FROM THE STRIP-CHART RECORDER TO THE TELEMETRY RECORDER-WORKSTATION

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ABSTRACT
The strip-chart recorder has evolved from a simple pen-writing instrument to an instrumentation platform. Today's Telemetry Recording Workstations not only provide a permanent hard copy of telemetry data, but also offer high resolution videographic displays with real-time point-of-writing representation, the ability to efficiently store data digitally, and customizable user interfaces. Host control and digital data transfer can be achieved using Ethernet networks, making the instrument an integral part of a telemetry system. The Telemetry Recording Workstation is a fundamental instrument for any telemetry application or installation, due to its abilities to display, print and store real-time data.

KEYWORDS
Data display, data recording, strip-chart, videographic

INTRODUCTION
The strip chart recorder has been an important part of telemetry systems for many decades. Its unique ability to graphically represent real-time data has continued to be useful for a variety of applications. These recorders are used in many applications including flight testing, rocket and missile launch monitoring, and satellite testing. Recording technologies have changed and improved over the years and have included the pen-based galvanometer, lightbeam oscillographs, electrostatic array and thermal array recorders. The telemetry recorder has evolved into a recorder-workstation and has become an instrument that not only graphically displays data, but also allows the user to work with that data in an interactive environment.
THE LATEST TECHNOLOGIES AND CAPABILITIES

The latest generation of telemetry recording systems greatly expand upon the thermal array chart recorder platform. This platform succeeded the galvanometer-based pen recorders as well as electrostatic recorders since it offered a number of advantages. Thermal array recorders offered high resolution (300 dpi) printing, high frequency response, flexible chart formats, and alphanumeric annotation. Full host control was a major advancement for thermal array recorders, finally closing the loop between telemetry system and recording system. Thermal array recorders were also designed as platform instruments, which meant that options could be added as new technologies became available. The thermal array recorder became much more than a basic recorder and evolved into a recording system.

The latest evolution of these instruments not only perform the traditional strip chart functions, but offer the engineer a complete data collection and review workstation. These systems offer complete customization of the data viewing and printing and also allow the user to define the control interface. The network connectivity of the telemetry recorder make it an integrated component of the telemetry installation.

The most recent designs of telemetry recorder-workstations offer inputs for analog or digital data. This ensures compatibility with the latest telemetry installations, as well as legacy systems. These advanced designs also employ a modular architecture, proven to be a success with the previous generation of recorders, which allows the system to be expanded in the future.

INTERACTIVE TOUCH PANEL DISPLAYS

One of the major advancements in the latest generation telemetry recorder is a large real-time display which shows the signals in a waterfall format. While waveform displays have been available on telemetry recorders for a number of years, they were limited by size and resolution and only allowed the user to make approximate measurements. The latest displays are 18-inch backlit color LCD's with 1280x1024 resolution. This type of display offers the significant advantage of allowing the user to see a large amount of data on the screen. The use of color allows for instant waveform identification and adds the ability for the signal to change color based on a preset alarm limit. The increased resolution also allows for graphical templates indicating grid values and annotation, similar to the paper-based templates that flight test engineers have used with pen-based recorders for many years (figure 1). In addition, split-screen displays and multiple real-time XY plots can be viewed on the screen, without compromising the viewing of real-time data.
These displays also offer the important benefit of a real-time pen emulation. In many applications such as flutter and flight safety testing, the ability to see the pens move is paramount. Important test and safety decisions are constantly being made based on these pen movements. Historically, the users for these applications were unsatisfied with the thermal array printing technology due to the time delay for real-time signal printing at very slow chart speeds. For the first time, these high-resolution displays allow a realistic simulation of an analog pen movement (figure 1) which eliminates these delays. In addition, a pen-sound simulation can be found in some of the latest recorder designs. The visual and audible feedback from the pen movement create a realistic equivalent to a pen-based analog strip chart recorder.

Touch-panel interfaces are also used on the more advanced telemetry recorders. This type of interface replaces the hardware knobs and buttons that have historically been the controls for telemetry recorders. A well designed touch-panel interface, with a quick response and intuitive layout, offers benefits for both new and experienced users. Some of the recorder designs allows users to create macros, which can perform a number of repetitive functions quickly. The latest recorder designs allow users to create the entire front panel, creating a customized control panel (figure 2).

The customized control panel gives the user complete flexibility over which controls are on the front panel. For example, a user with a simple application may need a few chart speed buttons and a recording start/stop button. A more advanced exercise may need to instantly access controls for signal adjustments, triggering, data capture and historical data review. These control panels can also be password protected for security purposes, preventing unauthorized modifications to an existing custom setup. Another important benefit of this customization is that a telemetry installation that is utilized for a number of different programs can keep a library of these customized control panels. These could be based on the type of aircraft or weapon being tested, or the personal preferences of the users.
For the first time, the telemetry recording system offers an interactive environment for the user. During a flight test, an engineer watching a strip-chart will often write on the chart when a planned maneuver is performed, or if something unexpected happens. With a touch-panel interface, the engineer can simply touch the display at a specific point and add annotation to the data. This can be in the form of pre-defined phrases or free-form text. A mark is placed at that point in time and the annotation is saved and printed with the waveform data. Touch-panel interfaces also allow for on-screen cursor measurements that can be activated by touching a specific data point. A large touch-panel is well suited for measurements such as timing, amplitude and frequency.

A touch-panel interface also has the advantage of an environment that has the "touch and feel" of paper. A flight engineer could use a split-screen mode, for example, that allows for viewing of historical data without interrupting real-time recording. The portion of the screen with the historical data can be reviewed by touching and dragging, analogous to flipping through sheets of paper. The designs of these touch-panel interfaces are such that the engineer who may be familiar with using pen-based recorders will quickly become proficient with the new technologies.

