SUPERVISORY CONTROL AND TELEMETRY USING EMULATION-TYPE MICROCOMPUTER

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Summary. An advanced Supervisory Control and Telemetry system has been developed to meet the diversified requirements from the widening range of application fields such as utility industries, highways and railways. The transmission procedure employed is Cyclic Digital Transmission (CDT)a procedure most widely adopted in Japan, especially in the electric power control field. The master station possesses the capability of accomodating equivalently as many as 32 remote stations linked over 1200 b/s carrier channels on a real-time basis. This processing power has been achieved by the use of an emulation-type microcomputer, into which a specially developed set of microinstructions are incorporated as part of firmware to get the optimal tradeoff between hardware and software.

Introduction

Public and utility systems are in need of a number of “Control Points” spread over large areas in order to fulfill their social roles. Examples are such transports and distribution systems as gas and electric networks, water supply and sewerage disposal systems, freeways and railways. Recently, automation and centralized control facilities in such control systems have been advanced for the purposes of improvement of their services and reduction of personnel expenses. Also required are supervisory control functions of remote points of larger scale than ever before. With the scale expansion and diversification of the application fields, there have arisen the requirements for extensive processability and flexibility satisfying the diversified needs to Supervisory Control and Telemetry systems.

In the electric industry, where supervisory control systems have been made use of at many power- and sub-stations for a long time, the recent trend is that ever larger Control Points are becoming unattended and remotely controlled. Incidentally, in Japan, Supervisory Control and Telemetry systems are utilized most in the electric power field, where Cyclic Digital Transmission (CDT) procedure recommended by the Institute of Electrical

Engineers of Japan is widely adopted*. Such CDT based systems are also used in other fields, which CDT was not necessarily meant for the time of recommendation.

These trends are now forcing the equipment at the controlling side of the Supervisory Control and Telemetry system (called Master Station) to have more powerful and versatile functions, with the equipment at the remote-controlled side (called Remote Station), on the other hand, ranging widely in terms of size and performance.

This paper describes the Supervisory Control and Telemetry system developed for the purpose of making the Master Station highly integrated and flexible, which is based on a emulation-type microcomputer with a special built-in set of machine instructions.

CDT Procedure

Although CDT is widely used in Japan as a standard procedure, especially in the electric power control field, very few are found overseas. This section, accordingly, gives an outline of CDT, to begin with.

Concepts of CDT. CDT is a data transmission system based on PCM-TDM method, which was developed for the continuous transmission of supervisory and telemetering data. The main features of CDT are, as the term "Cyclic" implies, continuous supervision of measurands changing smoothly and continuously, immediate transmission of informations changing intermittently with the time resolution of the transmission cycle, and constant monitoring of the main functions throughout the transmission circuit. The continuous grasp and periodic diagnosis of operating status of the remote transmission facilities are strongly required particularly because the remote stations are unattended. Another incidental advantage expected is that symptoms of faults may be detected before becoming catastrophic.

Economical situations played important roles in the background during the evolution of the CDT concept. It was first discussed in 1967, when ICs were still considerably expensive and accordingly a simplified transmission control procedure was required in order to reduce equipment cost. Therefore, the CDT procedure was determined to be simple and effective by eliminating the start/stop control of transmission sequence. Another economical condition was that the rise in cost due to the continuous usage of transmission channels was not so serious a problem, because electric power and railway industries possessed their own data transmission networks. These original considerations are

*Communications Study Committee of the I.E.E. of Japan, "Standard Specification of Cyclic Digital Information Transmission Equipment", Technical Report of I.E.E. of Japan (Part I), No.91, August 1969 generally justified still now; as simple equipment configuration and continuous channel monitoring contribute to the system reliability improvement as well.

CDT systems, as shown in Fig.1, are basically simplex, point-to-point transmission sstems using 200-1200 b/s carrier channels. The basic scheme for reliability betterment is the duality of transmission routes and time-shared common components such as analog-to-digital converters, parallel from/to serial converters, and power supply units.

