FIBER-OPTIC LOCAL AREA NETWORK FOR REAL-TIME TELEMETRY

Tom Bartley
Loral Instrumentation
8401 Aero, Drive
San Diego, California 92123

ABSTRACT

For years, standard telemetry decommutators have proven the practical effectiveness and other advantages of using a data-driven (or data flow) broadcast bus for collecting, merging, and distributing continuous flow, real-time data. Bus length constraints have limited the use of the wideband broadcast bus to within a single chassis or closely mounted multiple chassis. Standard fiber-optic interfaces now make it possible to extend a real-time, greater than 5 million word/sec tag and data broadcast bus over kilometers at costs comparable to computer local area networks (LANs). Other advantages of this type of LAN include: no software protocol or handshaking, great flexibility in widely distributed processing and data base management, data security, and readily available off-the-shelf products. This paper discusses design considerations for conceptual networks, shows a sample design based on standard products, and suggests opportunities for product development for various types of network nodes. Also discussed are the implications to distributed processing and merging of real-time continuous data streams into the more blocked environment of general purpose computer processing and data base management.

BACKGROUND

When real-time telemetry systems began to get serious in the 1940s and 50s, engineers used simple analog systems as depicted in Figure 1 to acquire, store, display, and analyze test data. The analog strip chart was and is well suited to the continuous nature of the observed measurements. The arrival of the “digital age” required sampling theory and analog to digital converters. After going through some hybrid encoding schemes such as pulse-duration modulation (PDM) and pulse amplitude modulation (PAM), the telemetry world settled on the all digital pulse-code modulation (PCM) formats as the popular choice. The Inter-Range Instrumentation Group (IRIG) carefully described each of these techniques in a set of internationally used technical standards, as they had done previously for FM analog formats.

It is worth noting that all of the past telemetry formats follow the style of continuous flow data with minimum overhead synchronization requirements and need little or no data storage buffers. Timing correlations for multiple data sources were done with time codes on strip charts and time words in the data streams.

The digital age also brought digital communication systems and Van Neuman machine digital computers. Unfortunately each of these systems maintains its own internal clock and timing system. Also, the Van Neuman architecture has an inherent bottleneck for program and data information within the central processing unit (CPU). While digital computers offer virtually limitless flexibility, they pay the price in reduced speed, increased price and complexity of software, and limitations of data input and output (I/O). Even with increasing processor speeds and decreasing computer price/performance ratios, the increasing data rate requirements of PCM streams dictated the use of more hard-wired and less flexible decommutator circuit designs. As depicted in Figure 2, second and third generation telemetry ground stations used either separate or integrated special purpose circuits for each of the telemetry functions. Notice that a digital computer is used for setup and control as well as processing of compressed data, report generation, and data base management.

The fourth generation telemetry ground station uses a more integrated design at the front end to simultaneously acquire, preprocess, and merge multiple types of data from multiple sources. With the additional functions of digital data storage, increased preprocessing from better parallel microprocessors, and custom host computer interfaces, telemetry front ends require wide bus and multibus architectures. The ADS 100, as depicted in Figure 3, is an example of a wide multibus structure with an internal data driven (or data flow) bus architecture that allows true parallel processing uniquely suited for continuous real-time data.

Fifth generation telemetry and data acquisition front ends are now emerging and continue to utilize multibus data flow architectures to handle more faster and more flexibly than ever before. The power of the microprocessor and relatively inexpensive workstations is changing the role of the host computer and encouraging more widely distributed real-time processing for display and analysis.

For a more detailed discussion of telemetry front end evolution, see Berg and Friedman(1).

DATA FLOW ARCHITECTURE

The success of the fourth generation data flow architecture is attested to by over 500 systems and over 1000 chassis in use in the field. The key to the achievement of true parallel processing and efficient real-time bus utilization is putting decommutated or acquired data words onto the data flow bus in parallel with a unique tag that identifies the data word. Other processing, storage, or output modules sitting on the same bus that have been programmed to recognize this tag will "grab" this data word and start performing their programmed functions. Thus, each data word carries its own program via the setup tag information. Because this is a true "broadcast" bus, all transfers of the same data word occur simultaneously and processing is accomplished in parallel. A round robin priority arbitration scheme assures worst-case latency for access to the bus by data sourcing modules. By following the architecture rules, engineers can independently develop a library of modules to handle input, output, storage, and processing. Multiple types of modules and multiple modules are assembled from off-the-shelf standard products to "customize" any system.

