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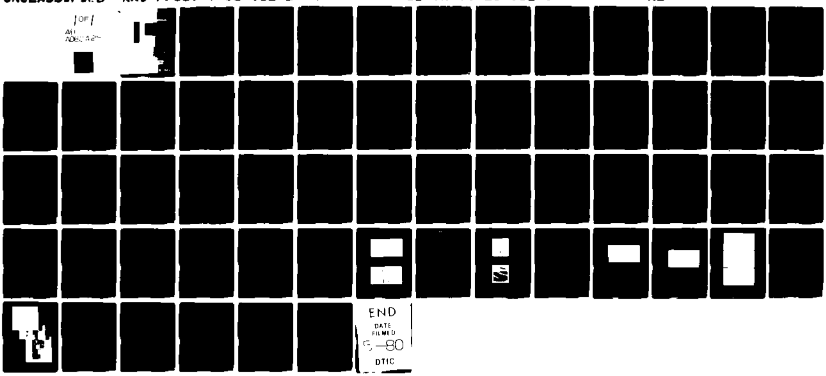

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APPENDIX A. SURVEY OF AVAILABLE IR DATA PROCESSING OPTIONS FOR SIRE.

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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Interactive Processing
Commercial Data Reduction Techniques
DoD Data Reduction Techniques

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

As a consequence of its extensive background in infrared technology and data processing of experimental measurements, Riverside Research Institute was selected by the Air Force's Space and Missile Systems Organization to provide a data processing perspective to the development of the Satellite Infrared (SIRE) Sensor, and establish requirements for the SIRE data processing and the system and operations for that processing.

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Blk. 20: While this activity has continued uninterrupted since 1976, the emphasis of this report is in the review of RRI's activities from April through September 1978; an interim report of RRI's work from December 1976 through March 1978 has already been issued. The topics covered in this report can be divided into four principal areas: (1) data processing perspective to the SIRE payload, (2) SIRE data processing requirements, (3) definition of the SIRE coordinator, and (4) survey of applicable commercial and DOD data reduction techniques to SIRE.

This appendix presents the results of a limited survey of commercial suppliers of image processing equipment and IR data reduction centers. The purposes of the survey were to assess the commercial availability of IR data processing hardware and software. Interest in manually interactive systems resulted from various SIRE data processing system configurations which could permit the evaluation, assessment, and partial analysis of SIRE data and the required status feedback to test planning in lieu of full, automated data analysis.

AUTHORIZATION

This report describes research performed at Riverside Research Institute and was prepared by Thomas Ciccarelli and Ronald Cestaro.

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A. SURVEY OF AVAILABLE IR DATA PROCESSING OPTIONS FOR SIRE

1. Introduction

This appendix presents the results of a limited survey of commercial suppliers of image processing equipment and IR data reduction centers. The purposes of the survey were to assess the commercial availability of IR data processing hardware and software with emphasis on manually interactive (image processing and color graphic display) systems and to review the experience of other IR data reduction programs as to design philosophies, development and operational costs, degree of manual interaction utilized in data reduction processes, problems encountered, etc. Interest in manually interactive systems resulted from various suggested SIRE data processing system configurations which could permit the evaluation, assessment, and at least a partial analysis of SIRE data, and the required experiment status feedback to experiment planning, in lieu of a full, automated data analysis capability. It was an objective of this survey to assess the utility of interactive systems used in such a mode, and to permit an evaluation of the extent to which such systems would cost impact the SIRE data processing system.

The potential sources of commercial hardware and/or software surveyed were the Electromagnetic System Laboratory (ESL), COMTAL, RAMTEK, and the University of Southern California (USC). The Jet Propulsion Labs (JPL), Teledyne Brown Engineering, Air Force Geophysics Laboratory (AFGL) and ESL were surveyed with regard to their recent experience in IR data processing.

2. Survey Summary and Recommendations

Commercial interactive processing systems with color graphic terminals are available with a variety of capabilities and costs, ranging from peripheral-only systems with very limited capability at a price of approximately $35,000 to full-turnkey systems with array processors and extensive interactive software at a price of $500,000 to $600,000 and more. The apparently less costly systems with relatively limited capability require the development of interface and other SIRE specific software; thereby actually increasing the overall cost of using such systems. The higher priced, full capability systems have extensive software available, but it is supplied with limited rights. This may make user modification of supplied software difficult, if not prohibitive.

The chief cost drivers of interactive systems are the required memory size, the required throughput rate, and required specialized algorithms. Memory size is driven by the desired display resolution, and the number of images and amount of data to be stored within the interactive system. Required throughput rate is driven by the amount of data to be processed, the processing to be performed and the turnaround time required. Software required is driven by the desired outputs and displays. Hence, it is recommended that the amount of SIRE data to be processed, the extent of interaction required, the display resolution required and the throughput rate required be quantified, and the specific types of displays and interactive capabilities (algorithms) desired also be quantified so that refined system sizing and cost estimates can be generated. Trade-off studies should be performed and should include a determination of the cost effectiveness of using less costly peripheral systems, and developing the required software vs the purchase of the more expensive highly interactive systems.

The IR data processing centers surveyed have developed and sucessfully used, or are in the process of developing, data processing systems ranging from highly automated, batch mode systems to highly interactive image processing systems for the reduction of IR data. The experience of these centers indicates that real data are required before refined, automated computer algorithms for the processing of IR data can be developed. All of the surveyed centers who have processed IR data had to contend with unexpected problems which required software updating. Manually interactive systems have the advantage of placing a human operator in view of the data so that on-the-spot decisions can be made and optional algorithm techniques can be quickly applied to cope with unexpected effects. In addition, due to the interactive nature of these systems, they are valuable tools in the development and testing of new algorithms. However, extensive manual interaction tends to limit the throughput rate and can potentially lead to low turnaround times or the need for many interactive terminals. Low turnaround time in the SIRE case can result in data backlogs and reduced feedback capability to experiment planning. On the other hand, the use of many interactive terminals to speed up turnaround, if this be necessary, can drive up the system cost. Again, the pertiment SIRE data processing requirements need to be quantified and appropriate trade-off studies performed to determine the type (e.g., batch vs interactive system) and cost of the system required.

A number of the IR data processing centers have experience with processing data of the type and quantity to be processed by SIRE. Along with RRI, JPL and AFGL are potential sources of valuable information for point source processing and boresight reconstruction algorithms. AFGL also has experience in the processing of zodiacal and earth limb data. Teledyne Brown has developed tracking algorithms for reentry systems albeit under less stressing target signal and background noise conditions than is expected for SIRE. They have also had to cope with many unexpected system problems. ESL has extensive experience in the use of interactive, color graphic systems and in their usage for the processing of IR data.

3. Commercial Equipment Survey

a. COMTAL Systems[A-1]

COMTAL Corporation, located in Pasadena, California, builds a variety of image processing systems including the Vision One stand-alone system, the 8000 series peripheral-only system, and the 200 series of image processors with large memory capability.

The COMTAL Vision One[A-2] system is a complete image processing system which provides built-in interactive processing and control capabilities. The system produces a high spatial resolution video image over a full range of brightness levels in shades of gray, pseudo-color or full color. The system, see Fig. A-1, consists of an integrated LSI 11 processor, image processing electronics, refresh memory with either CCD or 16K RAM, and application firmware. Digital data may be entered into the system from magnetic tape with the optional stand-alone magnetic tape controller or from any external data source connected to the standard interface. An optional computer controller provides the interface circuitry between an external computer and the system standard interface. A summary of the system's general specifications is given in Table A-I. The system does not have a data base management system (DBMS), does not have a disk storage capability and is limited to one interactive terminal. The system comes supplied with a limited amount of software and firmware; a subset of the interactive functions performed by this system is given in Table A-II.

A-1. References are given at the end of this appendix.

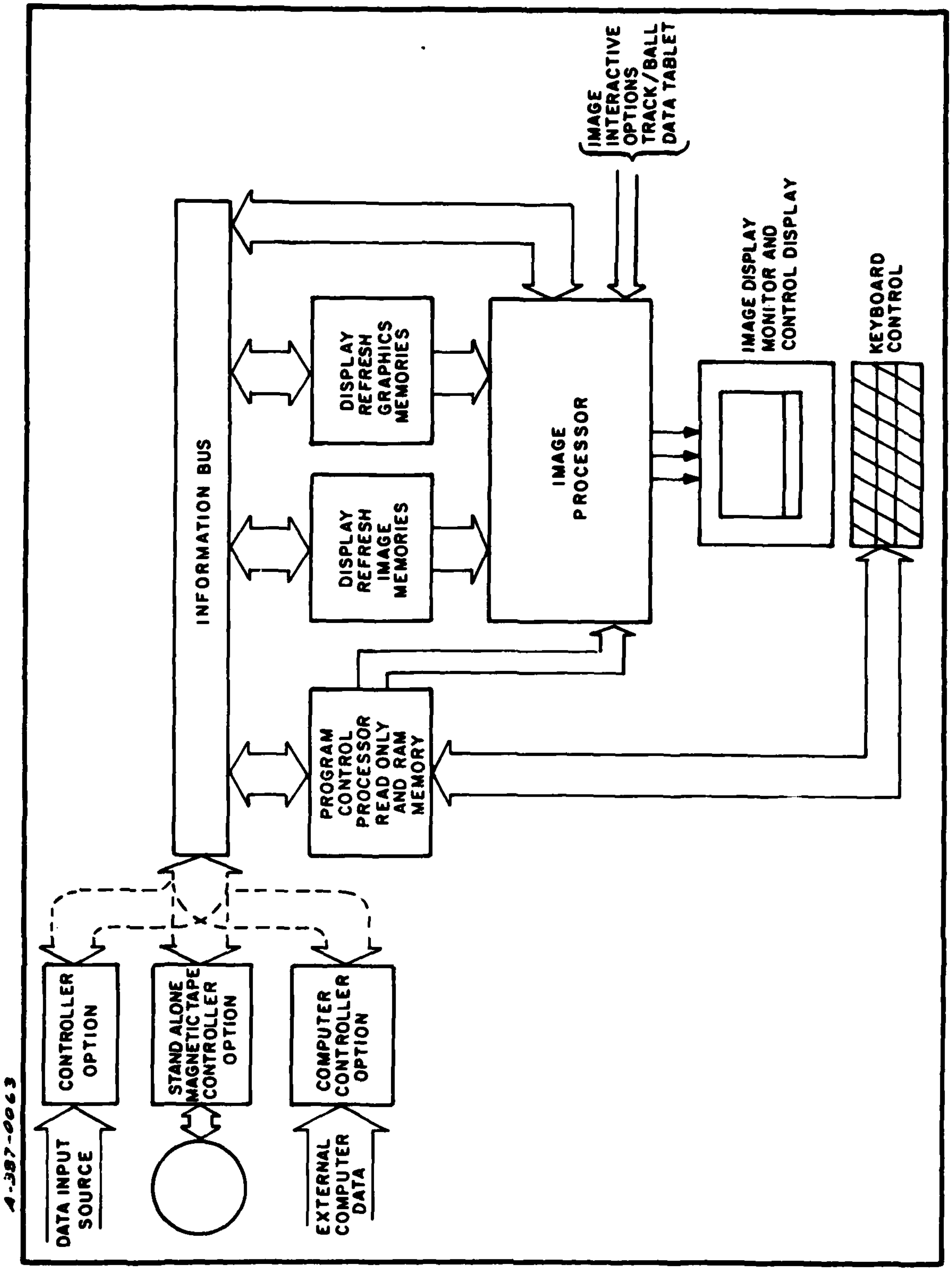


FIG. A-1 COMTAL VISION ONE BLOCK DIAGRAM
(Obtained from Ref. A-2)