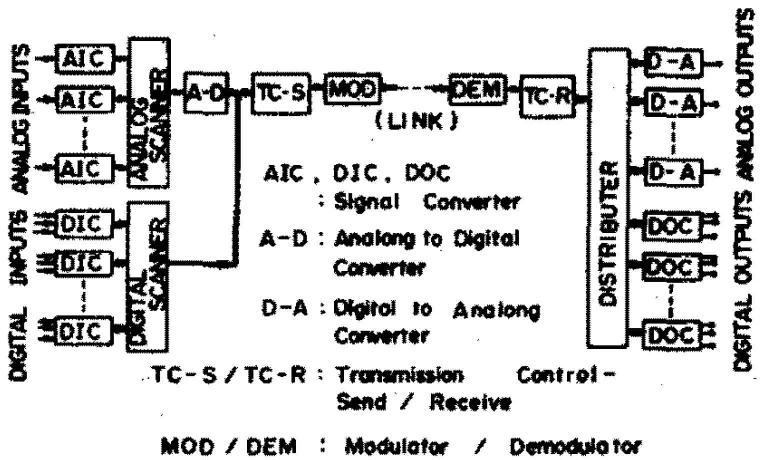


Fig.1 Cyclic Digital Transmission (CDT) system configuration

Transmission format. The basic transmission format of CDT is illustrated in Fig.2. Although the format can carry a variety of data, it has a common hierarchical structure consisting of a Cycle, Frames, Words and Bits. Transmission is performed periodically Cycle-wis and is controlled Word-wise. Frame is a block of Data Words to synchronize the sending and receiving timings; this Frame synchronization is accomplished by detecting the unique-pattern Sync Word inserted at the head of each Frame. Cycle comprises either one or two Frames, and each Data Word is idetified by the Word Address which is assigned such that no more than one idetical Word Addresses appear within one Cycle.

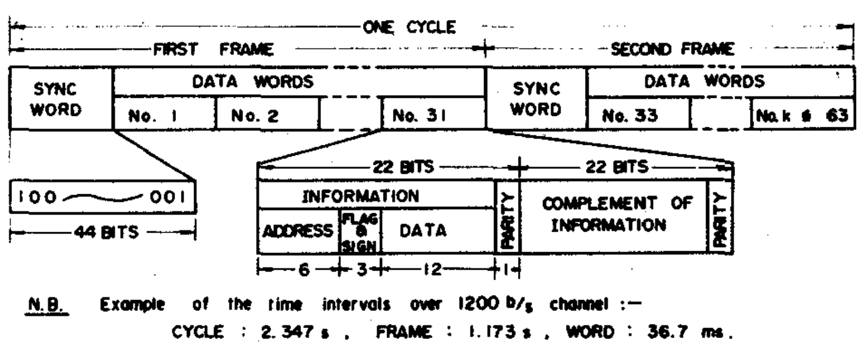


Fig.2 Transmission frame format of CDT system

Data Word, a 44-bit word, basically consists of Word Address, Flag, Sign and Data, together with error-detecting redundant bits. Here the Data bits contain either select/operate commands, measurands or status indications, as the case may be. Transmission errors are checked for by means of parity checking and complementary-repeat-and-compare technique. Sub-commutation and super-commutation are often adopted to virtually increase Data numbers, and to shorten the sampling period, respectively, as are required.

CDT based Operating Command Transmission uses a variation of the basic format, as shown in Fig.3, to raise reliability and adaptability. Functionally it is not cyclic, but acyclic which transmits select/operate commands with a shortened Frame only when the commands are issued. However, Frames with special pseudo-commands of “NO-SELECTION, NO-OPERATION” are transmitted when no commands are given, whereby the system is always kept active, retaining the merits of cyclic transmission.

