

# **MODULAR TELEMETRY SOFTWARE FOR REAL-TIME APPLICATIONS**

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## **ABSTRACT**

A modular software system, operating in conjunction with unique direct-memory-access hardware modules, provides control of real-time high-speed telemetry data entry, storage, processing, and display in any of a family of small general purpose minicomputers. The software operates with engineer-language commands.

## **INTRODUCTION**

In the typical computer system, the computer controls all actions. It asks for data when all previously-assigned tasks have been completed. Most data sources are responsive to on-off commands from the computer, and will hold data indefinitely between requests. The magnetic tape recorder, card reader, disk, or other peripheral is always ready, but never impatient.

On the other hand, in the telemetry/computer system the data stream is generated at some location remote to the computer site, and cannot be controlled by the computer. The system must run itself, based on timing signals and other information in the data stream. In the most widely-used form of telemetry, pulse-code-modulation (PCM), the multiplexer generates a frame synchronization pattern and then scans a frame of data, each measurement of which is quantized and output serially. On completion of a frame, another frame synchronization pattern is generated immediately, then another frame of data. Whether the data is to be entered into the computer immediately (in "real time"), or later (via playback of instrumentation tape recordings), the data words occur in the same continuous sequence, interrupted only by periodic frame synchronization patterns.

This paper describes a unique software system called TELEVENT (Telemetry EVENT-operated), which was developed to handle telemetry data. To obtain the high-speed control

which is necessary in telemetry, TELEVENT recognizes and responds to events or interrupts which indicate actions to be performed by the system. For example, TELEVENT is keyed to the occurrence of frame synchronization patterns, and enters every data word from every frame into computer memory. The entry of data is started coincident with the beginning of one of the frames, and the words of the frame are organized in buffer memory in an identifiable manner. When a section of buffer memory is filled, another section is opened instantly and the necessary action started to process or store data from the first buffer while the second is filling. Each frame may be tagged with the time of occurrence. Status can be entered into the computer with the data, so that any data obtained during uncertain synchronization is identified as being of questionable quality. All of this takes place at data rates as high as 250,000 words (up to 16 bits each) per second, without the loss of a single word. The entire process can be controlled by an engineer or technician, rather than by a specially trained programmer.

Such a unique application demands, and TELEVENT is a high-speed system, optimized for telemetry data rates. It is modular, so that a user can add hardware elements or processing tasks as needs expand. It is efficient in use of memory and computer processing power. It is easy for an engineer or technician to use, even operating in the interactive mode to minimize the need to learn setup language. It operates with the most popular and most widely used minicomputer family, the Digital Equipment Corporation (DEC) PDP-11 and VAX-11 systems.

## **FUNCTIONS (SUMMARY)**

The TELEVENT software performs five functions in most systems. These are:

1. Set up the telemetry front-end equipment characteristics automatically to enable it to acquire the data formats which are expected.
2. Set up one or more paths for entry of data into the buffer memory, and determine the characteristics of the buffer areas.
3. Enter high-speed telemetry data into a single buffer or into alternate buffer areas as described below.
4. Process or output the contents of each newly-filled buffer as rapidly as it was filled, to get it ready for new data.
5. Run low-priority programs if time permits, on a priority-interrupt basis.

## **Hardware/Software Inter-action**

The TELEVENT-operated system is a unique collection of software. The system actually runs itself --- totally. An operator establishes the conditions, and enables it to start itself. Every real-time data handling action, however, is accomplished automatically based on the occurrence of recognizable and meaningful events.

Such a software system is unique, of course. And as one would suppose, the related hardware is unique also. In the system, special computer-controllable front-end devices respond to setup commands and handle much of the routine work of the system (searching for and recognizing synchronization patterns, for example). They also recognize predefined conditions and generate many of the event pulses which operate the system for real-time data acquisition and processing.

Similarly, the computer is unique -- the DEC PDP-11 or VAX-11/780 family, with UNIBUS interface for direct access to the central processor and memory. Without this system, TELEVENT is not able to function.

Another aspect which should be understood is that there is no single software package called "TELEVENT". Instead, the term relates to a multitude of software elements, many of which are used for any given system. There is a "tree trunk" onto which branches can be attached; system designers attach the first branches, but a user can (and usually does) continue to attach branches as the system is used. Most systems can be expanded or modified by the user almost as easily as a new amplifier is plugged into an oscilloscope. The modular concept makes this possible, and is one of the outstanding features of TELEVENT.

