BRA    C1
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```
B848  39            C4      RTS
                    *       SUBROUTINE                SUMFAR
                    *       SUMS PARTIAL PRODUCTS FOR UP,VP,UV,U,V
                    *       ENTER WITH L, TEMP1_TEMP4
B849  86 01         SUMFAR  LDAA    #1
B84B  B7 18 37              STAA    BDRY
B84E  B7 18 3A              STAA    BDRYPT
B851  4F                    CLRA
B852  BD BB B4              JSR     PUSH41
B855  FE 18 00      LSM1    LDX     TEMP1
B858  B6 18 3A              LDAA    BDRYPT
B85B  BD BB 8E              JSR     PUSH44
B85E  86 0B                 LDAA    #11D
B860  BD 80 00              JSR     MATH              S=S+S1(BDRYPT)
B863  7C 18 37              INC     BDRY
B866  B6 18 41              LDAA    L
B869  B1 18 37              CMPA    BDRY
B86C  2D 0B                 BLT     LSM2
B86E  B6 18 3A              LDAA    BDRYPT
B871  8B 04                 ADDA    #4
B873  B7 18 3A              STAA    BDRYPT
B876  7E B8 55              JMP     LSM1
B879  B6 18 5C      LSM2    LDAA    KKKK
B87C  BD BB B4              JSR     PUSH41
B87F  86 09                 LDAA    #9
B881  BD 80 00              JSR     MATH
B884  FE 18 02              LDX     TEMP3
B887  4F                    CLRA
B888  BD BB 68              JSR     PULL4
B88B  39                    RTS
                    *       SUBROUTINE                INIZE
                    *       INITIALIZES RAM VARIABLES
B88C  BF 18 01      INIZE   STS     TEMP2
B88F  CE 18 E2      LIN2    LDX     #BCDAR
B892  4F                    CLRA
B893  A7 00         LIN3    STAA    0,X               ZERO LOWER RAM
B895  08                    INX
B896  8C 20 00              CPX     #MS1MS+400D
B899  26 F8                 BNE     LIN3
B89B  8E 1A E6              LDS     #BDRYLF+4
B89E  CE B9 34              LDX     #TABLE+94D
B8A1  A6 00         LIN1    LDAA    0,X
B8A3  36                    PSHA
B8A4  09                    DEX
B8A5  8C B9 2F              CPX     #TABLE+89D
B8A8  26 F7                 BNE     LIN1
B8AA  8E 18 E1      LIN4    LDS     #DELTA+9
B8AD  CE B9 2F              LDX     #TABLE+89D
B8B0  A6 00         LIN5    LDAA    0,X
B8B2  36                    PSHA
B8B3  09                    DEX
B8B4  8C B9 25              CPX     #TABLE+79D
B8B7  26 F7                 BNE     LIN5
B8B9  8E 18 61      LIN6    LDS     #CORSE+1
B8BC  A6 00         LIN7    LDAA    0,X
B8BE  36                    PSHA
B8BF  09                    DEX
```

```
B8C0  8C B8 D5           CPX    #TABLE-1
B8C3  26 F7              BNE    LIN7
B8C5  4F         LIN8    CLRA
B8C6  5F                 CLRB
B8C7  CE 18 62           LDX    #ST
B8CA  A7 00      LIN9    STAA   0,X              CLEAR UPPER RAM
B8CC  08                 INX
B8CD  5C                 INCB
B8CE  C1 31              CMPB   #49D
B8D0  26 F8              BNE    LIN9
B8D2  BE 18 01   LIN10   LDS    TEMP2
B8D5  39                 RTS
B8D6             TABLE   EQU    *
B8D6  00 00              FCB    0,0              PHASE
B8D8  00 3B E7           FCB    $0,$3B,$E7       XOZERO=3926
B8DB  F0                 FCB    $F0
B8DC  00 33 25           FCB    $0,$33,$25       YOZERO=3352
B8DF  C0                 FCB    $C0
B8E0  00 3B C4           FCB    $0,$3B,$C4       X1ZERO=3917
B8E3  C8                 FCB    $C8
B8E4  00 33 12           FCB    $0,$33,$12       Y1ZERO=3347
B8E7  C8                 FCB    $C8
B8E8  00 00 00           FCB    0,0,0            COR1 TO BDRYD
B8EB  00 00 00           FCB    0,0,0
B8EE  00 00 00           FCB    0,0,0
B8F1  00 00 00           FCB    0,0,0
B8F4  00 00 00           FCB    0,0,0
B8F7  00 00 05           FCB    0,0,5            DTIME
B8FA  31 00 00           FCB    49D,0,0          JSTART
B8FD  03 00 00           FCB    3,0,0            NBDRY
B900  00 10 04           FCB    0,$10,4          NSAMP,LOGS
B903  00 00 00           FCB    0,0,0
B906  C8 00 00           FCB    $C8,0,0          LIMIT
B909  00 00              FCB    0,0
B90B  00 00              FCB    0,0
B90D  F4 48              FCB    $F4,$48          X1INC=-30
B90F  0B B8              FCB    $0B,$B8          Y1INC=30
B911  10 00 00           FCB    $10,0,0          NPT
B914  00 00 00           FCB    0,0,0            PUSHST,THR11,THR12
B917  00 08 01           FCB    0,8,1            THR21,THR22,HOW
B91A  00 00 00           FCB    0,0,0            IJPTR
B91D  00 10 40           FCB    0,$10,$40        FINE,K$G
B920  00 00 00           FCB    0,0,0
B923  10                 FCB    $10              KKKK
B924  00 3C              FCB    0,$3C            CORSE
B926  27 0B 27           FCB    $27,$B,$27       DELTA
B929  0B 00 04           FCB    $B,0,4
B92C  00 00 00           FCB    0,0,0
B92F  00                 FCB    0
B930  31 46 5B           FCB    49D,70D,91D      BDRYLF
B933  5B 5B              FCB    91D,91D
B935                     END
```

STATEMENTS =623