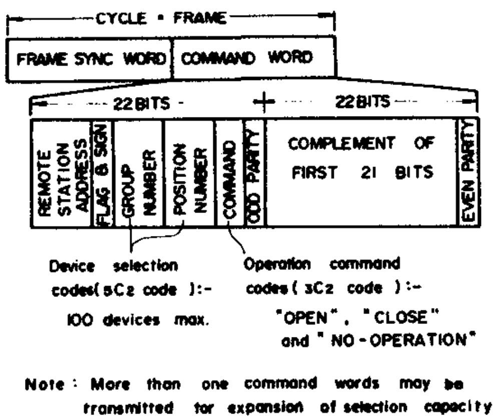


Fig.3 Remote operation frame format as a variation of CDT

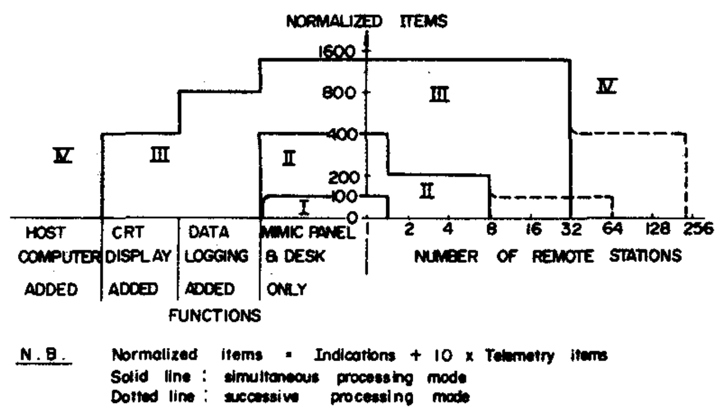


Fig.4 Four scale grades of Supervisory Control and Telemetry systems

Control procedures. Since CDT is of continuous transmission, it does not involve complex procedures excepting sub-commutation, super-commutation and Frame shortening. The Frame shortening is a procedure which can improve the response for urgent information in a system transmitting a great many Words over low speed channels. As soon as a control circuit accepts a signal of urgency, it shortens the current Frame so that only the predetermined Words are sent for the preset number of cycles, after which the transmission resumes the normal mode of operation.

The Word which has been detected to have error bits by the error checking methods mentioned above, is abandoned and kept from going to output devices. Since another data sample of this item is coming one cycle later, error correction can be dispensed with. To some output devices, however, even if some error are detected, data are transfered as they have been received, with the Flag bit indicating that the data are not effective, so that the output devices also can detect the erroneous transmission conditions.

Although the CDT format puts the basis on continuous transmission, it can be applied to transmission procedures of “Polling” or “Transmit-after-status change”, which are really used with a multi-drop channel in transportation field, or with a common carrier channel to save the lease cost. In the multi-drop environment, for example, the Master Station polls a certain Remote Station and it responds with one or two Cycles of transmission, or with a frame of “no-change”; the frame is usually shortened to save the polling time when there are no status changes.

Purpose of using a microcomputer

System configuration. The system scale of Supervisory Control and telemetry is characterized by

(1) number of Remote Stations,
(2) number of supervision and control items,
(3) variety of functions.

Additionally time-related conditions such as transmission speed and supervisory control response affect the system configuration, but these conditions can be converted into the equivalent amount of information by keeping identical the products of transmission speed and data amount. We classify the system scale into the four grades, I, II, III and IV, as shown in Fig.4.

As a system structure that is well adaptable to a wide range of applications the modular one is quite suitable. This approach can increase the productivity at factory in the sense that a variety of application system can be built up by a combination of the standard modules and a few dedicated ones. From the customers’ viewpoint, on the other hand, this modularity has a number of advantages such as good maintenability, wide expandability, and an optimal tradeoff between the inefficiency and complexity of the general purpose machine and the excessive developing cost of the special purpose machine.

Although there have long since existed modular structures adopted in Supervisory Control and Telemetry system which are based on hardware modules, the new technology is a much more integrated and flexible modularity that incorporates hardware and software modules utilizing the power of a microcomputer and a compatible minicomputer.

The usage of a microprocessor or a microcomputer is divided into three types:

(1) assemble the microprocessor as a large IC in the control equipment

(2) use only the hardware of a stand-alone microcomputer system,

(3) use the microcomputer as a computer system completely equipped with hardware and software.

The type (1) is adequate for a dedicated small system, but not for a system of large scale and high function covering the whole applications. The type (2) and (3) are different only in the structure of software, and hence their modules can exist as the different yet cooperative components within systems of the same concept. There, the structure (2) may be particularly suitable to medium or large systems with medium level functions, and the structure (3) may be well suited to large or very large systems requiring high level functions.

