

DAVID FLORIDA LABORATORY THERMAL VACUUM DATA PROCESSING SYSTEM

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ABSTRACT

During 1991, the Space Simulation Facility, located at the David Florida Laboratory conducted a survey to assess the requirements and analyze the merits for purchasing a new Thermal Vacuum Data Processing System for its thermal vacuum testing facilities. A new, integrated, cost effective PC-based system was purchased and it uses commercial off-the-shelf software for operation and control. This system can be easily reconfigured and allows its users to access a local area network. In addition, it provides superior performance compared to that of the former system which used an outdated mini-computer and peripheral hardware.

This paper introduces the Canadian Space Agency's David Florida Laboratory then gives essential background on the old Data Processing System's features, capabilities, and the performance criteria that drove the genesis of its successor. This paper concludes with a detailed discussion of the Thermal Vacuum Data Processing System from its components, features, and its important role in supporting our space-simulation environment and our capabilities for spacecraft testing, here at DFL today. The Thermal Vacuum Data Processing System was tested during the ANIK E spacecraft test, and was in full operational mode at DFL in November 1991.

INTRODUCTION

Located on the outskirts of Ottawa at Shirley Bay, the David Florida Laboratory (DFL) is the Canadian Space Agency's facility for the assembly, integration, and environmental testing of both satellites and other space hardware (spacecraft). DFL is available to domestic and foreign companies or organizations involved in aerospace and telecommunications. DFL's integration and assembly areas comprise three large temperature- and humidity-controlled clean areas.

The thermal vacuum (TV) facility contains multiple TV chambers used for space simulation testing. The infrared (IR) testing system is used to test and verify the thermal design, and the workmanship of spacecraft. Our customers use DFL's vibration facility to perform vibration tests and our staff do vibration and modal analyses to ensure that spacecraft structural integrity is maintained. Finally, antennas and RF payloads are evaluated using our anechoic chambers.

BACKGROUND

The Old Data Processing System (old DPS)

The old DPS was in use for more than a decade before its performance became questionable. Attempts to improve its reliability and efficiency were disappointing because its configuration was out-of-date. The old DPS's hardware was three DEC PDP 11 minicomputers (one 11/23 and two 11/34s), three 5 Mb hard disk drives for system control and temporary data storage, one 800 bpi tape drive for data archival, and peripherals for sampling input data and displaying output data from the old DPS. In the event of a system failure, one of the minicomputers was ready as a backup to the primary. If left to continue operating, the old DPS's hard disk glitches and computer outages could compromise DFL's capabilities. DFL policy is to safeguard expensive spacecraft.

At DFL we made a survey of customers and staff to assess the requirements of a replacement system that met the new industry specifications and provides the means to continue to successfully bid against other aerospace testing facilities. The following discussion of the old DPS's capabilities will provide the background against which we established its successor, the Thermal Vacuum Data Processing System (TVDPS).

Old DPS Configuration and Capabilities

Software calibration curves to the 5th-order polynomial were done to all (64) telemetry input channels and half (384) of the available sensor input channels. At maximum configuration, the old DPS processed 64 telemetry input channels from two telemetry decommutation units as well as 768 sensor input channels from six dataloggers. Each datalogger processed a maximum of 128 sensor input channels. Sensor input channels used the standard inputs for thermocouples (TC), resistive temperature detectors (RTD), and voltage measurements, as well as special inputs such as calculations (averaging and rate-of-change determinations). As required by a TV test, alarm checking for all data was done and up to six sets of alarm limits were set by the users. Each set of alarm limits had four parameters such as low, lower, high, higher and all parameters, which could be modified during the test. A maximum of 420 old DPS outputs could be defined for CRT display; 168 of these displayed at any one time and of these, 45 were displayed graphically. In addition to its CRT displays, all old DPS outputs were displayed in either historical or single record hard-copy formats.

The old DPS temperature measurement system enabled temperatures to be accurately measured due to the configuration of the old DPS, the design of a Uniform Temperature Reference (UTR) block and case assembly, and the design of specialized feedthroughs. While maintaining a homogeneous temperature throughout all the attachment points, the UTR could accept up to 30 TCs. Two separate copper extension cable assemblies interfaced each UTR block to a datalogger. The reference temperature for the TCs therefore, became UTR temperature. This UTR temperature is measured by comparing it with a 0 °C reference TC immersed in an ice bath outside the vacuum environment.