Another feature of TELEVENT is the ease with which an engineer or technician with no "programming" experience can set up and use the system. Some observers seem to feel that "any system which is so easy to operate must not be very powerful". On the contrary, the internal workings of a TELEVENT module are complex in order to make it look simple and operate with just a few hours of instruction.

TELEVENT operation is not possible without certain hardware interfaces between the Telemetry Front-End (TFE) equipment and the computer. In fact, these interfaces were designed specifically to support TELEVENT. Following the practice of letting hardware devices perform repetitive functions whenever possible, two unique hardware devices share intimately with TELEVENT in performing the functions of front-end setup, data stream setup, and high-speed data entry into the computer. They are:

**Buffered Data Channel (BDC), and Priority Interrupt Module (PIM)**

Each of these devices plugs directly into the UNIBUS, thereby becoming an extension of the computer and a direct access to memory and to the central processor.

## **1. Buffered Data Channel**

As shown by the functional diagram, Figure 1, the Buffered Data Channel provides two parallel data interfaces through input port A or input port B to the computer UNIBUS, or one high-speed data or command interface through output port O to an external destination.

Two data inputs and one data output are provided; each is a 16-bit parallel port. The Buffered Data Channel and its software driver provide a channel for automatic data entry at high rates, with capability for periodic insertion of time tags, status, or other information, if desired. Data is input via two, three, or four independently specified buffers in computer memory. When a buffer is filled, entry is automatically transferred to another buffer and an interrupt is generated for use in starting a processing routine for the new data. Similarly, data can be output from a buffer at high rates by the Buffered Data Channel.

## **2. Priority Interrupt Module (PIM)**

The PIM contains eight complete priority interrupts for events communications between external equipments and the PDP-11 or VAX-11 computer. Eight separate interrupt input lines are provided for connections to the external equipments. Any of the interrupts may also be generated internally under program control for testing.

### **Function 1: Set Up Front End of System**

With TELEVENT, an engineer or technician with no programming expertise can issue the necessary commands from the keyboard or via disk or tape to set up telemetry front-end equipment. Through a unique internal design, the system is able to recognize these commands, convert each into the appropriate machine-language instruction, route it to the appropriate unit, and notify the operator if there are any errors in the process. The system can accommodate several identical front-end units (Bit Synchronizers, for example), identifying each by a numerical suffix (BSY 1, BSY 2).

Operator setup commands are accepted in engineer language, and each is converted into 16-bit machine-language command words by Unit Driver software. The Unit Drivers have several significant characteristics:

1. Each driver has error-checking capability, such that each input from the operator is checked automatically. If the command is valid, it is translated; if not, an error message is sent to the operator.

2. Each driver provides linkage to other programs, so that they can be referenced in the setup rather than writing the extra information into the driver.
3. A driver is the same whether it is part of one TELEVENT system or another. The user can change from IOX computer software to RT-11, for example, without buying new unit drivers.
4. More than one unit of a type can be set up through a single unit driver. Two Bit Synchronizers in a system can be addressed by number, as BIT SYNCHRONIZER 1 and BIT SYNCHRONIZER 2, for example, and the unit driver will route each command as directed.
5. A user can write Unit Drivers for other units in a system, following the instructions which are given with system documentation on TELEVENT.

Machine-language commands from Unit Drivers are stored in computer memory until a complete series of words are ready for output. These storage areas are called Data Blocks.

Use of Data Blocks offers several advantages to a user:

- All related information for a given unit setup is accessible at one location.
- Setup programs can be interrupted by higher-priority programs, then re-entered with no problems.
- Only one Unit Driver program is required for a given type unit, regardless of how many of that type unit are in the system.
- Memory is saved, since Data Blocks are short and concise.

Relationship between the Unit Driver and a Data Block is shown in Figure 2.

## **Function 2: Set Up Data Input Path**

With the TELEVENT system, each incoming telemetry data and time word must be placed into buffer storage in the computer memory as soon as it is received. For each data stream (PCM 1, PCM 2, PAM, etc.), the associated data path must be set up in advance. After setup, the associated interface hardware modules route each data word to a preassigned buffer in the computer memory, insert a time word in place of each frame synchronization pattern, switch buffers when one is filled, and notify the software system when such switching takes place.