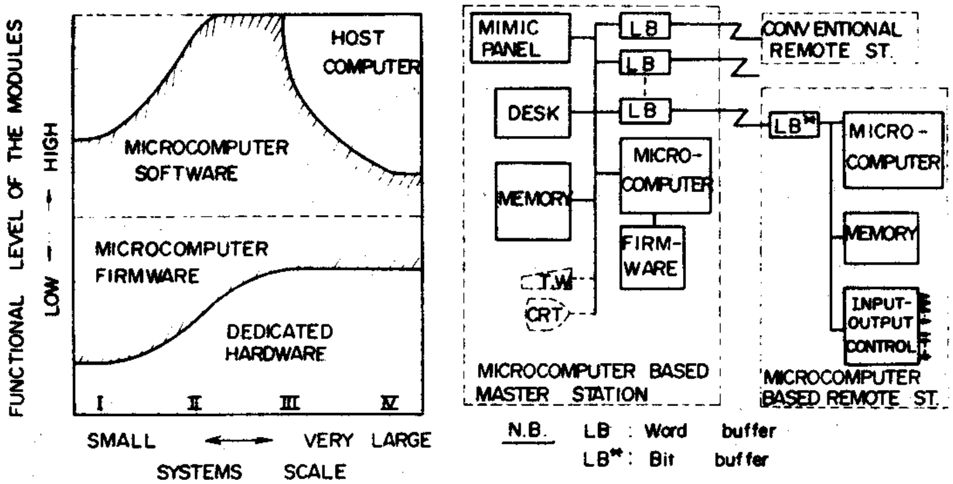
Two strategies of modularity, i.e., functional modularity and incremental modularity, could be considered. Fundamental functions of Supervisory Control and Telemetry are roughly summarized as follows:

Master Station	transmission control, indication processing, operating command issuing, test/diagnosis, etc.,
Remote Station	transmission control, input data processing, operating command execution, test/diagnosis, etc.

Each function can be implemented as either a hardware module or a software module; hence the term functional modularity.

In case of the incremental modularity, a required number of unit modules are assembled so that the supervisory control and telemetry functions as a whole are implemented for a specified number of items for either the Master Station or the Remote Station. This concept would become very attractive when the multi-processor techniques now utilized for large computers come down to the microcomputer field.

The functional modules can implement the whole functions by combinations of dedicated hardware, firmware and software of a microcomputer, and, if necessary, a host computer system. The concept of sharing various levels of functions among them is shown in the left half of Fig.5. In case of a smaller system most of the functions can be performed by the microprocessor, while in a larger system, higher capabilities such as simultaneous processing of multi-directional remote stations can be accomplished by an increased firmware ability by means of assigning bit-oriented send/receive control to the hardware. The right half of Fig.5 illustrates an example of such structure for a large system.



(a) Concept of function sharing among software, firmware and hardware (b) System model of the grades II ~ III

Fig. 5 Systems configuration using a microcomputer

Furthermore in a very large system, an advanced data processing and powerfull man-machine control can be achieved by connecting a host computer that has machine instructions compatible with the microcomputer. Then the microcomputer works as a front-end communications processor to the host and reserves the rest of processing power for backing up the host in case of emergency.

Technical problems in using a microcomputer

There is not any fundamentally new problem in applying a microcomputer to Supervisory Control and Telemetry systems, since a number of computer based systems have been developed and put into operation [**],[***]. One of the strong points of microcomputers is compactness which conventional computers never have. If a microcomputer keeping its compactness can construct a Master Station with multi-directional Remote Stations, the Master Station will be compact as well as flexible with a high degree of performance that was never realized conventionally. Here we discuss the problems in using a microcomputer to make up a Master Station.

Functional sharing. Functions of the Master Station, shown in Fig.6, must be shared among hardware, firmware and software to optimize the cost-performance under the constraints for compactness, flexibility, backward compatibility, etc. The hardware is good at sharing the functions which are simple but speed-critical, and common to many different systems. Software and firmware, on the other hand, are suited to share the contrastive functions. Firmware should share the functions like subroutines that are called

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[**]E.B.Tuner, “Computer Based Supervisory Control Systems”, IEEE trans. on Industry Applications, vol.IA-10, no.2, pp.305-315, March/April 1974

[***]L.S.Cole, “Processors for Remote Supervisory Control Stations”, IEEE trans. on Industrial Electronics and Control Instruments, vol.IECI-20, no.1, February 1973.