Requirements For The New Data Processing System (TVDPS)

The TVDPS must be capable of processing in excess of 1000 channels simultaneously and meet the following criteria:

1. High reliability. To ensure reliable TVDPS software and hardware, and that the TV chambers could operate 24 hours a day, seven days a week
2. Maintainability. A maintainability program is always active to ensure that preventative and remedial maintenance is performed on equipment as specified or necessary
3. Flexibility. Able to interface to industry-standard data acquisition and control equipment, including programmable logic controllers, board-level A/D converters, dataloggers, and high-performance external A/D converters. Interface communications to be standard IEEE-488 (GP-IB) or RS-232 (serial) connections through either a SCSI interface, or shared-RAM plug-in boards.
4. Versatility. TVDPS to be modular, users could add features such as graphical display devices and drivers, data storage and management options, and custom programming utilities.
5. User interface. TVDPS to allow users to quickly and efficiently master system commands from our graphical user interface's pull-down menus – each supplemented with on-line Help and editor screens.

Market Research And In-House Testing Results

In 1991, during the ANIK E spacecraft testing, DFL staff finished the preliminary investigations into the requirements for the proposed TVDPS that could process more than 1000 channels simultaneously and meet the following:

The preliminary investigation used the following hardware:

- a file server (80386)
- a data acquisition computer (80286) with an 8-line serial interface to communicate with eight data loggers (Kaye)
- three user stations (80286/80386sx)
- Ethernet LAN cards and cabling
- a custom, serial I/O box for simultaneous monitoring of data loggers by both the old system and the new system
- Novell SFT Netware software.

Testing of the TVDPS software was performed by a software analyst using ASYST (scientific and engineering software that performs data acquisition using three type of interfaces, A/D, GP-IB/IEEE-488, and RS-232). ASYST tests on the TVDPS were done in parallel with the TV testing of the ANIK E satellites (Flight 1 and 2). Results were compared to those obtained from the old DPS. Although few software bugs were found in the TVDPS, testing results indicated that the TVDPS's reliability was satisfactory, its performance on the required tasks was slow but could be improved by using faster PCs (80386 or 80486) and state-of-the-art data monitoring software, and also using PC-based hardware and software that is capable of handling the functional requirements of a spacecraft data acquisition system.

The test results of the TVDPS allowed DFL staff to conduct a vendor survey of state-of-the-art data acquisition software. They reviewed the following software:

- Autonet by Imagination Systems Inc. (QNX)
- Scadix by Pioneering Controls Technology Inc. (UNIX)
- Labtech by Laboratory Technologies Corp. (UNIX)
- Paragon 500 by Intec Controls Corp. (DOS)
- FIX DMACS by Intellution Inc. (DOS)

As a result of the analysis, the Autonet software package was chosen to replace the old DPS software, mainly because Autonet met most of the listed requirements.

THE TVDPS TODAY

The TVDPS controls one or several TV tests while acquiring raw-data, performing real-time computations on raw-data, and storing both the raw- and massaged-data. The TVDPS's human-factors engineered operator interface and its system reports, test reports, and process information, is easily understood by the technician, computer operator, and customer. For research scientists and engineering personnel, the TVDPS provides access to detailed historical system data and file management data. All of this information is available in soft-copy and hard-copy formats.

The TVDPS's operating system is real-time, multi-tasking, multi-user, with peer-to-peer distributed network capability. Depending upon the devices attached, TVDPS communication is serial (RS-232, 422, 485) or parallel (IEEE-488). The TVDPS monitors about 1000 data channels,

The integration of the current TVDPS was made at DFL with PC hardware from Dell Corporation. A distributed peer-to-peer architecture and built-in network capability was incorporated into the system integration plan.. Enhancements were made to existing patch panels (junction cabinets for data lines).

Major elements of the current TVDPS are: analog input devices, a primary node controlling analog input data, a user node, and local area network hardware. Any combination of TC, RTD, V and I inputs may be connected to the TVDPS dataloggers. Wherever UTRs are provided for interfacing sensor inputs to TVDPS dataloggers, temperature measurement accuracies of ± 0.5 °C are achieved for all TCs measuring temperatures between ± 200 °C (Error does not include TC inaccuracies of as much as 1 °C).