Independent module development also nicely allows continued development of new functional modules and new technology insertion for updating of "old" module designs. Again, as an example, the ADS 100 design as shown in Figure 4 has maintained a 4M word, 32-bit parallel MUXbus broadcast bus for 16 bits of tag and 16 bits of data since introduction in 1982. During that time 57 standard and custom modules have been developed.

THE PROBLEM

Just as terminals, PCs, and data sharing local area networks (LANs) have proliferated to virtually every engineer's desk, emerging technology and data users' new expectations are increasing the pressure for more widespread distribution of wide bandwidth real-time data. The trend to decentralized distributed processing is similar to disbanding the word processing secretarial pools and putting a PC word processor on every secretary's desk. In another application it is desired to move massive amounts of data from an engine test cell to a centralized data processing and distribution center located some distance away. In other applications, dedicated data servers pass selected data to users over standard computer LANs.

Four approaches to distributing real-time continuous flow data are: standard computer interfaces and LANs, standard communication systems, PCM formats, and a data flow broadcast bus LAN. Computer interface and LAN standards have the advantages of interconnecting a lot of different types of and different manufacturers' equipment. Computer standards have the disadvantages of sending "blocked" data, which requires special buffers and drivers for real-time applications. The handshaking and protocols can eat up significant amounts of overhead, can require expensive hardware and software, and are generally limited to less than 10 Mbit data rates. For example, a fast 10 Mbit Ethernet may only pass 3 Mbits in real data rates. Much of the current literature is filled with descriptions of computer LANs for E-mail communications and data-base sharing (2,3,4). Other recent literature discusses factory automation applications (MAP) (5).

Standard communication sytems again offer the advantages of having interconnect and multiplexing standards, high bandwidth, and relatively low cost. However, these systems operate at fixed rates, are extremely inflexible, and require fill data or lose real-time data if the data rates are not precisely matched. The matching interfaces can quickly dissipate any cost advantage.

PCM formats were designed for real-time continuous data and work well for source data streams, but each node or port would require a repeat of expensive hardware which must also buffer and, in some cases, adjust the data rate automatically for varying rates of merged data. PCM formats, similar to digital communication standards, work best with a nonvariable data rate.

A data flow broadcast bus, where the speed can be high, the transfers are parallel, and bus activity occurs only when data is present, would be ideal. However there is no industry standard and the parallel configuration of the bus restricts the transmission distance to closely mounted chassis.

FIBER-OPTIC SOLUTIONS

As the technology has matured for fiber-optic transmission, line speeds have increased to 1.2 gigabits/sec over distances up to 52.5 km (6). Also, the costs of the fibers and the interconnects is competitive with wire and coaxial cable. In either case, fiber or coaxial, the major costs are usually associated with cable installation. Several manufacturers are now making fiber-optic network node ICs and workstation companies like Sun Microsystems Inc. Apollo Computer Inc., and Apple Computer Inc. are planning fiber-optic networks (2). The Fiber Distributed Data Interface (FDDI) token protocol approach at 100 Mbit/sec appears to be emerging as the standard of choice, but other approaches are conversions of wire and cable standards such as Ethernet (7). Other approaches have been described that rely on communications standards and the model for open system interconnection (OSI) of the International Organization for Standardization (IOS) (8,9,10).

All of the broad-based general approaches are focused on the computer and communication interface standards and generally suffer the same disadvantages described above: complexities in hardware/software overhead handshaking protocols, bridges, gateways, and not being well matched in concept to the continuous data flow requirements of real-time telemetry systems.

The world may not yet need another fiber-optic LAN standard, but fiber optics now makes it possible to extend the data flow broadcast bus over kilometers without introducing more protocols, complexity, or expense. The Toplink system from Integrated Photonics Inc., of Carlsbad, Calif. passed data over a single multimode fiber at data rates in excess of 400 Mbits/sec at distances up to a kilometer (11). The manufacturer provides proprietary single-chip ECL functional converters to do the parallel-to-serial and serial-to-parallel conversions at the transmitter and receiver. The system is data driven and a single uni-directional fiber could handle a 32-bit data flow bus at 12.5M words/sec or a 48-bit bus at 8.3M words/sec. The only system requirements are ECL-compatible parallel data and strobe.