```
1800                    ORG     $1800
1800            TEMP1   RMB     1
1801            TEMP2   RMB     1
1802            TEMP3   RMB     1
1803            TEMP4   RMB     1
1804            TEMP5   RMB     1
1805            TEMP6   RMB     1
1806            BCD1    RMB     1
1807            BCD2    RMB     1
1808            CTR     RMB     1
1809            CTR1    RMB     1
1812                    ORG     $1812
1812            PHASE   RMB     2
1814            XOZERO  RMB     4
1818            YOZERO  RMB     4
181C            X1ZERO  RMB     4
1820            Y1ZERO  RMB     4
1824            COR1    RMB     1           REAL
1825            COR2    RMB     1
1826            COR3    RMB     1           IMAG
1827            COR4    RMB     3
182A            COR9    RMB     1           THETA
182B            COR10   RMB     1
182C            I       RMB     1
182D            J       RMB     1
182E            ID      RMB     1
182F            JD      RMB     1
1830            UI1     RMB     1
1831            UI2     RMB     1
1832            VJ1     RMB     1
1833            VJ2     RMB     1
1834            MODE    RMB     1
1835            DTIME   RMB     1
1836            JSTART  RMB     1
1837            BDRY    RMB     1
1838            BDRYD   RMB     1
1839            NBDRY   RMB     1
183A            BDRYPT  RMB     1
183B            FIRST   RMB     1
183C            SENSOR  RMB     1
183D            NSAMP   RMB     1
183E            LOGNS   RMB     1
183F            BCDPTR  RMB     2
1841            L       RMB     1
1842            LIMIT   RMB     1
1843            X       RMB     1
1844            Y       RMB     1
1845            ZERO    RMB     4
1849            X1INC   RMB     2
184B            Y1INC   RMB     2
184D            NPT     RMB     1
184E            STACK1  RMB     1
184F            STACK2  RMB     1
1850            PUSHST  RMB     1
1851            THR11   RMB     1
1852            THR12   RMB     1
1853            THR21   RMB     1
```

```
1854    THR22   RMB   1
1855    HOW     RMB   1
1856    IJPTR   RMB   1
1857    IJPTR1  RMB   1
1858    ADRSW   RMB   1
1859    SETUP   RMB   1
185A    FINE    RMB   1
185B    K$G     RMB   1
185C    KKKK    RMB   4
1860    CORSE   RMB   2
1862    ST      RMB   2
1864    SAVESP  RMB   2
1866    MAX     RMB   4
186A    SUM     RMB   4
186E    XTRAN   RMB   2
1870    YTRAN   RMB   2
1872    DELX    RMB   4
1876    DELY    RMB   4
187A    VP      RMB   4
187E    UP      RMB   4
1882    UV      RMB   4
1886    VV      RMB   4
188A    UU      RMB   4
188E    STEPS   RMB   2
1890    ANGLE   RMB   2
1892    SMAG    RMB   4
1896    SAVEX   RMB   2
1898    SAVEY   RMB   2
189A    DIRECT  RMB   1
189B    DTHR11  RMB   1
189C    DTHR12  RMB   1
189D    DTHR21  RMB   1
189E    DTHR22  RMB   1
189F    MPLX    RMB   2
18A1    SIGNI   RMB   1
18A2    SIGNQ   RMB   1
18A3    SFLAG   RMB   1
18A4    SNFLAG  RMB   1
18D8            ORG   $18D8
18D8    DELTA   RMB   10D
18E2    BCDAR   RMB   512D
1AE2    BDRYLF  RMB   5
1AE7    BDRYCT  RMB   5
1AEC    S1VP1M  RMB   20D
1B00    S1UP1M  RMB   20D
1B14    S1UV1M  RMB   20D
1B28    S1V1M   RMB   20D
1B3C    S1U1M   RMB   20D
1B50    IJ      RMB   400D
1CE0    PS1MS   RMB   400D
1E70    MS1MS   RMB   400D
8000    MATH    EQU   $8000
BDD6    CORDIC  EQU   $BDD6
DFF0    DAS     EQU   $DFF0
A5F7    CORD    EQU   $A5F7
A612    IXST    EQU   $A612
A619    CALSDI  EQU   $A619
```

```
A636                SGNSET  EQU     $A636
A63D                IDEX    EQU     $A63D
B9A0                        ORG     $B9A0
                    *
                    *       SUBROUTINE DELAY1
                    *       GIVES 9.996MS*DTIME DELAY
B9A0   B6 18 35     DELAY1  LDAA    DTIME
B9A3   4D           D1      TSTA
B9A4   27 06                BEQ     D2
B9A6   BD B9 AD             JSR     DELAY
B9A9   4A                   DECA
B9AA   20 F7                BRA     D1
B9AC   39           D2      RTS
                    *
                    *
                    *       SUBROUTINE DELAY
                    *       9.996 MS DELAY
B9AD   CE 02 CA     DELAY   LDX     #2CAH
B9B0   09           LDY1    DEX
B9B1   27 02                BEQ     LDY2
B9B3   20 FB                BRA     LDY1
B9B5   39           LDY2    RTS
                    *       SUBROUTINE ADDRES
                    *       ENTRY USES I,J,SENSOR
                    *       REFERENCE SENSOR ORIGIN IN (MS TO LS)
                    *       (XOZERO TO XOZERO+3),(YOZERO TO YOZERO+3)
                    *       ALIGNING SENSOR ORGIN IN (MS TO LS)
                    *       (X1ZERO TO X1ZERO+3),(Y1ZERO TO Y1ZERO+3)
                    *       BCD RESULT WILL BE RETURNED IN (MS TO LS)
                    *       (UI1,UI2), (VJ1,VJ2)
B9B6   B6 18 3C     ADDRES  LDAA    SENSOR
B9B9   2E 03                BGT     LADDO
B9BB   7E BA 8A             JMP     LADD
B9BE   7D 18 58     LADDO   TST     ADRSW
B9C1   2C 03                BGE     LADDOO
B9C3   7E BA 81             JMP     LADD1
B9C6   FE 18 3F     LADDOO  LDX     BCDPTR          ADRSW>=0 GET BCD FROM ARRA
B9C9   08                   INX
B9CA   BD A6 12             JSR     IXST
B9CD   A6 00                LDAA    0,X
B9CF   B7 18 30             STAA    UI1
B9D2   A6 01                LDAA    1,X
B9D4   B7 18 31             STAA    UI2
B9D7   A6 02                LDAA    2,X
B9D9   B7 18 32             STAA    VJ1
B9DC   A6 03                LDAA    3,X
B9DE   B7 18 33             STAA    VJ2
B9E1   39                   RTS
B9E2   F6 18 2C     LADD3   LDAB    I
B9E5   4F                   CLRA
B9E6   BD BB D1             JSR     PUSH42
B9E9   B6 18 49             LDAA    X1INC           TRUE VALUE*.1 (TYPICAL)
B9EC   F6 18 4A             LDAB    X1INC+1
B9EF   BD BB D1             JSR     PUSH42
B9F2   86 0A                LDAA    #10D
B9F4   BD 80 00             JSR     MATH            I*X1INC
B9F7   FE 18 45             LDX     ZERO            TRUE VALUE*.1
```