Major software components are: a QNX operating system with embedded network capabilities, and AUTONET data control software. AUTONET software receives input sensor data, and processes it with user-defined calculations and control algorithms, and also checks alarm limits (stored in an area of the central processor's memory called the point database). The TVDPS's QNX operating system can monitor, log, limit-check, and graphically display data as it is updated. Data-update rates and data-throughput rates are dependent on the specific data acquisition unit being used and TVDPS configuration. Historical data may be accessed alongside current data. A typical task switch rate is 140 μ s on an 80386/20 MHz PC and 25 μ s on an 80486/25 MHz PC.

TVDPS HARDWARE

Computers

The current TVDPS uses three 80386 based, and twelve 486 (80486/dx33-66 MHz) PCs (from the same manufacturer) of which, three of the 80486 PCs have high speed tape backup capability. Each PC has 8 Mb of RAM (minimum). On a distributed PC network, the benefits of using similar computers by the same manufacturer allow the system to be easily reconfigured at any time.

The PCs are divided into three categories: primary nodes, backup nodes, and user nodes. The primary nodes are the kernel of the networked data acquisition system and are of two Dell 80486/dx33 MHz computers with 12Mb of RAM and a 650 Mb hard disk. Two identical PCs are physically located beside these primary nodes and as backup nodes, they provide backup capability in the event of a primary node, system failure. Beyond this backup capability, a third identical PC is idle and can be configured as a primary node if ever required. The remaining PCs are user nodes dedicated for data display and data analysis when the spacecraft test is in progress.

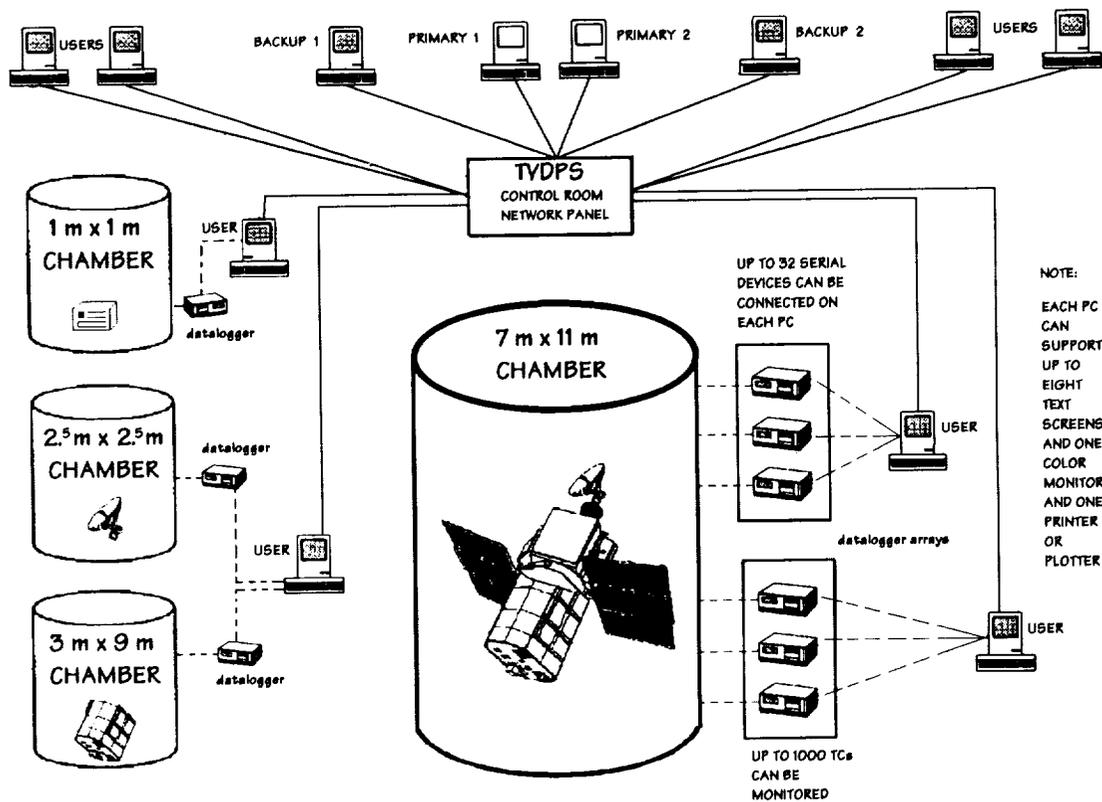


Figure 1. A Conceptual Schematic of the TVDPS

Peripherals

Each PC has an Arcnet (token ring) LAN interface board, and a Connect Tech Intellicon-8, serial coprocessor board. The Arcnet card provides very high speed communications between as many as 254 different computers. The Arcnet board uses Arcnet as its physical transport layer. It is a token-passing protocol that implements a high-speed, error-free, acknowledged transfer of data between computers. This means that the network is virtually immune to noise. The bit rate is 2.5 Mb/s. Every byte is transferred in 11-bit synchronous form resulting in a usable data transfer rate exceeding 200 Kbytes/sec. Arcnet implements low-level buffer negotiation in hardware and automatically performs flow-control