**NETWORKED HOST CONTROL AND FILE TRANSFER**

An increasingly important characteristic of telemetry recorders is their ability to communicate with other telemetry systems and sub-systems. The three main requirements for communications with telemetry recorders are:

1. Configuration and data file transfers to/from the instrument
2. Real-time command and control of the instrument (host control)
3. Real-time digital data interface to the instrument

The latest telemetry recorders utilize Ethernet (100BaseT or 10BaseT) for this communication. This interface offers a number of advantages such as high bandwidth, standard protocols, and inexpensive implementation. In addition to communication from a host system to a telemetry recorder, Ethernet also allows communication between telemetry recorders. The Ethernet interface can be used for a number of different functions. Figure 3 illustrates a block diagram of a host interface for telemetry recorders.
One of the uses of Ethernet is for transferring recorder configurations to and from a host workstation. Using the TCP/IP and FTP protocols, setup files can be quickly transferred to the telemetry recorder prior to a mission. This eliminates the costly set-up time associated with previous generations of recorders. Using this method, a telemetry facility can store a library of configurations ready to use for specific missions or user groups.

Another important use of Ethernet is for command and control of the telemetry recorder. Telemetry recorders have traditionally utilized RS232 or IEEE-488 for host control. Host control commands available for telemetry recorders include recording start/stop, change chart speeds, edit annotation buffers and analog settings modifications as well as queries for alarm limit status and system status. While the latest designs also offer these interfaces, as seen in figure 3, Ethernet is a more universal and cost-effective interface to implement.
Ethernet can also be used to send digitized data to the telemetry workstation. The traditional approach to sending digitized waveforms is to have the recorder look like a DAC where the host streams data points for each channel in real-time or close to real-time. Data rates and resultant loads on both host and recorder can be high. This method becomes risky when non-deterministic networks are used because of the problem of time synchronization.

An alternative method is to send line segments based on the minimum and maximum waveform values for a delta T. The value of delta T depends on chart speed. Raw signal sample rates are set by the host to maintain required bandwidth. The impact of transmission delays is minimal because the line segments are built in the host using a fixed time period that the telemetry recorder also uses to control the rate of printing and display. The data set containing the line segments can include time marks, an IRIG time stamp and grid information that provide the host with expanded control over the chart.

The segment approach eliminates the need for special hardware by using the telemetry recorder operating system to handle the incoming data. Optimum performance at higher speeds is obtained by having the host transmit segment data in blocks that are separated by at least 50 milliseconds. This limit implies that at chart speeds above a few millimeters per second, the host should send multiple segments in each block.

The network connectivity of the latest generation of telemetry recorders offers greatly capabilities for configuration, host control and data transfer. The interface also lends itself well to other possibilities. One of the concepts currently being explored is a host control mechanism that can be accessed via a standard web browser. When using Ethernet for host control, a thin server and web menu structure can be implemented. Any host computer that can establish a network or modem connection and is running a standard web browser can access the thin server. The host control server software could detect the host browser level and adjust the menus accordingly.

**DIGITAL DATA STORAGE**

Engineers are increasingly using strip-chart hardcopy output only when necessary and prefer to store data in a digital format more suited for analysis. The latest telemetry recorders have been designed for this requirement with the ability to store large amounts of data to hard drives or other magnetic media. The latest telemetry recorder designs utilize storage media that enables the user to save data independent of paper recording, while at the same time giving them the opportunity to play back data to paper later.

Multi-gigabyte SCSI hard drives are typically used in telemetry recorders for data storage. Some designs utilize a Redundant Array of Independent Disks (RAID) architecture to provide more storage capacity. While the capacity of hard drives gets larger as costs come down, many engineers are also looking for ways to reduce this large volume of data while preserving its fidelity. One solution can be taken from the advances in paper recording.

Paper is a good medium for data storage for lower frequency signals because of the high volume of data that can be included in a chart output. Traditionally, if the engineer needed more data resolution in the time axis, the paper speed would be increased. Due to the mechanical limitations of pen recorders, there
was signal attenuation at frequencies greater than 60 Hz. Thermal array recorders solved this problem by using min/max algorithms which offer the ability to print higher frequency signals regardless of the chart speed.

The most recent data storage technique utilizes a similar min/max algorithm to store line segments a hard drive. This data is stored exactly as it would appear on a chart and at a rate to match the equivalent chart speed. The resultant record acts as a Virtual Chart™ and allows a user to run a test with or without real-time paper output and still create hard copy after the test. The chart output is identical to a chart created in real-time, showing any changes to signal conditioner settings, annotation, or chart speed.

A key benefit of this technique is an efficient use of storage space. For example, a standard pack of z-fold chart paper is approximately 120,000 mm or 1,440,000 line segments at a print resolution of 12 dots per millimeter. A single chart segment (equivalent to 1 print line) requires 192 Bytes. This means that the Virtual Chart equivalent of a pack of paper requires 276 MB of disk space, which includes IRIG timing and grid synchronization. As another example, running a Virtual Chart for 5 hours at 100 mm/s only requires approximately 4 billion bytes. This data, since it is digital, can be used for post-mission review and analysis as well.

**CONCLUSION**

The telemetry recorder-workstation is an important tool for the telemetry community. These sophisticated instruments offer strip-chart recording, data displays, and data acquisition capabilities. The significant advances made by the latest generation of these instruments make them even more useful since the users have unprecedented control over how their data is viewed, printed and analyzed. As a direct result of the needs of telemetry engineers, today's telemetry recorder-workstation employs some of the newest technologies available and utilizes an architecture designed for the additional future requirements.