Setup of each data stream for direct-memory access (DMA) is accomplished by a short series of commands which:

- Specify the number of data words in each frame of telemetry data.
- Specify the number of frames to be stored in each buffer. (Generally, this will represent the size of each “record” to be generated on magnetic tape.)
- Specify the buffer preface size (typically, one word).
- Specify the buffer appendix size (as needed).
- Indicate the buffer ID to be stored with data (“PCM”, for example).
- Determine whether, after all system software is set up, the system is to wait for a pulse at the “External Start” input. Typically, this is used to align buffer storage with the frame or subframe rate of the incoming data.
- Specify the length of each subframe of incoming data.

As with Unit setup, a software stream driver translates operator language to machine language, and arranges a Data Block in computer memory for each stream in the system.

### **Function 3: Automatic Data Acquisition**

After the operator has set up the telemetry front end and each data path, TELEVENT is ready to acquire data and store it in pre-assigned buffer areas automatically. Data is entered into memory at real-time telemetry rates. Each buffer will start with word 1 of a telemetry frame (and frame 1 of a subframe, if desired). Time words can be entered into the buffers whenever frame synchronization patterns appear so that all data words can be identified as to their time of occurrence. Whenever a buffer is filled, the system switches to the other buffer automatically without loss of any data words as shown in Figure 3.

The system is enabled to start acquiring data when the operator issues an execute command for the related data stream, as “EXECUTE PCM.” When this command is issued, the next “start” event (real or simulated) into one of the interrupt inputs causes the actual data acquisition to begin automatically. A typical “start” event is a pulse from a Tape Search Unit when some specified time of day (as 17:32:59) occurs, another is a keyboard entry which stimulates the “start” event.

Perhaps other TELEVENT tasks are more easily visualized than the real-time data management task. Yet this aspect of TELEVENT (with the related Buffered Data Channel hardware) is the most demanding in the system. Data comes into the system at high rates; each word must be put into the buffer area in computer memory as it appears --- not a word can be lost. If that were not bad enough, time (or status) words must be merged with data during the brief pause for frame synchronization. When a buffer area is filled, switchover must be accomplished immediately --- again, without the loss of a word. And the computer must be notified that a buffer full of new data is ready for use.

Obviously, the operator is not a party to real-time data input. Having set up the rules for a given format and task, the operator's job is finished. The system must operate at speeds that a human is not able to follow.

The actual "permission" to start this high-speed task is given by the operator as an "execute" command:

EXECUTE PCM  
(or EXE PCM)

Data input does not begin with the EXECUTE command, nor even with the START INTERRUPT. The occurrence of a pulse at the EXTERNAL START input to the Buffered Data Channel signals the beginning of some significant grouping of data (start of a frame or subframe, for example), and this is when data entry begins. This makes data arrangement orderly in this buffer, so the computer can find any desired measurement by its location in memory.

As each word is ready at the output of the data source (Frame Synchronizer, for example), "handshake" pulses are exchanged between the source and the Buffered Data Channel, then the word is transferred to the input of the Buffered Data Channel.

Depending on setup, several words can be buffered in the FIFO (up to 14 words), or each can be transferred to memory as soon as it appears. Actual transfer of data words to memory is dependent on UNIBUS availability. For use of the UNIBUS, the Buffered Data Channel must get permission from the computer; individual words are output on a single-cycle transfer, or a group of words in the FIFO can be transferred as a "burst".

Each word is assigned to buffer memory without assistance from the computer. Memory word locations are normally assigned sequentially.

At the end of each multiplexer "frame", the Frame Synchronizer (if so connected and set up) automatically issues a "freeze" pulse to the Time Translator, which sends a "party line

control” pulse to the Buffered Data Channel. This pulse instantly switches the active port; handshakes and time word transfer occur at the new port, then the party line pulse is dropped, and the original input port becomes active again. Up to three time words can be transferred to the FIFO in less than one microsecond.

As each buffer area is filled, the Buffered Data Channel automatically and instantly switches to the new buffer area. This is not a computer transaction; it is a hardware transfer. An interrupt is generated for the computer coincident with the transfer, but computer action is not necessary for the transfer itself. Thus, no data words can ever be lost in switchover.

The action of buffer loading, switching, loading, switching continues automatically and indefinitely. If frame synchronization is lost, nothing is entered into the then-active buffer from the point of loss until the synchronizer is locked again. TELEVENT keeps a record of such loss, and one of the words entered into each buffer tells if there was a loss of lock (“frame search”) at any time during the loading of that buffer and, if so, the location (frame number) in the buffer where the first data was stored after restoration of “lock”.