TABLE A-I

SUMMARY OF COMTAL'S VISION ONE GENERAL SPECIFICATIONS[A-2]

1. Spatial Resolution: 256x256, 512x512, 1024x1024
2. One interactive terminal
3. Image Brightness Resolution: 2, 4, 6 or 8 bits
4. Up to 15 separate and independent images refresh stored at one time
5. Up to 16 separate and independent full-resolution dot map graphic overlays (each overlay may be displayed in any one of 16 colors)
6. Up to 4 separate and independent target/cursor overlays
   - Target/Cursor position controlled by optional trackball or firmware/software
   - Each target/cursor may be independently colored any one of 8 colors
   - Optional programmable target/cursor may be presented in any configuration that can be defined in a 15x15 dot map square.
7. User-developed processing routines can be added and used interactively without external control
8. Self-contained full alphanumeric keyboard plus 20 special function keys
9. Optional 9-track magnetic tape unit with controller provides image input and storage
10. Optional controllers for conventional mini-computers

TABLE A-II

COMTAL VISION ONE INTERACTIVE FUNCTIONS SUMMARY*

1. Pseudo-Color: Translation of intensities to color.
2. Function Processing: Linear and non-linear intensity transformations of displayed image.
3. Arithmetic Functions: Add, subtract, multiply, divide, average a set of images.
4. Histogram: Frequency of occurence vs pixel intensity.
5. Roll Function: Line deletion (addition) at the top (bottom) of the monitor to impart vertical motion to the displayed scene.
6. Utility Functions: Zoom (magnification); minify (image shrinking); warping; annotation; etc.
7. Flicker Mode: Sequences through previous display commands.
8. Inspect Mode: Selection and display of specific intensities.
9. Convolution Function: Spatial filtering, high and low pass filtering, multi-pole filtering.
10. Pixel Classifier: This function is used for multiple spectral images. The same coordinates may be generated and examined for different color bands.

* Only a sub-set of the available functions are listed.

The COMTAL 8000 series configurator system is an advanced peripheral system into which a solid state refresh memory has been incorporated. The standard configurations offer three spatial resolutions, 256x256, 512x512 and 1024x1024. Standard features for this series of processors include:

- function processor and memory
- pseudo color processor and memory
- movable target
- standard I/O interface
- manual control and maintenance panel
- test pattern generator
- function memory feedback
- pseudo color memory feedback
- refresh memory feedback
- target location feedback
- power supply

The COMTAL 200 series image processing systems were developed for rapid interactive processing of high resolution digital imagery obtained from such sensors as ERTS, LANDSAT, and others which provide data far in excess of the traditional 512x512 based displays. The 200 series can exploit imagery of 2048x2048 data arrays. The series is developed around five solid state memories (all accessible at near real time digital television rates) namely:

- 2048x2048x8 bits - Base Memory
- 1024x1024x8 bits - Monochrome Display Memory
- 512x512x8 bits - Scratch Memory 1
- 512x512x8 bits - Scratch Memory 2
- 512x512x8 bits - Zoom Memory

The COMTAL Series 200 has three display monitors. A high resolution (1024x1024) monochrome system includes a single function memory for remapping gray levels prior to display from the 1024x1024 refresh memory. Two 512x512 color monitor (Vision One) systems may have their function memories driven by any of:

- 512x512 Scratch Memory 1 or 2
- 512x512 Zoom Memory
- Any of 16 contiguous 512x512 partitions of the 2048x2048 base memory

Hence, the color display monitors have a large parallel source of full resolution images. Switching between any of the parallel display sources (memories) occurs in less than 50 nanoseconds, which allows flicker comparison modes of operation.

Detailed cost break-outs for the COMTAL Systems described were not available, but were stated to range from $75,000 to $250,000[A-1] depending upon the specific system configuration and memory size required.

b. ESL's Interactive Digital Manipulation Systems[A-3,-4,-5]

ESL's Interactive Digital Manipulation Systems (IDIMS) have been used to process digitized imagery ranging from multispectral data to electron micrographs (an example of IR processing performed is presented in Section 4 of this appendix). IDIMS is a complete stand-alone image processing system with various hardware configurations. The library of processing algorithms supplied with this system can be expanded to meet unique requirements. The algorithms, however, are supplied with limited rights regarding reproduction and modification; hence it may be difficult for the user to make changes to the supplied algorithms. The general features of this system include:

- Turnkey system
- Up to 10 interactive displays

- Hewlett-Packard 3000 computer with 128 kilobyte memory (expandable to 512 kilobytes)
- User oriented language
- Expandable library of processing algorithms (more than 230 currently available)
- 512x512 and 1024x1024 image display resolution
- Automatic image labeling, storage and retrieval (DBMS)
- Disk storage Subsystems are available (15 megabytes to 300 megabytes)
- High Speed Printers/Tapes available
- Optional Advanced Scientific Array Processor (ASAP)
- Military oriented (has been used to process IR data)

Figures A-2 through A-5 indicate four available system options, namely: IDIMS I, IDIMS II, IDIMS II/ASAP I, and IDIMS II/ASAP II. The difference between these system configurations revolve around the HP Computer series and memory size used, the input/output devices, and the addition of the available array processor. Note that the Interactive Image display consists of the COMTAL Vision One System.

ESL's Advanced Scientific Array Processor (ASAP) is an optional subsystem used to meet high throughput requirements. For example, a Fast Fourier Transform which requires 6 min. to perform without the ASAP can be performed in $\approx$ 10 secs. with the processor. The features of the ASAP include:

- 32-bit floating point processor
- Allows 24 bits of precision to minimize truncation errors
- Microprogrammable features allow user generated algorithms

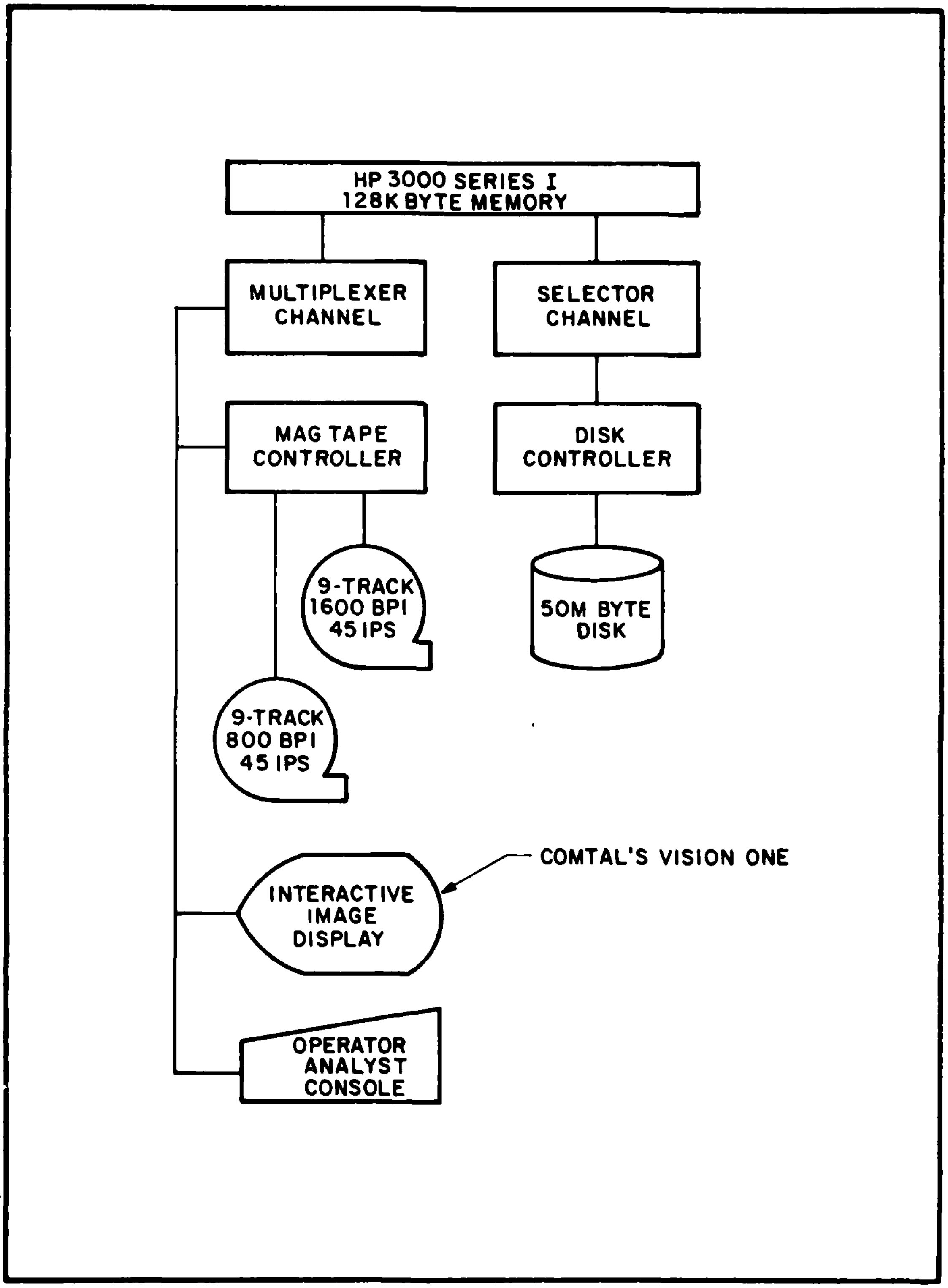


FIG. A-2 ESL's IDIMS I SYSTEM
(SUPPLIED COURTESY OF ESL INC.)

