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MEMORANDUM REPORT NO. 2790

AN INFRARED DATA ACQUISITION AND PROCESSING SYSTEM

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September 1977

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USA ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
USA BALLISTIC RESEARCH LABORATORY
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report presents a description of the BRL Infrared Data Acquisition and Processing System (IRDAPS). The description includes a discussion of the IRDAPS System hardware, system operating software, project oriented special software and its application to high energy laser beam diagnostic measurements. The report also points out that since the IRDAPS contains a flexible FORTRAN language based computing system, it is well suited to the general data acquisition and analysis area.

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I. INTRODUCTION

A. Background

Over the past several years the Ballistic Research Laboratory has conducted a series of experiments to determine spatial intensity distribution fluctuations, as functions of range and meteorological conditions, in a laser beam propagating in the near-earth atmosphere. The earlier of these experiments were conducted using low power HeNe lasers as the beam source and photographic emulsions as the detection and data storage medium. For the past three years, however, emphasis has been largely in the area of high energy, longer wave length devices such as the Tri-Service Laser (TSL), the Baseline Demonstration Laser (BDL) and the Navy ARPA Chemical Laser (NACL). The TSL is a gas dynamic laser operating at 10.6 micrometers. The BDL and NACL are chemically driven HF/DF lasers developed by TRW. Nominal operating wavelengths are 2.8 micrometers HF and 3.8 micrometers DF.

These wavelengths are well beyond the spectral response of photographic films. Moreover, power levels are sufficiently high so as to preclude use of direct "in the beam" types of imaging systems. Therefore, the spectral region of interest dictates some form of electronic detection while the high power levels involved dictate a non-interference imaging technique.

In response to these requirements the BRL has developed (1) an Infrared Scanning Camera (IRSC) and (2) an Infrared Data Acquisition and Processing System (IRDAPS). The IRSC utilizes the scatter component from optical surfaces in the beam path to form instantaneous images of the beam intensity distribution. The IRDAPS records and processes, *in situ*, the beam intensity distribution data from the IRSC and other infrared cameras. Also included in the system is a capability to acquire, process and correlate with the beam intensity pattern, meteorological data representing conditions along the beam path.

Although application of the IRDAPS to date has addressed, primarily, the high energy laser beam diagnostic problem, it should be noted that the IRDAPS contains a flexible FORTRAN language based computing system, well suited to the general data acquisition and analysis area.

The subject of this report is the IRDAP System. The Infrared Scanning Camera (IRSC) development has been previously described[1]. In this report, we discuss the IRDAP System hardware, system operating software, project oriented special software and its application to the high energy laser beam diagnostics problem. A functional diagram of the IRDAP System is presented as Figure 1.

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[1] *Alcaraz, E. C., Reedy, M. T., and Evans, J. M., "A High Speed Determination of a High Power CW Laser Beam Irodiance Profile," Proceedings of Fifth DOD Conference on Laser Technology (SECRET), Vol. I, pp 487-493, April 1972.*

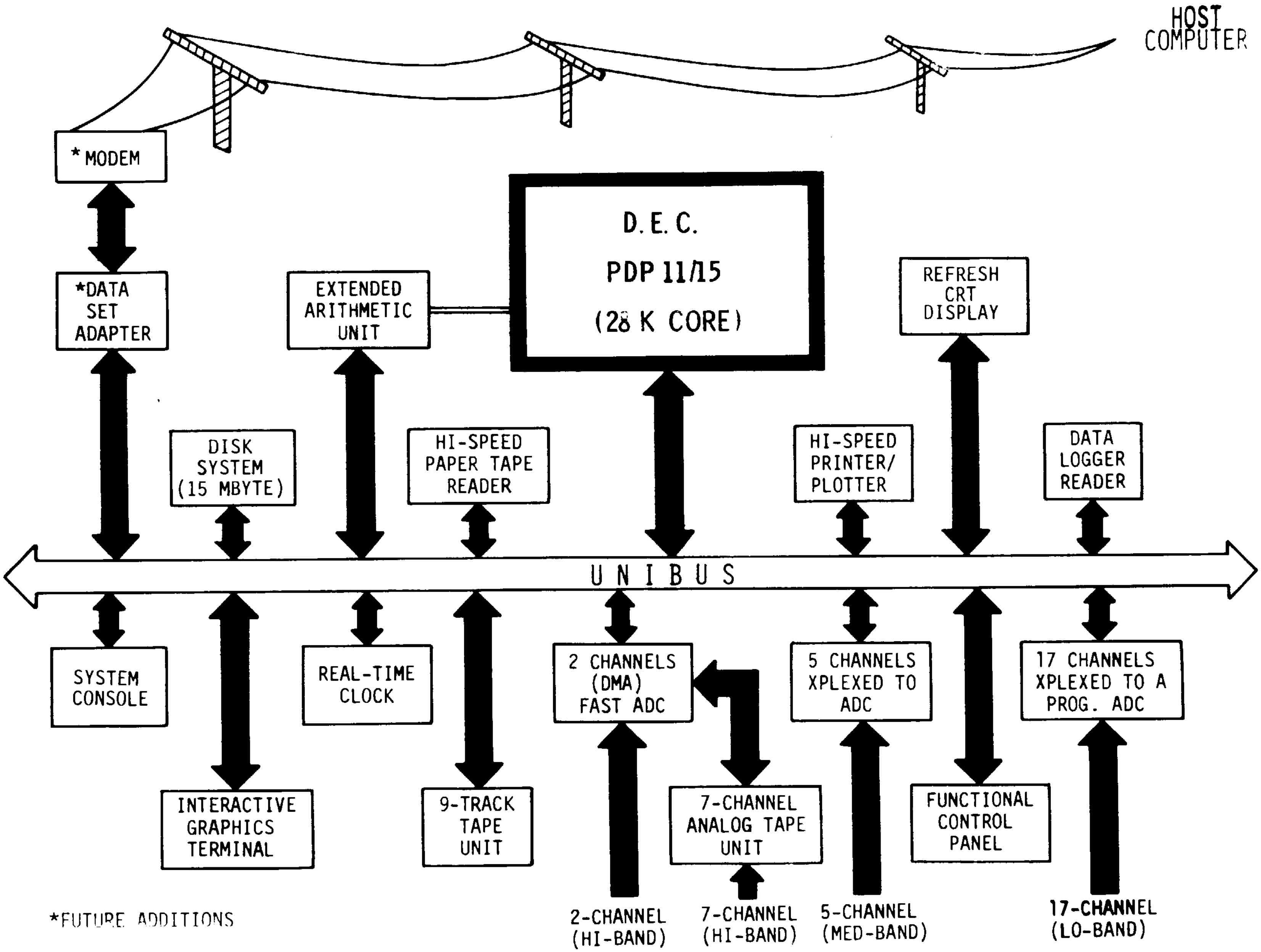


Figure 1 shows a functional diagram of the IRDAP system.