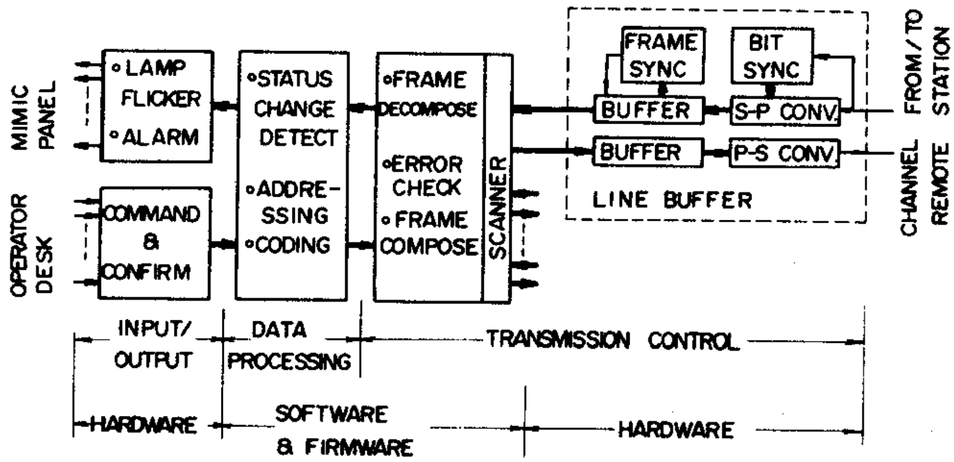

Fig. 6 Functionl block diagram of Master Station

up relatively frequently as compared with software. The functional sharing scheme in the concrete is as follows:

Hardware	interfacing with outer devices, serial to/from parallel conversion,
Firmware	channel scanning, compose/decompose of transmission words,
Software	transmission control, indication processing, operation command control, other miscellaneous functions including management of man-machine devices.

Since the interfaces implemented by hardware include the connections with transmission channels, supervisory panels and operators desks, the hardware could hardly be standardized to all applications without some functional decomposition. But indication output and command input circuits can be simplified and reformed into standard modules with the aid of the software absorbing a wide spectrum of application functions, since the man-machine interfaces such as indication and operation are of such a nature as needs to be processed at intervals of a few seconds at the fastest.

The items of Supervisory Control and Telemetry system, which sometimes amount to hundreds in large systems, are indicated and/or controlled individually, and so the indication and operating command control must be executed on a item-by-item basis where information is of only one-bit-per-item. However computers can not effectively process the bit-oriented informations. Fortunately, indication items of about ten positions (items for on-off status) are grouped into a Word or a Group, and hence the microcomputer can effectively process them in parallel Group-wise. An operation command consists of a group address, an individual (or point) address, flag bits and a command code, and the number of bits of the operation Word is equal to that of the indication Word. So that the operation command can also be processed in parallel Word-wise.
On the other hand, since transmission control can not be dealt with in parallel, it is a heavy load for a computer and it was one of the main causes that have reduced the ability of a

microcomputer when used for Supervisory Control and Telemetry. However the introduction of firmware technique has enabled a microcomputer to process the transmission control with the same speed as for other functions, and to realize a substantially higher processing power than without the firmware.

Reduction of processor overhead. Even in a microcomputer-based system, some Hardware modules are still necessary which interface with the external equipment including communication channels, mimic diagram panel, etc. These hardware modules are physically connected to the microprocessor, but logically done to its software as well. This logical connection between hardware and software is one of the new and crucial problems which does not exist with a hard-wired system.

Here, it is noteworthy that the system performance depends particularly on how efficiently the connection with communications channels is dealt with, since they should generally be processed with the highest priority on account of their random timings independent of the processor clock. Otherwise any incoming data might be lost, especially in the continuously running CDT system.

Most microprocessors are capable of three modes of connection with external devices:

(1) PCIO using an input/output instruction,
(2) MI using a store/load instruction, each device being handled virtually as a main memory element,
(3) DMA external devices accessing the main memory directly without the help of processor.

With whichever mode, either priority interrupting or fast scanning must be incorporated to coordinate the program to external devices. The interrupting is suitable to such a low-speed and non-cyclic connection as with man-machine interface devices, whereas the scanning is relatively advantageous for such a connection of cyclic nature as with communications devices. Although the interruption is generally accepted very quickly by the internal hardware of the processor, a program run of hundreds of steps is necessary in order that the interrupting device and the interrupted program may be selected out of many other devices and programs, respectively, which is the processor overhead that should be reduced to a minimum to improve the system size and performance.

Consequently, in a system dealing with a considerable number of remote stations over CDT channels, the interruption method may reduce the system performance sharply due to the overhead multiplied by the number of the channels. On the other hand, the program-driven scan method can avoid the excessive overhead since in this case all that is needed for all the channels is a one-channel equivalent overhead for the program initiation at the begining of each scan cycle.