A less expensive alternative approach to Toplink could be built from AMD TAXIchip(tm) devices but would require multiple fibers. A data flow LAN interface standard could simply be based on the strobed parallel word which contains tag and data. For example, the standard could describe the first 16-bit positions as tag and the remainder of the bits as data, and specify TTL logic levels and the minimum time between data strobes.

DESIGN CONSIDERATIONS

If we examine the ADS 100 example, fiber-optics technology can remove the present bus length constraints and a full-speed, real-time data bus can be extended to another MUXbus chassis located anywhere within an industrial campus. Each chassis would require the respective transmitter and receiver fiber-optics interfaces, but no other handshaking protocol or software interfaces are required and the same tag and data information appears in each chassis. Based on the ADS module design rules, each chassis easily becomes a node that can: repeat, filter, source, process, distribute, store or interface to other computers. Thus, the node capability can support virtually any network topology desired for distribution and reliability. Maxemchuk (12) discusses various topology strategies for linear unidirectional networks. Combinations of lines, loops, spirals, stars, and bidirectional switches are conceptually simple to implement.

While not particularly serious, there is one characteristic of data flow systems that is functionally similar to the overhead handshaking protocols of other networks: that is the passing of the tag identification information. This need only be done once prior to a typical real-time test run and once set up, need not disturb the data flow. In some cases, dynamic changes are desired but these are still insignificant compared to the data flow.

The using node must recognize the tags of desired data and can ignore everything else. This is typically done with a programmable tag decoder RAM. If a node is to generate or source data with new tag numbers, successive nodes must have that information to use the data. Again, for a real-time data flow network, this is done during setup and does not represent a problem.

Tag ID information can be passed around by various means: manually via handcarry, telephone, paper mail, floppy disk, etc., or automatically via slow computer communications (computer and communication LANs), or even with a synthetic data block within the data flow bus LAN. Similar to tag information, node status can also be passed around.

SECURITY CONSIDERATIONS

First, there are obvious EMI and ground loop advantages of fiber over metal cables. Second, without tag information a user cannot uniquely identify the data. Tags can be controlled and can be changed as often necessary. Third, the tag identification system can accommodate randomizing techniques within sensitive data words. Other password layers could be implemented at the node setup level.

DISTRIBUTED PROCESSING

Potentially, the most important value of this LAN approach is to provide convenient distributed interfaces between the real- time “continuous flow” environment and the “blocked” nature of the Von Neuman computer environment. There are various different ways that an analyst would like to collect data with his general purpose computer, such as:

Framing or Snapshot - all samples taken within 2 major or minor frames.

Current Value Table (CVT) - the latest or most current value of each possible data word or sample.

Array - continuous time sequential blocks of a single parameter for array and vector processing.

Multiple arrays - cross correlation processing.

Alarms - data close to and out of limits.

Alarm Times - times at which the data crosses limit boundaries.

Preprocessed Data - fully calibrated, compressed, engineering-unit converted (EUC), and formatted ready for use by the host computer.

Statistics - histograms, means, variances.

Because of real-time speed and buffering considerations, the nodes should be able to do these various types of data collection better than a general purpose computer, but under the command of the computer. This type of real-time data flow system with flow bus nodes and a broadcast LAN for distributed processing with general purpose computers supports (better than ever before) real-time data base management and real-time comparisons of historical and simulated data with ongoing results. This architecture also supports extensions into artificial intelligence (AI) management of test and evaluation. The ultimate benefits should offer safer operation and quicker turnaround of test information aimed at critical decisions.

REDUCTION TO PRACTICE

Probably the first product to use the fiber-optic extension of the broadcast MUXbus will be the System 500, shown in Figure 5, for the MUXnet connection between multiple acquisition 510 chassis and processor 550 chassis. In this case, tag information is passed around from the 520 workstations via Ethernet control to the various chassis.

CONCLUSIONS

This paper described a conceptual approach to extending the successful, proven, data flow broadcast bus technique beyond closely located chassis to a local campus area. For purposes of handling high-speed continuous data from a single sensor or high data rates from multiple sensors, this approach offers advantages over typical computer and communication standard LAN protocols. No timing overheads are required.

Also, the simplicity of the approach to a true parallel broadcast data distribution offers strong potential of establishing an industry standard for the interface at the parallel tag and data inputs and outputs of the fiber-optic LAN.