B. Current Applications

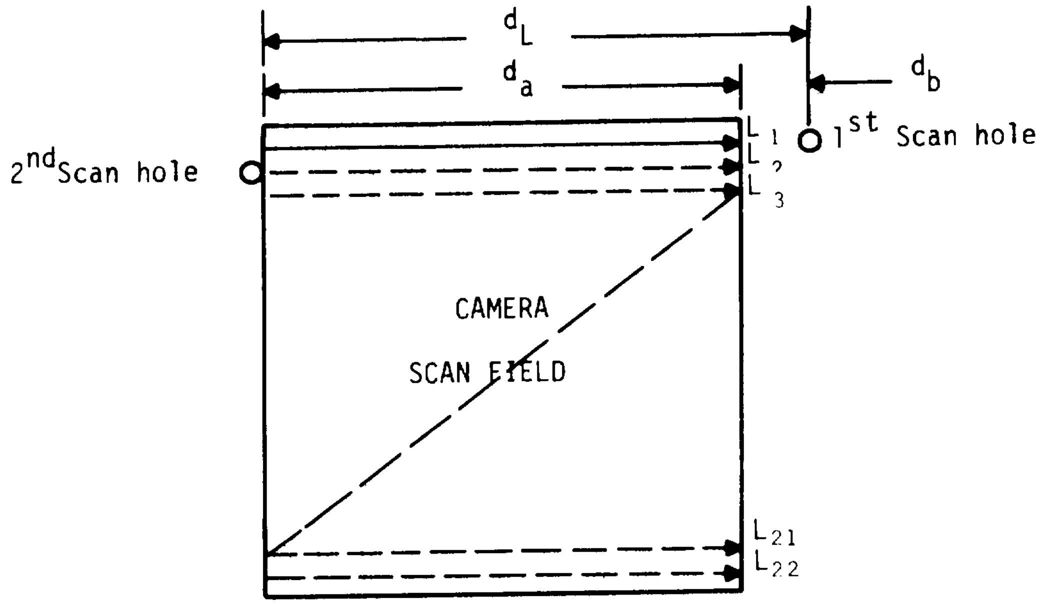
During the past three years the IRDAPS has been heavily involved in inter-service HEL programs at TRW, Capistrano Test Site (CTS), San Clemente, CA and at the Redstone Arsenal, Huntsville, AL. In all of these experiments either the previously mentioned BRL-IRSC or one or more of the similar Edgerton, Germeshausen and Grier (EG&G) Beam Diagnostic Scanners (BDS) have been utilized to generate beam profile data. The IRDAP System, due to its powerful and versatile processing capability, has successfully kept pace with the ever-changing complex data processing and analysis requirements associated with HEL beam diagnostics.

Because real time acquisition and fast, on site processing of these complex data demonstrates more fully, the "real world" functional aspects of IRDAPS we will take advantage of this and, in the IR Camera Data Management Section, trace a "typical frame" of IR Camera Data through the system from acquisition to final calculations and plotting. To supply background information needed to follow and fully understand this process a detailed description of the IRSC output data format is in order.

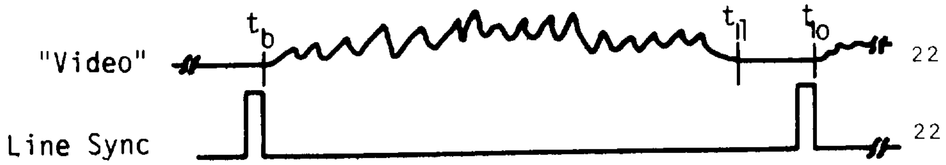
Figure 2a illustrates a typical "rastered" frame from the BRL-IRSC. The frame is generated by scanning the data field from left to right, top to bottom. The scanning aperture separation in the horizontal direction is made slightly larger to create a mechanical blanking period during which line synchronization (hereafter abbreviated to sync) information is generated. Frame sync is generated at the end of each complete frame, i.e., after N scan lines have been produced, where N = 22 for the BRL-IRSC and N = 27 for the EG&G-BDS. Interframe blanking, equal to one line period, is provided by eliminating the N + 1 scan aperture. Figure 2b illustrates the phase relationship between the "video" data and the line sync information. Figure 3 illustrates the phase relationship between the frame sync, line sync and "video" data from the BRL-IRSC. Proper maintenance of this phase relationship is crucial, since the IRDAPS digitization process uses the line and frame sync pulses as delimiters to maintain "video" format control. This process will be discussed more fully in the IR Camera Data Management Section.

The three IR Camera signals, frame sync, line sync, and "video", are produced as separate outputs and are recorded individually by IRDAPS during the data acquisition phase. During the processing phase, the frame and line sync pulses are used to drive logic gates which control the analog-to-digital conversion process.

The IRDAP System will accept input data from all cameras having an output format such as that just described. Frame rates may be anything up to 500 FPS for a 27 line per frame format. Trade offs, allowing a greater number of lines per frame at reduced frame rates are possible.



a. Typical IR Camera Scan Field



b. Video-Line Sync Phase Relationship

d_L = Scan hole horizontal separation

d_b = "Video" blanking distance

d_a = "Videa" line length = t_1

Figure 2a illustrates a typical "rastered" scan; 2b shows the phase relationship between the "video" data and the line sync information.

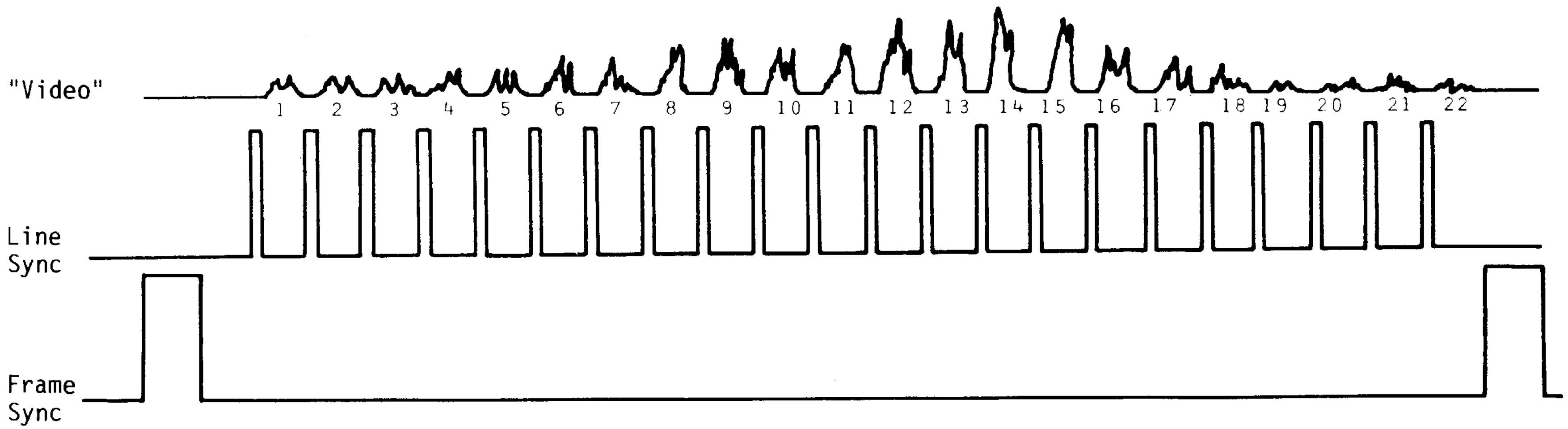


Figure 3 illustrates the phase relationship between the frame sync, line sync, and video data from the BRL-IRSC.

II. SYSTEM DESCRIPTION

A. Analog Section

The analog section of IRDAPS is composed of a single Honeywell 7600 Instrumentation Tape Recorder interfaced to the system "video" inputs. The main function of this unit is to provide bandwidth compression for the high speed IR Camera data. Bandwidth compression is accomplished by first recording the data at full (real time) bandwidth and then playing it back for processing at rates commensurate with the IRDAP system data throughput capability.

The Honeywell 7600 presently in use is an intermediate band recorder with a FM data bandwidth of 80 Khz at 120 ips tape speed. Frequency response is down 6 db at 100 Khz. This imposes a resolution limitation for camera data beyond 90 Khz (-3db point for this recorder). Projected utilization of IR Cameras at frame rates to 500 FPS will require recording bandwidths of 450 Khz. Therefore, to upgrade the analog portion of IRDAPS, a Honeywell Model 96, Wideband Group II Recorder has recently been purchased to replace the model 7600 unit. The model 96 has a FM data bandwidth of 500 Khz with full 14 track record/reproduce capability. This new addition will allow simultaneous recording of wideband data from two IR Cameras - a requirement identified during the recent Damage and Vulnerability Series I at TRW, CTS, San Clemente, CA.