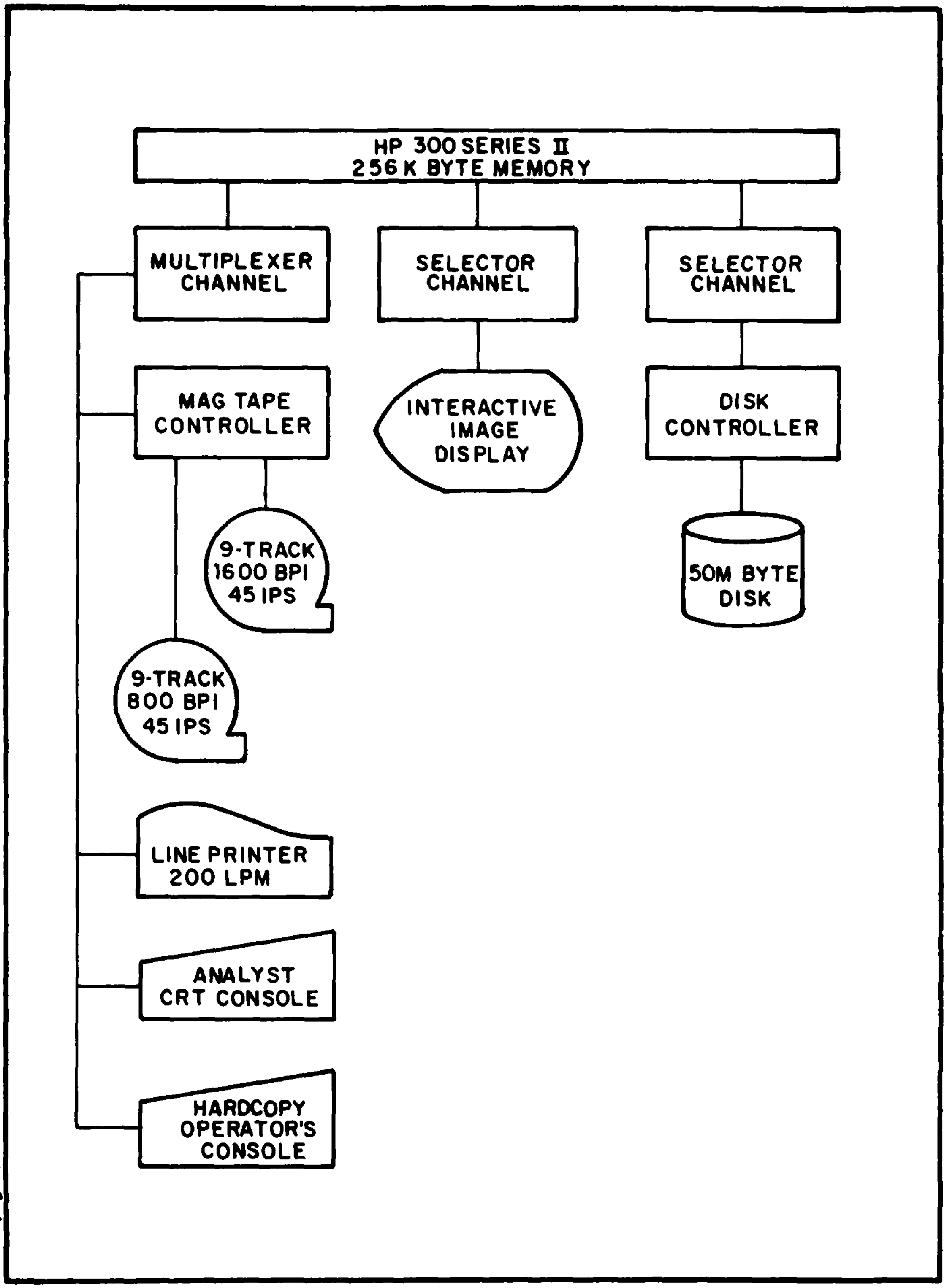


FIG.A-3 ESL's IDIMS II SYSTEM
(SUPPLIED COURTESY OF ESL INC.)

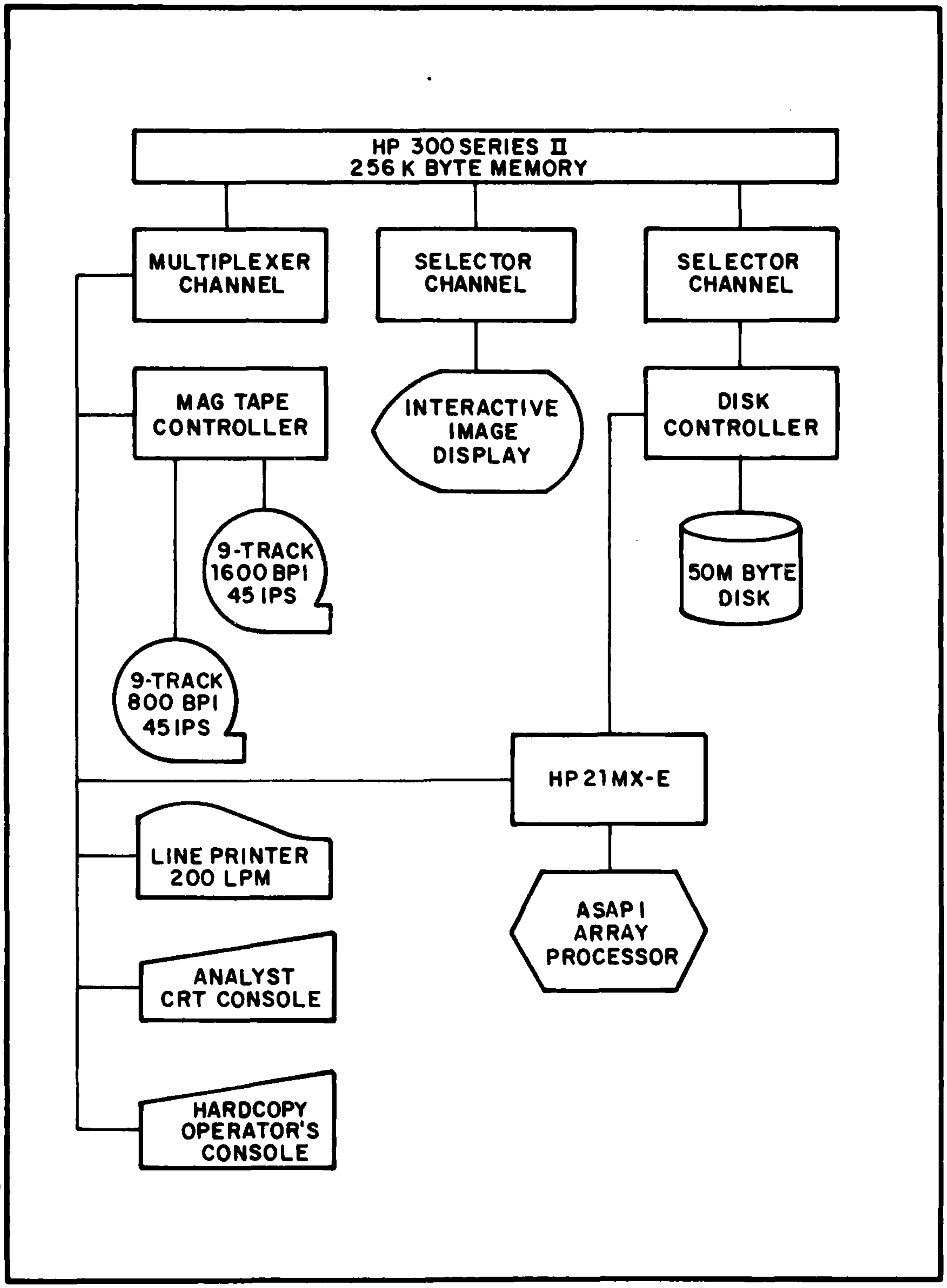


FIG. A-4 ESL's IDIMS II SYSTEM WITH ASAP I ARRAY PROCESSOR
(SUPPLIED COURTESY OF ESL INC.)

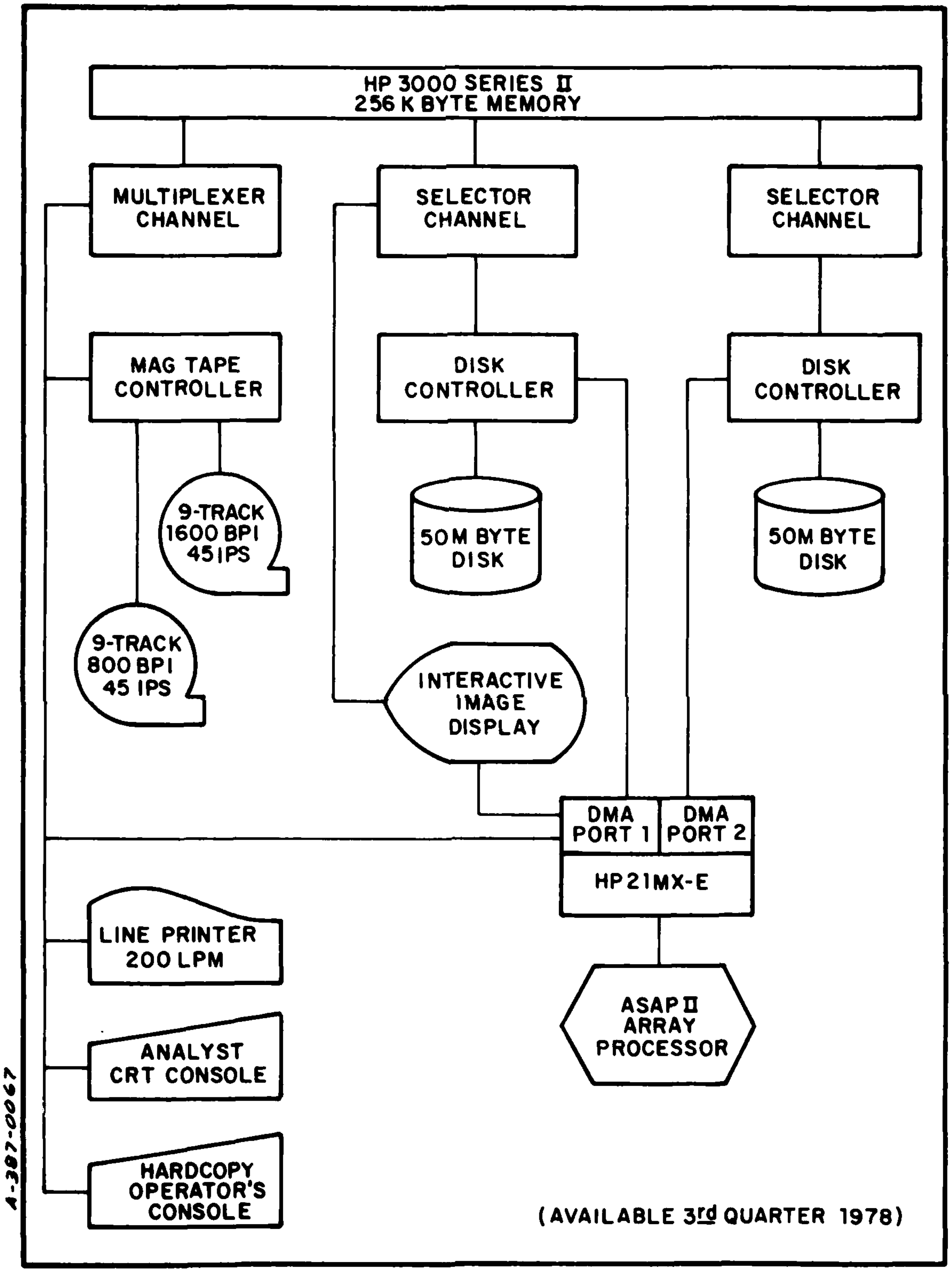


FIG. A-5 ESL's IDIMS II SYSTEM WITH ASAP II ARRAY PROCESSOR
(SUPPLIED COURTESY OF ESL INC.)