REFERENCES

1. Peter Berg and Paul Friedman, “Real-Time Telemetry Data Processing at Very High Throughput Rates Using the Field Programmable Processor in the ADS 100 and System 500 Architecture,” to be published in the proceedings of the European Telemetry Conference, held at Garmisch, Federal Republic of Germany, June 1988.

2. Mark Stansberry, “The Integration of Fiber Optics into Network Systems,” *VLSI Systems Design*, April 1988.

3. “Inside Technology” featuring eight articles on networking, *Electronics*, April 14, 1988, pp. 67-96.

4. “Cover Story” featuring nine articles on LAN connectivity, *PC Magazine*, June 14, 1988, pp. 92-272.

5. *Advances in Instrumentation - Proceedings of the ISA 87 International Conference and Exhibit*, Volume 42, part 2, Instrument Society of America. Eight different papers: 87-1110, 87-1111, 87-1112, 87-1195, 87-1196, 87-1197, 87-1206.

6. Charles L. Cohen, “Now, An Otoelectronic IC Replaces Hybrids for LANs,” *Electronics*, March 31, 1988, p. 34.

7. D. Rowarth and N. Howe, “Isolan: A Fiber Optic Ethernet,” *Electronics and Wireless World*, August 1987.

8. Orlando Ciaffoni, et. al., “Optical Networks and Laboratory Services,” *Nuclear Instruments and Methods in Physics Research,* A 257 (1987) 632-634, North-Holland Amsterdam.

9. F. Gagliardi, “A High-Speed Optical System for local area networking,” *SPIE*, Vol. 585 Fiber Optic Broad band networks (1985).

10. Philip D. Wilson, “Fiberway,” *SPIE*, Vol. 715, Fiber Telecommunications and Computer Networks (1986).

11. Larry Waller, “A Fiber-Optic Link that Runs with Supercomputers,” *Electronics*, March 3, 1988, page 74.

12. N.F. Maxemchuk, “Linear, Unidirectional Networks and Random Access Strategies in Fiber-Optic Local Distribution Systems, 1986, *Globecom ‘86 - Global Telecommunications Conference*, Houston, TX, Dec. 1-4 1986, Conference Record. Volume I (A87-45476 20-32). New York, IEEE, Inc., 1986, p. 29-33.

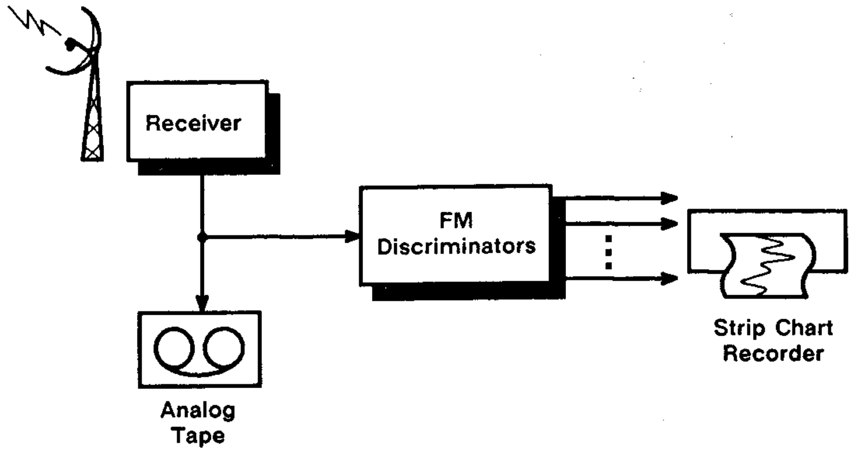

Figure 1. First generation telemetry ground station.