data transfer between computers without the need for complex buffer management. The Connect Tech-8 serial coprocessor board consists of eight intelligent multiports used to format data displayed on node monitors. Also located on existing nodes, are several laser printers and ink-jet plotters that are accessed from the network to generate either graphs or hard-copy reports.

LAN Hardware

All TVDPS PCs are connected to one another by an Arcnet LAN. The Arcnet LAN uses traditional star topology and can provide logical addresses for 256 devices. Active hubs connect up to eight PCs by coax cable (RG-62/U) to the LAN. As long as the rules for connecting LAN devices are observed, PCs can be removed or added to the LAN with ease. The LAN can be expanded by cascading up to eight hubs. Using coax cable, active hubs can be connected up to 2,000' apart.

Analog Input Instrument

The TV facility has ten, Kaye Digi-4 Link dataloggers as its primary analog input devices. Inputs from these dataloggers (or their equivalent) can be any combination of the following:

- Type 'T' TC inputs, internally referenced, (using the data logger's isothermal referencing hardware) with a minimum system accuracy of $\pm 0.006\%$, $+ 0.25\text{ }^{\circ}\text{C}$ @ $0.01\text{ }^{\circ}\text{C}$ resolution, and $\pm .003\%$, $+ 0.50\text{ }^{\circ}\text{C}$ @ $0.1\text{ }^{\circ}\text{C}$ resolution (based on a yearly calibration cycle)
- Type 'T' TC inputs, externally referenced using DFL's UTR blocks (isothermal uniform temperature reference) with a voltage-measurement accuracy (minimum) of 0.006% of reading $+ 1$ count $+ 2\text{ }\mu\text{V}$ based on 16 bit, + sign, A/D conversion (based on a yearly calibration cycle) with a maximum V to temperature conversion error of $\pm 0.06\text{ }^{\circ}\text{C}$
- Other major TC inputs, such as Type J, or K, internally referenced, @ $0.1\text{ }^{\circ}\text{C}$ resolution;
- RTD inputs (10 ohms cu, or 100 ohms pt) @ 0.1C resolution
- Voltage inputs, 0 V to $\pm 12\text{V}$ with a minimum system accuracy of $\pm 0.006\%$ of reading $+ 1$ count $+ 2\text{ }\mu\text{V}$ based on a 16 bit A/D (+ sign) conversion (based on a yearly calibration cycle), with a four voltage ranges (minimum)
- All datalogger inputs are internally converted to engineering-unit outputs where applicable, with an output resolution of 4 1/2 digits plus polarity sign (minimum)

Other instruments include the DFL thermal chamber and static load facility data acquisition systems, manufactured by HP (HP 3852 data acquisition and control unit), and an in-house-designed Microprocessor Level Controlled power supply for the TV facility's heater rack inputs (associated processors are configured as two Kaye dataloggers to achieve maximum input device configurations for communications purposes). The processors generate P, I, or V engineering-units as output data for all 256, microprocessor-controlled power supplies.

Any operator can isolate any physical input device (data logger, heater rack, or telemetry unit) from scanning. Input data values may be checked using the Operator's data terminal. Custom software is used to enable such devices as the ion gauge readouts, Quartz Crystal Microbalance (TQCM), and mass spectrometers, and display these on the TVDPS.

MAJOR SOFTWARE COMPONENTS OF THE TVDPS

Network management

Arcnet's token ring architecture consists of passing predefined blocks of data (tokens) around the network, one node at a time, with each token requesting data. If a node wishes to place data on the network it waits for an empty token and then occupies it. If the token is filled, a busy signal is sent so that other nodes cannot intercept it. The destination node then accepts the data, empties the token so it can request data again. There are no data collisions since only one node can transmit at a time and likewise, only one node can receive at a time.

Operating System

The TVDPS's QNX operating system runs under a modular real-time kernel similar to the UNIX operating system. The current QNX version (v.2.15) is highly efficient and occupies 150kb of RAM. Since the operating system is embedded in the TVDPS's software, access to the operating system by users is unnecessary.