- Parallel pipeline structure simultaneously allows 1 multiply, 2 adds, normalization, address indexing, control, 2 memory fetches, and 1 store in 430 nanosec.
- Standard algorithms implemented in ROM (Maximum of 4K 32-bit words can be used)
- 4096 words x 32 bits of 143 nanosec RAM for scratch pad operations
- Internal memory is used to minimize access and interference to host computer.
- Dual memory controller optional

The approximate price range for the four system options shown in Figs. A-2 to A-5 range from $200,000 to $600,000 (see Table A-III). These prices include the software package with more than 230 algorithms. The software provided includes all of the functions performed by the COMTAL system. Some of the additional algorithms provide the following functions:

- Rotation of displayed scene
- Auto-correlation
- Cross-correlation
- Average power spectrum
- Thresholding
- Fast Fourier Transform
- Inverse Fourier Transform
- Gaussian shaped filter
- Third-order polynomial filter

A list of existing IDIMS facilities and points of contact is provided in section 4-d of this appendix.

TABLE A-III

APPROXIMATE IDIMS PRICE RANGE*

IDIMS I	$200,000
IDIMS II	$250,000
IDIMS II with ASAP I	$370,000 - $380,000
IDIMS II with ASAP II	$500,000 - $600,000

* • Prices include software package
• Prices obtained from Ref. A-3

c. RAMTEK

RAMTEK Corporation, located in Sunnyvale, California, is a supplier of graphic display systems and components. RAMTEK peripheral systems are available with image display resolutions of 256x256 and 512x640 and come supplied with very limited software. Microprocessor firmware options include graphics packages to draw end-point vectors, plots and bar charts; image scaling; conics plotting; logical and arithmetic functions; scrolling; magnification; and cursor generators. Options exist for host programmable pseudo-color or gray scale translation. Refresh memory capability exists for 3 to 4 color images. Typical RAMTEC peripheral systems cost ≈ $35,000 per unit. SIRE DP use of these systems would most likely require a substantial amount of software development which would add to the total cost of using these systems.

d. University of Southern California

The University of Southern California (USC) was contacted primarily with regard to their image processing software package. The software package developed at USC is available for ≈ $1,000 and includes documentation. With the exception of a few specialized algorithms, this software package is the same as that supplied with the COMTAL Systems.

e. DATAMATION Study

A recent article which appeared in DATAMATION magazine[A-6] included the results of a study which was conducted for the Algerian government on specialized image processing systems which are capable of handling LANDSAT data and data from airborne sensing systems. The data presented in this section was abstracted from the article.

There are currently three U.S. LANDSAT satellites each orbiting the earth every 103 minutes. The purpose of the satellites is to gather information on the light and radiation coming from the surface of the earth and to be used primarily for studying the earth's natural resources. The sensor employs 24 detectors which operate in four visible and IR bands; namely: 0.5 to 0.6 μm, 0.6 to 0.7 μm, 0.7 to 0.8 μm, and 0.8 to 1.1 μm. Other characteristics of the system include a 9.95 msec sampling interval, a 6-bit sample word length, 3,240 samples per scan line and 2,340 scan lines per band. The four-band multispectral scanner thus generates more than 3×10^7 bytes per picture. The data is orginally recorded on ultrahigh-density magnetic tapes (10,000 bpi). The processing performed includes conversion to computer compatible tapes, correction of sensor errors, overlay of scenes, image enhancement, classification and interpretation.

The image processing systems reported on were selected based on their capability to support envisioned current and future LANDSAT program requirements, to support remote user stations via microwave or other communications, to support archival data base management, to be able to directly interface with an IBM 370, to provide array processors for high throughput, and to have extensive software backed by extensive training support. Six turnkey systems and one software system were compared and highlights of the comparison are presented in Table A-IV. The hardware systems include The International Imaging System's (I^2S) System 101, CDC's Cyber-Ikon System, the Bendix Multispectral Data Analysis System, General Electric's DIPS System, Electro-Magnetic System Laboratory's (ESL) IDIMS Image Processing System, and COMTAL's Vision One. The software system is IBM's ER-MAN II. Note that the systems reviewed were not intended to be directly comparable nor do they represent the full breadth of the product lines of the manufacturers involved.

TABLE A-IV TYPICAL IMAGE PROCESSING SYSTEMS*

Mfg. & Model	Bendix M-DAS	Comtal Vision I	Control Data Cyber-Ikon	ESL IDIMS II
Number installed	4 installed	40 installed	New product	9 installed
Processor	DCC PDP-11/35 or 70	DEC LSI-11	Cyber 18/20	HP 3000 II
Array processor	Available	No array processor	Available	Available
Color monitor resolution	320x240 or 512x512	512x512 or 1024x1024	640x525	512x512
Interactive terminals	Up to 4	One terminal (alphanumeric)	One color display	Up to 10
Memory	28K to 1MB	16K words	292K (16-bit) words	128K words
Recommended disc	1.2M words (batch DOS)	No disc (POM)	Two 50MB disc	300MB disc
Standard mag tape	Two @ 800bpi or 1600bpi	Two @ 800bpi or 1600bpi	Two @ 800bpi or 1600 bpi	Two @ 800 bpi
Support 10,000bpi tape (min.)	Supports ultrahigh density	No ultrahigh density support	Supports ultrahigh density	No ultrahigh density support
Software:				
Basic support level	Medium level	Low level	Medium level	High level
Data base manager	In-house dbms available	No dbms	No dbms	File manager for each user
Processing:				
Simultaneous processing	16 bands (software)	3 bands (software)	4 bands (hardware)	Any number (software)
Simultaneous display	16 bands displayed	8 bands displayed	16 bands displayed	Any number displayed
Simultaneous search on	49 parameters	4 parameters	256 parameters	180 parameters
Strengths:	Accepts airborne data Good support/ training Good cost/ performance	Highly interactive High quality image Low cost	Very high throughout Good growth potential Video overlay Programmable terminal	Good flexibility Good growth potential Good dbms support
Weaknesses:	Relatively slow Low growth potential	No growth potential Limited software	Limited software Unproven in field	Military orientation
Basic turnkey prices:	$300,000-$750,000	$100,000-$215,000	Approx. $1.3 million	$225,000-$750,000

* Abstracted from Ref. A-6

TABLE A-IV TYPICAL IMAGE PROCESSING SYSTEMS* (CONT'D)

Mfg. & Model	General Electric DIPS	IBM ER-MAN II	I^2S System 101
Number installed	11 installed	4 installed	3 installed
Processor	DEC PDP-11/35 or 70	IBM 370	HP 3000 II
Array processor	Available	To be available	Available
Color monitor resolution	512x512	512x512	512x512
Interactive terminals	Up to 4	One	Up to 17
Memory	256K words memory	350KB	256KB
Recommended disc	Two @ 85M words	30MB disc	50MB disc
Standard mag tape	Two @ 800bpi or 1600bpi	1 to 4 mag tapes	Two @ 1600bpi
Support 10,000bpi tape (min.)	Supports ultrahigh density	No ultrahigh density support	Supports ultrahigh density
Software:			
Basic support level	High level	High level	High level
Data base manager	No dbms	IBM 3850 interface	File manager for each user
Processing:			
Simultaneous processing	5 bands (hard)/ 16 (soft)	Any number bands (software)	19 bands (hard)/ 34 (soft)
Simultaneous display	5 bands + 1 video	30 bands displayed	14 bands displayed
Simultaneous search on	8 parameters	60 parameters	64 parameters
Strengths:	Extensive software Large user group Video overlay Good support/ training	Low software cost Good software library	Programmable terminal Extensive software Video overlay Good growth potential
Weaknesses:	Limited bands Relatively slow Expensive	No support, non-IBM hard Used only by IBM to date	Small company
Basic turnkey prices:	$350,000-$4 million	$55,200 (software only)	$275,000-$750,000

* Abstracted from Ref. A-6

4. IR Data Reduction Centers

a. Jet Propulsion Labs (JPL)

JPL was surveyed[A-7] as a potential source of IR data processing algorithms and to review the design approach and philosophy for their Infrared Astronomy Satellite (IRAS) data processing efforts. JPL is developing the Scientific Data Analysis System (SDAS) for IRAS. This system is being designed for batch mode operation on an IBM 360/75 computer, hence, little manual interaction is anticipated. User access to the data files will be provided so that specialized analyses can be performed utilizing user supplied software. The SDAS was estimated to cost \$4.3M for development and operation. (During later discussions with NASA personnel, it was indicated that the cost of the SDAS may increase to ≈ \$6.5M due to the addition, after SDAS PDR, of some new processing experiments. The SDAS Preliminary Design Review (PDR) was held in April 1978 and the Critical Design Review (CDR) is scheduled for April 1979. IRAS satellite launch is scheduled for February 1981.

1) IRAS Description[A-7,-8]

IRAS is tasked to perform a full sky infrared survey of "quasi-stationary" objects. Star maps will be generated in a manner that is at least conceptually similar to SIRE's. The satellite will be placed in a 102-min polar orbit. The sensor has a field-of-view (FOV) of $1^\circ \times 1/2^\circ$ and has a survey mode whereby it is scanned perpendicular to the orbit's plane covering a swath a degree wide along half a great-circle on each scan. Each swath overlaps the previous by more than 50%. The scanning motion consists of stepping the FOV by $1/4^\circ$ increments (half the width of the FOV). Hence, there is substantial overlap in coverage which provides multiple looks at each quasi-stationary source. The sensor has a "look-back" capability so that a sky patch can be reexamined within a 2- to 4-week period if necessary.

The focal plane contains 62 detectors with appropriate spectral filters for operation in the 8-15μm, 15-30μm, 40-89μm, and 80-120μm bands. Cheveron arrays operating in the visible region are also included. Detectors in adjacent columns are staggered to guarantee complete coverage. The detectors are distributed among 8 redundant sub-arrays (2 for each color band) so that two looks at each source for each spectral band are obtained in a single scan. Expected detector performance is more sensitive than SIRE's.

The data volume can be a maximum of 5.9×10^7 detector samples per 24 hours in the survey mode. Each sample consists of 16 bits of information encoded into 8 bit difference values. Data are downlinked during a 12-15 min period (every 12 hours) when the satellite is within the coverage of a ground terminal. Hence, the IRAS daily data volume is within a factor of 10 less than the expected SIRE daily data volume.

2) Mission Planning

An automated Mission Planning and Analysis System (MAPS) is provided at JPL for long range planning functions. This system, which is not part of the SDAS, is implemented on a UNIVAC 1108. Long range planning and analysis assistance is provided to resident Joint IR Science Working Group (JISWG) members at JPL. Short range (day-to-day) planning and the generation of detailed command structures are performed by a group in England.