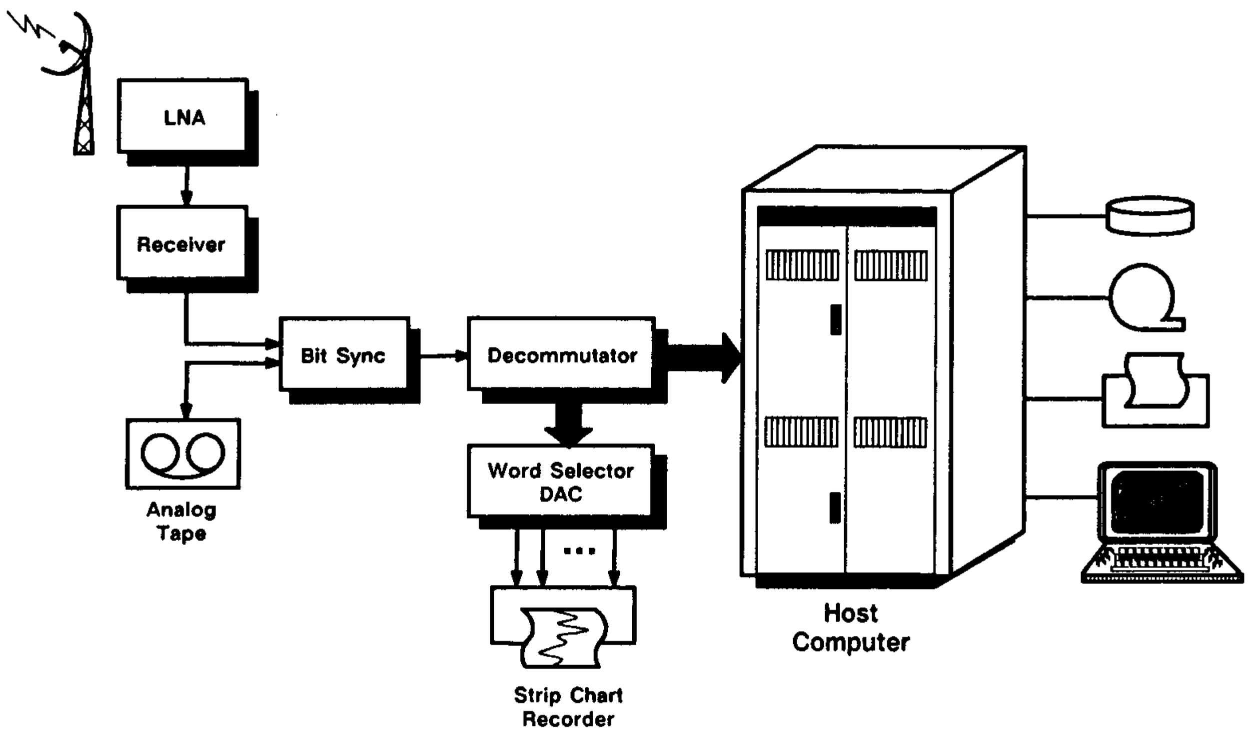

Figure 2. Second and third generation telemetry ground station.