In addition to the recently procured Honeywell Model 96 analog recorder, a High Density digital tape unit is planned. This unit will increase the system throughput by a factor of two, thereby, allowing faster processing of high speed data.

B. System Hardware

Referring again to the functional diagram of Figure 1 we see that a Digital Equipment Corp. (DEC) PDP-11/15 minicomputer with 28K of core memory drives the digital section of IRDAPS. Acquisition of meteorological data and processing, display and recording of all data are controlled by the minicomputer. Mass storage is provided by a Computer Labs Dual Disk System with two megaword capacity. Following is a list of 20 major system components:

- Minicomputer: Digital Equipment Corp. PDP-11/15 with 28K core, large system capability option KH-11 processor and extended arithmetic element.

- Disk System: Computer Labs Model 3002 Dual Drive - includes an eight drive controller.

- Computer Display Storage Terminal: Tektronix Model 4014-1 Direct View, Storage Tube Type.

- High Speed Printer/Plotter: Versatic Model D1200A with simultaneous print/plot option.
- Digital Tape Unit: Digital Equipment Corp. Model TU-10 - 9 track.
- High Speed Paper Tape Reader: Remex Model RRF6300 - 300 character/sec.
- Refreshed type CRT Display: Tennecomp Model TP 5600 with Hewlett Packard Model 1300A CRT and Tennecomp Model TP-1305 light pen.
- Functional Control Panel: Tennecomp Model TP-5000.
- Real Time Clock: BCD - one millisecond resolution. Systron Donner Model 8350.
- Data Logger Reader: Datel Model DL-2R.
- High Speed Analog-to-Digital Converter: Unipolar, 8 bit(2 ea).
- Medium Speed Analog-to-Digital Converter: 5 channel multiplexed, bipolar, 12 bit.
- Low Speed Analog-to-Digital Converter: 17 channel multiplexed, bipolar, 12 bit.
- Analog Tape Recorder: Honeywell Model 7600 (soon to be replaced with a Honeywell Model 96).

In the following paragraphs the salient features of each major system component is noted and a discussion of functional operation presented.

PDP-11/15 Minicomputer The IRDAPS minicomputer is equipped with 28K of core memory and an extended arithmetic element. These features, plus a large system capability option (KH-11 processor) provide the necessary computer hardware, which in conjunction with appropriate software and peripherals, makes the IRDAPS one of the most powerful, field portable, processing and analysis units currently in use in the HEL field.

Disk System The Disk System, used for program and intermediate data storage, consists of a dual disk drive with one fixed and one removable (type 2315) disk plus a controller with a capacity to handle four dual drive units. Total storage capacity is 2.048 million, 16-bit words. Each disk has 100 tracks per inch and a packing density of 2200 bits per inch (bpi). The disk system operates under DOS/BATCH Software Control-providing a means for fast and efficient entry of operating software programs and intermediate manipulation of experimental data. Two additional dual drives are presently being installed. This will increase storage capacity to 6.144 megawords.

Computer Display Storage Terminal The Tektronix 4014-1 Computer Display Storage Terminal, with the Enhanced Graphics Module (EGM), is an extremely versatile peripheral which functions as 1) the system console, 2) a conversational I/O device, and 3) an interactive graphics terminal. The 19 inch by 11 inch direct view storage tube can display up to 8512 alphanumeric characters (64 lines at 133 characters per line) or draw vectors at 5000 inches per second. The keyboard can send 96 characters, which include the full ASCII upper and lower case set. The EGM allows 12-bit addressability (4096 x 4096) of the display screen, dotted and dashed vectors, incremental plot, point plot and control of beam brightness. In the interactive graphics mode the computer can read the coordinates of a thumbwheel-controlled cross-hair cursor. As a conversational I/O device, the 4014 is used to preview data output for possible modification of program parameters before outputting to the line printer. Finally, the 4014 can emulate a Calcomp plotter.

High Speed Printer/Plotter The Versatec D1200A Printer/Plotter with simultaneous print plot option is the system's primary output device. It serves as the system line printer as well as the system plotter. Moreover, it serves as a hard copy device for the Tektronix 4014 Terminal. The D1200A uses an electrostatic matrix writing technique for printing and plotting. In the print mode it operates at 500 lines per minute. Resolution for both printing and plotting is 200 points per inch.

Digital Tape Unit The output tape unit is a Digital Equipment Corp. Model TU-10 transport with a TM11 controller. The write format is industry compatible 9 track maximum transfer rate, upgapped, 36000 characters per second. Packing density is 800 bits per inch. In a write operation, 8-bit data words are transferred from core memory to data buffer in the TM11 controller. When the 8-bit buffer is filled the buffer logic supplies the character to the tape transport write logic for recording. The TU-10 presently serves as the system long term data storage device.

High Speed Paper Tape Reader The Remex RRF-6300 Paper Tape Reader is used to read in system diagnostic programs and for building system libaries. Read rate, from fanfold paper tape, is 300 characters per second. The present interface also contains the necessary electronics to allow addition of a high speed paper tape punch.

Refreshed CRT Display The Tennecomp TP-5600 display system is a refresh-type CRT point plotting device which operates on a Direct Memory Access (DMA) basis. The display system contains no display processor and, therefore points to be displayed must be stored consecutively in core. The display section must then be instructed to perform a display cycle, i.e., display a specified number of points on the CRT. After completion of each display cycle the system halts and will not resume the display until a new display cycle command has been initiated. Plotting speed is approximately 125,000 points per second.

Functional Control Panel (FCP) The FCP is a simple yet effective and useful device. Essentially it is an arrangement (Figure 4) of five groups of components (lamps and switches) interfaced to the PDP-11/15 computer and is used to control various programmed tasks. The panel contains seven status lamps (on/off), eight toggle switches (SPST), eight pushbutton switches (momentry contact), four rotary switches (12 position) and ten thumbwheel switches (10 position). The status lamps are read/write. All switches are read only. The pushbutton switches can be used to generate interrupts to the computer and are being used, presently, to control various functions such as digital tape initialization, starting and stopping the digitized program and controlling tape playback to the display system. The thumbwheel switches are used to set in title information which is recorded on the digital tape at the beginning of each data file.

Real Time Clock The Real Clock (RTC) fucntions both as a time code generator and a time code reader/converter. The RTC consists of a Systron Donner generator/reader, millisecond counter, and a computer interface. As a generator, the RTC is used as a precise clock which produces an IRIG B coded time signal for recording on magnetic tape as a continuous time reference. As a reader/converter, the RTC will monitor a reproduced IRIG B time code during tape playback and convert that time information into a BCD format of hours, minutes, seconds, and milliseconds. This time information can then be recorded, with experimental data, on digital magnetic tape. The RTC has a feature, also, which allows the computer to be interrupted at jumper selected precise intervals (presently jumpered for one ms intervals) for a variety of applications purposes.

Data Logger Reader The Datel Model DL-2R1 Data Logger Reader (DLR) is a self contained unit designed for reading Phillips-type magnetic tape cassettes recorded in standard high density format on the Datel Model DL-2 Data Logger System. The DLR presents binary data in parallel output format for input to the IRDAPS' PDP-11/15 minicomputer. Parallel output data are presented along with identifying information such as word type, channel group, etc. A clock word, recorded before each data file on the cassett tape, is also presented for time correlation of experimental data. The Datel System (Data Logger 2 and Data Logger Reader) is used, primarily, to record and process meteorological data pertinent to the particular experiment being conducted. Complete specifications and operational description are contained in DOC. No. MLR-MH1601, Data Logger Reader Operator's Instruction Manual.