Reliability consideration. With the introduction of a microprocessor into which a great deal of functions are integrated, the reliability consideration as regards the processor in particular is an essentially important design aspect. From the viewpoints of parts and components, a relatively high reliability can generally be achieved with their reduced number as compared with that of a hard-wired system, together with a fieldverified quality control. In addition, from the system configuration point of view, four steps have been conceived corresponding to the four grades in

Grade I	:	single structure,
Grade II	:	single processor with line buffers, backed up by exchangeable spare plug-in boards,
Grade III	:	duplexed processors and memories with line buffers,
Grade IV	:	duplexed processors and memories with line buffers, partially backed up by a host computer.

Furthermore, there is a fortunate situation in the supervisory control field in that processing may be continued in case of a momentary error or fault if it is detected and does not develop into any serious malfunction thanks to the repetive transmission, while in the computer control field the system shutdown is an usual scheme even with the shortest error condition.

Experimental system and results

A prototype of medium scale Supervisory Control and Telemetry system which will cover the grades II and III as shown in Fig.5 has been experimentally developed based on the above-mentioned concept using a microcomputer.

System performance. For supervision and telemetry, information is transmitted from the Remote Station to the Master Station where on-off and analog data are generally indicated by lamps and display devices, respecttively. Usually, those lamps flash on status change along with audible alarm.

A select-before-operate technique has been employed for operational control in that a remote device to be controlled is first selected at the Remote Station and acknowledged at the Master Station, and then a operational command is transmitted to the Remote Station to control the device.

Microcomputer adaptation. Microcomputers do not necessarily possess enough power to process very large systems because they are required to handle a CRT display and a logging typewriter, in addition to automated control of remotely located machines. In order to develope a system architecture which will cover from medium to very large scale systems by continuous enhancement, an emulation-type microcomputer has been adopted which is compatible with a larger control computer family by its machine instructions. As a result of this compatibility, the software modules to support man-machine devices have been standardized between the grades III and IV.

The outline specifications of the employed microcomputer HIDIC-08 are given in Table 1. HIDIC-08 is an one-board processor using bipolar one-chip CPU elements, and has 47 basic instructions which can partly emulate the instruction set of the upper class control computers, and are implemented into the basic microprogram firmware of 512-word Read-Only-Memories (ROMs). Other optional instructions can also be supplemented into another set of 512-word ROMs as the optional microprogram firmware.

Table 1. Specifications of the employed microcomputer:HIDIC-08

Item	Specification
Main memory	
Word length	16 bits
Capacity	4 K to 64 K words
Cycle time	0.55 μsec (IC memory) 1.2 μsec (core memory)
Central Processing Unit	One printed-circuit board type (209mm x 305mm)
Instructions	Basic : 47 (built-in microprogram) Firmware : 96 max (optional microprogram)
Registers	8
Execution time	3.1 μsec (addition with IC memory) 3.5 μsec (" " core ")
Input / Output control capabilities	PCMA 2K words / sec max. DMA 400 K words / sec max. MI 20 K words / sec max.
Interruption	2 Levels Identification by Hardware Vectoring method
Ambient conditions	Temperature : 0 to 50°C Humidity : 10 to 95% RH

N.B. PCMA : Processor controlled memory access
DMA : Direct memory access
MI : Memory interface, i.e., handling a device as if in memory.

Hardware structure. The hardware structure of the experimental system is depicted in Fig.7. The Master Station has the processing power which can simultaneously control 32 remote stations linked via 1200 b/s fullduplex channels. Actually a full-duplex channel was connected and the signal transmission speed was increased up to 48 kb/s, which is comparable to 40 channels of 1200 b s in order to prove equivalently the specified processing power under the multichannel environment. To accomplish this high performance with the microcomputer HIDIC-08, the line buffer was designed to share part of transmission procedure; that is, to detect the Frame Sync pattern of CDT format and to buffer half a word. As for the interface control between HIDIC-08 processor and the line buffers, MI technique has been adopted, so the line buffers can be accessed by means of either “store/load” instructions or “memory execute” microinstruction.