3) Preprocessing Functions

The process of converting the wide band mission tapes to computer compatible tapes is performed at the satellite control center. Hence, the input tape to the SDAS is in computer compatible format.

4) Data Assessment

Data Assessment is provided as a closed loop to IRAS mission planning. If necessary, an experiment can be rescheduled over a 2- to 4-week period.

Three levels of checks are performed on IRAS data. The first is a "quick-look" which is performed during satellite pass at the operations control center in England. The quick-look consists of checking telemetry data (alarm limits, temperatures, pressures, etc.) to gain assurance that the satellite and sensor are operating properly.

The second level of testing has a 24-hour turnaround time and is also performed in England. This consists of confirming boresight (line-of-sight) and attitude against known stars, a preliminary photometric calibration to test for gross changes in detector characteristics, a preliminary analysis consisting of identification of a few known stars on the basis of a single scan of data (i.e., merging is not performed), and a check on radiation hits and noise to determine if either exceeds predefined limits. This second level of testing is to be a fully automated process, although specific algorithms to perform the tasks are not presently defined.

The third level of testing has a 2- to 4-week turnaround time. This function is essentially the SDAS processing which is described below. The purpose here is to perform a refined analysis (including merging) to develop improved statistics which will assure a high quality of data. One area of concern given as an example is the possible presence of a meteor shower during a data take which can result in too much data (e.g., saturation). Such a condition would require rescheduling this part of the experiment. This data quality check is to guarantee that 95% of the sky is covered at the required sensitivity with at least 98% of the sources reported and with less that 2% false sources in the output.

5) Detector Data Display

A display of detector data is provided to enable value judgments about the quality of input data. Raw detector data are displayed for an operator selected detector and between specified time limits. This display provides a means to visually evaluate noise characteristics and to determine the operability of individual detectors.

6) SDAS Data Processing

Point source processing for the SDAS includes algorithms for:

(1) Recognition of point sources,

(2) estimating noise characteristics,

(3) removal of cross-talk,

(4) calibration of data,

(5) performance of seconds, hours and months confirmation,

(6) merging of data between color bands,

(7) time-to-position conversion, and

(8) comparison of confirmed sources with known IR sources.

Additional SDAS processing functions include boresight pointing reconstruction, extended source processing, total flux processing and deep sky survey processing. These processing algorithms are functionally similar to those required for SIRE data processing.

The method proposed for the recognition of point sources consists of cross-correlating sensor data with an anticipated model pulse or template. This method can be used to locate the pulse peak in amplitude and time. It also provides a means to discriminate radiation particle hits, although, IRAS has on board electronics to filter radiation hits from the data.

It was pointed out in the discussion at JPL that non-Gaussian noise statistics are expected in the IRAS data. One reason for this has to do with potential nonhomogeneous off-axis-rejection characteristics of the IRAS telescope. Hence the SDAS will compute a running average noise value per detector vs time and will periodically compute noise power spectrums.

The cross-talk and calibration process consists of algorithms which remove false detections resulting from electrical cross-talk, correct the amplitude of coincident detections, and convert measured source amplitude and noise to source flux (watts/cm^2).

Seconds, hours and months confirmation are processes whereby multiple looks at a given source are associated thereby confirming the presence of the source. In seconds confirmation, the association is between detections made between the redundant sub arrays on a given scan. In the hours confirmation process, sources detected on subsequent orbits are associated. In the months confirmation, detections made at least two weeks apart are associated. Confirmed point sources are merged between color bands to permit temperature computations. It is expected that the processing involved here may to some part be similar to SIRE subarray data merging and star map merging processes.

The time-to-position conversion utilizes boresight pointing data to convert the time of a detection to position angles. Boresight pointing reconstruction utilizes the visible band cheveron detection of known visible guide stars and spacecraft and gyro data to determine pointing angles and attitude. Better than 5 $\widehat{\text{sec}}$ accuracy is expected in determining boresight position at the guide star. This accuracy can decrease to approximately 10 $\widehat{\text{sec}}$ at a source detection due to gyro drift and is a function of the number of available guide stars in the region of the source detection. These accuracies are comparable to those required of SIRE.

The deep sky survey processing will co-add data from many scans over the same small region of the sky in order to increase the signal-to-noise (S/N) ratio for the region and to extract low flux sources. It is expected that $\sqrt{n}$ improvement in S/N will result where n is the number of co-added scans.

The SDAS will also process extended source and total flux data. Extended sources are defined as a few $\widehat{\text{min}}$ in extent and can consist of HII regions and clumps in the zodiacal background. Total flux measurements are for sources of at least a few degrees in extent (e.g., zodiacal radiance). The extended source processing is similar to point source processing with one exception being the shape of the model pulse or template. Algorithms to perform extended source processing and total flux measurements have not been fully defined. Some of the problems involved here are baseline drift effects, and the fact that no on-board absolute calibration of the sensors will be performed.

7) <u>Deep Sky Simulation</u>

A deep sky simulation is being built for IRAS (possibly with JPL funding) to be used in the testing of algorithms and as a planning aid to estimate data volume, background conditions and threshold design. This simulation includes a sky model which includes the Walker model and models for meterorite radiation and asteroid motion. It also includes a telescope model which incorporates a telescope transfer function and simulated detectors. The telescope model scans the sky model to develop simulated telescope outputs.

8) Summary of JPL Survey

JPL was surveyed as a possible source of IR data processing algorithm information and for their IRAS SDAS design approach. The SDAS will be a fully automated system to operate in batch mode on an IBM 360/75 computer, hence, little manula interaction is anticipated with this system. The JPL design is beyond PDR with IRAS launch scheduled for February 1981, i.e., essentially the same time period as scheduled for SIRE launch. Hence, the IRAS SDAS design currently seems to be progressing at a somewhat faster rate than the SIRE DP system. The IRAS experiment was found to be conceptually similar to the SIRE star map measurements with possibly better detection sensitivity than SIRE and with similar daily data volume and accuracy requirements. Many of the IRAS SDAS point source and boresight reconstruction algorithms are potentially similar to those that will be required by SIRE. Hence, JPL may be a valuable source of algorithm information during SIRE DP development, and a potential source of auxiliary IR star map data during SIRE operations.

b. Teledyne Brown Engineering

Teledyne Brown processes IR data which is collected by the Ballistic Missile Defense Advance Technology Center's (BMDATC) Ground Based Measurement (GBM) sensor. The GBM sensor is located at the Army Optical Station at Roi Namur in the

Kwajalein Atoll and normally tracks ballistic missile systems during their reentry phase. The purpose of these measurements is to establish a reentry systems IR data base including IR signatures, spatial and temporal characteristics of RVs, decoys, tank fragments, etc., and their associated wakes.

Teledyne Brown was surveyed[A-9] to assess the applicability and availability of their target track algorithms for SIRE and to determine the design approach and extent of manual interaction used for their data processing.

1) Data Processing Design Philosophy

Low funding ($\approx$ \$0.5M) was available for the development of the data processor. Hence, the system was designed with maximum use of "off-the-shelf" hardware and software. The system is to be primarily automated, compatible with the Army Research Center's (ARC) computer, and with included flexibility for anticipated hardware changes.

Staffing included 4-5 people during hardware and software development and is currently staffed with $\approx$ 8-9 people for operations and system upgrading.

2) GBM System

Characteristics of the GBM system are summarized in Table A-V. The system has a narrow angle (2½x5 mrad field-of-view), scanning, two color IR ground based sensor designed to operate either slaved to azimuth and elevation signals of an external radar, video tracker, or manual gun sight; slaved to internal track signals following lock-on; or under direct manual control. The focal plane contains 52 detectors arranged in staggered columns in two sub arrays, which operate in the SWIR and LWIR spectral bands. The system has a 47.9 μrad resolution, collects 15,000 samples per sec per detector and has a 3.48 Mbps data rate on two channels.

TABLE A-V

GBM SYSTEM CHARACTERISTICS

- SCANNING IR GROUND BASED SENSOR
- TRACKING:
  - SLAVED TO AZ & EL SIGNALS OF RADAR, VIDEO TRACKER, OR MANUAL GUN SIGHT
  - INTERNAL TRACKING AFTER LOCK-ON
  - MANUAL CONTROL
- 2 SPECTRAL BANDS (SWIR, LWIR)
- 52 STAGGERED DETECTORS IN 2 SUB ARRAYS
- 2½ x 5 MRAD FOV
- 47.9 μRAD RESOLUTION (17 BITS)
- 15,000 SAMPLES/SEC PER DETECTOR
- DATA RATE: 3.48 MBPS ON 2 CHANNELS

Note, that in comparing this system to SIRE, the GBM system receives a fairly intense target signal (very high signal-to-noise compared to possible SIRE targets) and its background is relatively uncluttered (e.g., few stars are detected). Hence, processing for target detection and track formation is at least conceptually a somewhat less complicated problem for the GBM sensor.

3) Data Processing

Data processing is performed in two phases: data reformatting; and data reduction and analysis. The data reformatting consists of the process of converting the analog tapes to ARC computer compatible tapes and is performed at Teledyne Brown. Teledyne Brown built the Formatting of Raw Data (FORD) processor[A-10] for this task. The system operates on a DEC PDP 11/35 minicomputer with 120 K bytes of core (the original configuration had only 16 K bytes of core and had to be increased). A block diagram of the FORD processor is shown in Fig. A-6. The system was configured entirely with off-the-shelf hardware and software. Due to the very high throughput rate required, the analog tapes are first converted to 9-track tapes and then reconverted to ARC compatible 7-track tapes. The two 9-track, 75-ips recorders are used to record data virtually simultaneously, i.e., a block of data is sent to one unit and the next block to the other unit in a "ping-pong" fashion. This method achieves a throughput rate of 240,000 bytes per sec. Once the data are recorded on the 9-track tapes, they are interleaved and reformatted at a slower speed on the 7-track, 75-ips tapes. This processing is currently undergoing redesign in an attempt to remove the double tape conversion process. The system contains an electrostatic printer/plotter and strip plotters which can monitor and display radiometric data (e.g., the target blip can be displayed), housekeeping and