A sequence of data entry is halted when a pulse code occurs at the HALT INTERRUPT point. The proper actions are taken by the system after the interrupt --- such as completing the buffer which is in process.

The HALT INTERRUPT does not cancel all setup to the system. After it is received, all actions can be started again automatically if a pulse occurs on the START INTERRUPT line.

Another executive command from the operator ---

HALT PCM

will de-allocate buffers and do whatever else is dictated by the directory of HALT routines.

#### **Function 4: Automatic Real-Time Processing and Display or Storage**

Obviously, TELEVENT must do more than store data into buffer areas in computer memory. The tasks of acquisition and interim storage are difficult because of the necessity to respond to the telemetry “clock” of events, especially at high data rates, and TELEVENT has the ability to perform these tasks. However, each buffer area must be emptied as fast as it is filled to prepare for the next data entry.



With TELEVENT, several processing and storage programs are available as options. Additional programs can be provided to meet unique user requirements, or a user may elect to prepare unique programs after training. Processing and storage programs may include:

- Real-time formatting and storage of all data on an output magnetic tape recorder in “computer-compatible” seven- or nine-track format.
- Decommuration of selected words from the buffer for further processing.
- Display of decommutated channels in binary, decimal, or analog form, either before or after processing.

Once a program is stored in the TELEVENT system, an operator can connect the program to any data stream on the occurrence of the desired event. As an example, the Magnetic Tape Formatter program generates one tape record each time a memory buffer area is filled. Another program generates the end-of-record and file mark when a recording process is complete and the “halt” event occurs. These two programs can be connected into the system.

- Connect the Formatter program to the PCM stream when the “Blockend” interrupt occurs.
- Connect the Finish program to the PCM stream when the “halt” interrupt occurs.

TELEVENT allows more than one program to be connected to a data stream and offers considerable flexibility in use of “connect” statements.

### **Software Decommuration**

Another Real-Time Program which is widely used on TELEVENT systems is the one called “DECOM”, or decommuration. This program enables the operator to selectively retrieve specific measurements from a data buffer, perform unique processing on each, and route the processed data to displays or other output devices as shown in Figure 4. The program can be initiated by the frame rate pulse to retrieve data from frames, or by a subframe rate pulse to retrieve data from subframes.

Some characteristics of the DECOM program are:

1. The program is modular. That is, any sequence of process modules can be connected in a string to process a measurement. The same or different modules can be used on another measurement.

2. Setup of the program is simple. The operator specifies where to find the measurement (word number, frame number, strapping), what to do with the data, and where to put the result.
3. The program is called by interrupts, such that the data being processed is always fresh.
4. The same output device (CRT, printer, etc.) is time-shared by several measurements, and even by separate streams.

Several types of processes can be threaded to a DECOM program. Some of the processing functions include:

1. Data compression (by software)
2. Limit checking
3. Normalization
4. Conversion to Engineering Units
5. Algebraic operation
6. Logical operation
7. Time correlation
8. Time smoothing
9. Data correction

Outputs from the DECOM strings can go to:

- CRT Display
- Word Selector (analog output, discrete bit output, binary display, decimal display).
- Printer
- X-Y Plotter
- Magnetic Tape Recorder (via second buffer area and tape formatting program).

## **Function 5: Background Programs**

While TELEVENT is acquiring and processing data, the amount of “free” time is determined by the needs of the real-time programs being run on the system. Often these needs prohibit the performance of other tasks. However, TELEVENT has the ability to perform “background” programs as/if time permits.

Typical background programs include:

- Initialization of magnetic tapes
- Termination of magnetic tapes
- Dubbing of magnetic tapes
- Error polling
- Others

It is true that such programs could be run directly under the computer software system; however, there are several advantages to putting them under TELEVENT instead of under the main system:

1. All calls to operating programs can be made in the same format, rather than having to exit from TELEVENT and return after a program is run.
2. Background program calls from TELEVENT can be stored on a disk, to be loaded and run along with real-time program calls.
3. The TELEVENT background programs provide a means for reporting any errors to the operator. Even when a user writes a background program, the standard instructions define how the program should report errors.
4. Background programs under TELEVENT can reference routines which are part of the standard TELEVENT library.
5. Data Blocks can be established under TELEVENT and used by Background Programs in the same way that they are used in Unit Drivers and other modules. This means that a Background Program can be general-purpose, with separate Data Blocks (variables, constants, etc.) for different jobs. For example, one Background Program is named MTINIT (mag tape initialize). Separate Data Blocks can be used

for separate mag tape units, such that one is called by RUN MTINIT 1 and the other by RUN MTINIT 2.