```
      B9FA   4F                        CLRA
      B9FB   BD BB 8E                  JSR     PUSH44
      B9FE   86 0B                     LDAA    #11D
      BA00   BD 80 00                  JSR     MATH         ZERO+I*INC
      BA03   86 03                     LDAA    #3
      BA05   C6 E8                     LDAB    #$E8
      BA07   BD BB D1                  JSR     PUSH42
      BA0A   86 09                     LDAA    #9
      BA0C   BD 80 00                  JSR     MATH         DIVIDE BY 1000
      BA0F   CE 18 00                  LDX     #TEMP1
      BA12   4F                        CLRA
      BA13   BD BB 68                  JSR     PULL4
      BA16   BD BB 17                  JSR     BI$BCD       BINARY TO BCD
      BA19   FE 18 06                  LDX     BCD1
      BA1C   FF 18 30                  STX     UI1
      BA1F   B6 18 2D                  LDAA    J
      BA22   BD BB B4                  JSR     PUSH41
      BA25   B6 18 4B                  LDAA    Y1INC
      BA28   F6 18 4C                  LDAB    Y1INC+1
      BA2B   BD BB D1                  JSR     PUSH42
      BA2E   86 0A                     LDAA    #10D
      BA30   BD 80 00                  JSR     MATH         J*Y1INC
      BA33   FE 18 45                  LDX     ZERO
      BA36   08                        INX
      BA37   08                        INX
      BA38   08                        INX
      BA39   08                        INX
      BA3A   4F                        CLRA
      BA3B   BD BB 8E                  JSR     PUSH44
      BA3E   86 0B                     LDAA    #11D
      BA40   BD 80 00                  JSR     MATH
      BA43   86 03                     LDAA    #3
      BA45   C6 E8                     LDAB    #$E8
      BA47   BD BB D1                  JSR     PUSH42
      BA4A   86 09                     LDAA    #9
      BA4C   BD 80 00                  JSR     MATH
      BA4F   CE 18 00                  LDX     #TEMP1
      BA52   4F                        CLRA
      BA53   BD BB 68                  JSR     PULL4
      BA56   BD BB 17                  JSR     BI$BCD
      BA59   FE 18 06                  LDX     BCD1
      BA5C   FF 18 32                  STX     VJ1
      BA5F   7D 18 58                  TST     ADRSW
      BA62   2D 01                     BLT     LADD2
      BA64   39                        RTS                  ADRSW=0
      BA65   FE 18 3F     LADD2        LDX     BCDPTR       ADRSW=-1 STORE BCD IN ARRAY
      BA68   08                        INX
      BA69   BD A6 12                  JSR     IXST
      BA6C   B6 18 30                  LDAA    UI1
      BA6F   A7 00                     STAA    0,X
      BA71   B6 18 31                  LDAA    UI2
      BA74   A7 01                     STAA    1,X
      BA76   B6 18 32                  LDAA    VJ1
      BA79   A7 02                     STAA    2,X
      BA7B   B6 18 33                  LDAA    VJ2
      BA7E   A7 03                     STAA    3,X
      BA80   39                        RTS
```

```
BA81  CE 18 1C  LADD1   LDX     #X1ZERO
BA84  FF 18 45          STX     ZERO
BA87  7E B9 E2  LADD4   JMP     LADD3
BA8A  CE 18 14  LADD    LDX     #X0ZERO
BA8D  FF 18 45          STX     ZERO
BA90  20 F5             BRA     LADD4
                *
                *       SUBROUTINE READ
                *       READS,STORES REFERENCE DATA
BA92  BD BC 0D  READ    JSR     RDDEFT
BA95  FE 18 24          LDX     COR1
BA98  FF 18 6E          STX     XTRAN
BA9B  FE 18 26          LDX     COR3
BA9E  FF 18 70          STX     YTRAN
BAA1  7F 18 3C          CLR     SENSOR
BAA4  7C 18 58          INC     ADRSW
BAA7  BD B9 B6          JSR     ADDRES
BAAA  7A 18 58          DEC     ADRSW
BAAD  BD BB F4          JSR     TUNE
BAB0  BD B9 A0          JSR     DELAY1
BAB3  7A 18 3C          DEC     SENSOR
BAB6  BD BC 0D          JSR     RDDEFT
BAB9  86 01             LDAA    #1
BABB  B7 18 3C          STAA    SENSOR
BABE  7F 18 2A          CLR     COR9
BAC1  7F 18 2B          CLR     COR10
BAC4  BD A5 F7          JSR     CORD
BAC7  CE 1E 6E          LDX     #MS1MS-2
BACA  FF 18 00          STX     TEMP1
BACD  B6 18 00          LDAA    TEMP1
BAD0  F6 18 01          LDAB    TEMP2
BAD3  FB 18 44          ADDB    Y
BAD6  89 00             ADCA    #0
BAD8  FB 18 44          ADDB    Y
BADB  89 00             ADCA    #0
BADD  B7 18 00          STAA    TEMP1
BAE0  F7 18 01          STAB    TEMP2
BAE3  FE 18 00          LDX     TEMP1
BAE6  B6 18 24          LDAA    COR1
BAE9  A7 00             STAA    0,X             MS(Y)=MAG
BAEB  B6 18 25          LDAA    COR2
BAEE  A7 01             STAA    1,X
BAF0  B6 18 [illegible] LDAA    TEMP1
BAF3  C0 90             SUBB    #$90
BAF5  82 01             SBCA    #1
BAF7  B7 18 00          STAA    TEMP1
BAFA  F7 18 01          STAB    TEMP2
BAFD  FE 18 00          LDX     TEMP1
BB00  B6 18 2A          LDAA    COR9
BB03  A7 00             STAA    0,X             PS(Y)=PHASE
BB05  B6 18 2B          LDAA    COR10
BB08  A7 01             STAA    1,X
BB0A  FE 18 6E          LDX     XTRAN
BB0D  FF 18 24          STX     COR1
BB10  FE 18 70          LDX     YTRAN
BB13  FF 18 26          STX     COR3
BB16  39                RTS
```