High Speed Analog-to-Digital Converter (ADC) The High Speed ADCs are 8-bit, unipolar devices with a maximum conversion rate of 250 Khz. There are two such units in the IRDAP system accommodating two individual IR camera "video" inputs. Input range is 0 to + 5 volts. During the digitization of IR camera data these ADCs are driven by convert commands under control of the camera frame and line sync pulses. The data samples are taken only during the periods between line sync pulses. These data samples are stored consecutively, line by line, in core and the original field spatial format is maintained.

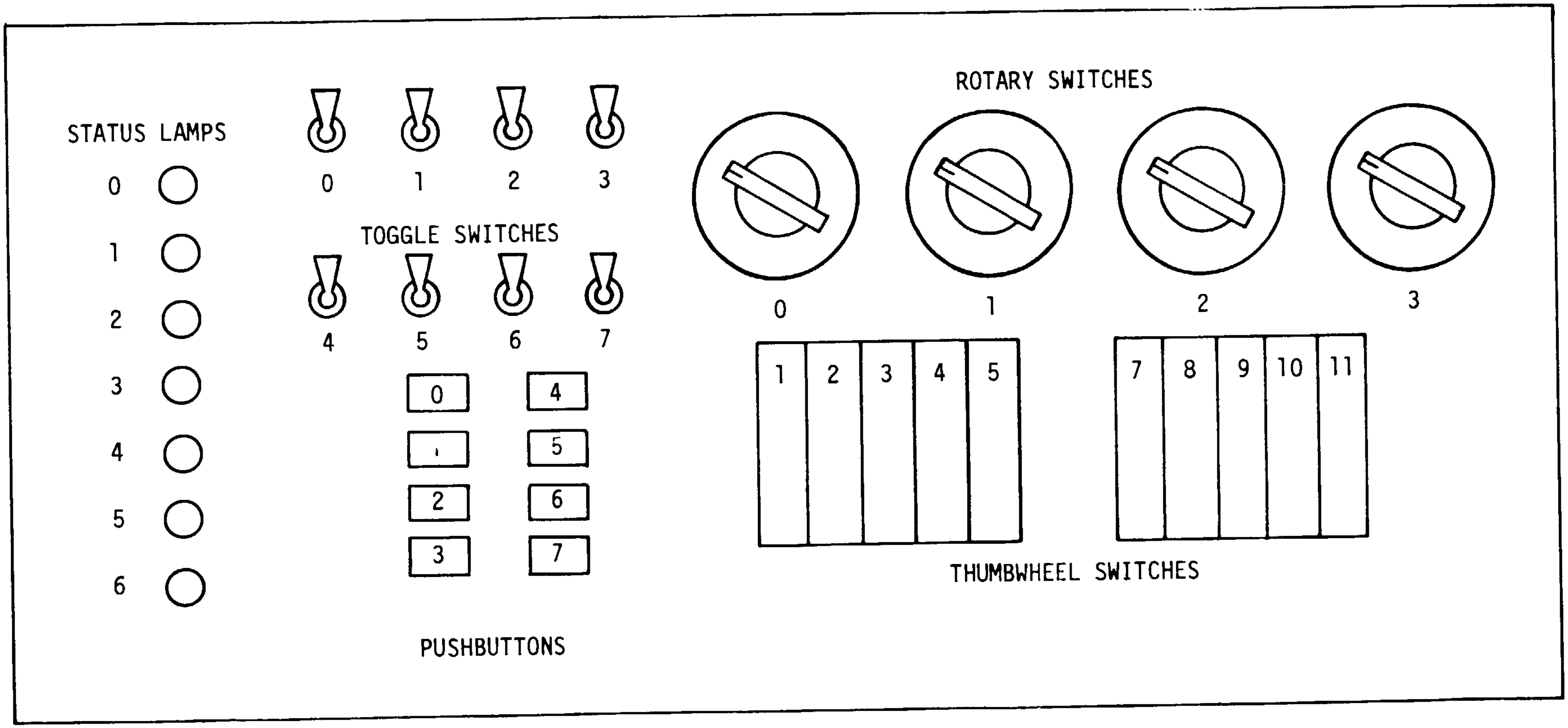


Figure 4 shows the FCP handler status lamps and switch panel.

Medium Speed Analog-to-Digital Converter The Medium Speed ADC is a 12-bit, five channel (switch selectable) multiplexed bipolar unit with a maximum input range of ± 5 volts. Maximum conversion rate is 10 Khz determined by a 100 Khz oscillator and a fixed divide by ten counter.

Other conversion rates, ranging from the maximum 10Khz to one sample every eight seconds are software selectable. The following table relates software selectable maximum conversion rates and rate divisions, number of operational channels (hardware selectable) and final per channel sample rates.

SOFTWARE SELECTABLE		NUMBER OF OPERATIONAL CHANNELS	PER CHANNEL SAMPLE RATE
MAX. RATE	INTEGER RATE DIVISOR		
10KHz	1-16	1-5	10KHz-125Hz
1KHz	1-16	1-5	1KHz-12.5Hz
100Hz	1-16	1-5	100Hz-1.25Hz
10Hz	1-16	1-5	10Hz-.125Hz

Low Speed Analog-to-Digital Converter The Low Speed ADC is a 12-bit, b~~un~~ipolar, 17 channel multiplexed unit with sample-and-hold capability. Input data, in the form of analog signals with maximum excursions between -5 volts and +5 volts, are fed through a network of 17 active low pass filters (one for each data channel). Bandwidth of the filters range from 50 Hz to 2 KHz. Filters may be interchanged, channel to channel, as desired. From the filters, signals are fed to a 17 channel multiplexer (MUX) which is under program control. Channels may be randomly addressed from software to facilitate super-commutation if desired. The output from the MUX passes directly into a sample-and-hold amplifier where it is held constant until the A/D conversion is complete.

The Low Speed ADC sample rate, up to a maximum of approximately 12000 samples per second, is determined by software timing loops. Hardware response limitations preclude rates beyond this range. A comprehensive discussion of the Low Speed ADC software implementation is reported elsewhere[2].

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[2] *Earl P. Weaver, The IRDAPS Programming Manual, BRL Report, to be published.*

C. System Software

The main reason for the flexibility and versatility of the IRDAPS in handling IRSC data and many other types of data is the fact that it is a programmable system. Although some very specialized programs must be written in PDP-11 assembly language, most applications programs may be written in Fortran. The repertoire of software currently in use by the IRDAPS is:

- DEC DOS/BATCH Operating System, Monitor Version 9C (DOS)
- Tektronix PLOT-10 and CALCOMP Preview Package
- Versatec VERSAPLOT I & II
- IRDAPS Specialized Software (ISS)

The IRDAPS presently uses the DOS software as the operating system. Most applications programs are written in Fortran and run under the auspices of DOS and are conversant with it. However, the ISS, when used, is always resident and does not communicate with DOS. Although the ISS could have been integrated with DOS, this was not done because various real-time constraints prohibit it from being managed by the generally slower DOS. This situation allows some services to be performed by either DOS or ISS, but it is obvious that the use of ISS is more practical.

The DOS is described in the DEC/DOS/BATCH Handbook, April 1974, and includes:

- MACRO, the assembler for PDP-11 assembly language
- FORTRN, the ANSII Fortran compiler (with extensions) and the Object Time System (OTS)
- EDIT, the text editor
- LINK, the linker
- ODT, the debugger
- PIP, the file processing utility package
- FILCOM, the file compare program
- VERIFY, the disk verify program
- FILDMP, the file dump program

The Tektronix software is described in the Tektronix Terminal Control User's Manual, DOC. NO. 062-1474-00. The TCS software is used for various applications requiring communication with the Tektronix 4014-1 in a mode other than that of a standard teletype-like device (the 4014-1 is supported by DOS only in the form of an ASR-33 Teletype). The PLOT-10 software essentially forms the basis for a complete system of alphanumeric and graphics input/output routines for use with the 4014-1.

This software includes the CALCOMP Preview Package which has the capability to emulate a Calcomp plotter on the 4014-1.