### **Use of Events**

After initial setup by an operator, all TELEVENT functions are caused automatically on the occurrence of specific events. This feature is an absolute necessity in a telemetry/computer software system since no operator would be able to respond manually at the data rates which are common in telemetry.

The choice of events to control a system is made at the time of system design and depends on the needs of the user. Even after a system is in use, more events can be added or the priorities or related processes revised by a trained user.

Events are input to the system via the Buffered Data Channel (two event inputs per module) and the Priority Interrupt Module (eight event inputs per module) as shown in Figure 5.

By pre-programming the system, the computer is able to identify the source of each event as it occurs, evaluate the relative priority of the occurrence, and cause a specific action to occur as a result. For example, the "buffer complete" event will start the desired processes to handle the data in the just-completed buffer (a new record may be generated on magnetic tape).

### **System Limitations**

The TELEVENT software system was developed for use on medium-sized single-user telemetry-computer systems such as the one shown in Figure 6, where high data rates were expected. The original DEC software systems under which TELEVENT ran were IOX (a paper-tape-based operating system, limited in function) and DOS-BATCH (a disk operating system for batch processing). Neither of these systems is supported by DEC now. However, they offer another disk-based real-time software system, RT-11, which provides support for TELEVENT in high-data-rate single-user environments. The RT-11 system is optimized for such applications as telemetry; data entry rates and interrupt response times are excellent with the Buffered Data Channel and Priority Interrupt Module.

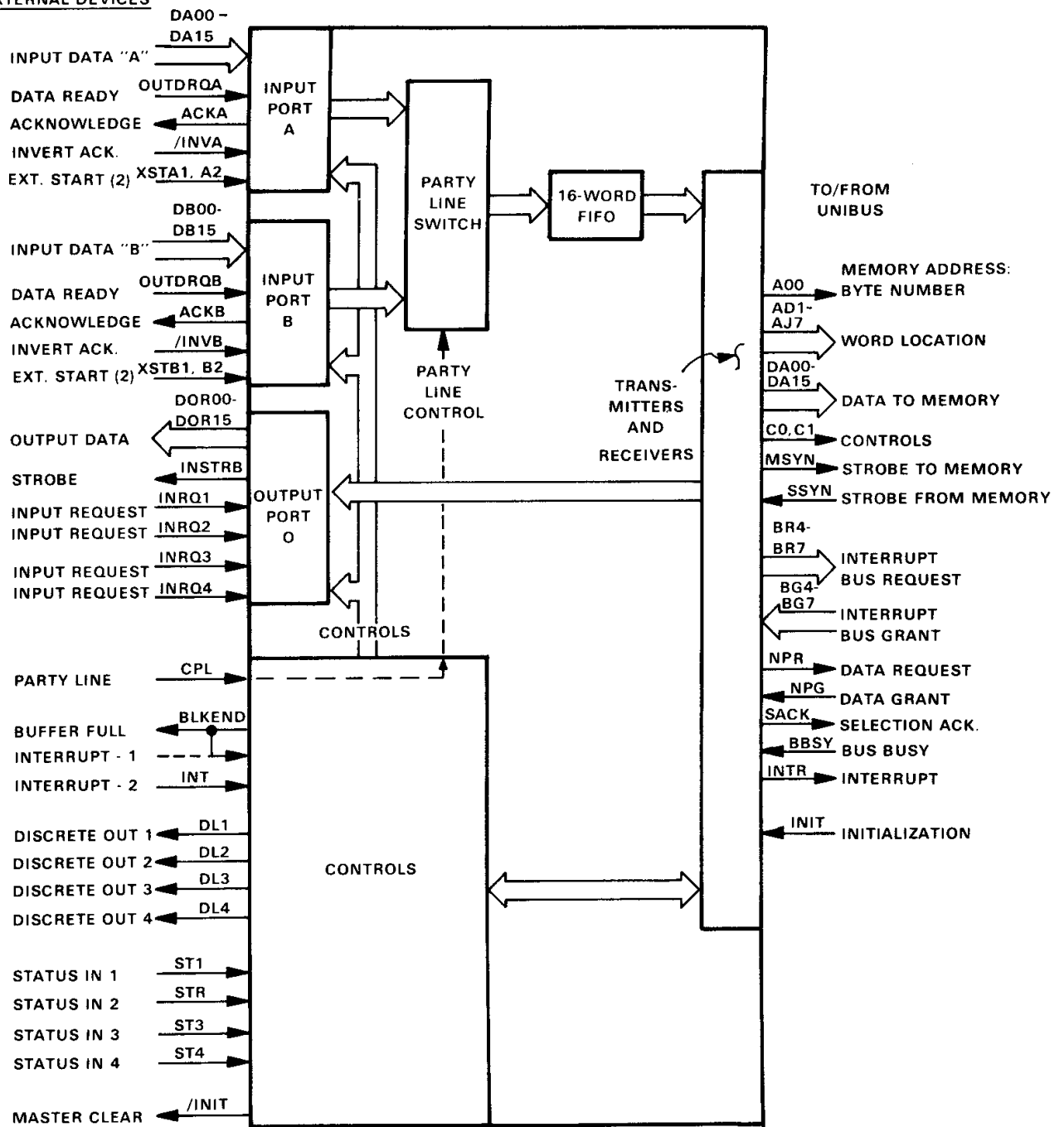
Many telemetry systems are of necessity multi-user systems, however. TELEVENT has been expanded to operate under DEC's most popular multi-user system, RSX-11M, and is also adapted for use on the VAX-11 Computer family under the VAX/VMS software. Ironically, these more advanced, more flexible systems involve more housekeeping in data