```
                        *       SUBROUTINE                    BI$BCD
                        *       BINARY TO BCD
                        *       BINARY IN (MS TO LS) (TEMP3,TEMP4)
                        *       BCD IN BCD1,BCD2
                        *       BINARY NUMBER MUST BE POSITIVE
BB17  7F 18 06  BI$BCD  CLR     BCD1
BB1A  7F 18 07          CLR     BCD2
BB1D  86 10             LDAA    #16D
BB1F  B7 18 09          STAA    CTR1
BB22  BF 18 04          STS     TEMP5
BB25  8E 18 01          LDS     #TEMP3-1
BB28  86 08     LBIB1   LDAA    #8D
BB2A  B7 18 08          STAA    CTR
BB2D  33                PULB                          GET ANOTHER BYTE
BB2E  58        LBIB2   ASLB                          TEST RIGHT MOST BIT
BB2F  24 12             BCC     LBIB3
BB31  86 01             LDAA    #01                   ADD 1
BB33  BB 18 07          ADDA    BCD2
BB36  19                DAA
BB37  B7 18 07          STAA    BCD2
BB3A  B6 18 06          LDAA    BCD1
BB3D  89 00             ADCA    #0
BB3F  19                DAA
BB40  B7 18 06          STAA    BCD1
BB43  7A 18 09  LBIB3   DEC     CTR1                  SKIP DOUBLE IF LAST
BB46  27 1C             BEQ     LBIB4
BB48  B6 18 07          LDAA    BCD2                  DOUBLE
BB4B  BB 18 07          ADDA    BCD2
BB4E  19                DAA
BB4F  B7 18 07          STAA    BCD2
BB52  B6 18 06          LDAA    BCD1
BB55  B9 18 06          ADCA    BCD1
BB58  19                DAA
BB59  B7 18 06          STAA    BCD1
BB5C  7A 18 08          DEC     CTR
BB5F  27 C7             BEQ     LBIB1                 NEW BYTE
BB61  7E BB 2E          JMP     LBIB2                 SAME BYTE
BB64  BE 18 04  LBIB4   LDS     TEMP5                 RESTORE STACK
BB67  39                RTS
                        *       SUBROUTINE                    PULL4
                        *       PULLS 4 BYTES OFF STACK
                        *       STORES 1ST (MS) BYTE IN ADDRESS X REG+A REG ...
                        *       STORES 4TH (LS) BYTE IN ADDRESS X REG+A REG+3
BB68  33        PULL4   PULB
BB69  F7 18 4E          STAB    STACK1
BB6C  33                PULB
BB6D  F7 18 4F          STAB    STACK2
BB70  4D                TSTA
BB71  27 06             BEQ     LP42
BB73  08        LP41    INX
BB74  4A                DECA
BB75  27 02             BEQ     LP42
BB77  20 FA             BRA     LP41
BB79  32        LP42    PULA
BB7A  A7 00             STAA    0,X
BB7C  32                PULA
BB7D  A7 01             STAA    1,X
```

```
BB7F  32                  PULA
BB80  A7 02               STAA    2,X
BB82  32                  PULA
BB83  A7 03               STAA    3,X
BB85  F6 18 4F            LDAB    STACK2
BB88  37                  PSHB
BB89  F6 18 4E            LDAB    STACK1
BB8C  37                  PSHB
BB8D  39                  RTS
                *
                *
                *
                *         SUBROUTINE              PUSH44
                *         PUSHES 4 BYTE NUMBER ONTO STACK
                *         ADDRESS OF LS BYTE IS X REG + A REG + 3
BB8E  33        PUSH44    PULB
BB8F  F7 18 4E            STAB    STACK1
BB92  33                  PULB
BB93  F7 18 4F            STAB    STACK2
BB96  4D                  TSTA
BB97  27 06               BEQ     LP442
BB99  08        LP441     INX
BB9A  4A                  DECA
BB9B  27 02               BEQ     LP442
BB9D  20 FA               BRA     LP441
BB9F  A6 03     LP442     LDAA    3,X
BBA1  36                  PSHA
BBA2  A6 02               LDAA    2,X
BBA4  36                  PSHA
BBA5  A6 01               LDAA    1,X
BBA7  36                  PSHA
BBA8  A6 00               LDAA    0,X
BBAA  36                  PSHA
BBAB  F6 18 4F            LDAB    STACK2
BBAE  37                  PSHB
BBAF  F6 18 4E            LDAB    STACK1
BBB2  37                  PSHB
BBB3  39                  RTS
                *
                *
                *
                *         SUBROUTINE              PUSH41
                *         PUSHES 4 BYTE NUMBER ONTO STACK
                *         3 MS BYTES ARE SIGN BITS
                *         ENTER WITH LS BYTE IN A REG
BBB4  33        PUSH41    PULB
BBB5  F7 18 4E            STAB    STACK1
BBB8  33                  PULB
BBB9  F7 18 4F            STAB    STACK2
BBBC  36                  PSHA
BBBD  48                  ASLA
BBBE  24 04               BCC     LP411
BBC0  86 FF               LDAA    #$FF            NEGATIVE
BBC2  20 01               BRA     LP412
BBC4  4F        LP411     CLRA                    POSITIVE
BBC5  36        LP412     PSHA
BBC6  36                  PSHA
```

```
BBC7  36                 PSHA
BBC8  F6 18 4F           LDAB    STACK2
BBCB  37                 PSHB
BBCC  F6 18 4E           LDAB    STACK1
BBCF  37                 PSHB
BBD0  39                 RTS
                *        SUBROUTINE              PUSH42
                *        PUSHES 4 BYTE NUMBER ONTO STACK
                *        2 MS BYTES ARE SIGN BITES
                *        ENTER WITH LS BYTE IN B REG, NEXT LS BYTE IN A REG
BBD1  F7 18 50  PUSH42   STAB    PUSHST
BBD4  33                 PULB
BBD5  F7 18 4E           STAB    STACK1
BBD8  33                 PULB
BBD9  F7 18 4F           STAB    STACK2
BBDC  F6 18 50           LDAB    PUSHST
BBDF  37                 PSHB
BBE0  36                 PSHA
BBE1  48                 ASLA
BBE2  24 04              BCC     LP421
BBE4  86 FF              LDAA    #$FF            NEGATIVE
BBE6  20 01              BRA     LP422
BBE8  4F        LP421    CLRA                    POSITIVE
BBE9  36        LP422    PSHA
BBEA  36                 PSHA
BBEB  F6 18 4F           LDAB    STACK2
BBEE  37                 PSHB
BBEF  F6 18 4E           LDAB    STACK1
BBF2  37                 PSHB
BBF3  39                 RTS
                *
                *        SUBROUTINE              TUNE
                *        TUNES SIGNAL GENERATORS
BBF4  B6 18 30  TUNE     LDAA    UI1
BBF7  B7 EE 11           STAA    0EE11H
BBFA  B6 18 31           LDAA    UI2
BBFD  B7 EE 10           STAA    0EE10H
BC00  B6 18 32           LDAA    VJ1
BC03  B7 EE 21           STAA    0EE21H
BC06  B6 18 33           LDAA    VJ2
BC09  B7 EE 20           STAA    0EE20H
BC0C  39                 RTS
                *        SUBROUTINE RDDEFT
                *        STORES RESULTS AS
                *        REAL: COR1,COR2   IMAG: COR3,COR4
BC0D  B6 18 3D  RDDEFT   LDAA    NSAMP
BC10  B7 18 08           STAA    CTR
BC13  7D 18 3C           TST     SENSOR
BC16  2B 07              BMI     RDD1
BC18  26 10              BNE     RDD2
BC1A  86 01              LDAA    #1              REF,1 SAMPLE (SENSOR=0)
BC1C  B7 18 08           STAA    CTR
BC1F  CE 02 03  RDD1     LDX     #$0203          REF,NS SAMPLES (SENSOR=-1)
BC22  FF 18 9F           STX     MPLX
BC25  7D 18 A4           TST     SNFLAG
BC28  27 06              BEQ     RDD00
BC2A  CE 00 01  RDD2     LDX     #$0001          ALIGN,NS SAMPLES (SENSOR=1)
```

MEASURE SUBROUTINES