Similarly, the Versatec software is a subroutine system for graphic output to the Versatec D1200A printer/plotter (as a printer, the D1200A is supported by DOS in the form of a DEC-LP-11 line printer). With this software, any general purpose graphic program can be written by describing vector plots as one would make with a pen. This software is documented in the VERSAPLOT Graphics Programming Manual - 50001 - 90003. For comparability with the Tektronix PLOT-10 CALCOMP preview feature, Versaplot II is a compatible extension of pen, Calcomp like, plotter software (Versatec, Versaplot II Pen Plotter, Emulation Library 500010-90001A).

III. IRDAPS SPECIALIZED SOFTWARE

A complete description of the ISS appears in another BRL Report[2], the IRDAPS Programming Manual, hence only an overview will be presented here.

The current ISS is typified by its simple, concise approach to expedient efficiency. Since real-time constraints were placed on many operations, every effort was made to program for optimum efficiency. And in contrast to standard systems programming practice, very little error checking is done by the subroutines. For example, subroutines do not check on the leaglity of parameters passed to them, nor do they check for device hardware errors. The reason for not having the subroutines check for illegal parameters is obvious when one considers that the system can be operating under severe time constraints and recovery from such errors would be impossible without loss of experimental data. Instead, it is left to the programmer to thoroughly debug and test his programs before using them in critical situations. When hardware errors do occur (very rarely) during real time acquisition, any data lost is irrecoverable (except) possibly for magtape parity errors, in which case the magnetic tape can be backspaced and rewritten if the incoming data rate is not too fast).

The ISS comprises five classes of applications:

- FCP and, high-speed ADC handlers
- Magnetic tape operations
- CRT display programs
- Arithmetic subroutines
- Housekeeping programs.

The FCP handler is a Fortran-callable subroutine named FCP which can read the positions of the FCP switches, or read, or turn on or off the FCP status lamps. Each call to the FCP subroutine causes communication with any one of the five groups or components (Figure 4).

The switches and lamps can be used to control various programmed tasks limited only by the imagination of the programmer. Typically, the FCP is used to start and stop the digitizing of IRSC data, or to control the display of the digitized IRSC data being reviewed on the CRT from magnetic tape.

VIDEO is a subroutine which controls the high-speed ADCs. VIDEO is used only for digitizing (one frame at a time) IRSC data. Each call to the VIDEO subroutine causes one frame of IRSC data to be digitized and stored in core in 8-bit samples. The arguments in VIDEO tell the selected ADC how many samples to take for each line and the total number of samples to take per frame. The digitizing process operates on a block transfer basis under direct memory access. VIDEO functions with either real-time data or recorded data played back from analog tape.

The Fortran-callable magnetic tape operations subroutines are used to command the digital tape unit to perform reading, writing, and spacing operations. Although DOS performs the same operations, these ISS subroutines are special purpose, for use only with digitized IRSC camera data, and operate independently of DOS. They are more efficient than their DOS counterparts because the DOS routines are very general in nature and require proper (and lengthy) protocol for their use. The ISS magnetic tape subroutines operate on fixed-format binary records--the most efficient mode of operation for magnetic tape. The subroutines are named:

- SPF - space forward one record
- BTAPE - space backward one record
- FTAPE - write one record
- IRTAPE - read and translate one record into integer form
- EOF - write an end of file record (EOF)

A record corresponds to a frame of digitized IRSC data along with other pertinent information. For example, the record length for a frame of EG&G-BDS data is 1472 characters and includes the run number, a code number, the frame number, time of day in hours, minutes, seconds and milliseconds, and 1458 8-bit samples from a 27-line field at 54 samples per line. All the records for a run, i.e., the number of frames digitized, are organized into a file on magnetic tape. Files are separated by an EOF record. Figure 5 shows the magnetic tape file structure for IRSC data. Following the last file on the tape are two extra EOF records. Three EOF records in a row mark the logical end of the data.

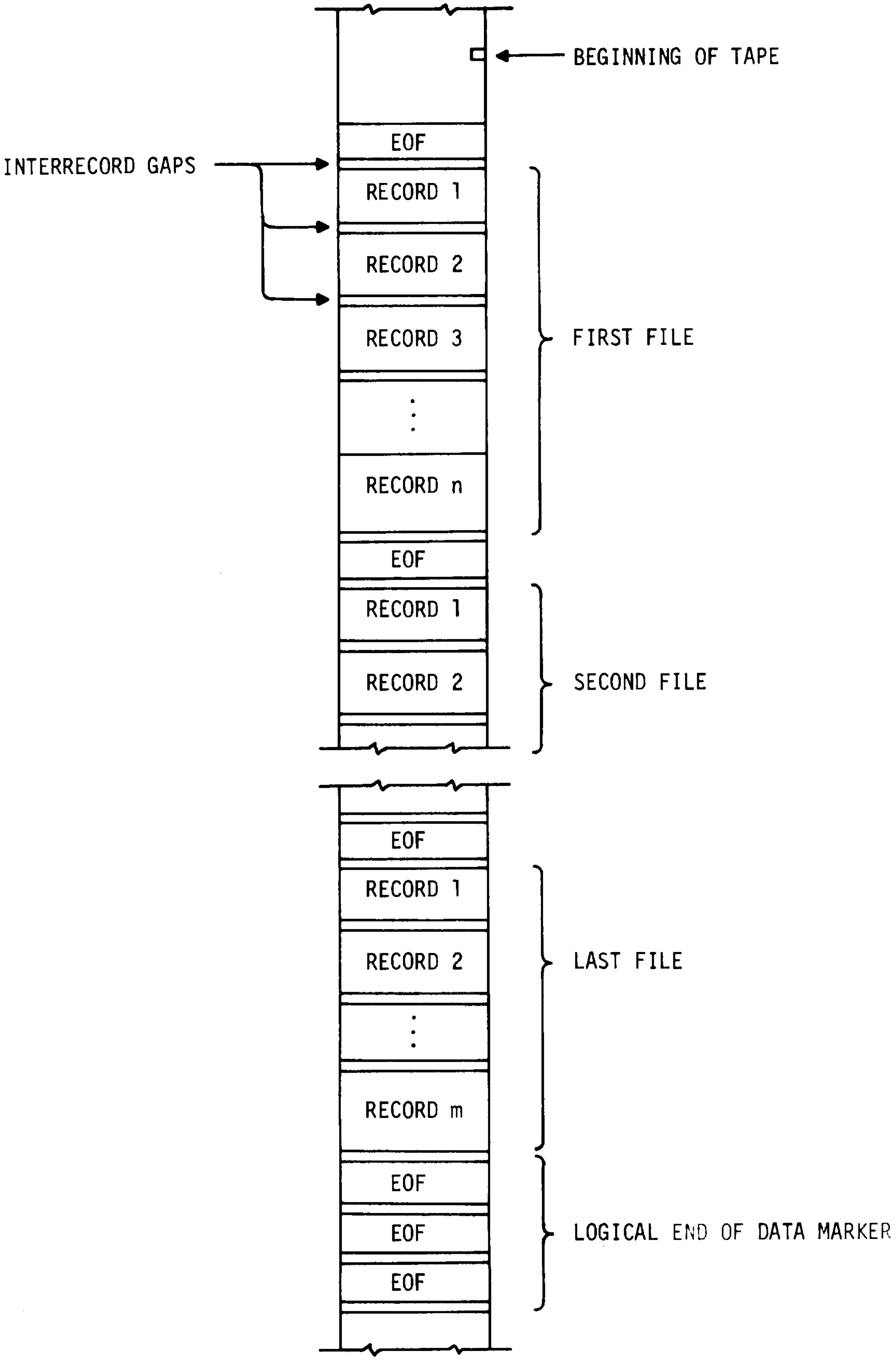

Figure 5 shows the magnetic tape file structure for IRSC data.