entry and interrupt handling, and the telemetry operation is not as fast and efficient as with the smaller, simpler RT-11 software. Certain steps have been taken to get around these limitations; these must be the subject of a future paper, however.

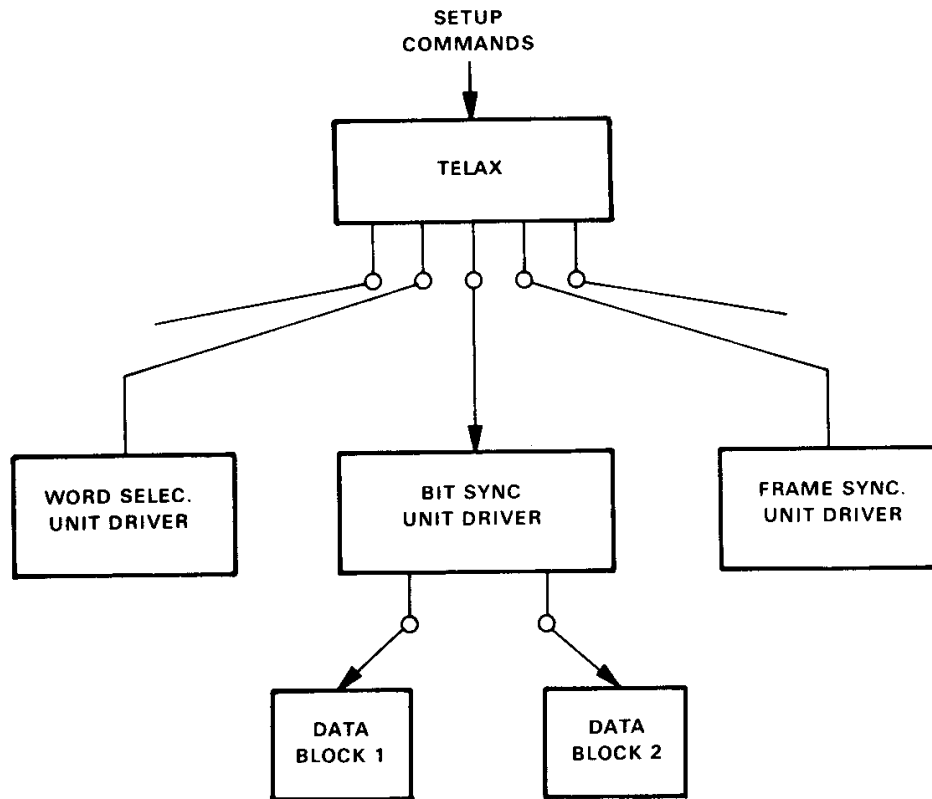
### **Conclusions**

The telemetry-computer software system called TELEVENT, used with related interface modules and a DEC computer in a medium-sized single-operator system, offers setup in high-level language, high-speed data entry, processing, storage and/or display, and optional background programming. The system is powerful and expandable, yet easy for a non-programmer to use in normal applications.