```
BC2D  FF 18 9F          STX    MPLX
BC30  CE 00 00  RDD00   LDX    #0
BC33  FF 18 24          STX    COR1
BC36  FF 18 26          STX    COR3
BC39  FF 18 28          STX    COR4+1
BC3C  7D 18 08  RDD3    TST    CTR
BC3F  27 3E             BEQ    RDD4
BC41  BD A6 19          JSR    CALSDI
BC44  B6 18 26          LDAA   COR3
BC47  BB 18 01          ADDA   TEMP1+1
BC4A  B7 18 26          STAA   COR3
BC4D  B6 18 25          LDAA   COR2
BC50  B9 18 00          ADCA   TEMP1
BC53  B7 18 25          STAA   COR2
BC56  B6 18 24          LDAA   COR1
BC59  B9 18 A1          ADCA   SIGNI
BC5C  B7 18 24          STAA   COR1
BC5F  B6 18 29          LDAA   COR4+2
BC62  BB 18 03          ADDA   TEMP3+1
BC65  B7 18 29          STAA   COR4+2
BC68  B6 18 28          LDAA   COR4+1
BC6B  B9 18 02          ADCA   TEMP3
BC6E  B7 18 28          STAA   COR4+1
BC71  B6 18 27          LDAA   COR4
BC74  B9 18 A2          ADCA   SIGNQ
BC77  B7 18 27          STAA   COR4
BC7A  7A 18 08          DEC    CTR
BC7D  20 BD             BRA    RDD3
BC7F  7D 18 3C  RDD4    TST    SENSOR
BC82  27 3A             BEQ    RDD5
BC84  B6 18 3E          LDAA   LOGNS
BC87  B7 18 08          STAA   CTR
BC8A  7D 18 08  RDD6    TST    CTR
BC8D  27 2F             BEQ    RDD5
BC8F  B6 18 24          LDAA   COR1
BC92  47                ASRA
BC93  B7 18 24          STAA   COR1
BC96  B6 18 25          LDAA   COR2
BC99  46                RORA
BC9A  B7 18 25          STAA   COR2
BC9D  B6 18 26          LDAA   COR3
BCA0  46                RORA
BCA1  B7 18 26          STAA   COR3
BCA4  B6 18 27          LDAA   COR4
BCA7  47                ASRA
BCA8  B7 18 27          STAA   COR4
BCAB  B6 18 28          LDAA   COR4+1
BCAE  46                RORA
BCAF  B7 18 28          STAA   COR4+1
BCB2  B6 18 29          LDAA   COR4+2
BCB5  46                RORA
BCB6  B7 18 29          STAA   COR4+2
BCB9  7A 18 08          DEC    CTR
BCBC  20 CC             BRA    RDD6
BCBE  FE 18 25  RDD5    LDX    COR2
BCC1  FF 18 24          STX    COR1
BCC4  FE 18 28          LDX    COR4+1
```

```
BCC7  FF 18 26           STX     COR3
BCCA  39                 RTS
BCCF                     ORG     $BCCF
                   *     SUBROUTINE INDEX
                   *     INCREMENTS NORMALIZED ADDRESS IN FREQUENCY
                   *     PLANE FOR REFERENCE SEARCH
                   *     ADDRESS IS (I,J) (REAL,IMAG)
                   *     RETURNS INCREMENTED I,J
                   *     USES A,B
BCCF  B6 18 2C  INDEX    LDAA    I
BCD2  4D                 TSTA
BCD3  27 03              BEQ     IN2
BCD5  7E BC E7           JMP     IN3
BCD8  F6 18 2D  IN2      LDAB    J                 I=0
BCDB  5D                 TSTB
BCDC  2E 09              BGT     IN3
BCDE  86 07              LDAA    #7                J<=0
BCE0  B0 18 2D           SUBA    J
BCE3  B7 18 2D           STAA    J
BCE6  39                 RTS
BCE7  F6 18 2D  IN3      LDAB    J                 I=0 AND J>0 OR I NOT=0
BCEA  BD A6 36           JSR     SGNSET
BCED  F0 18 2C           SUBB    I
BCF0  82 00              SBCA    #0
BCF2  2D 05              BLT     IN7
BCF4  2E 17              BGT     IN8
BCF6  5D                 TSTB
BCF7  26 14              BNE     IN8
BCF9  F6 18 2D  IN7      LDAB    J                 J-I<=0
BCFC  BD A6 36           JSR     SGNSET
BCFF  FB 18 2C           ADDB    I
BD02  89 00              ADCA    #0
BD04  2D 19              BLT     IN10
BD06  2E 0E              BGT     IN9
BD08  5D                 TSTB
BD09  26 0B              BNE     IN9
BD0B  20 12              BRA     IN10
BD0D  86 07     IN8      LDAA    #7                J-I>0
BD0F  BB 18 2C           ADDA    I
BD12  B7 18 2C           STAA    I
BD15  39                 RTS
BD16  B6 18 2D  IN9      LDAA    J                 I+J>0
BD19  80 07              SUBA    #7
BD1B  B7 18 2D           STAA    J
BD1E  39                 RTS
BD1F  B6 18 2C  IN10     LDAA    I                 I+J<=0
BD22  80 07              SUBA    #7
BD24  B7 18 2C           STAA    I
BD27  39                 RTS
                   *     SUBROUTINE GSRCH
                   *     SEARCHES 180 KHZ SQUARE IN 30 KHZ INCREMENTS
BD28  B6 18 2E  GSRSH    LDAA    ID
BD2B  27 03              BEQ     GS0
BD2D  B0 18 62           SUBA    ST
BD30  B7 18 8C  GS0      STAA    UU+2
BD33  B6 18 2F           LDAA    JD
BD36  B0 18 62           SUBA    ST
```