This logical end of data marker is used to position the tape for subsequent writing. The tape is positioned such that the last two EOF records are overwritten when another data file is added.

There are two CRT Display Programs, MONITOR and REPLAY. Both present an isometric representation of an IRSC master image as shown in Figure 6. The top line and the left edge of the displayed image correspond respectively, to the first line and left edge of the IRSC field. Since the refreshed CRT is a point plotting device, both programs "Smooth" the data by placing a linearly interpolated point between each real data point. Note that the "smoothing" is done only to make it easier for the viewer to conceptionalize beam intensity profiles. The interpolated points do not, at any time, appear in the analytical data.

MONITOR has two functions: (1) to continuously display real-time IRSC data at a rate of approximately 50 frames per second, and (2) to provide a playback display for previewing the IRSC data recorded on analog tape. During a test, MONITOR, as its name implies, acts as a monitor for the IRSC data. At other times MONITOR is useful for various calibration functions, such as determining the IRSC field of view as seen by the IRDAP system. During replay of the analog tape, MONITOR is used to preview and edit the data before digitizing and recording magnetic tape.

Replay displays an IRSC representation similar to that of MONITOR except that the raster image is constructed from the digitized IRSC data previously recorded on magnetic tape. REPLAY also presents the run and frame number of the data being displayed as well as other coded information indicating conditions under which the data were recorded and processed, e.g., experiment identification, analog channel numbers, gain levels, etc.

The Fortran-callable arithmetic subroutines, CLEAR, EXCHNG and DPIADD form a simple but extremely useful class of the ISS. They were developed during the Joint Army-Navy (JAN) Propagation Series in an effort to speed up the execution of an earlier Fortran application program, PROOF. The original PROOF program did all of the IRSC data computations in floating point. Since the computer is not equipped with a floating point hardware option. It must do all floating point operations by software. This required ~~a~~ many program instructions for each iteration and is, therefore, rather slow.

A method whereby the number of instructions required in the iterative section is minimized is to use integer arithmetic. This method is easily implemented in this case since all iterative computations involve only simple summations. Also, since all data are ≥ 0 we need be concerned only with positive integers. The PDP-11/15 uses one 16-bit work to represent an integer number, and because of its 2's complement notation the largest positive value an integer can assume is 32,767. This places a severe limitation on the total number of frames of IRSC data that can be summed.

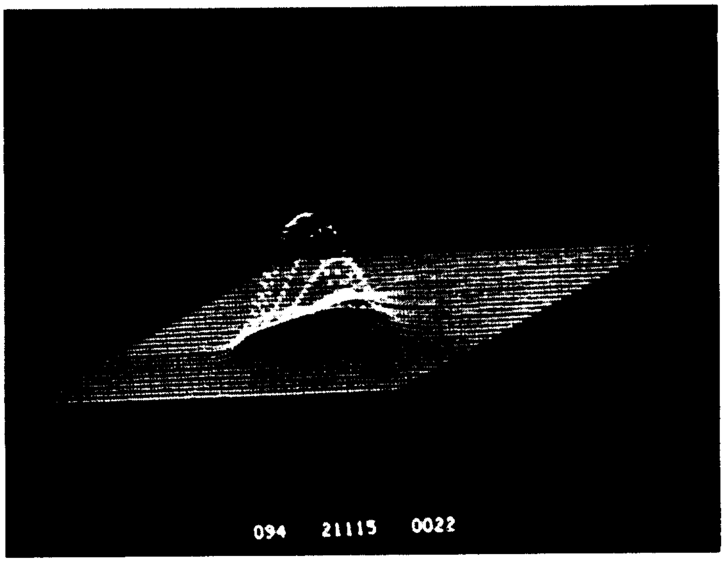

Figure 6 illustrates a typical IRSC raster image as viewed on the system CRT.

The arithmetic subroutines overcome this limitation by taking advantage of the fact that all IRSC data are ≥ 0 and using two 16-bit words to represent an integer number. This increases the number of frames which can be summed from 128 to 16,843,000 frames. The use of these subroutines increase execution speed (per frame) by a factor of 3. Since almost all applications programs integrate (sum) the IRSC data, these subroutines are indispensible for insuring timely reduction of experimental data.

IR Camera Data Management

The main objective of laser beam diagnostics is to quantify the spatial intensity distribution of the propagated beam as a function of time for correlation with target damage results and/or with theoretically predicted propagation effects. Ordinarily these measurements are made as close to the target as is practical in order to minimize measurement error resulting from geometric extrapolation to the target plane. Ideally, these measurements should be made directly in the target plane so that extrapolation is unnecessary. A typical example of a beam diagnostic experiment designed to measure peak and average beam power centroid motion, coordinates of the peak intensity, etc. for correletion with target damage results is shown in Figure 7. The diagnostic mirror is located in the target plane for the first second of "beam on". The mirror is then automatically removed and replaced by a succession of appropriate targets. Scattered energy from the diagnostic mirror surface is imaged by the IR camera optical system and scanned in fashion by an aperture wheel located in the camera focal plane. A field lens, located behind the aperture wheel, collects and focuses the scanned energy onto a suitable detector. The detector output is, therefore, an analog representation of the intensity profile of the impinging high energy beam.

Referring to Figure 2 note that the camera output timing is such that data is blanked for some fractional portion of each scan line. This feature is mechanically designed into the IR camera to allow time for generation of line sync information necessary to control the A/D conversion process and hence the spatial reformatting of data after processing. Frame sync pulses, also necessary for format control, are generated at the end of each data field. Blanking, during this period, is provided by simply eliminating one of the scanning holes, thereby, allowing one scan line period per "field" during which frame sync information may be generated.

The IRDAPS' High Speed, or "Video", ADC control circuitry use the IR camera frame and line sync information to control the digitizing process. Furthermore, each ADC may be driven from either of two separate clocks. Thus, the system can accomodate any one of four individual camera configurations. For example, by timing each of the four ADC clocks to properly sample the "video" data from a particular camera, the tedious taks of retiming the system for each different camera format is eliminated.