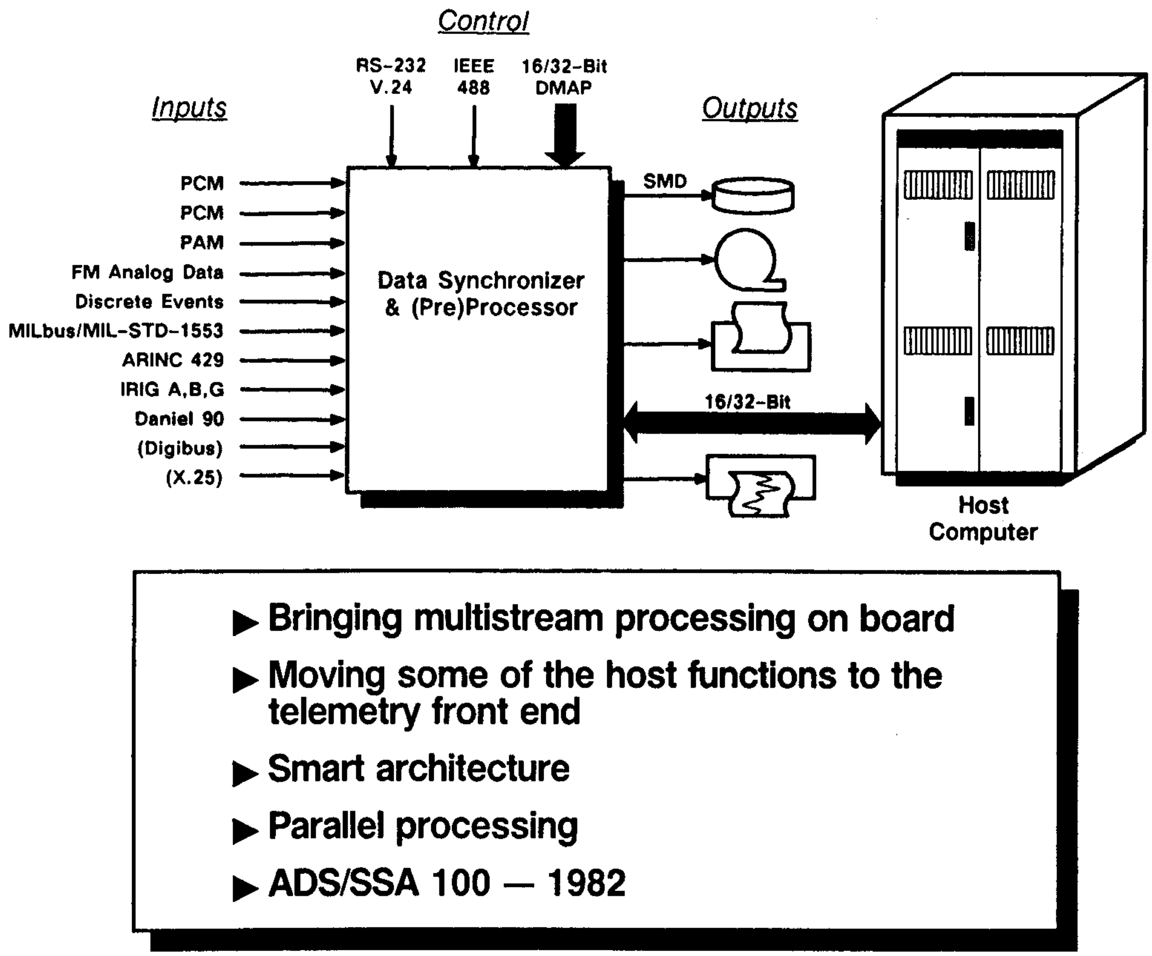

Figure 3. Fourth generation telemetry ground station.

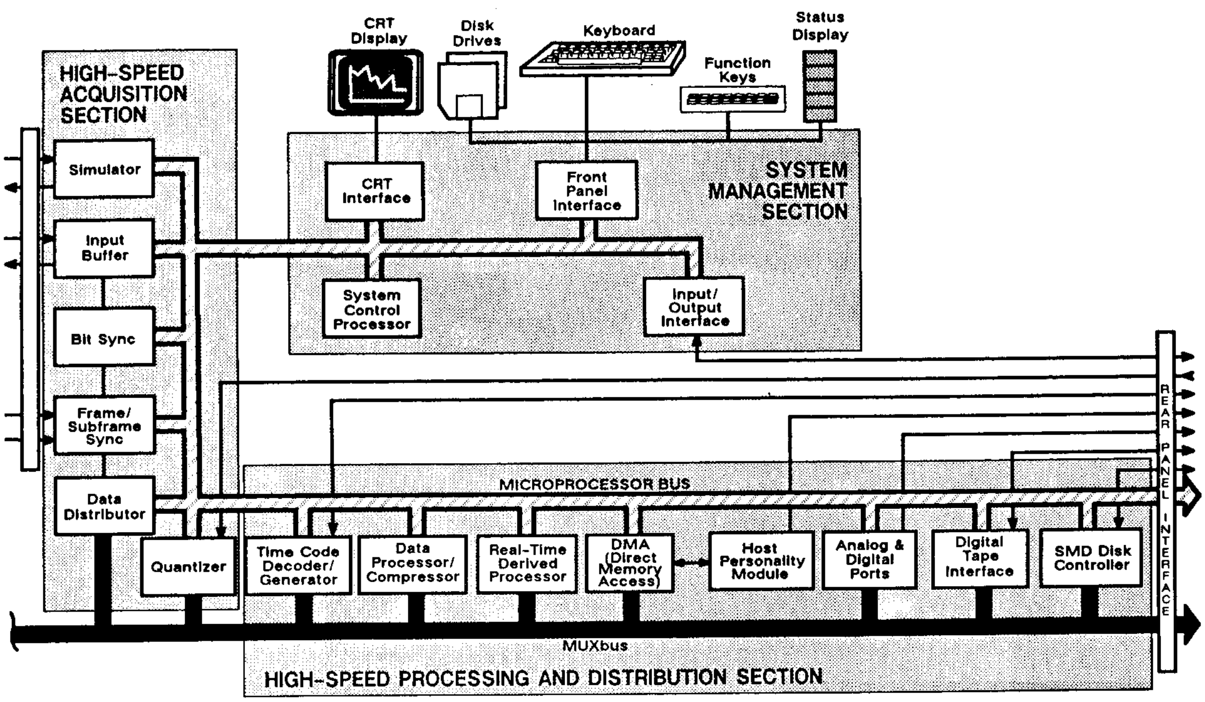

Figure 4. Typical ADS architecture.