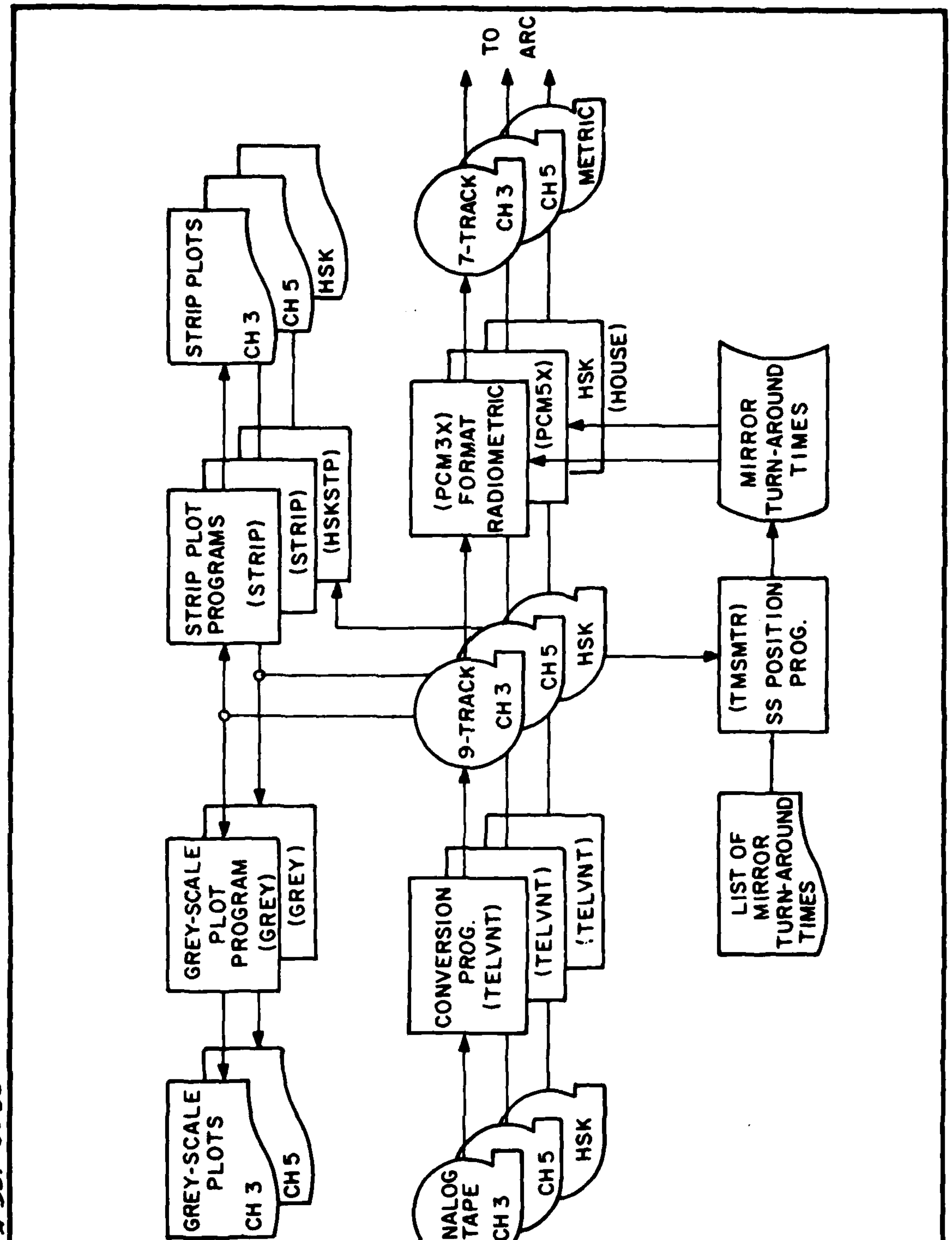


FIG. A-6 FORMATTING OF GBM DATA AT FORD
(SUPPLIED COURTESY OF TELEDYNE BROWN ENGINEERING)

engineering data (e.g., critical temperatures, pointing directions, scanning mirror-turnaround times, etc.).

Data Reduction and Analysis is performed on the ARC CDC 7600 computer. The processing performed includes:

(1) Metric Computations: Target range is computed from mission data, including track radar inputs.
(2) Merging and sorting
(3) Point Target detection: Including calibration and bulk filtering, which performs a fit in amplitude, slope and baseline to a model pulse.
(4) Cross-color correlation
(5) Computation of emissivity-area product and apparent temperature
(6) Track file formation
(7) Kalman filtering to determine the ballistic coefficient, β

The ARC system has a colorgraphics display (no interactive processing) which is used to display target tracks and RV wake contours. Pseudo color is used to generate intensity maps across the wake contours.

4) Problems Encountered

A number of unexpected problems, both with the GBM system and the data reduction system, led to substantial hardware and software updates and have resulted in a backlog of GBM data to be processed. Some of the problems encountered are summarized below.

a) Focus

Installation problems with the GBM system led to a defocusing of its optics. There was no on-site calibration equipment to properly refocus the system. This led to a number of attempts at manual refocusing with resulting variations in the optical image size. In general, the optical image size resulting was larger than that used in the derived data reduction theory and a number of modifications to the computer algorithms were needed. This was a recurring problem to the date Teledyne-Brown was surveyed[A-10] and it was anticipated that the GBM optics would be sent back to the manufacturer for proper adjustment and recalibration.

b) Electrical Noise

Electrical noise, which entered the GBM electronics from adjacent track radar sidelobes, created signal detection problems requiring special filtering techniques to process the target data. Additional electrical isolation has been added to the GBM sensor to reduce this effect for the more recent missions.

c) Tracking Instability

Instability in the GBM tracking functions caused the optical image to wander over many detectors, and intermittently out of the field-of-view. This complicated the data reduction required for track formation.

d) Nonresponsive Detectors

A number of the GBM sensor detectors were nonresponsive and others operated intermittantly. This reduced data reliability and complicated the target line-of-sight and data merging algorithms.

e) Saturation Effects

In some of the missions the SWIR band saturated before detection occurred in the LWIR band. This complicated the processing for merging and target temperature computation where data from both bands are required.

f) Data Processing Hardware

A number of hardware associated problems were encountered particularly with the tape drives. Tape skewing caused interface problems between the FORD processor generated tapes and the ARC system tape units. This required a process of adjustments and calibration both at Teledyne Brown (on the FORD processor tape units) and on the ARC system tape units. A considerable amount of time was lost in this process.

Another problem which also affected the FORD processor/ARC interface had to do with tape stretching and thickness. It was determined that tapes have to be recertified before each new usage at the bit rates and packing densities to be used.

5) Summary of Teledyne Brown Survey

Teledyne Brown was surveyed as a possible source of target track algorithms and for information on their data processing design approach. Their system is basically automated with some color graphic display capability but with no interactive processing. Target detection and track formation is conceptually simpler for the GBM data than that expected for SIRE since relatively high signal-to-noise and clean backgrounds are encountered by the GBM system.

Low funding for development led to maximum use of "off-the-shelf" hardware and software by Teledyne Brown. Unexpected problems encountered both with the GBM system operating characteristics and the data processing hardware led to extensive hardware and software updating requirements and have resulted in a GBM data backlog for processing.

c. Air Force Geophysics Laboratory[A-11]

The Air Force Geophysics Laboratory (AFGL) has long been engaged in performing IR surveys of the sky, including discrete stellar sources, zodiacal radiance and the earth limb, with rocket-borne probes. AFGL has published a number of basic catalogs of IR sky sources.[A-12,-13] Some initial results on zodiacal radiance measurements are in the process of being published. Consequently, AFGL was surveyed with regard to their experience in the processing of IR data and to review their data processing approach.

The data reduction and analysis performed at AFGL is performed in a batch mode on a CDC 6600 computer. Extensive manual interaction is used, i.e., each computer run is manually assessed prior to applying the next level computer analysis technique to the data. Broad computer procedures were developed before probe flight but post-flight modification was required. Some of the problems encountered which affected the data reduction and analysis process include detector outages, telemetry dropouts, non-homogeneous off-axis-rejection effects of the telescope and on-board log-amplifier sensitivity problems. The data volume is typically 10-20 Mbits per probe flight.

The data processing algorithms used for point source processing are essentially the same as those planned by JPL for IRAS data; namely, the processing includes:

(1) Digital filter for optimum S/N

(2) Cross-correlation with an ideal point source response for peak detection

(3) Mean & RMS noise computations at various stages of reduction (e.g., raw data, filtered data)

(4) Thresholding

(5) Cross Color merging

(6) Detected source positions compared with other catalogs

(7) Confidence criteria computation as a function of

- Observations in more than one color band
- Multiple observations over rescans

AFGL representatives gave some suggestions for SIRE in order to avoid possible future processing problems. These included:

(1) Focal Plane Testing

The data processing (DP) contractor should be involved in focal plane testing. This would give the DP contractor familiarity with SIRE data characteristics and assure that DP required data is not overlooked. Focal plane calibration should be performed on the ground and should include measurements of those characteristics which cannot be conveniently measured in orbit. These include, for example, detector response vs wavelength and temperature, detector response vs scan direction, and telescope off-axis-rejection characteristics.

(2) Algorithm Optimization

While broad procedures can be developed prior to flight, real measurement data will be required for final algorithm optimization.

(3) Sensor Requalification

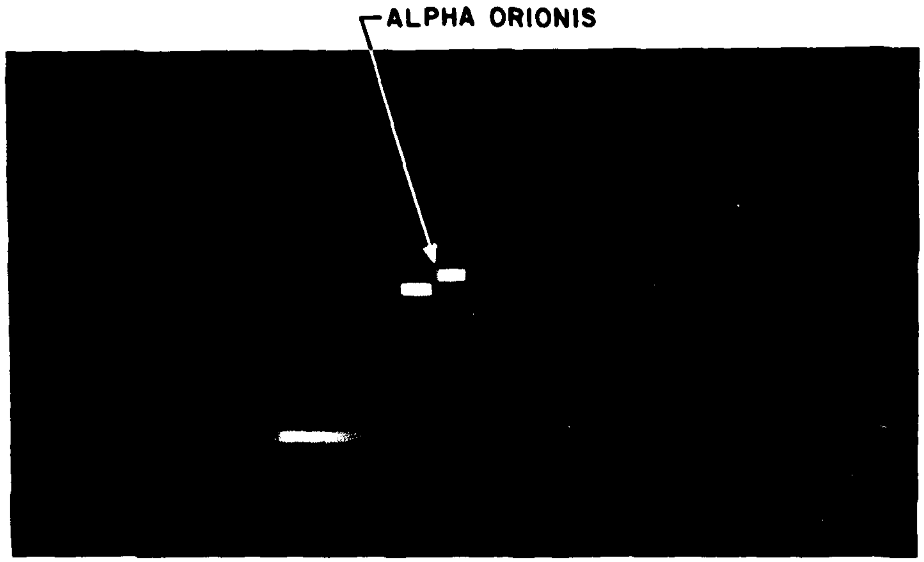
Since it is possible for SIRE sensor performance characteristics to change as the sensor is varied through different operating modes, e.g., from earth limb measurements to stellar source measurements and, possibly, back to earth limb measurements, the sensor should be requalified (recalibrated) after each change of experiment.

d. Electromagnetic Systems Laboratory (ESL)

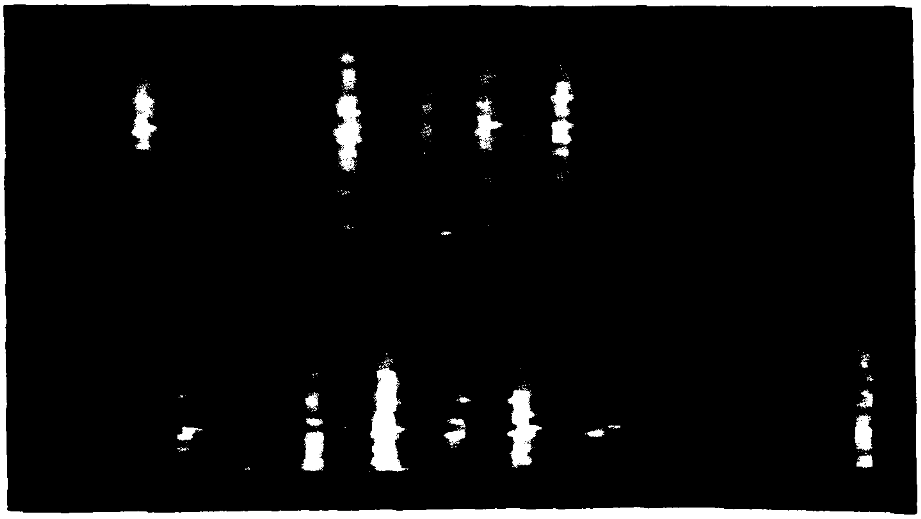
ESL was surveyed[A-3] both as a potential source of image processing systems (see discussion in Section 3 of this appendix) and to review their experience in applying image processing techniques to IR data. ESL has successfully processed ballistic missile system reentry and star measurement IR data using their IDIMS. The data reduction was typically performed to demonstrate the feasibility of using these interactive systems for the reduction of this type of data and as an aid in the development of computer algorithms. Hence, while feasibility was proven, ESL has not utilized these systems in a full "production line" fashion. ESL asserts these systems can be used for rapid, bulk processing of large amounts of IR data and such systems are being utilized by others (see list in section 5 below) to process satellite data.