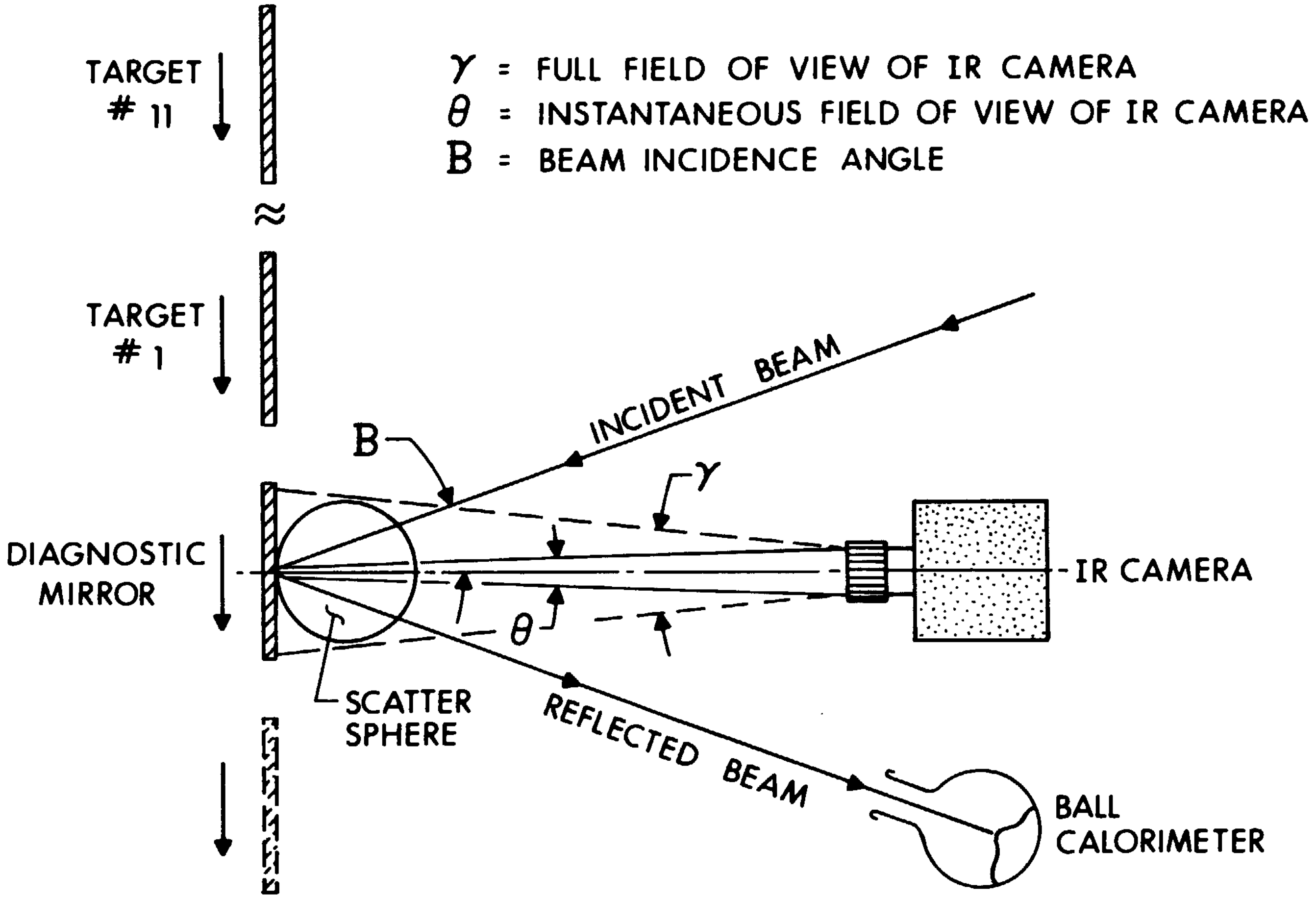

Figure 7 shows a typical example of beam diagnostic experiment.

The system is presently timed to properly process data from the BRL-IRSC and from the EG&G-BDS. [One of the remaining two clocks will be used, in the future, to process AGA camera data]. The BRL-IRSC is a 200 FPS, 22 line per frame unit. The EG&G- BDS is a 125, 250 or 500 FPS unit with 27 data lines per frame, while the AGA camera operates at 16 FPS and has 80 lines per frame. This wide range of frame rates and attendant high data bandwidths are accommodated by first recording the data on an FM-analog tape and then playing it back at reduced rates for processing. As one example of this technique, consider the following:

The BRL-IRSC has a frame rate of 200 frames per second and 22 scan lines per frame. Total frame time, therefore, is 5 milliseconds, and total time to scan one line is 5 ms/22 lines = 227 microseconds per line. Allowing 10 microseconds during which line sync information is generated, the total data line time is 217 microseconds. This particular camera is designed to have 22 resolutions elements per line, i.e., each scan line is 22 scan aperture diameters long. The data sample rate (F_s), is determined from the sampling theory relationship $F_s = 2\ F_m$, where F_m is defined as the reciprocal of the time required for a scan aperture to traverse its own diameter. Thus, if there are 22 elements per line the sample rate is 2 x 22 = 44 samples per line. It follows, therefore, that the time t_s per sample is 217 μs per line/44 samples/line = 4.93 μs/sample and real time sampling frequency is 1/4.93 μs ≃ 203 K samples per second.

The IRDAP system data throughput rate is limited by the writing speed of the output magnetic tape unit. Write rate for a gapped tape is approximately 20K, eight bit words per second. Thus, it becomes necessary to reduce the data rate by 203/20, or a factor approximately equal to ten. In order to maintain maximum fidelity, the analog data are recorded at the highest tape speed available, which, in this case, is 120 inches per second. A ten-to-one reduction, therefore, requires a playback speed of 12 inches per second. However, analog tape speed step changes are generally binary by design and the next speed reduction available which is equal to or greater than 12 is 7.5 inches per second. This gives 16:1 record/playback ratio and a corresponding reduction in required sampling frequency which satisfactorily maintains the data rate well within the system throughput capability.

The following discussion will trace a typical camera data frame through the digitizing and recording process.

The "Video" channel from the analog tape, upon playback, is fed directly to the data input of the high speed (video) ADC. Before digitization of the data can proceed, however, several events must occur in proper sequence. First, the ADC subsystem is initialized as the software program loads the ADC control status register with information containing the required number of samples per line and the required number of samples per frame. This information is required to properly maintain organization of the data. This will become clear as we proceed, step by step, in the following paragraphs.

After system initialization, the first frame sync pulse to arrive sets a flip-flop which enables a second flip-flop to be set by the first line sync pulse. The output of the second flip-flop is used to gate a variable rate clock, preadjusted to produce the proper sampling rate for the particular camera configuration in use. When the system is operating in real time (MONITOR Mode) the clock pulses are sent directly to the ADC and thus serve as convert commands. When operating in the digitize mode (playback from analog tape) the clock pulses are sent to a divide-by-sixteen counter before being passed as convert commands to the ADC. This feature provides the required 16:1 data rate reduction.

As each suceeding data sample appears at the output of the ADC, a counter, preset by each line sync pulse to the proper number of samples per line, is decremented. When the counter reaches zero (proper number of samples have been taken), it issues a command which resets the line sync flip-flop which subsequently closes the variable rate clock gate and stops the convert command string to the ADC. Data samples are consecutively stored in two 8-bit buffers and transferred to core as one 16-bit word. The process is repeated until the proper number of samples per frame, set during initialization, have been taken and stored. At this time, the software program reinitializes the ADC subsystem and sets the state for the next data frame.

As the next frame of data is being digitized and stored in a different section of core, the first frame is written onto digital magnetic tape. This technique, commonly known as double or "ping-pong" buffering, is used to prevent loss of high speed continuous data during the tape write operation.

Once the data is on digital tape, the frame by frame permanent record can be used as input for a variety of data reduction, computational and plotting programs. For example, Figure 8 shows the results of a program which integrates (sums) laser beam data over a preselected number of frames, computes the coordinates of the centroid and peak of the spatial intensity distribution; makes a printer plot of various contour levels; computes the cross sectional area of the beam at various selected intensity levels and determines the flux (volume) through each level; computes the spatial variance of the frame by frame centroid and many other parameters of interest.

Figure 9 shows a plot of isoirradiance contours produced by IRDAPS. The plot represents the actual beam size, while the border surrounding it represents the actual camera field of view. Presented as Figure 10 is a three-dimensional representation of the same data, viewed from the left edge of the camera field.

```
 *** U. S. ARMY BALLISTIC RESEARCH LABORATORY ***
           RUN DATE: 30-NOV-76     16:12:54

      HIGH ENERGY LASER PROGRAM BEAM DIAGNOSTICS

        PROJECT:    UNFTP - D 8 V   II

NRL TEST: SHOT 43, ETS-2
COMMENTS:
NACL RUN VL2-104                CODE 22115
  31 FRAMES FROM   17 ON, TIME 15 28 10.868

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         111111111111111111111111111111111111111111111111111111
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COORD      X         Y
PEAK      5.153     5.643
CENT      5.381     4.610
VARIA     0.018     0.169
PK100     0.094
PK98      0.092
PEAK   5927.000

CONTUR         1         2         3         4         5         6         7         8         9
% PEAK       0.0       1.5      10.0      20.0      40.0      50.0      60.0      80.0      98.0
LEVEL      0.000    88.905   592.700  1185.400  2370.800  2963.500  3556.200  4741.600  5808.460
AREA     139.563    45.181    23.548    19.336    11.295     7.658     5.073     1.436     0.191
VOLUME 6.721E 04 6.334E 04 5.792E 04 5.420E 04 4.056E 04 3.069E 04 2.228E 04 7.812E 03 1.133E 03
```

Figure 8 shows a typical printer plot and data tab from the EG&G IR camera.