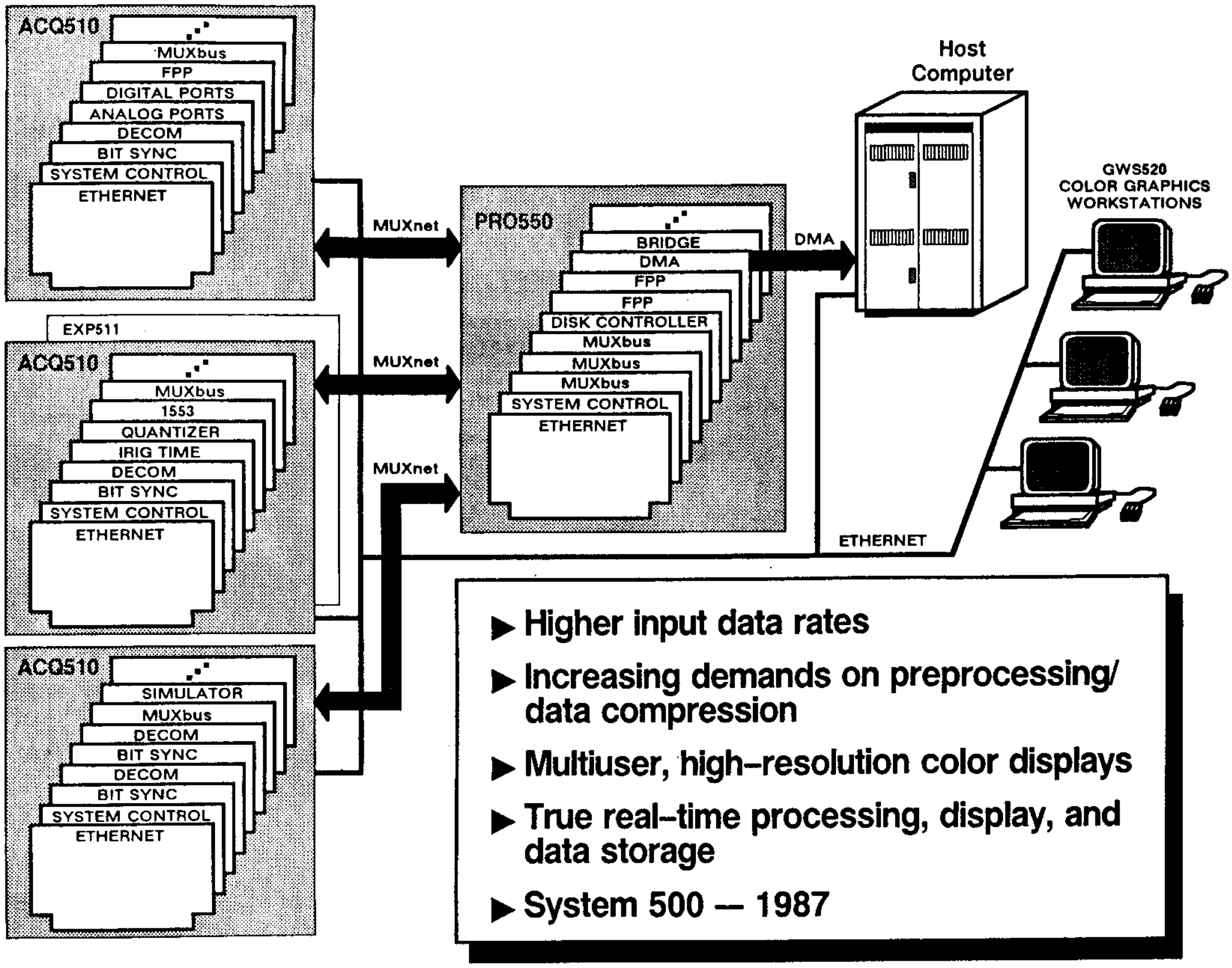

Figure 5. Fifth generation System 500.