Real-Time Processing

The TVDPS's QNX operating system has the ability to monitor, log, limit check and graphically display data updates in real-time. Update rates and throughput rates are dependent on the data acquisition unit and the system configuration. Data from the point database can be directly accessed in real-time for output control, for plots or tabular data analysis, or for saving datalogging features to a hard disk drive. Historical data can be accessed when the TVDPS is operating. The typical task switch rate is 140 μ s on an 80386/20 MHz PC and 25 μ s on an 80486/25 MHz PC.

Multi-Tasking

The TVDPS O/S allows the operator to multitask. In other words, it permits the TVDPS to perform multiple tasks concurrently. Examples of multitasking include: the receipt of sensor values from data acquisition units, the monitoring of system alarm conditions, transmitting data to a printer, processing graphics on CRTs, and enabling data to be stored disk. A maximum of 200 concurrent tasks may be run at a given time.

Multi-User

The TVDPS supports multiple users on each PC, locally or on the LAN. Nodes can connect physically or by modem to a remote PC as required. When a node is in terminal mode, only text based screens may be accessed.

AUTONET'S SPECIFIC FEATURES

Autonet offers multiple features that can be exploited depending on the requirements of the host system and the complexity of the host network. Some of the specific features include the following:

- Easy to Use and Set-up
- Menu Driven, Range Checking, Pop-Up Windows, Menu Security
- Real time operator displays
- Tools such as: Bar graphs, Panel Meters, Dial Meters, Circular Charts, Trend Graphs, Strip Charts, X-Y Plots, X-Y-Y profile, Spreadsheets, Instrument and Control Panel.

The Trend Display option offers the capability to define both real-time and historical Trend Displays with the following features:

- definable time base to display the data in seconds, minutes, hours, or days
- independent, user-definable, left and right Y axis scaling
- up to 15 different channels displayed on one trend graph
- select from 16 different colors for the each channel
- select from 12 different symbols to uniquely identify each channel on the node's viewscreen or its hard-copy printout
- select data from that stored on the hard disk (for any time period) to create an absolute, or relative-trend display on the node's viewscreen or its hard-copy printout
- the historical trend display allows a trend plot over a practical length of time to be seen on the node's viewscreen or its hard-copy printout
- horizontal orientation with dynamic scrolling from right to left on the node's viewscreen.

The instrument and control panel feature allows the operator to replace or supplement electro-mechanical instruments. With emulation of over 100 different instruments, each instrument and control panel is easily configured through a menu-driven fill-in-the-blank process. The instrument and control panel feature can update at a speed of 60 Hz.

Logging administrator capabilities

The TVDPS provides various methods of logging sensor data to the host workstation's hard disk drive. The logging method is dependent on the type of data acquisition unit used. Multiple and varied logging schedules can run concurrently. The summary logging routine summarizes interval-based data that was previously logged to the host workstation's hard disk. The summary log performs the following calculations for all previously recorded data that was logged in the selected time period: minimum and maximum value with time of occurrence, average, total, and total number of logged values. Logged data is available for display on a node's viewscreen, for historical trend reports, and for conversion to standard DOS file format. Logged data can be grouped for summarizing as often as once per minute, as infrequent as once per day, or even over a period of a range of days.

The File Transfer feature provides the export of historical data to a variety of formats. Data may be exported to a floppy disk, hard disk, or RS-232 serial port in the following data formats: ASCII, DIF, PRN, DFBIII and SCN. It also supports Kermit transfer protocol and host login script activation.

Alarm administrator capabilities

The alarm administrator offers the following capabilities: real-time alarm monitoring, file management, and utilities.

Real time alarm monitoring has the following features:

- Up to four threshold limits and one rate of change limit per channel
- Option for user acknowledgment of each alarm
- Alarms automatically time-stamped and logged to disk
- Viewed via alarm summary screen, color coded and prioritized
- User-defined alarm limit video display colors
- Alarm reports and acknowledgments (check-time for alarm limits is < 50 μ s).

Utilities (Serial I/O Module)

The serial I/O module is capable of transferring scanned data from a TVDPS node, from remote and local RS-232 communications, to another TVDPS node, as well as receive data from an RS-232 device. The RS-232 output utility permits the transfer of real-time data over an RS-232 communications link, direct-connect or modem, from one TVDPS node or host computer to another host computer. The Kermit communications protocol ensures error-free file transfer. Output scans for multiple devices can be defined by the user. Each output scan can be configured to include scan rate, communications parameters, record separators, and so on, for use in transferring real-time data to remote TVDPS graphics workstation, or a non-TVDPS computer.