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HIGH ENERGY LASER PROGRAM BEAM DIAGNOSTICS
PROJECT: UNFTP - D & V II

SHOT 43, ETS-2

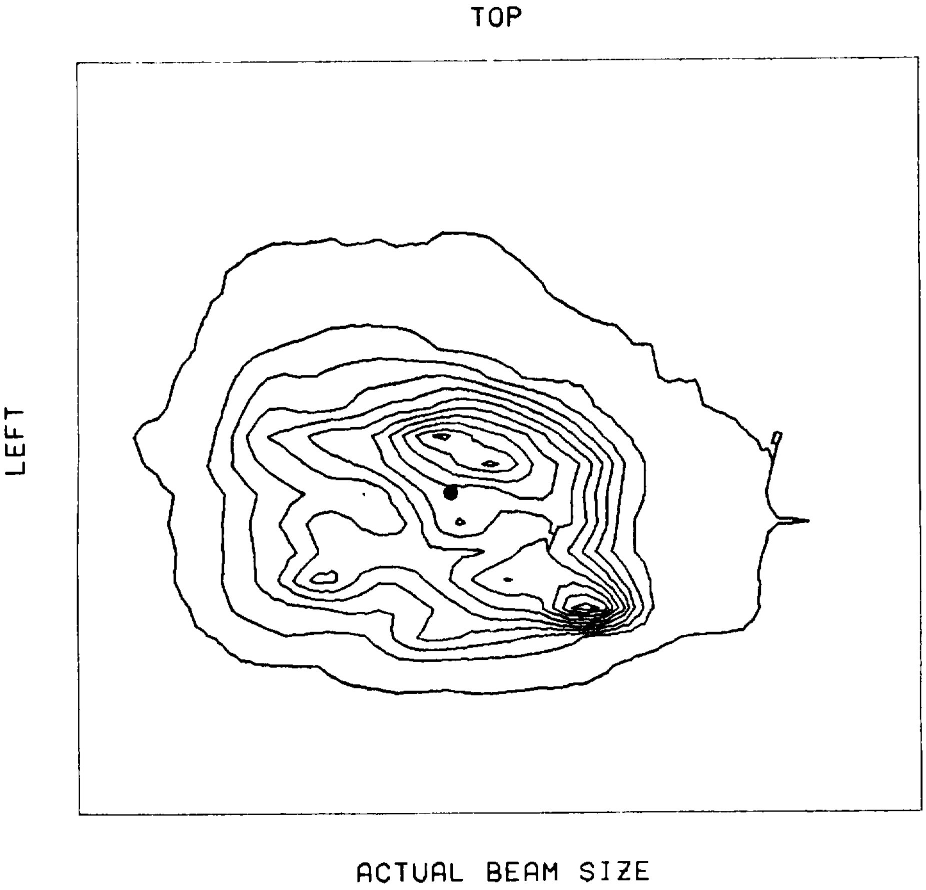

Figure 9 illustrates an isoirradiance plot generated by IRDAPS.

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PROJECT: UNFTP - D & V II

SHOT 43, ETS-2

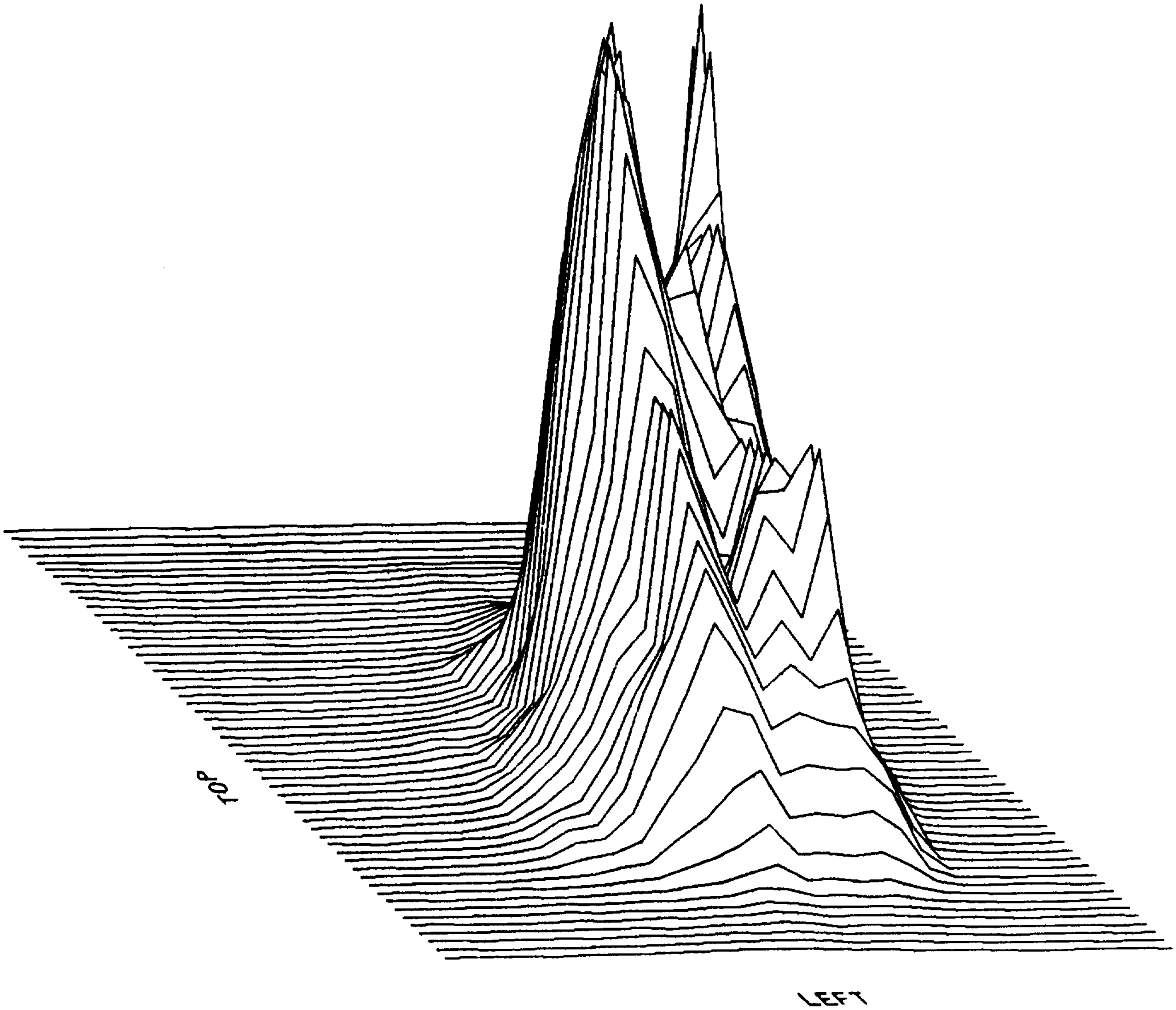

Figure 10 shows a three dimensional plot produced by IRDAPS

IV. SUMMARY

During the past few years the IRDAPS has been more or less dedicated to the task of High Energy Laser Beam Diagnostics. Demands from the HEL community have been heavy and consequently most of the applications software development has been directed toward better and faster analyses of laser beam phenomena. The system, however, is just as well suited to other non-HEL related tasks. The high degree of hardware sophistication makes it possible to generate and implement specialized software tailored to most any field experimental program. The multiple data input channels (24) and wide range of sampling rates (up to 250 Khz real time) plus a capability to time correlate all data, should make IRDAPS a natural choice for a multitude of remote field data handling tasks.

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