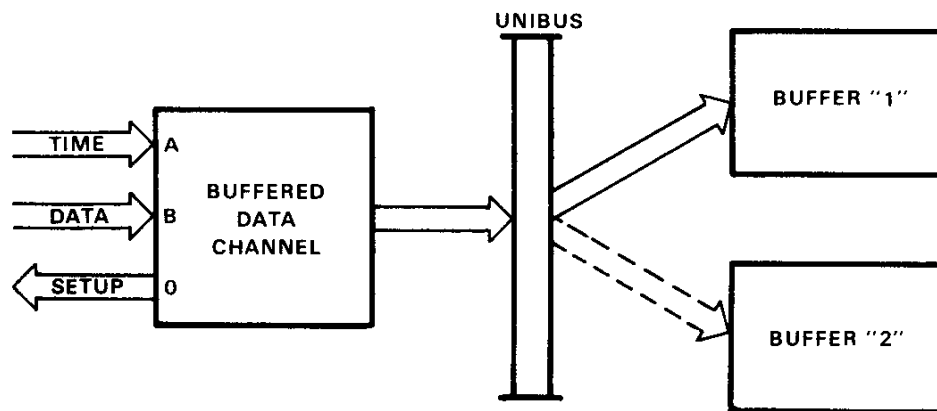
**EXTERNAL DEVICES**



**Figure 1. Buffered Data Channel Functional Diagram**



**Figure 2. Unit Drivers and Data Blocks**



**Figure 3. Automatic Data Acquisition**