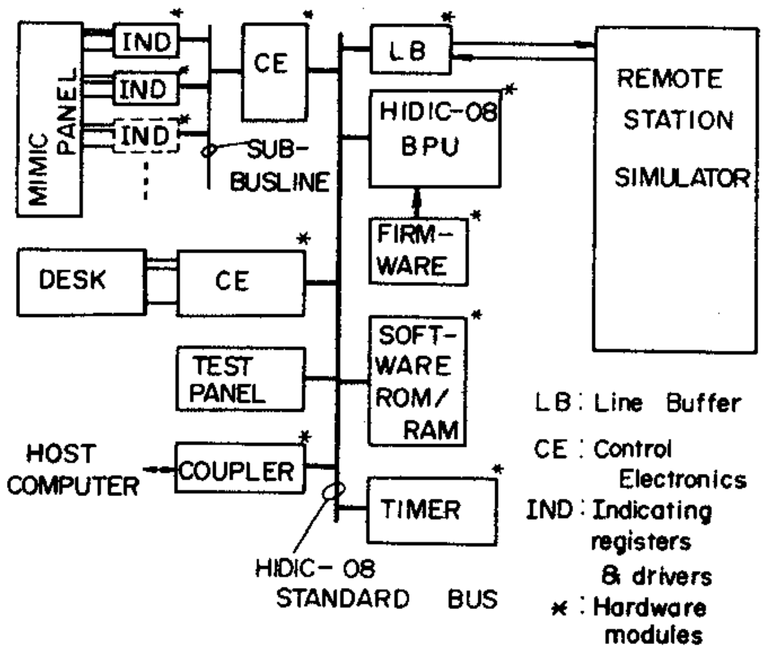

Fig. 7 Hardware structure of the experimental system

In the convetional systems a great deal of hardware was needed to control the indicating lamps which flash with status changes. However in this newly developed system the indication processing is implemented by software leaving only latch registers and lamp drivers in the control electronics for indication. As regards operator desk control, the interlocks among various operation switches are also performed by software, the hardware being decreased basically to simple gate circuits, and status registers for separating priority interrupt factors. As a result of this extensive software functions the amount of hardware of the system as a whole has been reduced to one fifth in size.

Software structure. The functional structure of the whole system as a combination of hardware, firmware and software is based on a hierarchical modular scheme. Fig.8 depicts

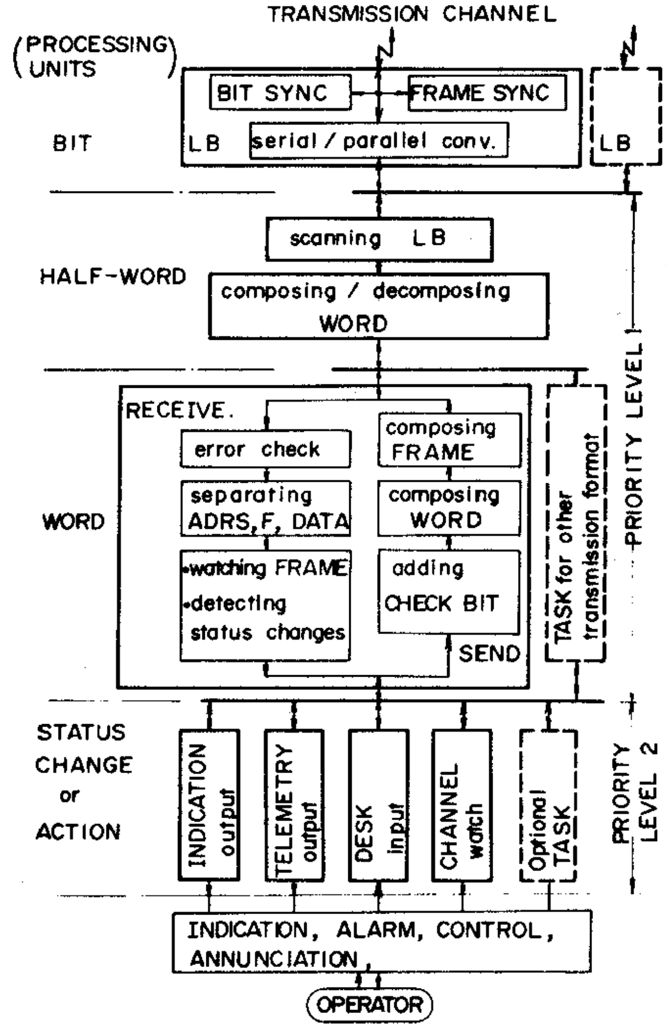

Fig. 8 Hierarchical structure of functional modules in Master Station

an example specifically arranged for CDT format. The hierarchy is divided into the following four strata according to the natures of processed data and information:

(1) Bit: synchronizing, serial to/from parallel conversion and buffering,
(2) Half-word: channel scanning and Word composing/ decomposing,
(3) Word: transmission procedure control,
(4) Status change or action: all other functions.