This section will concentrate on an example of ESL's use of image processing techniques for LWIR data reduction.[A-14] The data to be discussed was collected with a scanning, airborne sensor containing 160 detectors which operate in the SWIR, MWIR and LWIR bands. Each spectral band has a staggered linear array of detectors. The MWIR detectors are approximately half the size of the detectors in the other two bands. The sensor has electronics for preamplification, filtering, peak holding, multiplexing, log amplification and PCM recording.

Fig. A-7 shows an example of the IR data to be processed. Fig. A-6a shows a high S/N SWIR scan of Alpha



a. HIGH S/N SWIR IMAGERY WITH NO ENHANCEMENT



b. LOW S/N, MWIR IMAGERY WITH "PICKET FENCE" NOISE

FIG.A-7 EXAMPLE OF ALPHA ORIONIS DATA*

* Supplied courtesy of ESL Inc.

Orionis. Fig. A-7b shows a similar scan at MWIR where the signal is obscured by a "picket fence" noise feature which they encountered with this type of data. In order to interpret scanned radiometer data as the images shown in Fig. A-7a, the data are formatted as a sequence of two dimensional data sets rather then as a set of individual detector outputs. The images shown are built up by displaying the output with time of each detector channel as one (Fig. A-7b) or two (Fig. A-7a) TV lines. Sensor pointing angles and platform attitude are processed and translated to locate the individual scans and picture elements (pixels) in space. Each response to a point target results in a horizontal line approximately 6 pixels wide with a rising and falling intensity pattern characteristic of the detector output. Each pixel displays 8 bits of intensity data. A second response to a point source often occurs due to the finite size of the blur circle and to the overlap of adjacent detectors. The second response is delayed approximately 5 samples (pixels) from the first which corresponds to the time lag between the blur circle crossing the two adjacent columns of detectors.

1) <u>Image Processing for S/N Enhancement</u>

ESL performed a number of experiments with their image processor in order to demonstrate the signal-to-noise (S/N) enhancement and detection facilitation. This example will deal with the data previously shown in Fig. A-7b, and was abstracted from Ref. A-14. The "raw" image shown has a S/N of 1.86 where S/N is defined as the ratio of the peak signal to the mean value of the image (i.e., of all pixel intensity values).

In the first experiment, a two-dimensional Fourier transform was taken of the image and the result displayed (see Fig. A-8). In this manner, the dominant noise frequencies

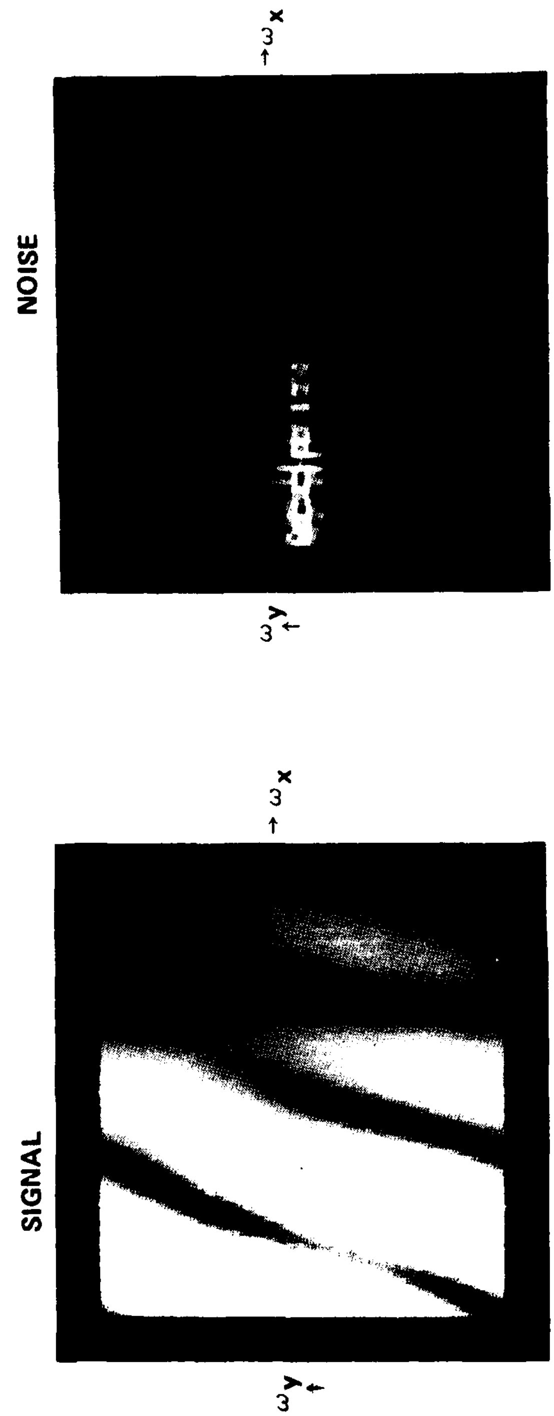


FIG. A-8 TWO DIMENSIONAL FOURIER TRANSFORMS OF MWIR DATA*

* Supplied courtesy of ESL Inc.

were determined. A two-dimensional Fourier notch filter was then designed around the known noise frequencies and applied to the data. This resulted in an enhanced image with a S/N of 6.82 (a factor of 3.67 improvement over the raw image).

A second experiment was performed to establish the utility of simple spatial domain filters in this application. Visual inspection of the raw image (Fig. A-7b) shows little regularity in the horizontal direction, but roughly constant intensity in the vertical direction. This suggested the use of a filter which replaced each pixel by the difference of the pixel value and the average of the pixel values above and below it. The result was an image with a S/N of 6.97, as shown in Fig. A-9. This type of filtering has the advantage that no direct or inverse Fourier transforms are required thereby decreasing the computer processing time required.

A third experiment utilized a one dimensional optimum filter to remove the "picket fence" noise. A modified "matched" filter was used, where a clean scan of the data provided the signal characteristics to design the matched filter; the known noise spectrum variation with frequency was then used to modify the matched filter to obtain the "optimum" filter. This process resulted in an image with a S/N of 11.61 (see Fig. A-10).

A final experiment utilized the known fact that there were responses in two adjacent detectors. After performing spatial filtering, alternate TV lines on the display were offset by 5 samples to account for the detector spacing (see Fig. A-11a). Alternate lines of the image were averaged (see Fig. A-11b) resulting in a S/N improvement of $\sqrt{2}$ over that obtained from spatial filtering only. Coincidence processing was then performed where each pixel value was replaced by the

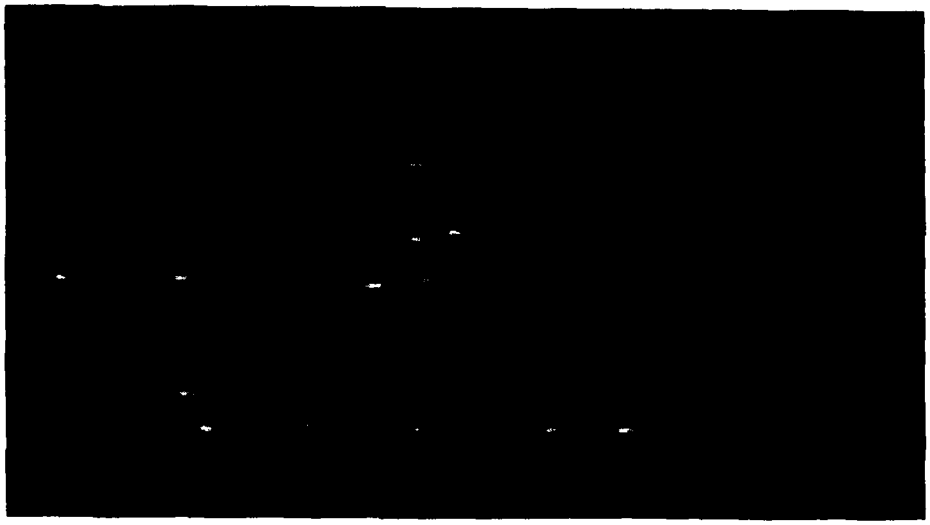


FIG. A-9 MWIR IMAGERY AFTER SIMPLE SPATIAL FILTERING TO REMOVE "PICKET FENCE" NOISE*

* Supplied courtesy of ESL Inc.