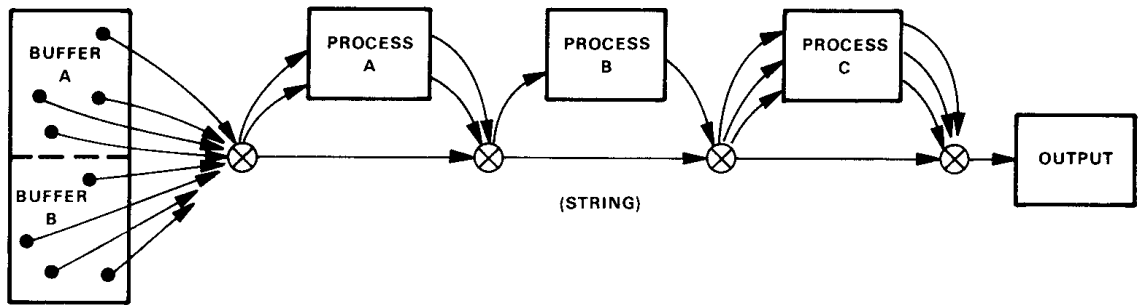


Figure 4. Decom Program

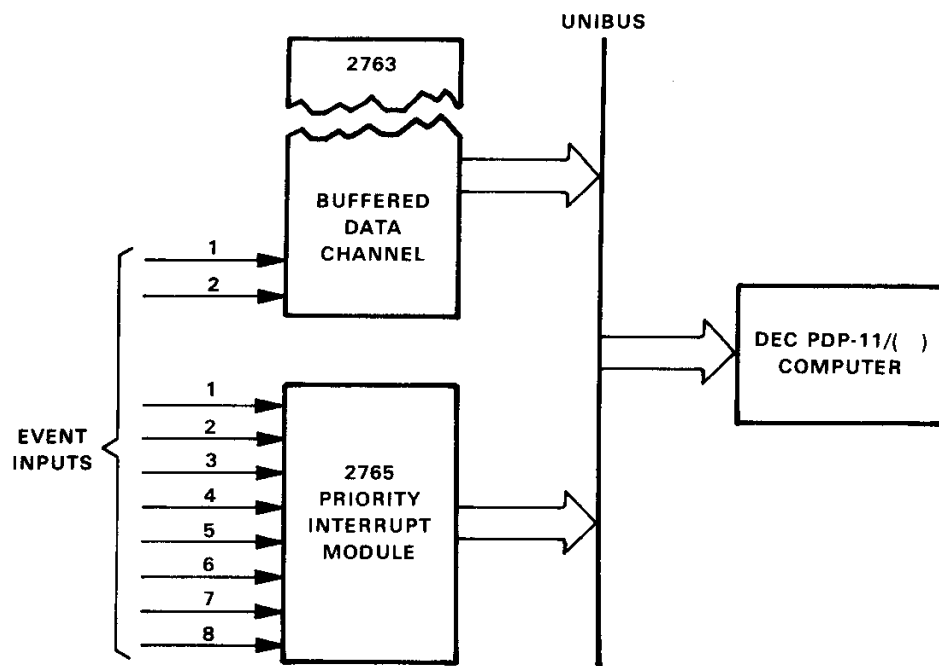


Figure 5. Event Inputs



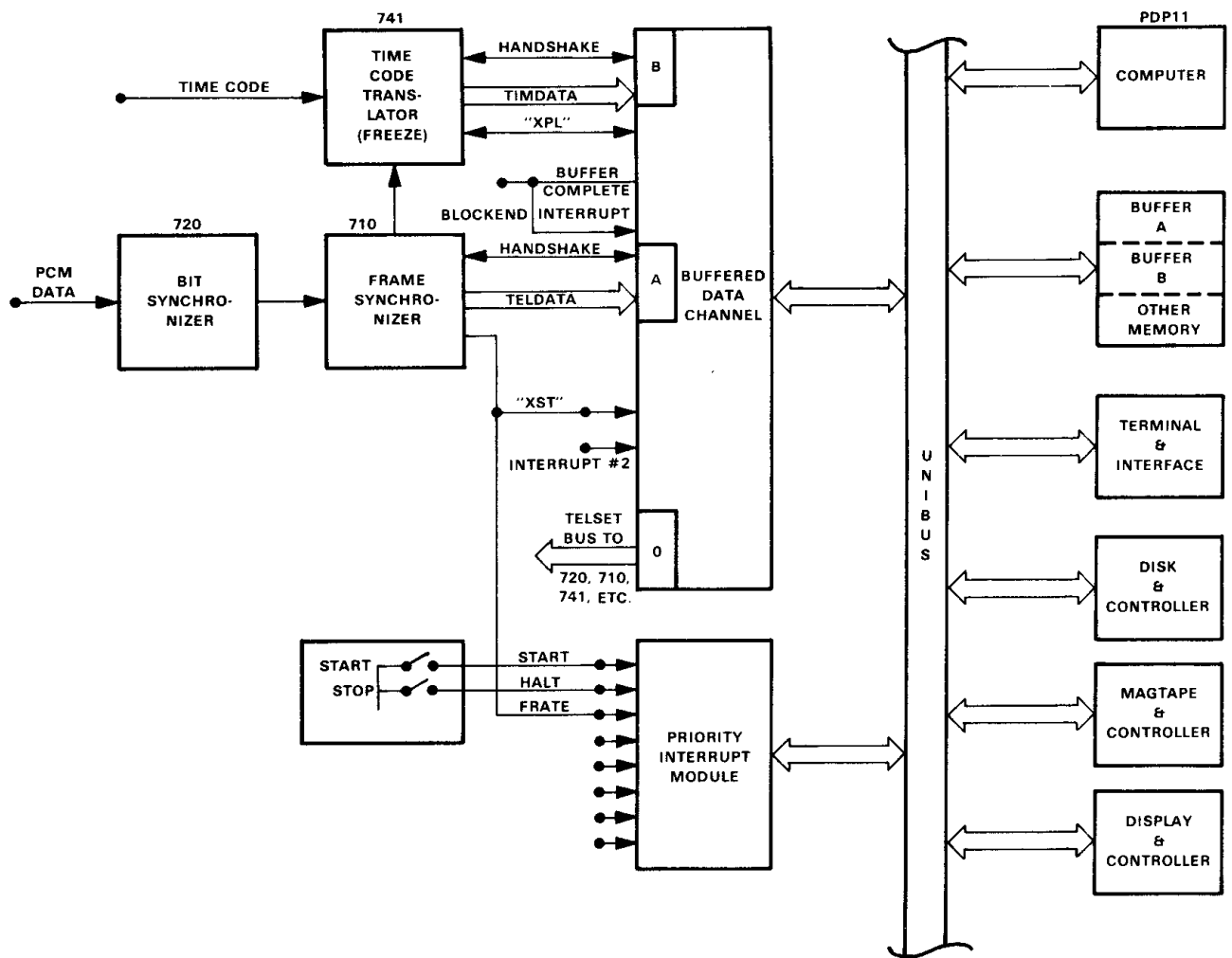


Figure 6. Typical Teletype-Operated System