```
BD39  B7 18 88          STAA   VV+2
BD3C  7F 18 82          CLR    UV
BD3F  7F 18 83          CLR    UV+1
BD42  7F 18 84          CLR    UV+2
BD45  7F 18 85          CLR    UV+3
BD48  B6 18 8C   GS1    LDAA   UU+2
BD4B  BB 18 84          ADDA   UV+2
BD4E  B7 18 2C          STAA   I
BD51  B6 18 88          LDAA   VV+2
BD54  BB 18 85          ADDA   UV+3
BD57  B7 18 2D          STAA   J
BD5A  BD B9 B6          JSR    ADDRES
BD5D  BD BB F4          JSR    TUNE
BD60  BD B9 A0          JSR    DELAY1
BD63  BD BC 0D          JSR    RDDEFT
BD66  7F 18 2A          CLR    COR9
BD69  7F 18 2B          CLR    COR10
BD6C  BD BD D6          JSR    CORDIC
BD6F  B6 18 24          LDAA   COR1
BD72  F6 18 25          LDAB   COR2
BD75  F0 18 67          SUBB   MAX+1
BD78  B2 18 66          SBCA   MAX
BD7B  2C 02             BGE    GS2
BD7D  20 12             BRA    GS3
BD7F  FE 18 24   GS2    LDX    COR1              MAG>=MAX
BD82  FF 18 66          STX    MAX
BD85  B6 18 2C          LDAA   I
BD88  B7 18 8A          STAA   UU
BD8B  B6 18 2D          LDAA   J
BD8E  B7 18 86          STAA   VV
BD91  7C 18 82   GS3    INC    UV
BD94  B6 18 82          LDAA   UV
BD97  81 03             CMPA   #3
BD99  27 02             BEQ    GS4
BD9B  20 2B             BRA    GS7
BD9D  7F 18 82   GS4    CLR    UV
BDA0  7F 18 84          CLR    UV+2
BDA3  7C 18 83          INC    UV+1
BDA6  B6 18 83          LDAA   UV+1
BDA9  81 03             CMPA   #3
BDAB  27 02             BEQ    GS5
BDAD  20 0D             BRA    GS6
BDAF  B6 18 8A   GS5    LDAA   UU
BDB2  B7 18 2E          STAA   ID
BDB5  B6 18 86          LDAA   VV
BDB8  B7 18 2F          STAA   JD
BDBB  39                RTS
BDBC  B6 18 85   GS6    LDAA   UV+3
BDBF  BB 18 62          ADDA   ST
BDC2  B7 18 85          STAA   UV+3
BDC5  7E BD 48          JMP    GS1
BDC8  B6 18 84   GS7    LDAA   UV+2
BDCB  BB 18 62          ADDA   ST
BDCE  B7 18 84          STAA   UV+2
BDD1  7E BD 48          JMP    GS1
BDD4                    END
```

```
                        *       REAL IN COR1,COR2 (MSH,LSH)
                        *       IMAG IN COR3,COR4 (MSH,LSH)
                        *       PHASE IN COR9,COR10 (MSH,LSH) (RADIANS/PI)
                        *       IF PHASE=0 RETURNS
                        *       .41169MAG IN COR1,COR2
                        *       PHASE IN COR9,COR10 (RADIANS/PI)
                        *       IF PHASE NOT=0 RETURNS
                        *       .41169(REALCOSTHETA-IMAGSINTHETA) IN COR1,COR2
                        *       .41169(REALSINTHETA+IMAGCOSTHETA) IN COR3,COR4
                        *       USES CORDIC ALGORITHM: 16 ITERATIONS
1824                            ORG     $1824
1824                    COR1    RMB     1               REAL OR MAG
1825                    COR2    RMB     1
1826                    COR3    RMB     1               IMAG OR ANGLE
1827                    COR4    RMB     1
1828                    DNUP1   RMB     1               DOWN UP
1829                    DNUP2   RMB     1
182A                    COR9    RMB     1               THETA
182B                    COR10   RMB     1
1800                            ORG     $1800
1800                    COR5    RMB     1               RESCALE FACTOR
1801                    COR6    RMB     1
1802                    COR7    RMB     1               TEMPORARY X
1803                    COR8    RMB     1
1804                    COR11   RMB     1               LOOP CTR
1805                    COR12   RMB     1
1806                    COR13   RMB     1               ALPHA ADDRESS
1807                    COR14   RMB     1
1808                    COR15   RMB     1               TEMPORARY Y
1809                    COR16   RMB     1
180A                    COR17   RMB     1               TEMPORARY THETA MSH
180B                    COR18   RMB     1               ZERO
180C                    CFLAG   RMB     1               VECTORING OR ROTATION MODE
BDD6                            ORG     $BDD6
BDD6  86 01             CORDIC  LDAA    #01
BDD8  FE 18 2A                  LDX     COR9
BDDB  8C 00 00                  CPX     #0
BDDE  27 02                     BEQ     LCOR0
BDE0  86 80                     LDAA    #80H            ROTATION MODE
BDE2  B7 18 0C          LCOR0   STAA    CFLAG
BDE5  B6 18 2A                  LDAA    COR9
BDE8  B7 18 0A                  STAA    COR17
BDEB  7F 18 0B                  CLR     COR18           NEED A ZERO
BDEE  B6 18 24                  LDAA    COR1
BDF1  F6 18 25                  LDAB    COR2
BDF4  BD BF 50                  JSR     SCALE           REAL SCALE FACTOR
BDF7  FF 18 00                  STX     COR5
BDFA  B6 18 26                  LDAA    COR3
BDFD  F6 18 27                  LDAB    COR4
BE00  BD BF 50                  JSR     SCALE           IMAG SCALE FACTOR
BE03  FF 18 02                  STX     COR7
BE06  7D 18 01                  TST     COR6
BE09  26 06                     BNE     LCOR1
BE0B  7D 18 03                  TST     COR8
BE0E  26 01                     BNE     LCOR1
BE10  39                        RTS                     REAL=IMAG=0
BE11  B6 18 01          LCOR1   LDAA    COR6
```