Special design considerations here to get the best tradeoffs among hardware, firmware and software are that the functions of the first stratum are implemented by a hardware module i.e. line buffer and that basic processor operations for the transmission procedure control are micro-programmed in the form of firmware.

Since the microcomputer HIDIC-08 has two levels of interruptions, the higher priority level is assigned to the second and the third functional strata, while the fourth stratum is interrupted with the lower level priority.

Functions in the first and second strata can be adapted to variations of the basic CDT format by changing only some parameters, but in the third stratum, in order to avoid the overhead due to generalization, functions are integrated as a task (a set of program modules) on a format-by-format basis. Therefore only the necessary kind of tasks are actually built in and extra tasks can be added on occasion of dealing with other nature of formats.

For the purpose of reducing the overhead of the operating system(OS), it is given the lower priority level than the second and third strata tasks, so that the transmission control may start soon after the interruption by the scan interval timer without any delay due to the OS overhead loss.

The tasks in the fourth stratum are managed by OS, they are initiated according to the software priority levels on receipt of priority interruptions. The program module as a task is made on a function-by-function basis; hence if a new function such as data logging is required additionally, a new task will be added to meet it.

Firmware. Microprograms implemented in the optional ROMs, called here collectively as firmware, improve the processor performance by:

(1) reducing the overhead in basic instructions, or increasing the number of microinstructions executed in each step,
(2) reducing the number of memory references, preparing a work area in the scratchpad-memory for microprogram execution,
(3) reducing the number of branch instructions, or utilizing the technique of direct branching in firmware.

As a result of studying the effect of the above-mentioned schemes, an improvement in the processing speed is possible by a factor of up to three according to operating conditions.

In the experimental system the following functions have been implemented more or less by firmware : (1) channel scanning, (2) elementary functions for the send/receive task, and (3) bit-oriented memory set/reset functions. All of the firmware takes the form of optional machine instruction set to increase the compatibility with software as listed in Table 2.

Table 2 List of microprogram firmware dedicated to Supervisory Control and Telemetry

Mnemonic Name	Remarks
1. SLB	Scan line buffers
2. SPW	Separate transmission words
3. SFD	Separate fields in a word
4. CGP	Check/Generate parity
5. CKR	Check complementary-repeat
6. DST	Detect status changes and store data
7. CAD	Check and store analog data
8. CSA	Calculate subcommutation address
9. LDW	Load work register
10. SDW	Store data from work register
11. ATQ	Change channel address to queue table
12. QTA	(inversion of ATQ)

Results. The execution speed of each microprogram in Table 2 is averagely three times faster than what would be with software execution, and as regards the microprograms which do not require memory references such as CGP and CKR, the execution time has been shortened by a factor of from five to ten. Actually, SLB, a relatively highly integrated firmware modules, has been proved to tle approximately ten times more speedy than a software level program.

In a CDT system, since information is transmitted continuously one Word after another as shown in Fig.2, each Word must be processed within as short a period as the one-Word time slot, e.g., 36.7ms with the 44-bit Word format over 1200 b/s; that is, much of the processor time should necessarily be assigned to the transmission control. The test data shows the maximum utilization factor for the function has been approximately 60% with 32 Remote Stations over 1200 b/s channels.

Other tasks, such as indication and desk support, may wait to be processed under the management of OS, so their executions are not critical in terms of urgency; the overall utilization factor for these tasks has been less than 20% with the maximum of 32 Remote Stations.

With the introduction of a microcomputer along with the modular system configuration scheme, an improvement has been achieved particularly of system flexibility. With regard to the fundamental functions of Supervisory Control and Telemetry, most of the transmission procedure alternatives can be met with a slightest change or modification of hardware, firmware or software modules.

Conclusion

A Supervisory Control and Telemetry Master Station based on a firmware-centered microcomputer has been demonstrated to be feasible which is capable of simultaneously dealing with 32 Remote Stations linked over 1200 b/s carrier channels on a real time basis. The microprogram modules for transmission procedure control, the heaviest load to the processor, has been developed and implemented in the firmware, which are a factor of from five to ten faster than with software. Since this special modules can be incorporated into the microprocessor as optional machine instructions in combination with the basic ones, they can easily be connected with software.

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