$$H(\omega) = \frac{F^*(\omega)\ \mathrm{EXP}\ (-i\omega T)}{\sigma^2(\omega)}$$

WHERE

$F(\omega)$ = FOURIER TRANSFORM OF SIGNAL

$\sigma(\omega)$ = FREQUENCY DISTRIBUTION OF NOISE

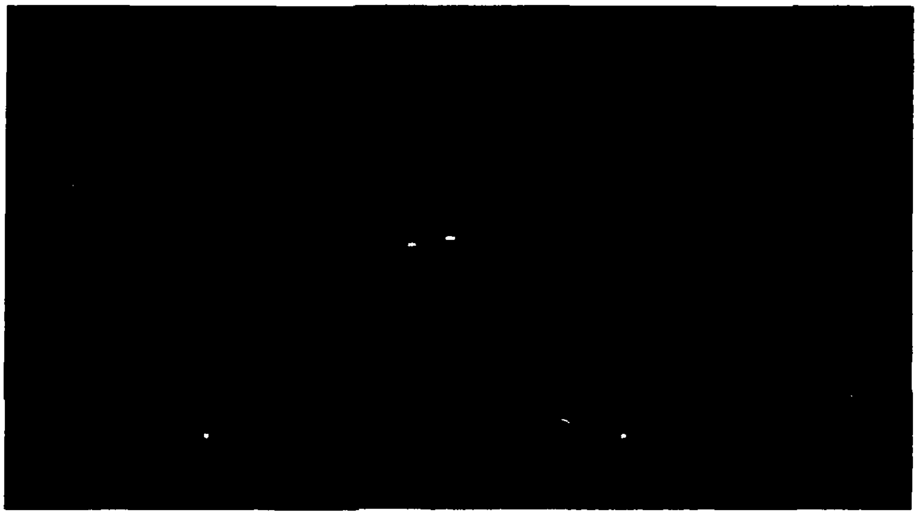
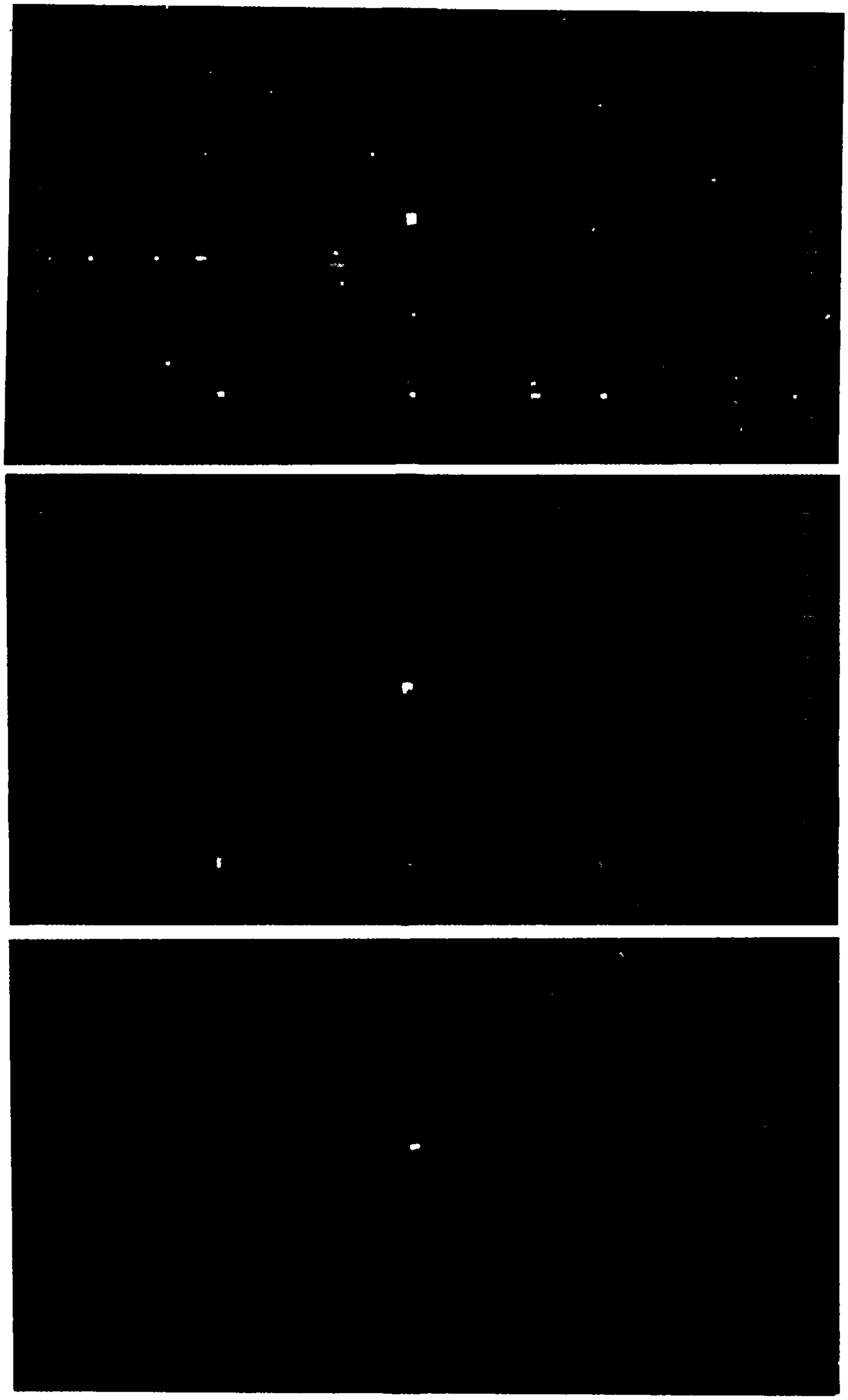


FIG. A-10 OPTIMUM FILTERING OF MWIR IMAGE*

* Supplied courtesy of ESL Inc.



a. OFFSET CORRECTION

b. ADDITIVE FILTER

c. MULTIPLICATIVE FILTER

FIG.A-11 COINCIDENCE DETECTION*

* Supplied courtesy of ESL Inc.

product of that pixel value and the value of the pixel immediately above it, i.e.,

$$G(x,y)=f(x,y) \cdot f(x,y+1).$$

This resulted in the refined image shown in Fig. A-11c. It should be cautioned, however, that this technique can only be used when it is known that two adjacent responses occur - this is not always the case.

2) Assessment of Image Improvement

A number of interactive techniques exist with the IDIMS system which facilitate the assessment of image enhancement techniques. These include: before and after displays of the image; before and after displays of one- or two-dimensional transforms of either individual detector channels or of the entire image; and before and after displays of image histograms. Image histograms display the frequency of occurrence of each intensity in an image.

3) Example of Track Data

Fig. A-12 shows an example of how track data can be established utilizing interactive processing techniques. Target detection data segments were extracted from processed scans and positioned into an azimuth-elevation space image according to track data. The graphic overlay with the "Xs" represents auxiliary beacon track data. The detections in scans 11 through 15 are dual (on adjacent detectors) and, hence, easily visible. Scans 8 and 10 are single detections and not as obvious; however, they can be located by their similar position in the scans as compared to the dual detections. The ability to see detections is a function of the figure reproduction quality and relative intensity. Since the intensity of the detected points increases as scan number increases (the targets are approaching the sensor), the earlier scan detections are harder to see.

FIG. A-12 MOSAIC IN Az-EL SPACE*

* Supplied courtesy of ESL Inc

4) Summary of ESL IR Processing Survey

ESL has successfully utilized image processing techniques to process IR data. However, they have not used their systems in a "production line" mode as may be required by SIRE. Other ESL system users are performing satellite data reduction and may be processing large volumes of data. Some of the interactive techniques utilized by ESL and some of the problems they encountered are illustrative of potential SIRE processing complexities. The ESL system is commercially available (see Section 3 of this appendix) with limited rights for the reproduction and (possibly) modification of supplied computer algorithms.

5) Existing IDIMS Facilities

This section presents a list of facilities*, including points of contact currently using ESL's IDIMS. The list follows:

(1) EROS Data Center
Sioux Falls, South Dakota
Don Orr, (605) 594-6511
Installed April 1976
IDIMS I, Tektronix Display, COMTAL Display (8000 Series) and associated peripherals.

(2) EG&G Aerial Measurements Division
Las Vegas, Nevada
Dr. William Ginsberg (702) 739-0511
Installed January 1978
IDIMS II
COMTAL DISPLAY (Vision One, CCD Memory)
Large disk subsystem, electrostatic printer/plotter associated peripherals.

(3) Government Office of Research
Washington, D.C.
Mr. Keith Hazard, (202) 351-2957
Installed February 7, 1977
Upgrade August 1978

* Provided by ESL

IDIMS II - HP3000, Series II, COMTAL Display (8000 Series) and associated peripherals. Upgrading to a fast array processor subsystem at the present time.

(4) Gulf Science and Technology Company
Pittsburgh, Pennsylvania
Dr. Mat Matthews, (412) 362-1600
IDIMS II - 4 March 1977; Microprocessor Subsystem-Installed 1 April 1977
IDIMS II, Microprocessor (ASAP I) subsystem, Tektronix display, COMTAL Display (8000 Series), a wide electrostatic printer/plotter, and associated peripherals.

(5) NASA Ames Research Center
Moffett Field, California
Mr. Ben Briggs (415) 965-5897
Installed March 1978
IDIMS II - HP3000 Series II
Model 6 with shared 5000 Series COMTAL, and associated peripherals.

(6) NASA Ames Research Center
Moffett Field, California
Mr. Martin Knutson, (415) 965-5358
Installed March 1976
IDIMS I - HP3000, COMTAL Display (5000 series) Geographic entry station, and associated peripherals.

(7) Naval Intelligence Support Center
Washington, D.C.
Mr. Norman Smith, (202) 763-1004
Installed April 1975
Four COMTAL Display subsystems.

5. References for Appendix A

A-1. Discussions with Richard W. Jones, V.P. Marketing, COMTAL Corporation, 169 North Halstead, Pasadena, Calif. 91107, 2 May 1978.

A-2. "VISION ONE Users Manual," COMTAL Corporation, Pasadena, Calif. 91107, 1 February 1978.

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6. Glossary

AFGL	-	Air Force Geophysics Laboratory
ARC	-	U. S. Army Research Center
ASAP	-	Advanced Scientific Array Processor
AZ	-	Azimuth
BMDATC	-	U. S. Army Ballistic Missile Defense Advance Technology Center
BPI	-	Bits Per Inch
CCD	-	Charge Coupled Device
CDC	-	Control Data Corporation
CDR	-	Critical Design Review
CRT	-	Cathode Ray Tube
DBMS	-	Data Base Management System
DEC	-	Digital Equipment Corporation
DIP	-	Digital Image Processor
DP	-	Data Processor (Processing)
EL	-	Elevation
ERTS	-	Earth Resources Tracking Station
EROS	-	Earth Resources Orbiting Satellite
ESL	-	Electromagnetic System Laboratory
FORD	-	Formatting of Raw Data
FOV	-	Field of View
GBM	-	Ground Base Measurement Program
HP	-	Hewett-Packard
IBM	-	International Business Machines Corporation
IDMS	-	Interactive Digital Manipulation System
I/O	-	Input/Output
IPS	-	Inches Per Second
IR	-	Infrared
IRAS	-	Infrared Astronomy Satellite

I^2S	- International Imaging System
JISWG	- Joint IR Science Working Group
JPL	- Jet Propulsion Laboratories
LWIR	- Long Wave Infrared
MAPS	- Mission Planning and Analysis System
MBPS	- Millions of Bits Per Second
MWIR	- Medium Wave Infrared
NASA	- National Aeronautics and Space Administration
PCM	- Pulse Code Modulation
PDR	- Preliminary Design Review
RAM	- Random Access Memory
RV	- Re-entry Vehicle
SDAS	- Scientific Data Analysis System
SIRE	- Satellite Infrared
S/N	- Signal-to-Noise Ratio
SWIR	- Short Wave Infrared
TV	- Television (Raster Scan)
USC	- University of Southern California