```
BE14  B0 18 03             SUBA    COR8
BE17  2F 03                BLE     LCOR2
BE19  7E BE 22             JMP     LCOR3
BE1C  FE 18 02   LCOR2     LDX     COR7
BE1F  FF 18 00             STX     COR5
BE22  B6 18 01   LCOR3     LDAA    COR6
BE25  B7 18 01             STAA    COR6          RESCALE FACTOR
BE28  CE 00 00             LDX     #0
BE2B  FF 18 02             STX     COR7
BE2E  FF 18 08             STX     COR15
BE31  FF 18 28             STX     DNUP1
BE34  B6 18 01             LDAA    COR6
BE37  4C                   INCA                  PREVENTS OVERFLOW
BE38  4C                   INCA
BE39  4C                   INCA                  FIXES IST ITERATION
BE3A  B7 18 29             STAA    DNUP2
BE3D  B6 18 24             LDAA    COR1
BE40  F6 18 25             LDAB    COR2
BE43  BD BF 8A             JSR     UP            SCALE REAL UP
BE46  B7 18 24             STAA    COR1
BE49  F7 18 25             STAB    COR2
BE4C  B6 18 01             LDAA    COR6          GET RESCALE FACTOR
BE4F  4C                   INCA                  PREVENTS OVERFLOW
BE50  4C                   INCA
BE51  4C                   INCA                  FIXES 1ST ITERATION
BE52  B7 18 29             STAA    DNUP2
BE55  B6 18 26             LDAA    COR3
BE58  F6 18 27             LDAB    COR4
BE5B  BD BF 8A             JSR     UP            SCALE IMAG UP
BE5E  B7 18 26             STAA    COR3
BE61  F7 18 27             STAB    COR4
BE64  7F 18 04             CLR     COR11
BE67  86 10                LDAA    #16D
BE69  B7 18 05             STAA    COR12         INITIALIZE
BE6C  CE BF 3F             LDX     #LAGMSH+15
BE6F  FF 18 06             STX     COR13         ALPHA ADDRESS
BE72  FE 18 06   LCOR4     LDX     COR13         MAIN LOOP
BE75  A6 00                LDAA    0,X           LOOK UP ALPHA
BE77  E6 10                LDAB    16,X
BE79  BD BF EA             JSR     TSTCFL        SIGN OF Y(I-1) OR THETA(I-1)
BE7C  2C 03                BGE     LCOR5
BE7E  BD BF 6B             JSR     COMP          -ALPHA
BE81  FB 18 2B   LCOR5     ADDB    COR10
BE84  B9 18 2A             ADCA    COR9
BE87  BD BF 7B             JSR     OFLCK
BE8A  B7 18 2A             STAA    COR9
BE8D  F7 18 2B             STAB    COR10         THETA DONE
BE90  B6 18 05             LDAA    COR12
BE93  B7 18 29             STAA    DNUP2
BE96  B6 18 26             LDAA    COR3
BE99  F6 18 27             LDAB    COR4
BE9C  BD BF EA             JSR     TSTCFL
BE9F  2C 03                BGE     LCOR6
BEA1  BD BF 6B             JSR     COMP
BEA4  BD BF BA   LCOR6     JSR     DOWN
BEA7  FB 18 03             ADDB    COR8
BEAA  B9 18 02             ADCA    COR7
```

```
BEAD  B7 18 02           STAA   COR7
BEB0  F7 18 03           STAB   COR8        X DONE
BEB3  B6 18 05           LDAA   COR12
BEB6  B7 18 29           STAA   DNUP2
BEB9  B6 18 24           LDAA   COR1
BEBC  F6 18 25           LDAB   COR2
BEBF  BD BF EA           JSR    TSTCFL
BEC2  2D 03              BLT    LCOR7
BEC4  BD BF 6B           JSR    COMP        SGNY(I-1)X(I-1)
BEC7  BD BF BA  LCOR7    JSR    DOWN
BECA  FB 18 09           ADDB   COR16
BECD  B9 18 08           ADCA   COR15
BED0  B7 18 26           STAA   COR3
BED3  F7 18 27           STAB   COR4        Y DONE
BED6  B6 18 02           LDAA   COR7
BED9  F6 18 03           LDAB   COR8
BEDC  B7 18 24           STAA   COR1
BEDF  F7 18 25           STAB   COR2
BEE2  B6 18 26           LDAA   COR3
BEE5  F6 18 27           LDAB   COR4
BEE8  B7 18 08           STAA   COR15
BEEB  F7 18 09           STAB   COR16
BEEE  B6 18 2A           LDAA   COR9
BEF1  B7 18 0A           STAA   COR17
BEF4  7A 18 05           DEC    COR12
BEF7  7A 18 07           DEC    COR14
BEFA  FE 18 04           LDX    COR11
BEFD  8C 00 00           CPX    #0
BF00  27 03              BEQ    LCOR8
BF02  7E BE 72           JMP    LCOR4
BF05  B6 18 01  LCOR8    LDAA   COR6
BF08  B7 18 29           STAA   DNUP2
BF0B  B6 18 24           LDAA   COR1
BF0E  F6 18 25           LDAB   COR2
BF11  BD BF BA           JSR    DOWN
BF14  B7 18 24           STAA   COR1
BF17  F7 18 25           STAB   COR2
BF1A  B6 18 01           LDAA   COR6
BF1D  B7 18 29           STAA   DNUP2
BF20  B6 18 26           LDAA   COR3
BF23  F6 18 27           LDAB   COR4
BF26  BD BF BA           JSR    DOWN
BF29  B7 18 26           STAA   COR3
BF2C  F7 18 27           STAB   COR4
BF2F  39                 RTS
BF30            LAGMSH   EQU    *
BF30  00                 FCB    0
BF31  00 00 00           FCB    0,0,0
BF34  00 00 00           FCB    0,0,0
BF37  00 00 01           FCB    0,0,1
BF3A  02 05 09           FCB    2,5,9
BF3D  12 20 40           FCB    12H,20H,40H
BF40            LAGLSH   EQU    *
BF40  01                 FCB    01
BF41  01 03 05           FCB    01,03,05
BF44  0A 14 29           FCB    0AH,14H,29H
BF47  51 A3 46           FCB    51H,0A3H,46H
```