Performance of the TVDPS

Since replacing the old DPS, the TVDPS system has proven to be the right choice for our aerospace testing facility. The new hardware proved very reliable with only few, infant-mortality type failures during the first months of operation. Our current software had some bugs not detected earlier due to the mode and complexity of network operation. However, all reported bugs were corrected by Autonet's manufacturer for its next version, but we are using the existing version because we have a reliable workaround to sustain us during the current work schedule. As a result, a new I/O Ram Cache card was installed on the primary node to accelerate the recovery time of the data base in the event of a node failure. The design of the TVDPS's user interface has reduced the learning curve to produce real savings in time required for test setup, definition of I/O channels, and data displays (graphical and tabular formats supported).

So far, over 90 tests were done and the number of TCs used in these tests ranged from only a few to over a thousand. For example, MSAT's complex IR test required the setup of over 1460 input channels on the TVDPS. They were as follows: 710 devoted to MSAT spacecraft and the IR rig structure, 240 for telemetry, 210 for thermal control, 165 for calculations, and 139 for miscellaneous inputs. Immense processing power was required to compare telemetry data with the MSAT spacecraft's temperatures during each phase of the test. For this purpose, one TVDPS node was connected to the MSAT spacecraft telemetry system (DEC 4000/200 VAX). An interface routine was implemented to serially receive ASCII formatted data at 9600 baud from the DEC 4000/200 VAX. This information was sequentially

retrieved and stored in the TVDPS's internal database. Then, real-time or historical time plots could be generated to correlate any number of activities, at any time, during the test.

Intermittent node failures due to unreported bugs only interrupt our datalogging for at most, only a few minutes. DFL's future plans are to upgrade the existing Autonet version within six months. The plans include using the new features of Autonet's modular software. These new added features will permit the TVDPS to be more versatile, flexible, and continue to maintain the open architecture concept needed to integrate new computer platforms as required.

TVDPS BENEFITS

Major improvements have been achieved since the introduction of the TVDPS into the DFL. These benefits include the following:

- Significantly improved system reliability and diagnostic capability
- Increased efficiency of test article data monitoring from using state-of-the-art software and 32-bit PC hardware. Also, the TVDPS hardware configuration provides 100% backup of the TVDPS's real-time data monitoring capability (old DPS backup capability was 50%). Historical data processing capabilities will run concurrently with full-up spacecraft real-time data monitoring
- Elimination of adverse impacts on customer testing that resulted from failure of the old DPS and current computers and peripheral hardware. Simplified switchover to backup system support due to main node system failure
- Significant enhancements to test article mnemonics definitions, calculation capabilities, display, print spooling capabilities, hard-copy and data transfer capabilities to remote PCs, and so on. Also, data storage requirements will be streamlined, cutting permanent data storage costs by 75% to 85%. Capability to support future requirements for the expected sophisticated, knowledge-based, data acquisition design enhancements will be supported
- Significant reductions in hardware maintenance costs. Expect over \$100K in savings over the first five years
- Significant reductions in software maintenance costs from substantial usage of off-the-shelf software
- Significant cost reductions in both hardware and software procurement costs during future expansions of the facility due to increased usage of PCs
- Sharing of resources in a peer to peer LAN PC workstation providing clear test, or process information in formats familiar to the technician or computer operator as well as providing detailed historical analysis and file management functions useful to research or engineering personnel.
- Test data can be transferred on different media on diskette or tape using standard data compression routines (can be up to 100:1 compression on test data files). Test data can be in an data interchange format ready for user analysis (post-test) on any standard PC spreadsheet program. This method will save an tremendous amount of data storage space and resources as compared to the old DPS methods (which was mainly hard-copies).

CONCLUSION

The TVDPS has proven profitable for DFL's requirements. Its main advantage is the relative low cost of today's powerful PC based systems vs. higher priced workstations and mainframe computers. The TVDPS is also flexible enough to allow it to be reconfigured and redesigned as necessary, and its user friendliness is appreciated by first time customers. Also, output data can be transferred on different media (floppy, tape, compact disk). Finally, the ability of the operator to develop customized applications makes the TVDPS very beneficial to the customer.