```
BF4A  8B 11 FB              FCB     8BH,11H,0FBH
BF4D  E4 00 00              FCB     0E4H,0,0
                   *        SUBROUTINE SCALE
                   *        A=MSH, B=LSH
                   *        RETURNS RESCALE FACTOR IN X
BF50  CE 00 00     SCALE    LDX     #0
BF53  4D                    TSTA
BF54  2C 03                 BGE     LSC1
BF56  BD BF 6B              JSR     COMP            CHANGE SIGN
BF59  4D           LSC1     TSTA
BF5A  27 06                 BEQ     LSC2
BF5C  47                    ASRA
BF5D  56                    RORB
BF5E  08                    INX
BF5F  7E BF 59              JMP     LSC1
BF62  5D           LSC2     TSTB
BF63  27 05                 BEQ     LSC3
BF65  54                    LSRB
BF66  08                    INX
BF67  7E BF 62              JMP     LSC2
BF6A  39           LSC3     RTS
                   *        SUBROUTINE COMPLEMENT
                   *        A=MSH, B=LSH
                   *        RETURNS 2'S COMPLEMENT IN A,B
BF6B  5D           COMP     TSTB
BF6C  26 06                 BNE     LCP1
BF6E  81 80                 CMPA    #80H
BF70  26 02                 BNE     LCP1
BF72  C6 01                 LDAB    #01             8000H TO 8001H
BF74  43           LCP1     COMA
BF75  53                    COMB
BF76  CB 01                 ADDB    #01
BF78  89 00                 ADCA    #00
BF7A  39                    RTS


                   *        SUBROUTINE OVERFLOW CHECK
                   *        OVERFLOW BY LIMITING
                   *        A=MSH, B=LSH
BF7B  28 0C        OFLCK    BVC     LOF2
BF7D  4D                    TSTA
BF7E  2C 05                 BGE     LOF1
BF80  C6 07                 LDAB    #7H             SHOULD BE PLUS
BF82  C6 FF                 LDAB    #0FFH
BF84  39                    RTS
BF85  86 80        LOF1     LDAA    #80H            SHOULD BE MINUS
BF87  C6 01                 LDAB    #01             DON'T LIKE 8000H
BF89  39           LOF2     RTS
                   *        SUBROUTINE UP
                   *        A=MSH,B=LSH,DNUP2=RESCALE FACTOR
                   *        RETURNS A,B SCALED UP 15-DNUP2 PLACES
BF8A  FE 18 28     UP       LDX     DNUP1
BF8D  B7 18 28              STAA    DNUP1
BF90  B6 18 29              LDAA    DNUP2
BF93  80 0F                 SUBA    #0015D
BF95  B7 18 29              STAA    DNUP2
```

```
BF98  B6 18 28           LDAA    DNUP1
BF9B  7F 18 28           CLR     DNUP1
BF9E  7D 18 29           TST     DNUP2
BFA1  2E 0B              BGT     LUP2
BFA3  27 14     LUP1     BEQ     LUP3
BFA5  58                 ASLB
BFA6  49                 ROLA
BFA7  08                 INX
BFA8  8C 00 0F           CPX     #015D
BFAB  7E BF A3           JMP     LUP1
BFAE  27 09     LUP2     BEQ     LUP3
BFB0  47                 ASRA
BFB1  56                 RORB
BFB2  09                 DEX
BFB3  8C 00 0F           CPX     #015D
BFB6  7E BF AE           JMP     LUP2
BFB9  39        LUP3     RTS
                *        SUBROUTINE DOWN
                *        A=MSH, B=LSH, DNUP2=RESCALE FACTOR
                *        RETURNS A,B SCALED DOWN 15-DNUP2 PLACES
BFBA  FE 18 28  DOWN     LDX     DNUP1
BFBD  B7 18 28           STAA    DNUP1
BFC0  B6 18 29           LDAA    DNUP2
BFC3  80 0F              SUBA    #0015D
BFC5  B7 18 29           STAA    DNUP2
BFC8  B6 18 28           LDAA    DNUP1
BFCB  7F 18 28           CLR     DNUP1
BFCE  7D 18 29           TST     DNUP2
BFD1  2E 0B              BGT     LDN2
BFD3  27 14     LDN1     BEQ     LDN3
BFD5  47                 ASRA
BFD6  56                 RORB
BFD7  08                 INX
BFD8  8C 00 0F           CPX     #015D
BFDB  7E BF D3           JMP     LDN1
BFDE  27 09     LDN2     BEQ     LDN3
BFE0  58                 ASLB
BFE1  49                 ROLA
BFE2  09                 DEX
BFE3  8C 00 0F           CPX     #015D
BFE6  7E BF DE           JMP     LDN2
BFE9  39        LDN3     RTS


                *        SUBROUTINE TSTCFL
                *        IF CFLAG=1 TESTS SIGN OF Y(I-1) (VECTORING MODE)
                *        IF CFLAG=80 TESTS SIGN OF THETA(I-1) (ROTATION MODE:
                *        RETURNS CONDITION CODE REGISTER STATE
BFEA  7D 18 0C  TSTCFL   TST     CFLAG
BFED  2E 0D              BGT     LTSTC2
BFEF  7D 18 0A           TST     COR17
BFF2  2C 04              BGE     LTSTC1
BFF4  7D 18 0B           TST     COR18
BFF7  39                 RTS
BFF8  7D 18 0C  LTSTC1   TST     CFLAG
BFFB  39                 RTS
```

CORDIC

```
BFFC  7D 18 26  LTSTC2  TST     COR3
BFFF  39                RTS
C000                    END
```

STATEMENTS =285

FREE BYTES =4864

NO ERRORS DETECTED

GLOSSARY OF ACRONYMS

ACIA	- Asynchronous Communications Interface Adapter
ADC	- Analog-to-digital converter
A/D	- Analog-to-digital
BCD	- Binary-coded decimal
CCTV	- Closed-circuit television
CRT	- Cathode-ray tube
DAS	- Data Acquisition Subsystem
DEFT	- Direct Electronic Fourier Transform
EPROM	- Erasable Programmable Read-Only Memory
LED	- Light-Emitting Diode
LSB	- Least Significant Bit
MSB	- Most Significant Bit
NMI	- Non-Maskable Interrupt
PIA	- Peripheral Interface Adapter
RAM	- Random-Access Memory (read/write)
ROM	- Read-Only Memory
SAW	- Surface Acoustic Wave
UV	- Ultraviolet

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3 of 3

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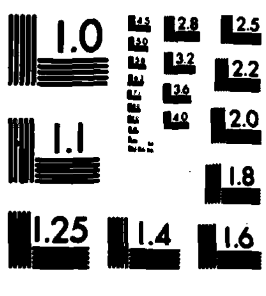

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